Keep the “Hard Workers” moving!

An analysis to solve the Inventory Routing Problem on Returnable Transportation Items in the Supply Chain of Johma.

Master thesis Industrial Engineering and Management by

S.H.M. van Haagen BSc

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Author
S.H.M. van Haagen BSc

Educational institution
University of Twente

Faculty
School of Management and Governance

Educational program
Industrial Engineering and Management – Production and Logistics Management

Company of interest
Johma Salades B.V. in Losser

Supervisors
Martijn Mes – Assistant Professor at the University of Twente
Matthieu van der Heijden – Associate Professor at the University of Twente
Remco Rijsenbrij – Director Operations at Johma
Willeke Nijhuis – Logistics Manager at Johma

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“A worker may be the hammer’s master, but the hammer still prevails. A tool knows exactly how it is meant to be handled, while the user of the tool can only have an approximate idea.”

Kundera, Milan

Management Summary

Johma Salades is the biggest salad producing company in the Netherlands. During negotiations with their logistic service provider Müller Fresh Food Logistics (MFFL) on total transportation costs, MFFL noticed the opportunity to create savings for Johma by improving the return flow of Returnable Transportation Items (RTI). The items under consideration in this research are the secondary packages called CBL-crates, consisting of multiple types that differ in size. The discussed problem encountered by Johma is formulated as:

Johma has limited insight in, and limited control over, the use of Returnable Transportation Items within the continuously changing Supply Chain. This causes a lack of control and more costs than legitimated.

Knowledge on the current use of RTI in the supply chain is the starting point in managing their future use. This brings up the goal of this research:

Developing methods for analysis, that contribute to an efficient use of Returnable Transportation Items along the Supply Chain of Johma. The acquired information can be used as input in the negotiations with different stakeholders.

Context information

Products of Johma are packed in RTI and shipped by MFFL from the production facility of Johma to the different customer locations. The collection of RTI at these locations remains the responsibility of the supplier who is legitimated to order a truck as long as the amount they sent to the customers exceeds the amount collected. The RTI is transported to the cleaning facility of Habé. Johma uses two types of RTI, Long Term Rentals (LTR) and Short Term Rentals (STR). In case the inventory levels at the cleaning facility are not enough to cover for total production demand, Johma has the opportunity to hire an additional amount of STR. If we account for a Cost of Capital (COC) of 5% on the deposit money paid by Johma for LTR-RTI, the STR-RTI are roughly 9 times as expensive as LTR-RTI.

Indication of a saving opportunity for Johma

The data analysis on the situation of 2011 shows that current LTR-RTI contracts are not in line with the observed demand. We identified three parameters that influence the optimal rental policy; 1) required time to create/deplete a truckload, 2) the proportion of LTR- versus STR-costs and 3) the number of RTI necessary as work-in-process. This last parameter is determined by the cycle time at the customers’ warehouses and the demand patterns at the production plant of Johma. We estimate a saving opportunity of 50% of almost €43.000 by contracting LTR-RTI that complies with current demand. The method followed to determine the optimal rental policy consists of eight steps, namely:

1. Clear the outstanding balances
2. Gather data
3. Determine the required time to create/deplete a full-truckload
4. Determine the proportional costs between LTR- and STR-RTI
5. Determine the cycle time and the required work-in-process
6. Set the number of LTR- and STR-RTI according to Kirby (1959)
7. Compare the costs of both situations
8. Adjust the contractual agreements accordingly

Model to solve an instance of the Inventory Routing Problem

We translated the practical situation of Johma and its difficulties to a more general problem, an instance of the Inventory Routing Problem (IRP) based on the model of Lee et al (2003). The objective function of this IRP aims to minimize total transportation and rental costs. The influence of customers and suppliers who participate in the pooling system are not considered explicitly but their influence is modeled as an exogenous process.

Conclusions

The mathematical Mixed Integer Linear Problem-formulation in solved for multiple problem instances that resemble the situation of Johma as close as possible. Nevertheless, we had to makes some assumptions due to the absence of enough (reliable) data. From this, we concluded:

- The experimental results support the hypothesis that it is possible to gain improvements by adjusting the current LTR-contracts. With 95% certainty we can realize savings between €5.676 and €5.856 if we move from the current LTR-RTI levels to the levels determined with the method of Kirby (1959).
- A decline of 40% in average inventory at Johma if we change the number of LTR-RTI to the proposed situation, a desirable situation to keep the RTI moving through the supply chain.

Recommendations

RTI-management is no core-business activity and increasing control over RTI from the perspective of Johma is difficult. Not only caused by the limited share of Johma compared to other participants, but mostly because the RTI flow in the external environment, outside Johma’s direct control. If we combine this with the fact that not all customers participante into the pooling model, the recommendations to improve Johma’s control, are summarized as:

- Start actively promoting the membership of the pool provider Pool Service for customers of Johma. To increase chances of success, Johma could work together with other suppliers and include the pool provider in this process.
- Johma may consider negotiation on a different pricing structure with the cleaning facility Habé and logistics service provider MFFL (both 50% shareholder of the cleaning facility in Holten), by introducing a ‘one-way-rental’ fee. The pool operator charges suppliers a variable price on a ‘per trip’ basis, with the operator responsible for collecting empty units after delivery.
- Before such a system is implemented, Johma still has the obligation to return the proper amounts of RTI on LTR-contract to Pool Service so the contracts can be changed towards the proposed future RTI-levels. These LTR-levels should be determined every year, based on expected long term demand-rates.

A yearly check on the contracts and forecasts and more awareness of important cost factors increases the insight of Johma and decreases total costs. Keeping the number of RTI, also known as “Hard Workers”, up to date decreases cycle times and keeps the RTI moving in the different supply chains.

Keep the “Hard Workers” moving!

Preface

This thesis is written to obtain my master’s degree in Industrial Engineering and Management. I would like to thank several people that supported me.

First, Johma for providing the opportunity to conduct my master’s thesis at the production facility in Losser and their contribution during our irregular meetings. Secondly, I thank my supervisors of the University of Twente. I enjoyed working together with Martijn Mes and Matthieu van der Heijden, they both encouraged me to improve the academic quality of my report.

Finishing my student-life at the University of Twente, makes me look back and realize how many inspiring contacts, amazing opportunities and unforgettable memories it brought me. They made me accept and manage the many challenges during these years.

Finally, special thanks to my parents for their continuous support and confidence that I succeed as long as I follow my intuition.

Suzanne van Haagen
Enschede – August 2012

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List of abbreviations

Abbreviation	Meaning
CBL	Centraal Bureau Levensmiddelenhandel
COC	Cost of Capital
CT	Cycle time
ERP	Enterprise Resource Planning
IRP	Inventory Routing Problem
LTR-RTI	Crate on a Long Term Rental basis
MFFL	Müller Fresh Food Logistics
MILP	Mixed Integer Linear Problem
PPE	Pallet Place Equivalent
RTI	Returnable Transportation Items
STR-RTI	Crate on a Short Term Rental basis
VMI	Vendor Managed Inventory
WIP	Work-in-process

1 Introduction

The products on the shelves in the supermarket are produced and transported by different suppliers. Different stakeholders from multiple supply chains come together in order to serve the final customers in the supermarket. During production and transportation, a lot of these products are packed in crates and/or piled on pallets. Pallets and crates are part of the larger group Returnable Transportation Items (RTI). “They come in a kaleidoscope of sizes, shapes and colors. The vast inventories of Returnable Transportation Items – the reusable bins, pallets, crates, wheeled trolleys and cages that are used to pack and carry goods from site to site or across the warehouse floor – represent a huge commercial asset.” (Motorola Solutions, 2010). An asset that is not part of the core business and therefore often neglected, but for now, they are the key interest in this research.

In this chapter, we give a short description of the subject for this thesis. Section 1.1 introduces the motivation of the research. Section 1.2 presents the problem where this research is about and Section 1.3 introduces the Dutch company where we performed our case study, Johma Salades B.V. located in Losser.

1.1 Problem Introduction

Johma Salades, a Dutch salad producing company, experienced a rough period, in which the profits and the market share decreased enormously. A lot of projects to improve the internal processes have been initiated and resulted in higher service levels with a decrease in wastes. Now it is time to look at the external costs. One of the projects resulting from this external view is the focus on reduction of transportation costs related to RTI.

In December 2011, Johma has closed an agreement with Müller Fresh Food Logistics (MFFL), a logistics service provider located in Holten. MFFL is responsible for the transportation of the forward and the reverse flow of products. This reverse flow consists of product returns and returned packaging material, the Returnable Transportation Items. With this contract, the collaboration is extended for at least two more years. Continuation of collaboration is interesting for Johma because the processes, operating procedures and information systems of Johma and MFFL are tuned during the previous years.

Competitors of MFFL lie in ambush to take over the contract with Johma at a lower price. Nevertheless, the competitive advantage of MFFL provides some respite. During the coming two years, MFFL has the opportunity to come up with a solution to decrease the transportation costs with at least 10%. MFFL indicates that this goal is realistic if they succeed in implementing a more efficient return flow of RTI.

Johma uses two types of packages, the so called primary and the secondary packages. This first group consists of plastic bins and covers that are used to pack the salad directly. The second group includes (reusable) bins, crates, wheeled trolleys, cages and so on. This group is used to pack and carry groups of individual products from site to site or across the warehouse floor.

This leads us to the subject of this research. Is it possible for Johma to create savings on the usage of RTI? We already discussed the transportation costs shortly, but there are also other costs involved, such as inventory costs, as we will see later on. To ensure availability of RTI at the production facility of Johma and to cover for the uncertainty of the reverse flow, inventory is held (Sussams, 1992). Reduction of the uncertainty of the reverse flow and reduction of the lead-time (for example by requesting smaller batches at more frequent intervals) can reduce the investment in inventory considerably.

The RTI, or as mentioned in the title of this report, the 'Hard Workers', should keep moving efficiently throughout the supply chain. With the aim to reduce the total related costs, consisting of cleaning costs, transportation costs, storage costs, rental costs and capital costs.

1.2 Problem Description

Johma wants all her operations to be executed in an effective and efficient way. Resources are committed in order to realize this, including different RTI. Nevertheless, due to the complexity, the ongoing changing environment and other priorities, Johma has not a lot of knowledge on the use and the corresponding costs of RTI in the supply chain. This causes that Johma depends on information from other stakeholders, holds contracts that might not suit the current situation best, and has to make daily ad hoc decisions which may not contribute to overall long-term efficiency. Hence, we formulated the problem statement:

Johma has limited insight in, and limited control over, the use of Returnable Transportation Items within the continuously changing Supply Chain. This causes a lack of control and more costs than legitimated.

1.3 Company Description

To formulate a good solution to the problem statement formulated in the previous section, it is necessary to know in what context this problem has emerged and how Johma handles its RTI right now. In this section we provide some necessary background information. For more information on the historical background, strategy, products, markets and the production process of Johma, we refer to Appendix A.

General Information

Johma is the largest and well-known salad producing company situated in The Netherlands. From 2009, until May 2012, Gilde Equity Management Benelux was the biggest shareholder of Johma Salades. The Gilde group participated in several food-producing companies, e.g., in Bakker Bart, De Banketgroep, and Hamal Signature. Since the last big reorganization, in which 70 people lost their job, the management of Johma is striving to turn Johma again into a stable and profitable organization. Since June 2012 it is owned by AAC Capital Partners.

Each core value of Johma, i.e. Craftsmanship, Neighborliness, Competitiveness and Customer is King[1], throws light on another aspect of quality. This, by Porter defined, quality-oriented differentiation strategy turned Johma into the overall market leader in the Dutch salad market with an average market share among the different market segments of 21,8% in 2011 (Daft, 2005). Johma's production facility, located in Losser, produces over 300 different Stock Keeping Units, which generated an annual sales volume of €65 million in 2011.

Production and logistics aspects

A distinction can be made between internal and external processes. The internal processes comprise of all activities performed at the facility of Johma Salades in Losser, including marketing, sales, planning, production, packaging and shipping. The external processes start from the moment the trucks with products leave Johma. First we will look briefly to the internal processes, for more detailed information on the different production aspects we refer again to Appendix A. At the end of this subsection we describe the external process briefly, the part where the focus is on in this report. For a detailed description, please refer to Chapter 3 and Chapter 5.

[1] For definitions, see Appendix A.

Figure 1 shows the internal processes. The planning department, where this research is performed, requires a forecast from Customer Service. This forecast is based on historical information, special offers and known orders and is entered in the Enterprise Resource Planning (ERP) system, called Infor LX. The planning department translates the forecast into actual production demand, demand for Raw Materials and Transportation Requirements. The daily production schedule is sent to the different departments in the factory, the raw materials are ordered at the different suppliers and the transportation schedule is sent to the logistics service provider, MFFL. After production, the salad is packed from the funnels into primary and secondary packages. The resulting pallets are transported to the finished goods warehouse, where they are stored until the order-picking process is triggered by the due date of a customer order.

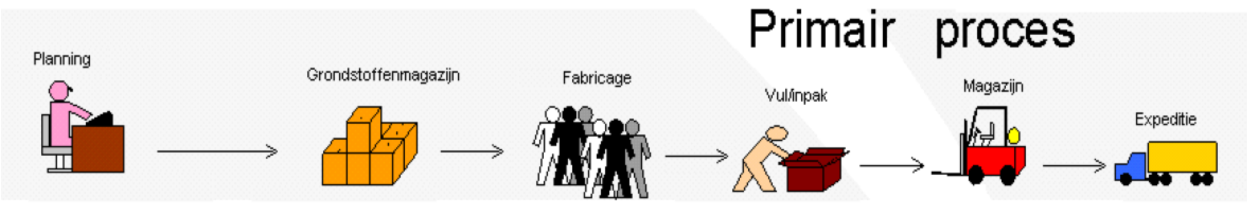

Figure 1: Internal processes of Johma

The trucks of MFFL arrive according to a time-schedule at the finished goods warehouse of Johma. The truck is connected to one of the docks and loaded. The orders are billed in the ERP system and the driver receives the administrative papers before he drives to the customer.

At this point the internal process is finished and the external process starts. The external process can be divided into two main parts.

1. A forward flow of products to the customer.
   Johma's serves two types of customers, namely: retail and foodservice clients. The supermarkets belong to the retail customers, and are delivered by Johma through different central distribution centers. These retailers are the main customers of Johma. The foodservice customers are delivered directly and can be further segmented in to catering, train- and fuel-stations, convenience shops (domestic caterers) and other institutions (like hospitals).

2. A reverse flow of RTI.
   The different processes in the reverse flow of RTI depend on the type of RTI involved. Pallets can be reused immediately but crates have to be cleaned at a cleaning facility before they can enter the production process of Johma again. In this research we focus on the reverse flow of crates, see Figure 2. During 2011, 430 different suppliers used crates, to send products to their customers. Johma shipped over 400.000 of them to the customer locations in Figure 3.

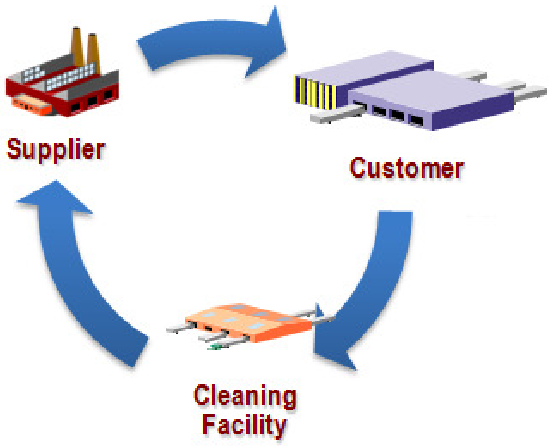

Figure 2: The cycle of RTI-crates

The crates sent to customers should be returned to Johma in order to keep enough crates available for production purposes. The demand for products and therefore the demand for crates are influenced by seasonal factors like Christmas, Easter and (sunny) weather conditions. This high seasonal fluctuation in demand together with the restricted storage life of products makes it impossible to create a stable deterministic production pattern. Another factor that influences the demand for certain RTI is the customer requirements which change frequently. Customers need certain types of crates to optimize their internal processes and therefore oblige Johma to pack the products in a pre-specified manner. Altogether a continuously changing situation that makes it hard to monitor and control efficiently.

Figure 3 RTI-crates customers of Johma in 2011

1.4 Conclusion

This short introduction gives some insight in the usage of RTI within Johma. In the following chapter we formulate the goal of this research and the accompanying research questions which are answered later on. In the end of our analysis on the use of RTI through the supply chain of Johma, we present a model that manages the RTI in a cost effective way.

2 Research Design

This chapter states the research goal of this thesis and the strategy to accomplish it. Section 2.1 presents the research goal which is based on the problem described in Chapter 1. Section 2.2 contains the research questions that will be answered in the following chapters. The scope for this research is discussed in Section 2.3 and finally, we conclude with the outline for the remainder of this thesis in Section 2.4.

2.1 Research Goal

Johma is convinced that it is important not to lag behind in the negotiations with stakeholders, like for example MFFL, and that knowledge on the current use of RTI in the supply chain is an important starting point in managing their future RTI usage. As described in Section 1.2, the problem this research deals with is that there is limited insight in, and control over the use of RTI. This brings up the goal of this research:

Developing methods for analysis, that contribute to an efficient use of Returnable Transportation Items along the Supply Chain of Johma. The acquired information can be used as input in the negotiations with different stakeholders.

The concepts included in the research goal are defined as:

- Efficient usage
  A property of performance, the result of using the lowest amount of inputs to create the greatest amount of outputs (and therefore aiming to reduce the waste of inputs). For this specific case we try to minimize yearly costs of using RTI in the supply chain while there are always crates available on time before production runs out of stock. The yearly RTI costs comprise of cleaning costs, transportation costs, storage costs, rental costs and capital costs.
- Returnable Transportation Items
  A lot of different types of RTI are available in the market, e.g. pallets, wheeled trolleys and crates. These items can be bought or rented on a long term or short term basis. If we refer to RTI in this research we mean the CBL-crates of size 7, 8, 11, 15, 17 or 23, of which a picture and further specification is included in Appendix B.
- Supply Chain
  All people, activities, information and resources involved in moving RTI from the production facility in Losser to the Dutch customer and eventually back to Johma again. The RTI-supply chain includes activities like demand planning, purchasing RTI, packaging of products, warehousing the inventory, transportation of customer orders and supply planning.
- Stakeholders
  The parties involved are the logistics service provider, the cleaning facilities, the short term rental facilities and the pool provider for long term rental.

2.2 Research Questions

To achieve the research goal stated in Section 2.1, we have formulated one central question which is subdivided into five research questions. The answers to these sub questions form, when combined, the solution to the problem statement. The chapter in which each research question is discussed is stated as well. Next to that, we provide in the following a short explanation on the question asked.

How should Johma manage their main Returnable Transportation Items through the Supply Chain in a cost effective way?

1. *How are the main Returnable Transportation Items used in the current situation and what costs are involved? (Chapter 3)*

The goal of this question is to describe the current use of the main RTI. An overview is given on the involved stakeholders in the different process steps, the contractual agreements with Johma and the different costs involved. This knowledge provides a starting point for signalizing improvement opportunities and the relations that have to be captured in formulating a decision model for future usage.

2. *How should the Returnable Transportation Items be handled in a Supply Chain according to the Literature? (Chapter 4)*
   The relevant research already performed on the management of RTI is described as a starting point for this analysis. This includes the differences between forward and reverse logistics, the different types of RTI-cycle models available and the reasons to keep inventory. To keep the RTI flow through the supply chain in order to fulfill demand of the production facility, we look for literature to determine the number of required items. Finally, we look into different instances of the Inventory Routing Problem, a conceptual model striving for a minimum level of total transportation and inventory costs. Also the similarities and differences with the situation of Johma, or more general with the pooling model, are treated.

3. *What can we learn from the current RTI-management to improve future handling? Which practical relations exist and should they be included in to a model? (Chapter 5)*
   By analyzing the available data from 2011, we discuss how the situation of 2011 should have been handled when we include current insights. We describe a method to determine a better rental policy, i.e., the number of crates used along the year and their split into LTR-crates and STR-crates. This provides an indication on the possibility to create savings for Johma. Looking at the parameters influencing this optimal split, we look for the effect of the cost of capital. The data analysis is concluded with more details on the time it takes to form a full-truckload because this might increase the lead time and thereby the number of RTI.

4. *How should a model for management of Returnable Transportation Items (within Johma's Supply Chain) look like in a pooling system? (Chapter 6)*
   To improve the RTI-management within Johma, a model is formulated. We come up with an alternative version of the Inventory Routing Problem. The differences between the model and the case study of Johma, the modeling assumptions and the model itself are given. The model captures the relations between the different stakeholders and the financial implications of certain changes in decision variables which are discussed separately. In the end of Chapter 6, the usefulness of the model for Johma is highlighted.

5. *What benefits can be realized with the model in the RTI-management (of Johma) and how can they be achieved? (Chapter 7)*
   The MILP-method used to solve the Inventory Routing Problem is given. Parameter settings and assumptions are important to increase practical usefulness of the model. Solving multiple problem instances with different supply characteristics will give more information on the effect of for example the number of available LTR. The effects of the switch from the current LTR-levels to the levels proposed by the method from Chapter 5 are shown.

2.3 Scope of the Research

The focus of this research is on Returnable Transportation Items, more specifically on the use of different CBL-crates (see Appendix B). The demand for these crates is influenced by customers' requirement which we cannot influence. The forecast is assumed given and accurate. Data is acquired from invoices and datasheets coming from the service provider and documents of contractual agreements. We assume that this data is correct and corresponding information is given and unchangeable in the short term.

We only look at the RTI used by the production factory of Johma located in Losser, therefore the relative few number of crates used in exceptional situations by the external warehouse in Hengelo (Cold store) are excluded.

2.4 Outline Thesis

The third chapter provides some background information on the subject and motivation for this research. In Chapter 4, we continue with a literature review on the management of RTI in supply chains which is used as input for the data analysis in Chapter 5 and the model development in Chapter 6. This sixth chapter transforms the management problem, the literature and the current situation into a model that contains the elementary characteristics of the supply chain of Johma. In Chapter 7, we present the solution method and the results. The last part, Chapter 8, provides the final conclusions and recommendations based on the original research question.

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3 Current Situation

In Section 1.3, we gave a short introduction to the company of interest for this research. In this chapter we explore some of the introduced topics in more dept. This context description provides necessary information to get a grip on the important concepts for the literature review and to support the data analysis in the Chapter 5. Section 3.1 describes the RTI-crates used by Johma and their specific characteristics. The demand pattern and seasonality is discussed in Section 3.2. Section 3.3 gives an overview of the processes and stakeholders involved in the RTI-flows. The precise roles and interactions between the stakeholders are described in Section 3.4. At the end of this chapter we describe the different cost involved in RTI-management (Section 3.5), which we attempt to decrease in Chapter 6. We finish this chapter with some brief conclusions.

3.1 Different RTI

The secondary packages, more specifically the RTI-crates, are available in different types. The different types of crates differ based on size, see Appendix B for more information. These differences in size cause that the crates are piled type by type on a specific pallet (see Figure 4). This sorting simplifies the internal processes of Johma and other stakeholders, like the cleaning facility, as well. For efficiency of the production processes of Johma it makes no difference in which type of RTI a product has to be packed.

Next to the sizing of individual crates, there is another cause of variety: the type of pallet used to pile and transport the RTI is not identical among the RTI. The RTI of Johma is transported on two different pallet sizes. In principle the RTI leave the cleaning facility on EURO pallets, but the cleaned crates of CBL-23 are piled on IPP pallets. The reason for this difference is unknown. The consequence is that a full truckload of CBL-23 on IPP contains 26 Pallet Place Equivalents (PPE) and a full truckload of EURO pallets with other types of RTI contains up to 33 PPE.

Figure 4 RTI warehouse

3.2 Seasonality

As mentioned, the demand for products and therefore the demand for crates are influenced by seasonal factors like Christmas, Easter and (sunny) weather conditions. This seasonal fluctuation in demand, together with the restricted storage life of products and de limited production capacity makes it impossible to create a stable deterministic production pattern.

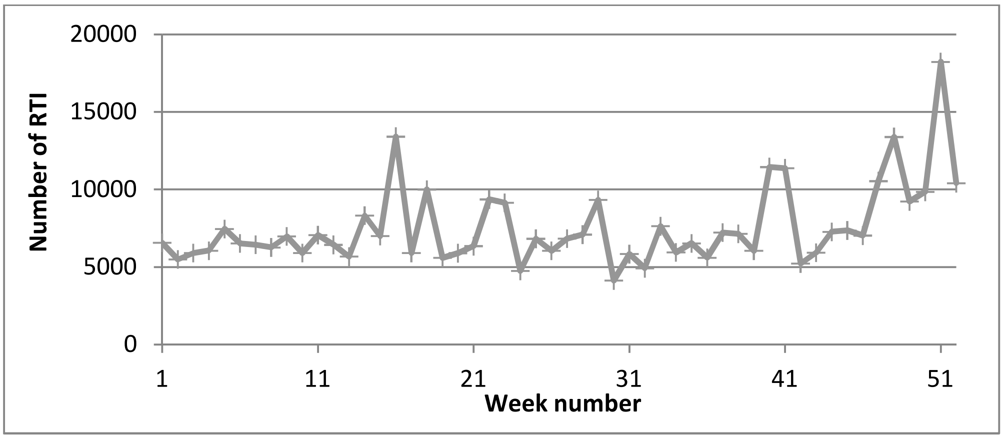

Figure 5: Weekly demand for RTI at Johma in 2011

In Figure 5 we gave the actual demand for crates during 2011. The data used to compose this graphs represents the RTI send weekly to the different customers, in reality the demand for RTI occurs somewhat earlier due to anticipation of Johma to the expected customer orders. Next to this, the figure is somewhat biased because Johma also uses crates for internal packaging of salads that are not transported in these specific crates. Naturally, this internal RTI demand is not visible in Figure 5. See Section 4.3 for more information on the different types of stock that occur in the supply chain of Johma and should be included in the final model.

3.3 RTI Process Flow

The forward and reverse flows are introduced in Section 1.3. When the products are delivered to the customers, the reverse flow of RTI is started. This process differs among two types of customers; see Figure 6 for an overview. This figure is based on the model of Bowman et al. (2009).

1. Large customers (or pool participants, see Section 3.4 for more information) store the received RTI at their facility and Johma collects them occasionally, in batches of a full truckload. These large customers are invoiced for deposit money.
2. Small customers who do not participate in the pooling system should return the RTI immediately when MFFL delivers the products. This is not always the situation in reality, but in principle MFFL collects these directly returned RTI at their warehouse in Holten until a full truckload can be loaded and transported to one of the five cleaning facilities.

As can be seen, the inbound flow of crates at the production facility of Johma is always coming from one of the five external cleaning facilities. The demand for RTI at Johma is driven by the planned production of end products.

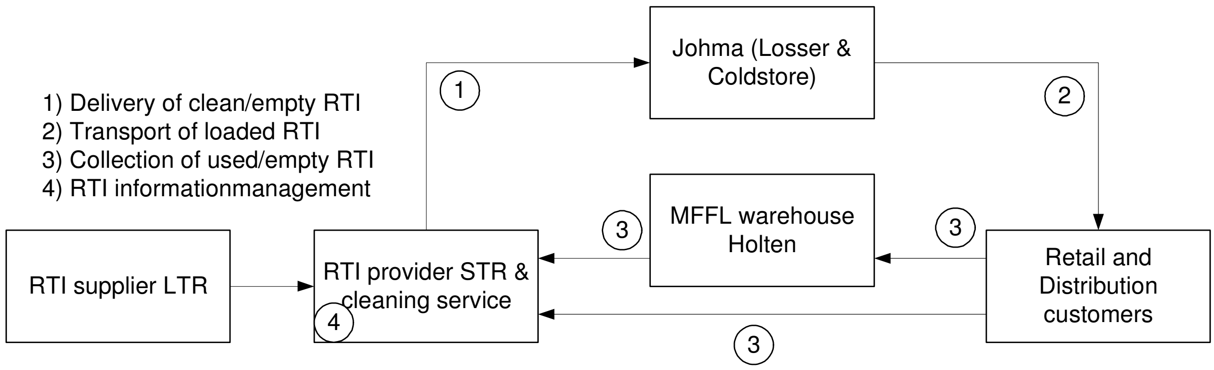

Figure 6: RTI flow model

Due to seasonality of demand (see Section 3.2) and changing customer requirements it is not possible for Johma to know on beforehand how many crates of each type are exactly needed during the year. Therefore Johma holds two contracts. The first type contains RTI that is rented on a long term contract with Pool Service (see section 3.4), the LTR-crates. The second type is rented on a short term basis at the cleaning facility of Habé (see section 3.4), the STR-crates. The only relevant difference between these two categories is the price paid by Johma. Habé and Pool Service support each other in this service. Johma acquires all crates, so LTR- and STR-crates, at one of the cleaning facilities of Habé and Habé registers this. The balance of outstanding crates is updated every week in the RTI information management system.

3.4 Stakeholders

Next to Johma and the customers, we referred already to a few other stakeholders. The logistics service provider MFFL, the pool provider Pool Service and the cleaning facilities of Habé. To get insight in the processes, costs and responsibilities of the stakeholders, the role of each is discussed in this section.

Logistics Service Provider - Müller Fresh Food Logistics

In general, the suppliers of Johma arrange the transport for their products flowing to the warehouses of Johma (inbound) and Johma is responsible for all transportation of finished products to its customers (outbound). An exception to this rule of thumb is the inbound transport of RTI. The regular logistics service provider of Johma, Müller Fresh Food Logistics (MFFL), is involved in the transportation activities between Johma, her customers (in The Netherlands) and the different cleaning facilities of Habé. Next to this, Johma contacts MFFL for retour freight of products and inbound freights of RTI. MFFL consists of three establishments in The Netherlands, Holten, Kaatsheuvel and Ochten. The establishment of MFFL Holten is used by Johma. (Müller Fresh Food Logistics, 2012)

Johma and MFFL negotiated a contract for 4 years, with a commencing date of 1 July 2011. This contract is based on the observation of Johma that other logistics service providers are willing to make similar agreements at lower costs. Nevertheless MFFL has the competitive advantage that it is familiar with the business processes, information systems and operating procedures of Johma. As mentioned in Chapter 1, both parties agreed to look for possibilities to improve their collaboration in the next two years, so MFFL can lower its total costs. If the savings of 10 percent on the transportation costs in total are not met within 2 years, Johma has the possibility to resign the contract early.

To give some indication on the size of transport in RTI management, we looked at the data of 2011. During the year, an estimated total of 270 trucks were used to carry the reverse flow of RTI from the customers to Johma. This means roughly, 135 freights of outbound RTI from the customer to the cleaning facility, 135 trucks of inbound RTI to Johma, and on average more than 2,5 truck arriving weekly at Johma.

Pool Provider – Pool Service B.V.

At the beginning of 2011, Container Centrale Full Service has pursued her activities for Stichting Versfust under a new name; Pool Service B.V.. Pool Service is owner of all crates in the Netherlands. The board consists of representatives of Dutch retailers and Dutch food producing companies and acts on behalf of the consumers of crates. Since 2008, Pool Service offers a so called pool management system. This system is developed to provide more coordination in the pool, better individual availability, savings on the operational costs and less tuning between retailers and producers.

RTI-type	# RTI
CBL-07	16.335
CBL-11	20.000
CBL-15	4.000
CBL-08	0
CBL-17	2.000
CBL-23	5.000

Table 1: LTR-crates

Johma holds a contractual agreement with Pool Service on the usage of RTI. This contract is limited to crates for Long Term Rent (LTR), for which Johma pays a yearly fee per crate. Table 1 and Appendix C show some basic information on the current LTR-contracts between Johma and Pool Service. As shown in Table 1, Johma holds currently 20.000 LTR-crates of CBL-11 and 0 of CBL-08. This means that Johma is not entitled to use CBL-08 at all and therefore Short Term Rent (STR) is a necessity. For STR we refer to a later part of this section on the cleaning facility of Habé.

As mentioned, Pool Service aims to maximize the individual availability of RTI by using a so called pool management system. Part of this system is an online marketplace for RTI that Johma can use[2]. In this way, Johma has more information to balance supply and demand for crates in order to maximize availability at Habé and to minimize (transportation, holding and rental) costs. If the balance

[2] http://www.cblmarktplaats.nl

of Johma at a certain customer yields a surplus in this system, Johma can arrange transport with MFFL to pick-up the required RTI. In case the customer does not have this amount of RTI currently available for pick-up, Pool Service is responsible to come up with another pick-up location.

Cleaning Service – Habé Middelencentrum B.V.
Johma holds an agreement with Habé Middelencentrum for cleaning, storing and renting STR-crates. From November 2011, there are five Habé cleaning facilities in the Netherlands, one in Amsterdam, Bleiswijk, Holten, Tilburg and Utrecht. Habé is responsible for counting, recording, sorting, cleaning, storing and issuing cleaned crates on behalf of Pool Service to for example Johma. The RTI returned by the customers of Johma may be contaminated. This could occur during transport, usage or while it was stored. To prevent the new products to be contaminated by these crates, Johma uses only cleaned crates. The crates have a lead time of 1 day for cleaning activities and in case they are longer stored at Habé, Johma pays storage costs (see Section 3.5).

In case the amount of LTR-crates on contract, displayed in Table 1, is not high enough to cover the current demand, Johma can rent STR-crates at Habé. MFFL collects these crates at one of the facilities and pays a fee to Habé until the crates are returned. The contractual agreements are given in Appendix D.

Johma
The core business of Johma is to run the production process (described in Appendix A) according to plan, smooth and with as little interruptions as possible. A prerequisite is the availability of crates.

Daily, an employee of Johma counts the number of crates available. He compares this to the expected production demand and the minimum balance of inventory required for each type. If the current level is below this minimum, a fixed order quantity is suggested and the item(s) is/are replenished in full truckload amounts. This type of inventory control is called an (R,s,nQ) replenishment policy (Silver et al., 1998). Every R periods (days), inventory is checked and if this is below a certain value s (see Table 2 for the current values), n replenishments (full truckloads) of size Q are placed. Multiple RTI-types can be combined in one freight from a certain origin to a given destination.

Type	Min Bal
CBL-07	250
CBL-08	2000
CBL-11	720
CBL-17	330
CBL-23	640

Table 2: Minimum Inventory

The financial department takes not only care of invoicing the customers for the delivered products, but they also account for the RTI delivered. Customers who do not return the RTI immediately at delivery are charged for deposit money. This will be returned when the RTI is collected again by Johma. Next to this, in case the customer participates in the RTI-pool, the number of RTI delivered is registered and the virtual balances are changed accordingly in the pool management system.

3.5 Cost Structure
Data on the number of crates transported to and from certain locations is available, but this is not enough to conclude anything on the budget spend on RTI-management. For example, how many CBL-crates fit in one truck? How expensive is one freight? How many crates are transported during the year and what costs come along with this? The cost structure of RTI is covered in this section, which is organized along the different cost types. All costs are excluding taxes.

Cleaning costs
Johma pays for the issue of cleaned crates at one of the Habé cleaning facilities. The costs per item are based on a yearly forecasted amount of 500.000-1.000.000 RTI-crates called-off at Habé. Actually

Johma used only 410.000 crates in 2011 at a total cleaning cost of roughly €37.000. The details can be found in Appendix C.

Rental costs

Johma rents RTI on long term and short term contracts, we discuss both:

1. Long Term Rental (LTR) contracts include two types of costs. A one-time deposit at the start of a contract and a yearly fee (on average €0,12 per crate) to cover for overhead costs and replacement costs. The exact amounts are listed in Table 11 in Appendix C. For now it is enough to know that Johma has paid a yearly fee of almost €6.000 and more than €150.000 on deposits. It should be noted that there is no contract present for CBL-08 crates. The implications of this are discussed in Chapter 5.
2. In case the used number of crates is larger than the available LTR-crates, Johma rents crates on a Short Term Rental (STR) contract from Habé. Johma pays €0,05 per crate per week (€2,60 per crate/year). The costs are given in Appendix C. Johma rented on average 7.500 crates of CBL-08 and CBL-23 a week, with a total value of €19.000 over 2011.

Storage costs

In case there are more crates arriving at Habé instead of being transported to Johma, the inventory level at Habé increases. Johma starts to pay holding costs of €0,53 per PPE/week for this inventory in case the total inventory summed over all locations at the end of week t is larger than twice the average number of crates transported to Johma during week t. So Johma pays storage costs in week t, if:

$$\sum_{i=1}^{n} Inventory\ at\ location\ i > 2\sum_{i=1}^{n} daily\ volume\ transported\ from\ i\ \ to\ Johma$$

Table 14 in Appendix C shows the average number of PPE stored at one of the Habé locations and the total storage costs incurred by Johma. In 2011, this was almost €10.000 in total.

Transportation costs

The crates are transported from the customers, by MFFL, to Johma. Johma has agreed a new pricing structure with MFFL. During the first half of 2011, they paid for each crate transported separately €0,0825. In this way, the price of a full truck load of RTI depends on the number of crates that are in this freight. Due to differences in size of the different RTI-types and the different pallets used to pile the crates, these prices for a full-freight ranged from €87,12 for CBL-23 up to €536,25 for CBL-08.

The calculations for the first half year, with the former pricing structure can be found in Appendix C. In the first semester of 2011, Johma transported 189.210 crates from the customer to the cleaning facility and 206.865 crates from Habé to the production facility in Losser, and so the transportation costs were almost €33.000. The second semester of 2011 Johma paid for each truckload €225, no matter how many crates where piled in a truck. Johma ordered 56 vehicles to bring the RTI to the cleaning facility and 67 vehicles to transport the crates to Johma. In total around 393.000 crates where transported at a total cost of €27.675. Therefore, the total expenditure on transportation of the reverse RTI-flow is over a €60.000 in total.

The decrease in transportation costs during the second half year is not expected to be a structural savings opportunity. Under the new pricing strategy it is cheaper to transport CBL-08 but more expensive to transport CBL-23 due to size differences. This becomes a disadvantage in the future. Johma expects an increase in CBL-23 and zero demand for CBL-08 based on customer orders. This will compensate for the 'gain' during the second half of 2011.

Overhead costs

There are still some costs remaining which cannot be attributed to one of the discussed categories. For example, storage space, handling costs, administrative costs and financial costs. For this analysis we do account for the capacity of Johma's warehouse but we do not put any price on the square meters used. We do include the capital costs of the invested amount in deposits paid to Pool Service. A cost of capital (COC) of 5% is suggested by the financial department (we come back to this assumption in Chapter 5) which means a current yearly cost of €7.500. Other overhead costs are considered out of scope or irrelevant to this research and therefore excluded for further analysis.

3.6 Conclusions

With the presented overview on the different cost factors, an answer can be given to the research question: how are the main RTI used in the current situation and what costs are involved? This conclusion can be drawn on the total costs for 2011 of which a calculation can be found in Table 3. As can be seen, Johma spends roughly €139.500 on the reverse RTI-flows in 2011.

Cost category	Amount	% of yearly costs	Frequency
Cleaning costs	€37.000	27%	Yearly
Rental costs • LTR • STR	 €150.000 €6.000 €19.000	 - 4% 14%	 Single investment Yearly Yearly
Storage costs	€10.000	7%	Yearly
Transportation costs	€60.000	43%	Yearly
Capital costs	€7.500	5%	Yearly
Total expenses	€139.500	100%	Yearly

Table 3: Total costs

In Chapter 6, we present a model that aims to decrease the relevant costs in RTI-management. To do this, we need to make sure that we understand the factors influencing the different cost categories displayed in Table 3. The cost factors show three relations, each relation is discussed briefly.

1. Transportation, storage costs and rental costs
   High truck utilization and low inventory balances at (intermediate) locations is not going hand in hand. If the truck utilization goes down (and the number of replenishments up) the transportation costs will rise. On the other hand, the average inventory level decreases and thereby the storage and rental cost factors as well. In order to minimize transportation and inventory costs we can use the literature presented in chapter 4 on Inventory Routing Problems (IRP).

2. Long-term rental and short-term rental costs
   The price paid for the use of crates and the stakeholder that receives this income are the only two differences between LTR- and STR-crates, the physical product is equal. Therefore Johma should optimize the budget spend on each RTI-type contracted. If the forecast is reliable, Johma can balance the costs for LTR- and STR-costs in the long run. Section 4.4 discusses the theory of Kirby (1959) on fleet decomposition. In section 5.4, we discuss the situation of Johma in 2011 based on the method of Kirby (1959).

3. Rental and capital costs
   As discussed in the previous relation, an important difference between LTR- and STR-crates is the cost factor. The costs for long-term rental are influenced by costs of capital invested in the deposit paid at the start of the contracts. To make a better trade-off between these two types of crates, we present a sensitivity analysis on the Cost of Capital in section 5.4.

There is no relationship between the cleaning costs and other cost factors. The cleaning costs are determined by two factors which cannot be influenced by efficient RTI-management. The price paid at the cleaning facility is settled in contractual agreements and the actual demand is assumed to be given and leading. For this reason, we exclude the cleaning costs in further analysis.

Now we know the existing relationships, the constraints and the decisions that have to be made, it is time to review the literature.

Keep the “Hard Workers” moving!

4 Literature Review

To determine how Johma should manage the RTI in the future, a literature study is performed. The results are presented in this chapter. The first part is dedicated to general literature on reverse logistics and the RTI cycle model, followed by a closer look to the function of inventories and their rental costs. We conclude with literature on the Inventory Routing Problem.

4.1 Forward and Reverse Logistics

In literature two types of logistic flows are defined, the forward flow of products and the reverse flow of, for example, packaging material or remanufacturing. We refer back to Figure 2 from Section 1.3 on the cycle of RTI-crates, it is clear that for RTI-crates we have to deal with forward and reverse logistics combined. The items are circulating from the supplier to the customers and are returned via a cleaning facility, back into the production process of the supplier. To understand the impact of circulating products, we start with two definitions on forward and reverse logistics.

Forward logistics is defined as "Part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services and related information from point-of-origin to the point-of-consumption in order to meet customers' requirements" (Council of Supply Chain Management Professionals, 2011). If we relate this to the case study of Johma, this definition refers to the processes starting at the purchase of, for example, raw materials at the vendors until the actual delivery of products at the customer locations.

Many researchers published definitions to answer the question 'What is reverse logistics?' The Reverse Logistics Execution Council uses the following definition of reverse logistics: "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or of proper disposal" (Rogers and Tibben-Lembke, 1998). The reverse flow may consist of both product and packaging. The reverse flow in the case study of Johma starts at the customers who hold inventories of RTI and finishes as soon as the RTI arrive at the cleaning facility. From this point of origin, the forward flow takes over again and the RTI re-enters the production process of Johma.

We identify two main differences between forward and reverse logistics described in literature:

1. The number of origin and destination points
   Fleischmann et al. (1997) pointed out that: "One of the largest differences between forward and reverse logistics is the number of origin and destination points. Whereas forward logistics is generally the movement of product from an origin to many destinations, the reverse movement of a product is the opposite, from many origins to one destination." (Fleischmann, 1997).
2. The type of driving force that influences processes
   In the forward logistics, this flow of remanufactured products to the customers is demand-driven, and the reverse flow of used products from the customer to the recoverable manufacturing system is supply driven (Flapper, 1995). This supply-driven flow creates uncertainty with respect to the quantity and timing of items. Since the supply may be out of direct control of the company, it may be difficult to forecast the quantities available at a certain point in time. Several authors have addressed the problems of forecasting returns (Goh, 1986).

The definition, the differences and the classification of forward and reverse logistics within Johma lead us to the two major issues in our case study:

1. To ensure available RTI at the production facility of Johma, the RTI is collected by MFFL (sometimes on request of the customer) and transported to the cleaning facility regularly. The rental and transportation costs are paid by the suppliers, in this case Johma. To minimize total costs, some insight in the dispersion of RTI among the customer locations is important. This information can be used for decision making on the quantities, timing and pick-up locations for a certain time period. As stated in the problem description of chapter 1.2, Johma has limited information on this to ensure good decision making and on top of that, it is hard for Johma to control the number of items circulating at her customers. Controlling the number of items at the customer is hard because of two reasons:
   - The internal lead time at the customers are long, not easy to influence by Johma and difficult to forecast.
   - The customer paid deposit for the RTI and has no further obligation or interest to return the RTI to the supplier who brought them. As a consequence RTI can 'disappear' as soon as they are collected by another supplier, not Johma. We will refer to this process as an exogenous process in Chapter 6 and Chapter 7.
2. A closed loop consisting of both the forward logistics with products to the customer and the reverse logistics of RTI from the customer through Johma (via a cleaning facility) is not obvious due to the uncertainty in supply. This management control problem in a closed-loop environment can be simplified by reducing the uncertainty in product returns (Savaskan et al., 2004). Or as Savaskan et al. (2004) mentioned that if a firm does not properly organize its access to used products, it cannot benefit from remanufacturing. As discussed at the previous issue, the relation between the forward flow of RTI and the moment these RTI are available at the customer is not clear. The risk of shortages at the production facility is covered by the possibility of additional short term renting of RTI at the cleaning facility. Nevertheless, this STR-RTI, increases the spend budgets enormously and creates the risk of neglecting the importance of thoughtful RTI-management. Costs increase gradually, but are not noticed as long as there are no shortages.

To conclude on these two issues, the uncontrollable external environment in which the RTI-pool is situated and the uncertainty of supply causes a yearly increase in RTI-costs. Chapter 5 provides an in dept analysis of the reverse flow of RTI in 2011 in which this effect is discussed numerically. In the next section we provide information on the different pooling models found in literature to get more insight in the implications of participating in a pooling system.

4.2 RTI Cycle Model

In section 4.1 we already introduced the term 'closed-loop'. However, we did not gave an definition because there are multiple models available to relate the forward and reverse flow of RTI. We look at how RTI cycle and who participates in that process. While there are many variations in RTI cycle models, they can be considered as belonging to one of three broad categories: closed loop, open loop and pool model, see Figure 7 (Motorola Solutions, 2010).

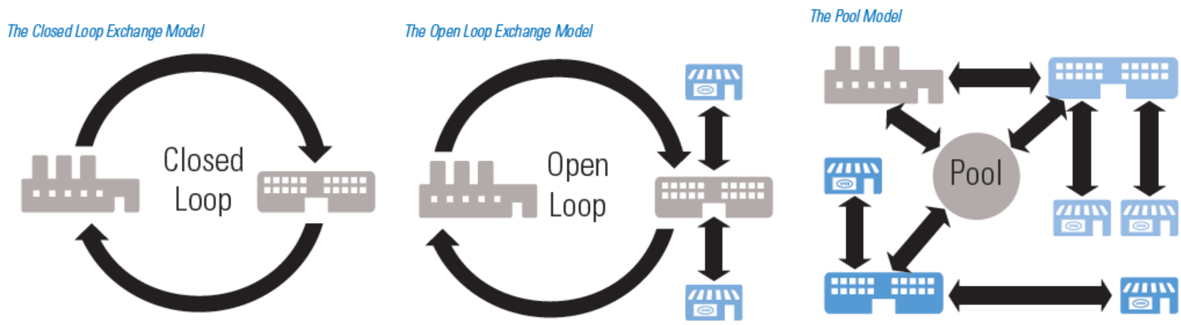

Figure 7: RTI Cycle Models

The closed loop model
RTIs are exchanged between two parties that are members of the same organization, for instance, moving parts from inventory to the manufacturing location.

The open loop model
An open loop exchange involves two or more companies who work together as trading partners, as when a manufacturing plant ships to regional distribution centers, which then deliver the product to retail customers. The RTI are typically owned by the originating shipper, who depends on regular return of empties through the supply chain.

The pool model
A pool operator owns the RTIs that cycle between the players. The operator matches quantity to their traffic needs. RTI can be pooled between a number of customers and manufacturers, with various options for accounting:

- *Variable pool*: The operator tracks the volume of RTIs issued and returned, charging the user per unit circulated.
- *Dynamic pool*: Each supplier is provided a dedicated, often uniquely branded pool of RTIs at a fixed price. They may be additional per-unit charges for special services from the pool operator, such as washing and logistics management. This pool is dynamic in the sense that the number of dedicated crates ‘in the pool’ versus ‘stored in the central warehouse’, changes over time.
- *Pool brokerage*: A brokerage can operate as either a variable or dynamic pool. Suppliers are invoiced directly for the RTIs they load, with customers paying a commissioned contribution to operating costs.
- *One way rental*: The pool operator charges suppliers a variable price on a ‘per trip’ basis, with the operator responsible for collecting empty units after delivery.

The model in which Johma participates is a combination of two pool-models, the variable pool and the dynamic pool. The crates rented on a LTR-basis belong to a dynamic pool of crates. The LTR-crates are reserved and guaranteed for the products of Johma at all times as long as the balances are positive and Johma pays a yearly fee. In periods of relatively low demand, the LTR-RTI is stored in a warehouse. In case of peak demand in which the LTR-RTI cannot fulfill demand (completely), Johma enters an additional variable pool at the cleaning facility.

The management problems of participating in a pool model are various, for example:

- The players are independent of each other and their processes and data are not synchronized. The processes of RTI audit and tracking are often performed manual, relying on paper documents and are therefore prone to error.
- The individual units cannot be tracked through the exchange system and so the pool manager cannot know the condition, demand or availability of RTI until they actually arrive. This makes it difficult to anticipate and prepare for fluctuations.
- The players tend to keep RTIs longer than they are needed, resulting in longer cycle times and unnecessarily high inventories (Motorola Solutions, 2010). The uncertainty and lack of information keeps the overall level of RTI higher than would be stricktly necessary to fullfill demand.

The difficulties of RTI-management within a pooling environment makes optimization hard. Especially the unpredicable relation to other suppliers creates a situation in which it is hard to grasp where the RTI flows and how many inventory is required. The purpose of inventory is discussed in Section 4.3.

4.3 Inventories of RTI in the Supply Chain

Inventories are a key element to prevent shortages that may lead to interruptions of, for example, a production process. The higher intermediate inventories, the more RTI is rented. To understand the purpose of inventory we introduce six broad decision categories of Silver et al. (1998), that aim to increase control of the aggregate inventory level (Silver et al., 1998). Discussion of the different categories explains the existence of inventory and their necessity. We conclude with some ideas to decrease the total average stocks along the supply chain of Johma.

Cycle Inventories
There are two types of cycle stocks, production lot sizing stock and transportation lot sizing stock (Silver et al., 1998). In production, the frequency of runs is an important determinant. In case of low setup times and low costs, it will be optimal to produce small batches that cause low cycle stocks. The contrary applies as well. For transportation to be optimal, a trade-off has to be made between the shipment quantity and transportation costs (Stadtler and Kilger, 2008). A reduction in transportation costs will increase the number of shipments and decrease thereby the cycle inventory.

Congestion Stocks
Inventories that exist due to competition among items because of limited capacity are called congestion stock (Silver et al., 1998). This is not applicable is the situation of Johma's RTI inventories, because there is no controllable process in which the items need the same production equipment. This might be the case at the cleaning facilities internally, but this is not important for this analysis due to agreements that RTI are always available within 1 day (only in case of positive balances).

Safety Stock
Safety stocks are hold to cover for uncertainties in demand and supply (transport disruptions, forecasting errors, and lead time variations). More safety stock generally means less risk on getting out of stock and therefore an increase in the level of customer service (Silver et al., 1998). Safety stocks are not required if the future rate of demand and the delivery time of an order are deterministic.

Anticipation Inventories
The stock intended to accumulate in advance of an expected peak in sales (for example seasonal fluctuation around Christmas), or in general, for situations in which the rate of supply is likely to be lower than the rate of demand (Silver et al., 1998).

Pipeline Inventories
The goods that are in between two levels of a multi-echelon distribution system (inventory in transit) or between adjacent workstations (work-in-process) in a factory are called pipeline inventories. According to Little's Law, this inventory is proportional to the usage rate and the transit time between the two locations. If throughput is the average number of completed jobs per unit of time, then (Silver et al., 1998)

$$Work\ In\ Process = Cycle\ Time \times Throughput$$

The two key insights of Little's law that are important to remember are that 1) an increase in WIP increases the average throughput until the maximum throughput of the bottleneck is reached and 2) cycle time increases with WIP.

Decoupling Stock
This last type of stock permits the separation of decision-making at two inter-dependent locations and reduces the need for output synchronization (Silver et al., 1998).

Stocks protect organization from additional costs, like with cycle inventories, or create extra possibilities to increase revenues, like for example with anticipation stock. This means that the overall goal is not to eliminate inventory but to balance it with the costs and benefits. An important lesson is that inventory should only be present in the supply chain in case it has a function, like prevention of breakdowns. In Chapter 5, we calculate the number of RTI by using Little’s formula. To keep this number low, it is important to balance demand and supply in order to keep the items flowing through the supply chain, like it mentioned in the title of this report. Information on the status of the inventory along the supply chain is a starting point for decision making and decreasing the total amount of required items.

Johma has a coping mechanism to the uncertainty of re-supply; in case there are not enough RTI available, additional RTI can be rented on a short term basis. To minimize the extra costs of STR, it is important to make a good decision on the number of RTI contracted for the long term (say, for example, 1 year ahead). This is the subject for the next section.

4.4 Long Term versus Short Term Rental costs

The question we would like to answer in this research is about the optimal split of LTR- and STR-RTI. A similar problem was solved by David Kirby in 1959, which is known as one of the classic fleet composition problems (Sussams, 1992). This problem is about the question on how many wagons should be bought versus the number that can be hired on a weekly basis. The solution of Kirby (1959) states:

“If hired wagons are k times as expensive as owned wagons, then wagons should need to be hired on exactly one day in k days.”

Kirby (1959) proofs this by minimizing the total cost function, including the probability of a certain demand level. Suppose the fleet consists of n wagons, each costing 1 unit per day, hired wagons costing k units per day, and suppose that on any day x wagons are required with probability p(x). Then,

$$\int_{n}^{\infty} p(x)dx = \frac{1}{k}$$

To determine how many LTR-crates should be available to serve all customers during the year we apply the rule of Kirby, the simple rule to assess whether the pool of LTR-crates for Johma is the right size (Kirby, 1959) becomes:

“If STR-RTI is k times as expensive as LTR-RTI, then STR-RTI should need to be hired on one day in k days.”

The optimum involves using LTR-crates plus or minus some peak STR-crates, depending on the relative costs of LTR- and STR-crates. The implications of this rule become clear in the calculations presented in Section 5.3, including some sensitivity analysis on the importance of the ratio k.

4.5 Inventory Routing Problem

The discussed literature so far is useful for data analysis in Chapter 5. This analysis provides a lot of information on current practices and flaws. To improve future situations, daily decisions should be in line with the overall objective to decrease relevant costs by maintaining availability of RTI for production. To realize a trade-off between transportation costs, holding costs and rental costs, we are looking at the effects of inventory management on transportation management and vice versa. This section discusses an area in which this trade-off is a key element, the area of Inventory Routing Problems.

Transportation managers aim on high truck utilization while inventory managers aim for low inventory levels. The result may be many small replenishment orders and much different freights. The exchange curve in Figure 8 shows the relationship between the costs of transportation and inventory. As the number of replenishments goes down, the order quantity increases. Hence, the inventory level goes up and the transportation costs decline (Savelsbergh, 2012).

In conventional inventory management systems, the customer monitors its inventory levels and places an order in case balances are too low compared to the expected demand. The supplier, who produces the required goods, assembles the order, loads a vehicle and delivers the product according to an (optimal) routing schedule. This situation may lead to a lot of variation and thereby unbalanced workloads, a relative low average utilization of resources and unnecessary high transportation costs. To overcome the disadvantages, some companies make a switch to Vendor Managed Inventory (VMI) in which the customer trusts the supplier to manage its inventory. In VMI the supplier sets the replenishment policy and decides on the timing, quantity and transportation mode in order to decrease total costs (Savelsbergh, 2012). VMI creates savings for suppliers who are able to coordinate the deliveries to different customers more effectively.

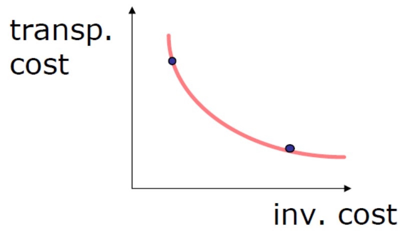

Figure 8: IRP trade-off

Determining a solution in which inventory control and vehicle routing are integrated into a cost-effective strategy for the distribution of products, is known as the Inventory Routing Problem (IRP) (Li, 2010). The objective of IRP is minimizing distribution and inventory costs without causing any stock-out occasions over a finite horizon (Savelsbergh, 2012).

In the most basic form, an IRP has one production facility (see Figure 9), a single product and n customers who are delivered by a fleet of m homogenous vehicles with a fixed capacity Q. For each customer the storage capacity, the initial inventory, and the demand rate or probability distribution of demand is known in advance. Possible extensions are found in, for example, problems with delivery time windows (Savelsbergh, 2012).

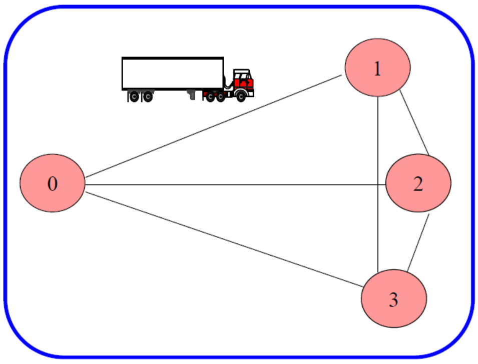

Figure 9: Single plant IRP

Generally, inventory and transportation policies assign customers to routes and then determine the replenishment timing and collection size for each customer (Moin et al., 2010). The solution approaches can be divided in two directions, the cases with deterministic demand and the ones with stochastic demand (Savelsbergh, 2012).

- <u>Deterministic demand, based on the expected average demand.</u> To find a solution, there are two phases, one in which is determined which customers receive a delivery on a specific day of the planning horizon. And a second step in which the precise delivery route is created. This situation can be modeled on a rolling horizon basis.
- <u>Stochastic demand, based on the probability distribution of demand.</u> The key issue is the problems arising from the variable delivery quantities. Possibilities to overcome the situation are to increase the delivery amount, decrease the delivery amount of postpone deliveries to upcoming days. This makes it nontrivial to determine what the maximum amount of products is that must be delivered to a specific predetermined route.

For a complete overview of literature on instances of the Vehicle Routing Problem, we refer to Moin and Salhi (2007) (Moin and Salhi, 2007). We discuss the problem considered by Lee et al. (2003) and Moin et al. (2010), by giving a short summary followed by a comparison between this article and the problem we solve.

Dynamic Inventory Routing Problem

Lee et al. (2003) presents a class of the IRP with multiple suppliers and an assembly plant in an automotive part supply chain. Each supplier supplies a distinct product and the objective is to minimize the total transportation and inventory cost over the planning horizon. The problem is formulated as a Mixed Integer Linear Programming (MILP) model. Simulated annealing is applied to generate and evaluate the alternative routes after which the model reduces to a Linear Programming model. This LP model is solved and determines the optimum inventory level of each product (Lee et al., 2003).

Model formulation (Lee et al., 2003):

1. "Each supplier provides one part type, whose demand is part specific, deterministic, and varies over time;
2. No backordering is allowed since it will incur excessive cost;
3. Part-specific unit holding costs at the assembly plant are given for each part type and inventory cost at the suppliers is not considered;
4. An unlimited number of capacitated and identical vehicles are available at the depot and all vehicles have to return to the depot upon completion of a route;
5. The locations of the assembly plant, the suppliers, and the depot are given and fixed;
6. The route length for any truck may not exceed a user-specific limit;
7. The transportation cost per trip consists of a fixed charge incurred for each trip plus a variable cost proportional to the travel distance;
8. A supplier may be visited by one or more trucks in any given period;
9. The planning horizon is finite and given;
10. The production system supplies unlimited quantity of parts at any time."

The problem solved with the MILP formulation of Lee et al. (2003) shows a lot of similarities with the case study of Johma, when the suppliers of automotive parts resemble the customers of RTI. The similarities like products flowing from multiple origins to only one destination, the cost structure and the deterministic demand return in the problem formulation in Chapter 6. There are three main differences:

1. The customers of Johma hold inventory of multiple products (that, on top of that, overlap between different customers);
2. The number of items circulating influences the rental costs;
3. Routing issues are not considered in the case of Johma.

Routing is assumed to be irrelevant because the fleet and customer numbers of MFFL are big enough to come up with efficient routings and combinations of different orders itself. The transportation costs are included by looking at the distances between the customer locations and the cleaning facility in Holten. This trip fee is assumed to include possible scaling advantages, benefits from efficient combinations and absorbs the extra costs for necessary empty movements.

4.6 Conclusions

The research question for this chapter is: How should the RTI be handled in a supply chain according to the literature? This answer can be subdivided into three broad categories, namely: characterization of the context of RTI-management, required items in the supply chain and improvement strategies for future usage.

Characterization of the context

Section 4.1 shows that in reverse logistics, we usually have to deal with products that flow supply driven, from many origins to one destination. Reduction of the uncertainty in the return flow is a big challenge for reverse logistics. In the situation of Johma, the forward and reverse logistic processes have to be connected. Meaning that inventory and maximum pick-up quantity at the customers is treated as a deterministic input parameter that closes the loop between the forward and reverse flow.

Nevertheless, the forward flow is not influenced by the management practices concerning the reverse flow. The RTI cycle model applied has implication on the routing of the reverse flow; we discussed the possible configurations in Section 4.2. The RTI of Johma is part of a pooling system in which a lot of suppliers and (their) customers participate. The consequence of a pooling system, combined with a deposit system, is that the RTIs are uncontrollable for the supplier upon delivery at the customers' site. The crates rented on a LTR-contract belong to a dynamic pool of crates. The outstanding balance is dedicated for Johma and available for pick-up at all times, in periods with relatively low demands, the LTR-RTI can be stored in the warehouse of Habé. In periods with peak demand it may happen that the LTR-RTI cannot cover for this fluctuation and additional STR-RTI should be hired. The STR-RTI belongs to a variable pool that fluctuates every week. The reverse flow of RTI, in this uncontrollable external environment, with a cost structure that puts the (financial) risks/responsibilities of renting RTI at the suppliers is an important issue to solve for Johma.

Required RTI in the supply chain

The forward flow is connected to the reverse flow and vice versa, this means the RTI cycles through the supply chain of Johma (and other suppliers) and (their) customers. A decrease in the rental costs can be achieved by using less RTI. For this reason we looked in Section 4.3 for the reasons to keep inventory. From this perspective we concluded that stocks protect organization from additional costs or it creates possibilities to increase revenues.

It is important to balance demand and supply in order to keep the items flow through the supply chain, like is mentioned in the title of this report. Information on the status of the inventory along the supply chain is a starting point for decision making and decreasing the total amount of required items. Therefore a detailed analysis follows in Chapter 5. The method of Kirby (1959), described in Section 4.4, describes the optimal split between LTR- and STR-RTI. We return to this in Section 5.3.

Improvement strategy for future usage of RTI

A trade-off between transportation, holding and rental costs is necessary to decrease total budgets spend on RTI-management. Determining a solution in which inventory control and transportation management is integrated in a cost-effective way is known as the Inventory Routing Problem (IRP). IRP models described in literature can be classified according to planning horizon, demand characteristics and the number of items. The main differences between the case study of Johma and the discussed model of Lee et al. (2003) are, 1) the customers of Johma hold inventory of multiple products (that, on top of that, overlap between different customers), 2) the number of items circulating influences the rental costs and 3) routing issues are not considered in the case of Johma. The model of Lee et al. (2003) forms the basis of the instance of an IRP model that we present in Chapter 6.

5 Data Analysis

Analysis of available data on RTI transactions in 2011 illustrates how better RTI-management can lead to improvements in the rental policy of Johma. In this chapter, we continue where we stopped in Chapter 3, in which we described the different cost factors. After a short explanation on the data collection in Section 5.1, we look at the RTI transactions for each RTI-type separately to explain the current situation and associated problems in Section 5.2. Section 5.3 presents the different factors influencing the total rental costs, like the optimal split between LTR- and STR-RTI and the effect of a certain cost of capital (COC). The chapter concludes with a description of the method to determine the minimal rental costs and an overview on the calculated figures of 2011.

5.1 Data Source

A figure on the RTI flow model of Johma is given in Section 3.3; Figure 10 contains a simplified version of this model. Three different transactions (arrows) are displayed; we refer to them in the following as Johma outbound, Habé inbound and Johma inbound. Data on each of these flows is required for analysis. All data is collected in an Excel-file, the results and figures are discussed in the next sections.

Johma outbound

We need information on the demand pattern incurred at the production facility of Johma. To determine the demand pattern we look at the data on customer deliveries from the ERP system. In case we would like to estimate future demand we can use the forecast of RTI demand, provided by customer service and the planning department.

The demand data downloaded from the ERP system that could be used in case of forecasting, represents the number of specific crates actually shipped to a certain customer at a given day. The crates used internally at the production facility are not included in this demand data and should therefore be added to this realization from the ERP system. The crates used for internal purposes at the production facility are, like the other RTI, cleaned externally and therefore transported from Johma to a cleaning facility of Habé.

Habé inbound and Johma inbound

We rely on data provided by Habé and MFFL to get more insight in the RTI-flow between customers and Habé (Habé inbound), and from Habé back to Johma (Johma inbound). The transactions are recorded in invoices of MFFL and transaction reports of Habé. Information from both sources is checked, combined and added to the data for further analysis.

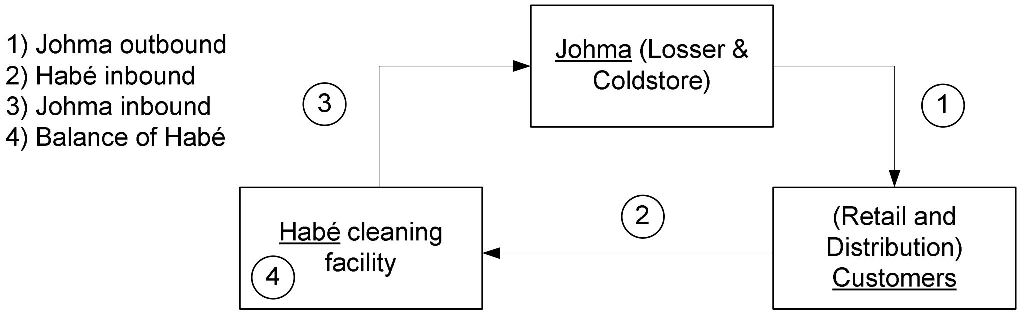

Figure 10: Definitions data labels

Balance of Habé

In Section 5.2 we will refer to ‘Balance of Habé’ as the differences between the numbers of crates flowing inbound respectively outbound at Habé.

5.2 RTI Transactions

All RTI-types are discussed separately after a minor introduction with some general background information and a central explanation on the figures. The important numbers are summarized for each product and some background information and/or conclusions on the figures are given.

General information

Almost all food producing companies and retailers are using the RTI for secondary packaging. The number of involved parties makes it difficult to isolate and control the RTI used by Johma. The amount of LTR-RTI used in the Netherlands is displayed in Table 4, almost 24 million in total. As mentioned in Chapter 3, Johma used over 400.000 cleaned crates in 2011. Pool Service indicates that the RTI have an estimated rotation speed of 15 cycles a year. From this figure we estimated that Johma used less than 30.000 different crates to fulfill demand. If we compare this number against the total number of RTI rented in the Netherlands, the share of Johma becomes negligible. Only 0,13% is dedicated to Johma.

RTI-type	LTR-contract
CBL-07	7.160.015
CBL-08	4.826.900
CBL-11	4.626.900
CBL-15	1.510.700
CBL-17	3.311.221
CBL-23	2.472.220
Total	**23.907.648**

Table 4: CBL in the Netherlands

When MFFL delivers a customer order, the situation at each customer's location can be described by one of the following:

- The customer is not a pool member and therefore switches the received crates immediately with MFFL.
- The customer is part of the pool and notifies the received RTI in the pool management system and pays a deposit fee to the supplier.
- The crate is neither registered nor switched. The supplier invoices the deposit of the delivered RTI, but unfortunately, the customer does not return the crate immediately. These items are often never returned, meanwhile the supplier keeps paying the yearly pool fee and in the end extra STR-costs due to the outstanding balances.

Unfortunately, there is no complete administration available on the current balance of Johma with respect to all customers

The deposit system in combination with many pool participants created a situation in which the relation between customers that receive RTI from Johma and the pick-up locations has vanished. Customers act as if the RTI in their warehouse belongs to them and suppliers prefer to collect RTI (only) at locations nearby their cleaning facility. A cluttered situation.

Not only is the inventory position of RTI in the supply chain increasing the complexity, also the associated transportation to the cleaning facilities contributed to this. Figure 11 shows that it is not an exception that freights of RTI are not transported to the closest cleaning facility. The RTI is transported across the Netherlands to a cleaning facility that is close to the next customer of MFFL, which is not always Johma. To overcome these extra miles, a cleaning facility in Holten, next to MFFL is opened in week 48 of 2011. This cleaning facility is expected to influence future routing of RTI positively.

Two preliminary conclusions are important, 1) there is no direct relationship between the customer orders from Johma and the pick-up locations visited and 2) RTI flows are influenced by other pool participants. To get more feeling on the use of RTI by Johma, it is time to look at each RTI-type separately and more closely.

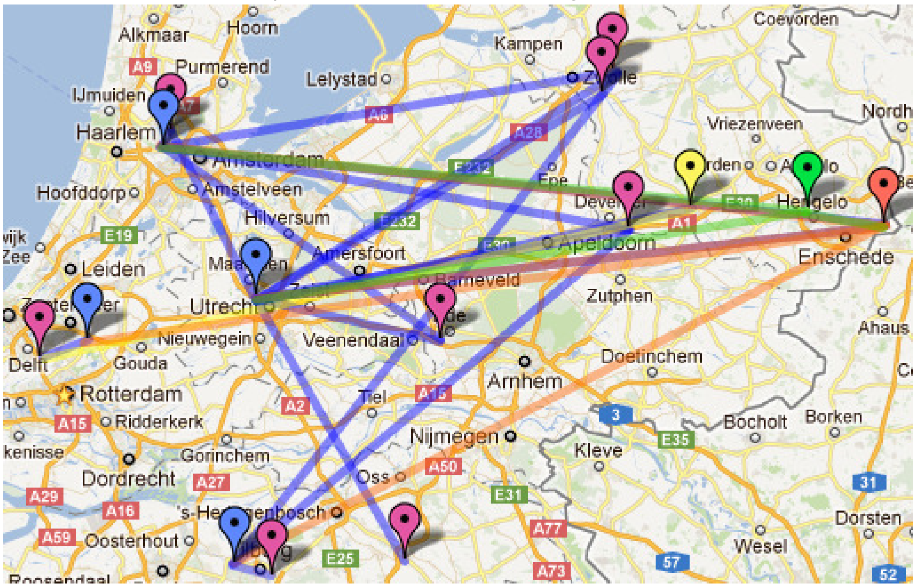

Figure 11: RTI freights in the Netherlands

Explanation on the figures

The figures 13-18 of this section present a lot of data at once. The data categories are comparable for each RTI-type and therefore we give some general explanation first.

The x-axis of each figure displays the time (in weeks) and the y-axis resembles the amount of RTI. All figures contain four data series which are introduced in Section 5.1, namely:

1. Habé Inbound
2. Johma Inbound
3. Johma Outbound
4. Balance at Habé

The series illustrated by bar graphs, represent 1) the truckload movements between customers and Habé (Habé Inbound) and 2) the freights between Habé and Johma (Johma Inbound). The height of a bar in a certain week represents the number of RTI that flows into Habé respectively into Johma. Due to the possibility to combine multiple RTI-types in one truckload it happens that these bars are smaller than may be expected from a full-truckload. Of course it is also possible to record an amount of RTI that is larger than one truckload if there are multiple RTI-shipments in one week. The two line series represent 3) the demand incurred at Johma (Johma Outbound) and 4) the balance of Johma at the Habé cleaning facilities (Balance at Habé). The demand includes the customer orders and the shipments of RTI from the production facility to Habé (refer again to Section 5.1 for further explanation). To understand the meaning of the registered balance at Habé we give some examples.

- The balance at Habé represents the difference between the number of inbound RTI at Habé and the number of RTI flowing to Johma. If we look for example, to Figure 12, we see that the line increases in the same time period as an inbound shipment at Habé is registered (represented by the bar graph). A decline of the balance is visible for inbound freights to Johma, recall from Figure 10 that an inbound freight to Johma is equal to an outbound freight at Habé.
- All figures present data from 2011, the starting values of the balances contain historical transactions that make it possible to have a highly positive balance without any visible inbound shipments at Habé in the data of 2011.

- In principle, a positive balance should represent the number of LTR-RTI stored at Habé and a negative balance should mean that Johma uses STR-RTI to fulfill demand. In practice this is somewhat different as we conclude later on in this section. The problem we encounter is that Pool Service does not account properly for the number of RTI Johma can pick-up at customer locations. As a consequence, Johma can pick-up more RTI than their total outstanding balances at the customers would imply and Johma create in this way a pool of ‘free-RTI’. We call it free-RTI because Johma does not pay any rental costs. At first side it looks attractive to use free-RTI, but it has an unfavorable consequence. It makes Johma dependent because they have no legal right at all to use the RTI.

With this in mind, we look at each figure in more detail.

Results for each RTI-type separately

The usage of CBL-07 can be summarized by the following.

Customers:	3
External demand:	1.700 crates/year
Internal demand:	6.000 crates/year
LTR-contract:	16.335 crates/year
Average STR:	0 crates/week
Average RTI stored:	10.000 crates/week

As we can see from Figure 12, the number of crates outstanding at Habé lies much higher than weekly demand, it is even higher than total yearly demand of 7.700 crates. Johma paid storage costs for the inventory at Habé, €2.200 in 2011. Another cost factor is the number of LTR-crates on contract. An explanation for the gap between the LTR-contract of 16.335 crates and the number of crates stored or currently used by Johma is that not all customers return their RTI.

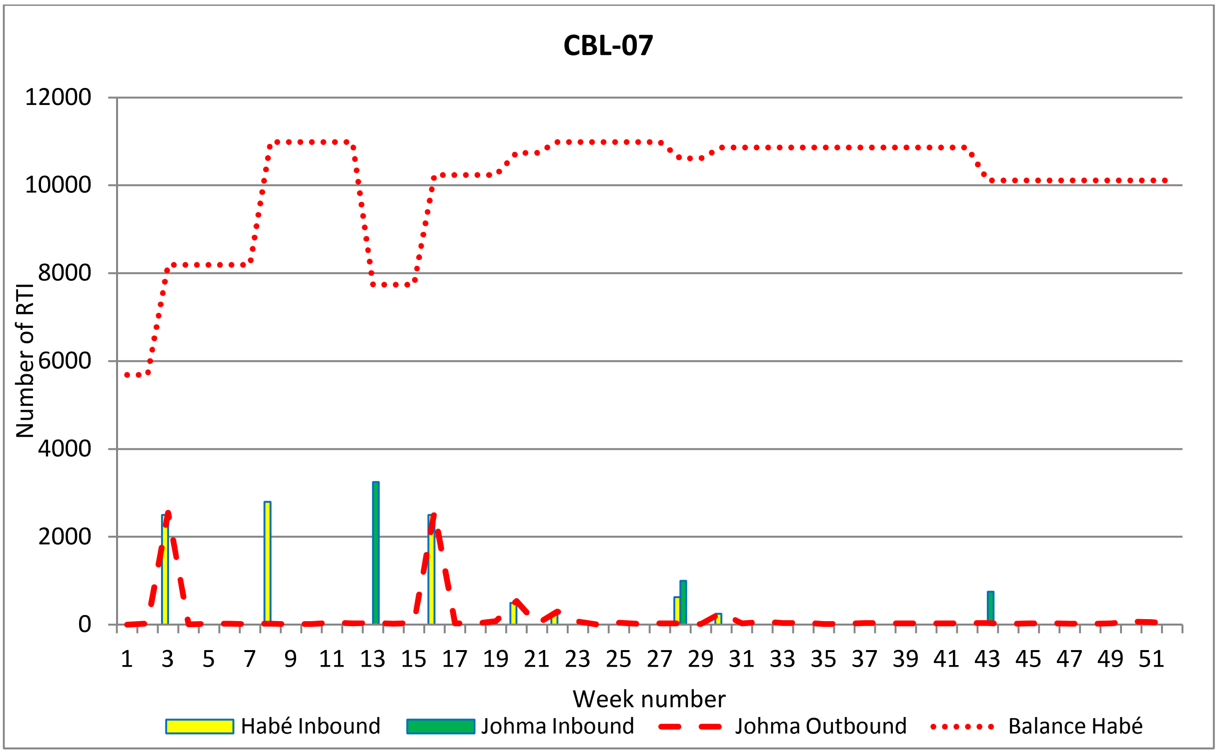

Figure 12: CBL-07 Transactions and balances

The usage of CBL-08 can be summarized by the following.

Customers:	6
External demand:	294.000 crates/year
Internal demand:	0 crates/year
LTR-contract:	0 crates/year
Average STR:	2.050 crates/week
Average RTI stored:	8.750 crates/week

The demand pattern for CBL-08 is given in Figure 13. As concluded before, Johma holds no LTR-contract for CBL-08. Therefore we would expect that Johma rents all crates on a STR-basis. In practice something else occurred. Johma got authorization of Pool Service to pick up truckloads of CBL-08 at different customer locations while their balances where negative. These crates where brought to the cleaning facility, which explains the positive internal balance at Habé given in Figure 13. As mentioned, Johma pays no rental costs for these crates. During summer and the Christmas-period Johma was not able to pick up enough crates at customer locations and therefore they hired the STR-crates of Habé to cover for demand. Nevertheless, in case the contractual agreements with Pool Service where followed, as we would have expected, Johma should have rented STR-RTI for the whole year. Of which the estimated cost are €50.000, the actual STR-costs look suddenly almost negligible small with €5.337 in 2011. This financial risk was a lot bigger.

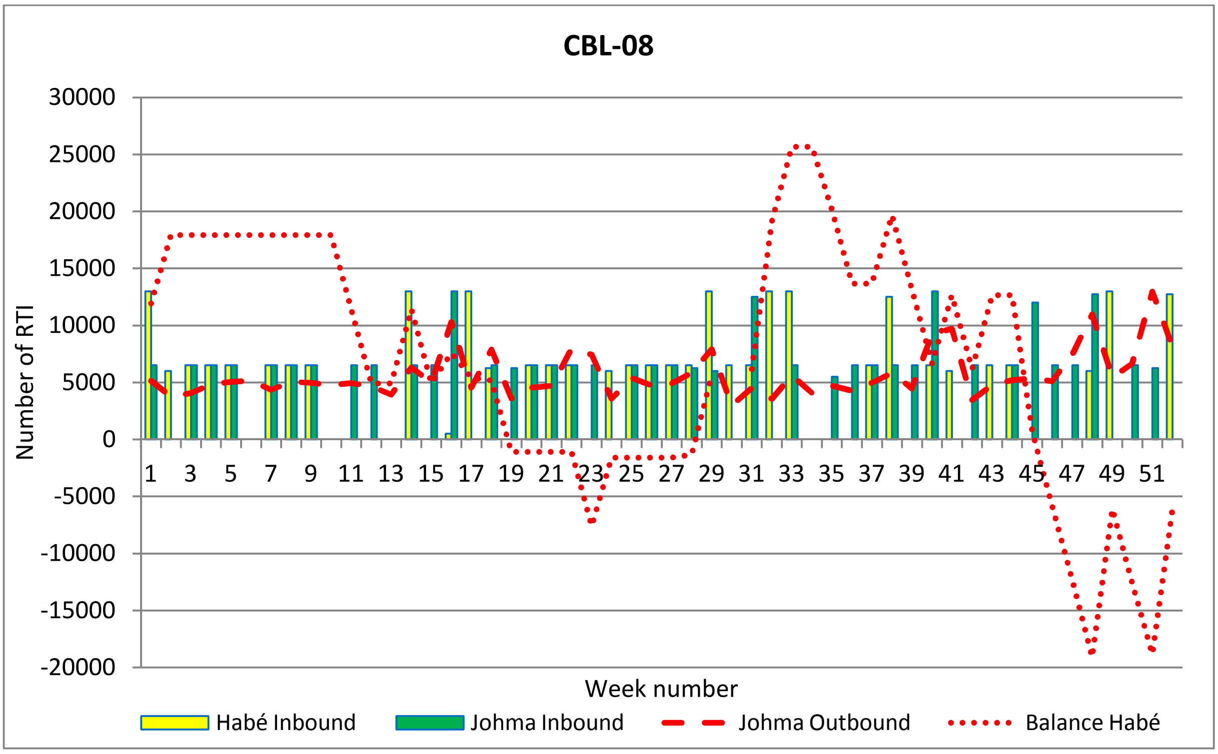

Figure 13: CBL-08 Transactions and Balances

The usage of CBL-11 can be summarized by the following.

Customers:	10
External demand:	15.500 crates/year
Internal demand:	13.500 crates/year
LTR-contract:	20.000 crates/year
Average STR:	0 crates/week
Average RTI stored:	12.300 crates/week

The demand for CBL-11 (Figure 14) is fluctuating during the year; this is caused by the internal demand and the seasonal peaks around Easter and Christmas. As we can see from the figure, the balance at Habé was always positive; this is due to the LTR-contract of 20.000 crates. For the RTI stored at Habé Johma paid €4.237 in 2011.

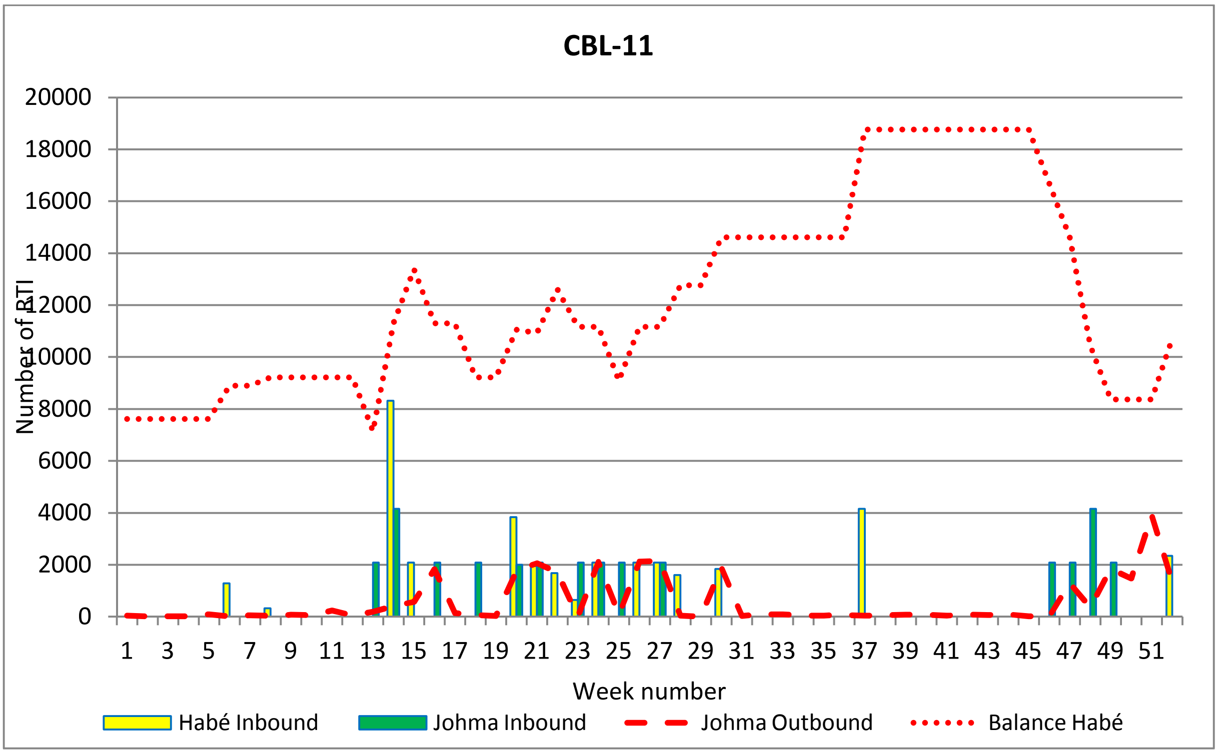

Figure 14: CBL-11 Transactions and Balances

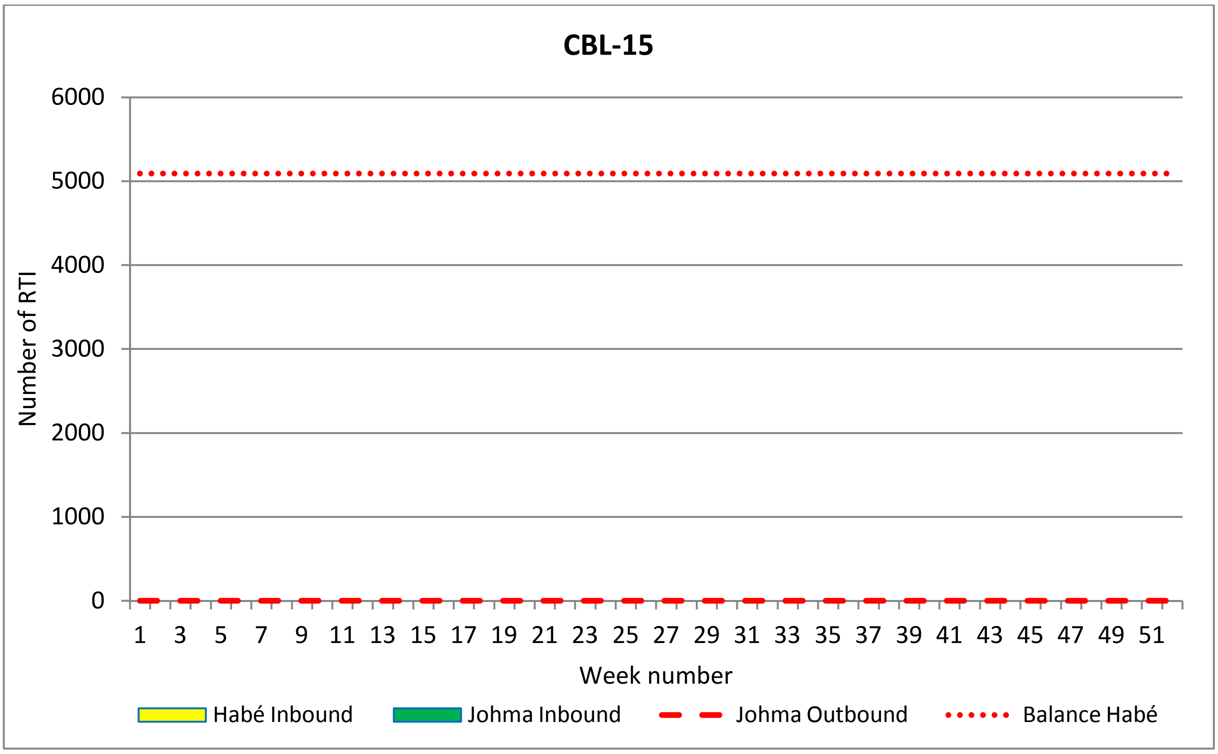

Figure 15: CBL-15 Transactions and Balances

The usage of CBL-15 can be summarized by the following.

Customers:	0
External demand:	0 crates/year
Internal demand:	0 crates/year
LTR-contract:	4.000 crates/year
Average STR:	0 crates/week
Average RTI stored:	5.100 crates/week

Figure 15 shows that the demand for CBL-15 is 0. Therefore it is curious that Johma holds a LTR-contract of 4.000 crates and picked-up an additional (authorized by Pool Service) amount of free-RTI 1.091 crates at customer locations. Johma paid storage costs for the total amount of crates €1.185 in 2011.

The usage of CBL-17 can be summarized by the following.

Customers:	80
External demand:	45.000 crates/year
Internal demand:	0 crates/year
LTR-contract:	2.000 crates/year
Average STR:	0 crates/week
Average RTI stored:	3.300 crates/week

In contrast to the discussed RTI, CBL-17 is demanded by a lot more customers, 80 in total. With a total demand of 44.860. As we can see, the demand pattern is more or less constant during the year, somewhere around 850 crates a week. The variation in Figure 16 is caused by the full-truckload deliveries of RTI and looks worse than in previous figures because of the smaller scale at the y-axis. The number of RTI stored at Habé is relatively high (on average 3.300 crates/week), since the number of LTR-crates is only 2.000. The storage costs incurred are €1.642 in 2011.

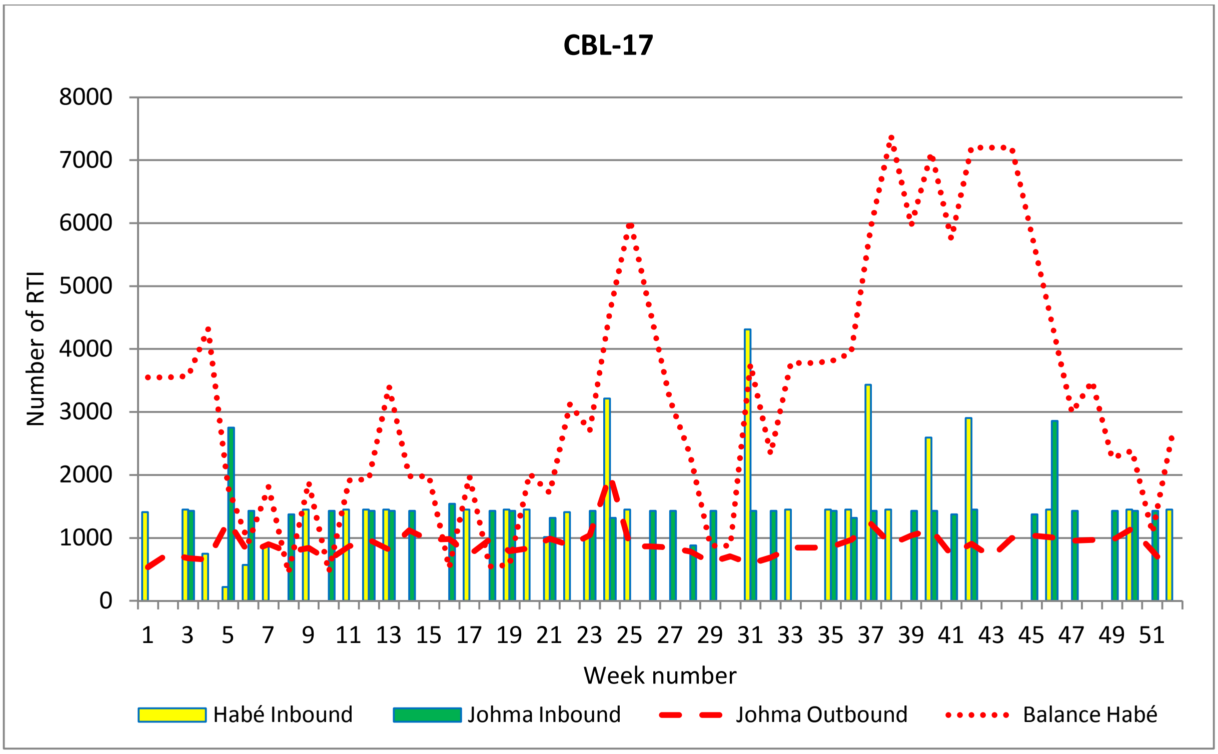

Figure 16: CBL-17 Transactions and Balances

The usage of CBL-23 can be summarized by the following.

Customers:	84
External demand:	36.700 crates/year
Internal demand:	0 crates/year
LTR-contract:	5.000 crates/year
Average STR:	5.400 crates/week
Average RTI stored:	0 crates/week

Like we have seen with CBL-17, this type is demanded by 84 customers and 36.777 CBL-23 crates in total. The rest of the story is quite different from those of other RTI: the balance of CBL-23 was negative all year round. So, there were no storage costs. It also means that Johma rented STR-crates at Habé continuously, with a total cost of €14.029. Johma needed to rent STR-crates because her LTR-crates were, most likely, circulating at the customer locations. The LTR-contract of 5.000 crates was already vanished at the beginning of 2011 and the situation got even worse, see Figure 17.

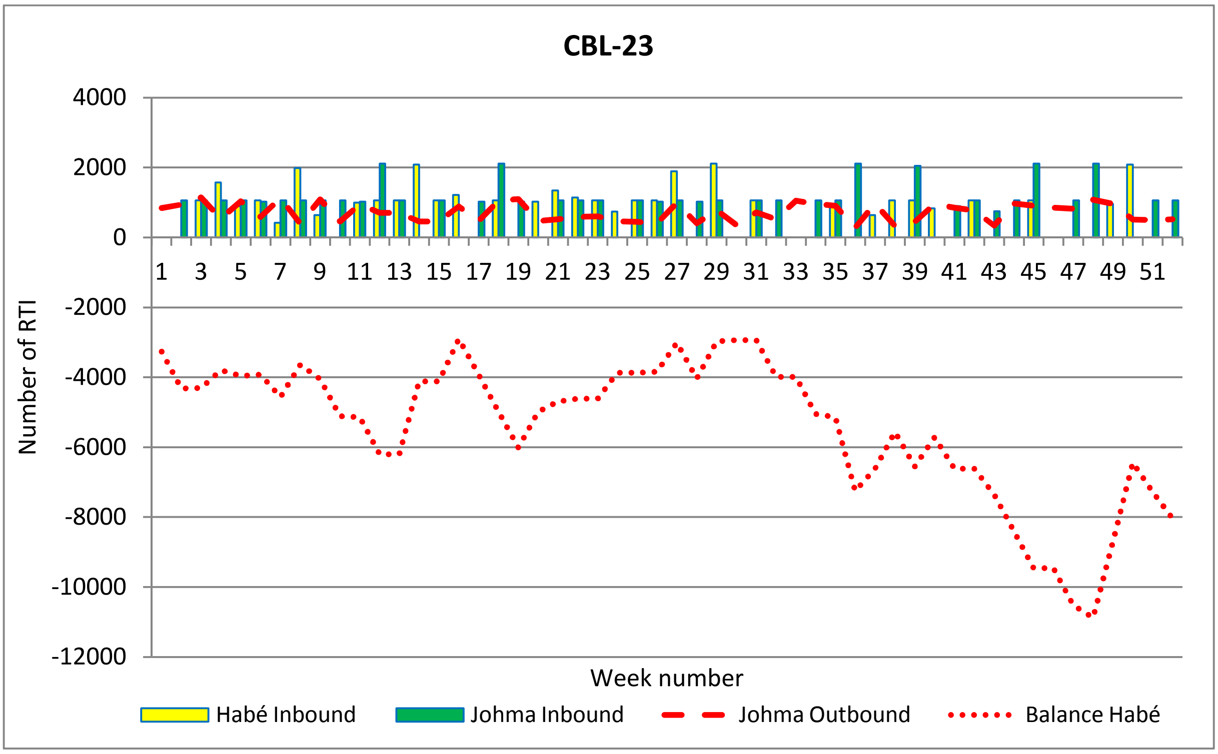

Figure 17: CBL-23 Transactions and Balances

Preliminary conclusions

As stated before, we conclude that there is no direct relationship between the customer orders from Johma and the pick-up locations visited and RTI flows are influenced by other pool participants. This influence of other participants and the fact that current contracts do not incur a yearly evaluation leads to the preliminary conclusion of this chapter: The number of crates hold on contracts is not in line with the current consumption of RTI.

In the next section we strive for some guidelines to determine optimal policies. What factors influence the number of RTI necessary to minimize total costs? What is the optimal split between STR- and LTR-crates? And what is, for example, the effect of the Cost of Capital (COC) on paid deposits?

5.3 Minimizing Rental costs

It is time to start calculating the number of RTI required in the supply chain. The optimal configuration depends on a number of criteria that we present in this section. From that, we first look for the time it takes to create/deplete a full truckload at the production plant of Johma or at the customer locations. Second we determine the optimal split between LTR- and STR-RTI based on the theory of Kirby (1959) discussed in Section 4.4. We show some sensitivity analysis on the used COC as well. We conclude this section with data on the required number of RTI as a work-in-process (WIP) for multiple cycle times (CT) and cost configurations. A summary of the method to make future decisions within Johma is given.

Influencing parameters

The configuration of the optimal rental policy depends on three groups of variables that we introduce here. Each of them is discussed in more detail in the remainder of this section.

- Required time to create/deplete a full truckload
- The proportion of LTR- versus STR-costs
- The number of RTI necessary as Work-In-Process
    - Cycle time at the customers warehouse
    - Demand pattern at the production plant

Required time to create/deplete a full truckload

The literature review on the different types of inventories in Section 4.3 shows that the longer it takes to form a batch or full truckload, the more stock is necessary to fulfill demand. If we look to the situation of Johma we can deduct three relevant situations.

1. The time to create full-truckloads at Johma
   In 2011, as we can see from Figure 18, 11 different freights were transported between Johma and the cleaning facility. In week 24 it were 2 freights due to capacity reasons. As discussed at Figure 14, CBL-11 fluctuated because of an increase in internal demand, an exceptional situation. Johma normally uses 'mandjes' to transport frozen products from their warehouse in Hengelo to Losser, but due to a shortage they decided to use CBL-11 for a temporary period. Looking at the other RTI-types it is only relevant to see how much time it took to create a truckload of CBL-07.

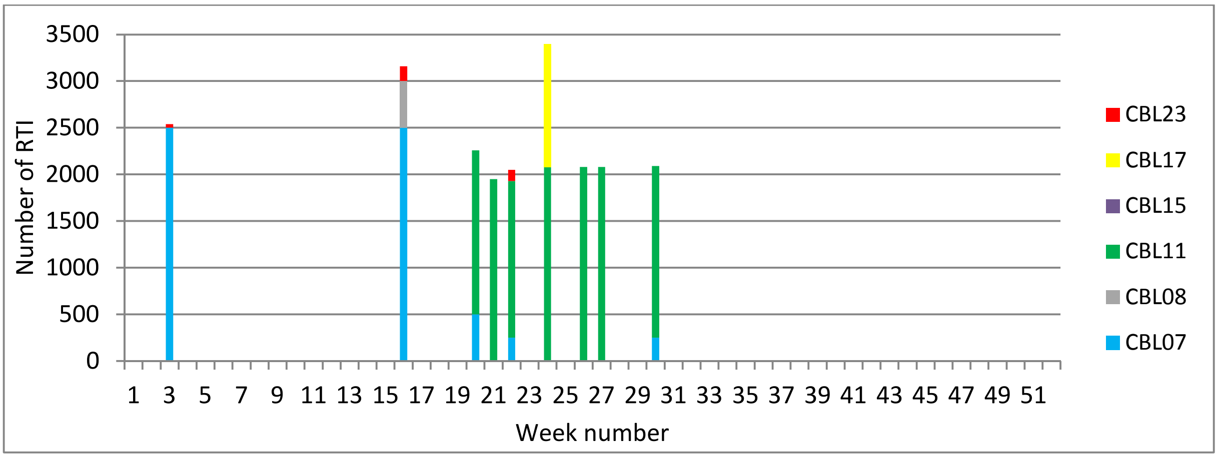

Figure 18: Transport from Johma to the cleaning facility

As we can see from Table 15 in Appendix C, one full-truckload consists of 3.250 CBL-07. Johma uses 125 CBL-07 per week for internal purposes, these crates are collected afterwards. An easy calculation shows it would take 26 weeks to complete a batch. In reality

Johma sent two batches of 2.500 crates and so it took 20 weeks to create these batches (if we assume a stable demand pattern).

2. The time to create full-truckloads at the customers
   In the current pooling system there is no direct relationship between delivery and pick-up location due to deposit arrangements. As soon as Johma delivers products to a customer and this customer confirms the number of received RTI (digitally), the overall balance of Johma increases. As soon as the balance of Johma is increased with the volume of one truckload, Johma has the right to send MFFL to a location to gather a full-truckload destined to the cleaning facility. Therefore we have to look to the demand pattern of the customers in order to calculate the elapsed time before the outstanding balances of Johma did raise enough.

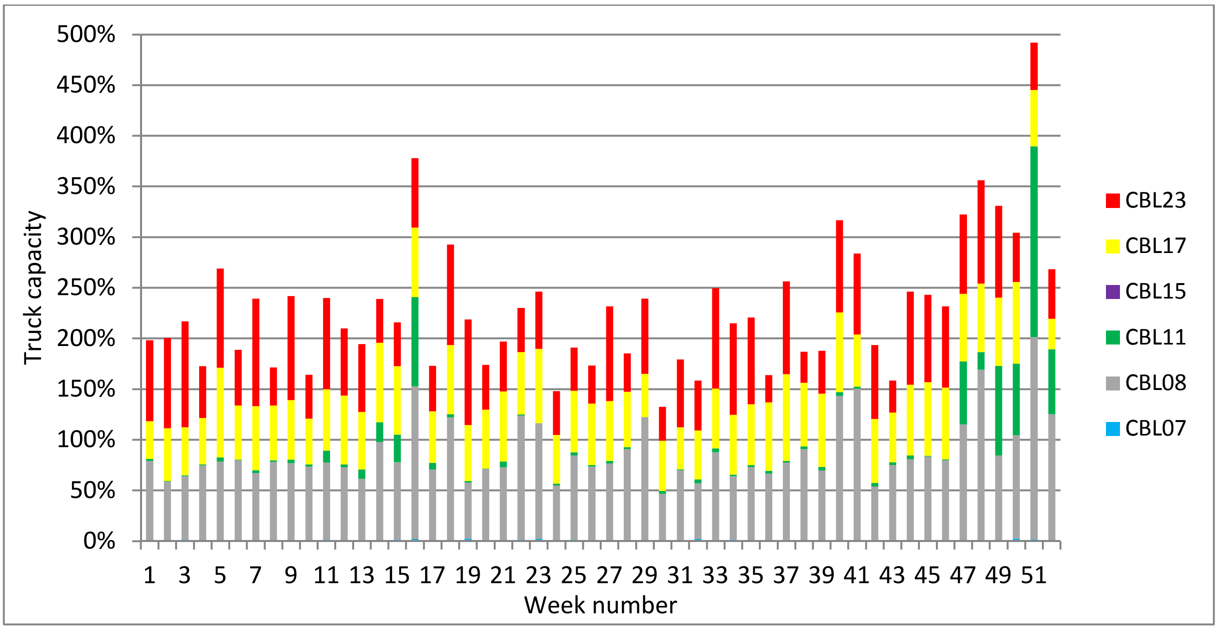

Figure 19: Return volumes in terms of truckloads

The horizontal axis in Figure 19 resembles the capacity used by each RTI-type compared to the trucks size (one full-truckload represents 100%). This means, that for example in week 50, there were 2 trucks of CBL-08, almost 2 of CBL-11, and one filled with a combination of CBL-17 and CBL-23. The amounts of CBL-07 are too small to see them in Figure 19. It takes too much time to wait for a full truckload of CBL-07, therefore it is wise to collect some individual Pallet Place Equivalents (PPE) of CBL-07 in case MFFL drives to a customer to collect RTI. The same applies most of the year to CBL-11, only a few weeks around Easter and Christmas it would be possible to wait for a (nearly) full-truckload.

3. The time to deplete a full-truckload at the factory of Johma
   These numbers are more or less equal to the ones presented in Figure 19. Nevertheless it is important to know this because it means that an extra inventory is kept, one at the customers and one at the production facility of Johma.

The proportion of LTR- versus STR-costs

We recall the rule of Kirby (1959) on the division between LTR-crates and STR-crates from Section 4.4.

"If hired STR-crates are k times as expensive as LTR-crates, then STR-crates should need to be hired on one day in k days."

Kirby (1959) proofs this by minimizing the total cost function, including the probability of a certain demand level. Suppose the fleet consists of n LTR-RTI, each costing 1 unit per day, STR-RTI costing k units per day, and suppose that on any day x RTI are required with probability p(x). Then,

$$\int_{n}^{\infty} p(x)dx = \frac{1}{k}$$

With this rule in mind, we calculate the desired level of LTR-crates. The optimal split is driven by the difference in costs to hire a crate on LTR basis versus STR.

- The cost for using STR-crates can be calculated easily because it has only one fixed component. STR-crates are rented for €0,05 per crate/week, which mean €2,60 per crate/year.
- In the situation of LTR-contracts, there are two cost-types. A yearly fixed pool fee of €0,12 per crate and some additional capital costs. These capital costs depend on the COC and the total amount invested. Table 5 shows the calculation on paid deposit by Johma. With a COC of 5%, the capital costs come down to €152.260/47.335, an average of €0,16 per crate/year. This implies a yearly LTR-cost of €0,28 (including a pool fee) per year.

What is the effect of the decision for a certain level of COC? Every 5% increase or decrease in the COC implies an increase or decrease of €0,16 per crate, a huge number if we realize there are currently 47.335 LTR-crates involved. Every 5% COC difference causes extra capital costs or savings of €7.500.

RTI-type	LTR-contact	Deposit pp	Deposit paid
CBL-07	16.335	€4,54	€74.160
CBL-08	-	-	-
CBL-11	20.000	€2,35	€47.000
CBL-15	4.000	€2,25	€9.000
CBL-17	2.000	€2,95	€5.900
CBL-23	5.000	€3,24	€16.200
Total	**47.335**		**€152.260**

Table 5: Paid deposit

The final effect of the COC on the ultimate decision for LTR- versus STR-crates can be seen from Figure 20. STR-crates are roughly 9 times more expensive than LTR-crates in case of a COC of 5%. Therefore, 8/9th of the peak demand we use LTR-crates and only 1/9th of the peak demand should be covered by an additional amount of STR-crates. In case the COC is set on a value of 10%, the STR-crates are only 6 times more expensive. This implies a share of peak demands of only 5/6 LTR-crates and 1/6 STR-crates. The values of k from the theory of Kirby (1959) can be seen in Figure 20 for COC from 0% to 30%. The higher the COC, the lower the amount of crates that should be rented on a LTR-basis (with equal demand pattern and uncertainties).

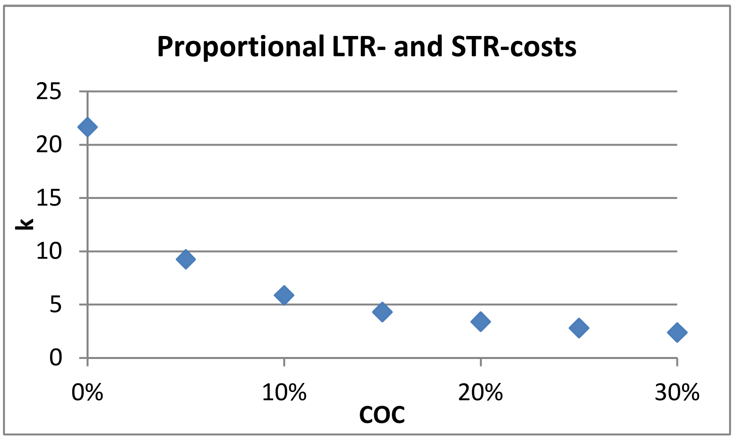

Figure 20: Influence of COC

The number of RTI necessary as Work-In-Process

To put the right amount of crates in a LTR-contract, Johma has to know how many crates are required to support its supply chain. In Section 4.3 we saw that the pipeline inventory can be determined by Little's Law:

$$Work\ In\ Process = Cycle\ Time \times Throughput$$

If we look at the throughput as the number of crates demanded by the production facility of Johma and we could make an estimate on the current cycle time (CT), the work-in-process (WIP) can be calculated. The demand data can be acquired from the forecast of products, which is known one year ahead. But for comparison reasons we look at the data of 2011 from which we can calculate the number of RTI required for this period. The historical demand information is one of the data sets presented in Figure 21 for CBL-23, for the other RTI-types we refer to figures 22-25.

Now the throughput data can be analyzed, the next information we need is the CT of RTI through the supply chain. According to the planning department of Johma, the returned RTI should be available within one week after delivery of the products to the customers. Nevertheless, the current situation is not in line with this theoretical situation. On average RTI are re-used 15 times a year by the pool participants, this means that the average CT is 24 days. At this moment, Johma is not pushing her customers to improve this number. Meanwhile, the Pool operator sees no direct opportunities to improve this number drastically. The goal for 2012 is improving this rotation speed to 17 cycles a year, which means a CT of 21 days.

As concluded in Section 4.1 by referring to Savaskan et al. (2004), it is important to organize access to used products if an organization would like to benefit from remanufacturing. A solution has to be found to decrease the average CT in order to create savings on the rental budget.

To give an indication on the effect of the CT on the level of RTI needed, we show two scenarios in Figures 21-25. One line represents the average WIP in case the lead time is one week and the second line in case of a CT of three weeks, a huge difference in WIP levels. Both lines are constructed with a summation of demand during one, respectively three weeks. This method is inspired to Rogers (2002), who mentioned that the products produced today are returned with some time lag (see Section 4.1) (Rogers and Tibben-Lembke, 2002). The effect of a period with peak demand is clear from the lines which rise suddenly to a level three times as high as the average demand.

The total demand for RTI is calculated by making an assumption on the expected CT. But how many of these crates should be rented on a long term basis? With the rule of Kirby (1959) in mind, we have calculated the desired level of LTR-crates with the current COC-level of 5% and for a COC of 20%. Figures 21-25 show two pairs of straight lines which represent this desired level. The peeks above these lines represent the number of STR-crates rented occasionally during the year.

Each figure shows three lines representing the number of RTI required (for different CTs) in total and four lines that represent the optimal LTR-level at two different COC-levels. If we compare the two situations in which the difference is maximal we look at the lines on 1) the option with a CT of one week and a COC of 20% and 2) the case with a CT of three weeks and a COC of 5%. In option one we see the lowest amount of LTR-crates due to a fast circulation of crates and relatively high costs for LTR-crates due to the COC influence. The second case is exactly the opposite, a long CT combined with relatively cheap LTR-crates. Figure 21 shows he number of LTR-crates for CBL-23 in situation 1) comes down to 1.000 and for 2) roughly 2.700, a huge difference. The analysis of the other RTI-types follows.

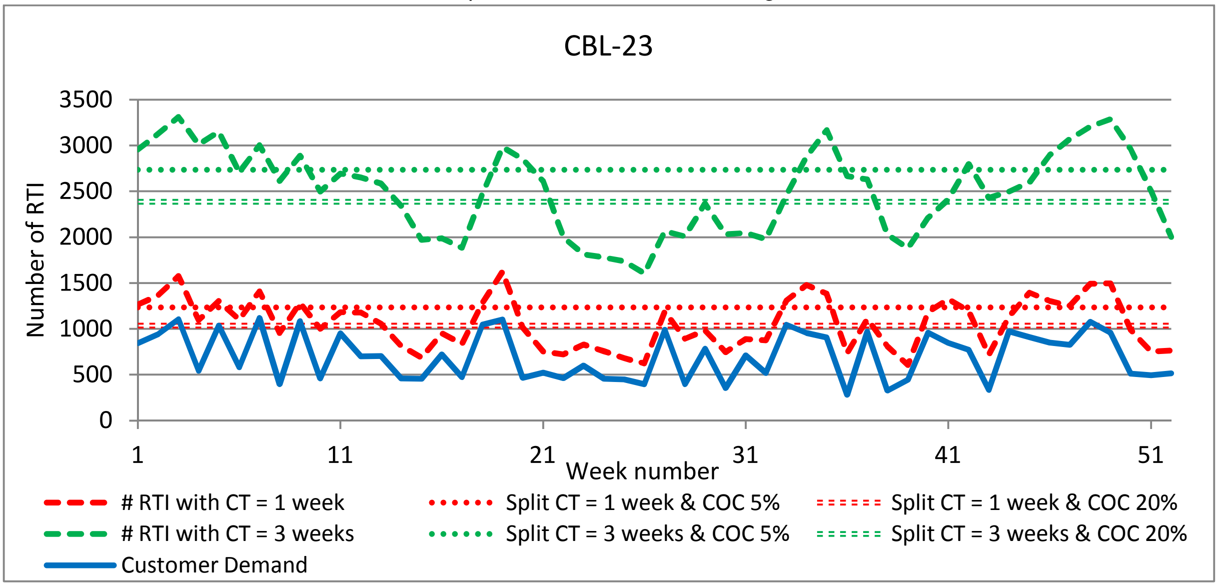

Figure 21: Weekly RTI Demand CBL-23

Figure 22 shows the demand for CBL-07. This RTI-type is used for re-packaging activities at the production facility (internal demand), for this reason not all actual demand is visible in the outbound flow from Johma to her customers. To overcome this flaw in the demand data we increased the outbound flow with 125 crates a week, the estimated average demand for internal use of CBL-07. Average CT of CBL-07 depends not only on the customer behavior, but much more on the time it takes before a batch is collected at Johma for cleaning purposes. Time to form a batch is discussed at the beginning of this section. Figure 22 shows that lead time has more effect on the optimal level LTR-crates than the COC, especially due to the relative flat demand pattern.

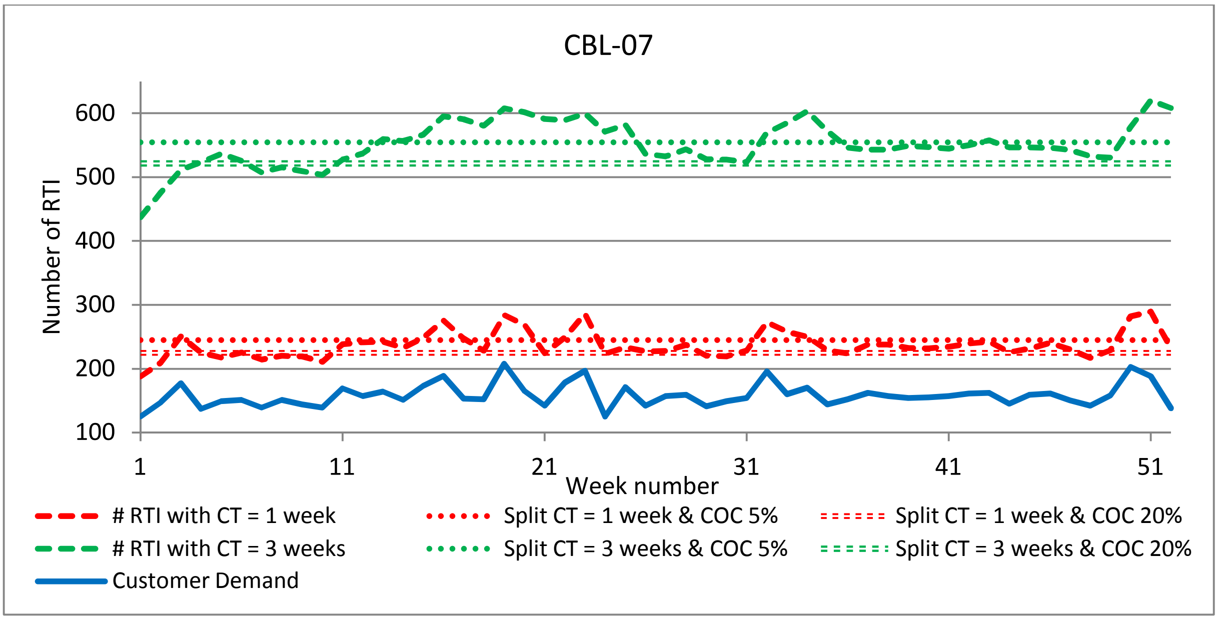

Figure 22: Split LTR en STR CBL-07

If we look at the graph of Figure 23 on CBL-08, the seasonal effects are clear. The effect of this fluctuation grows as the CT increases. Meanwhile, the rotation speed increases during peak periods, according to Pool Service, up to a maximum of 20 rotations a year (18 days).

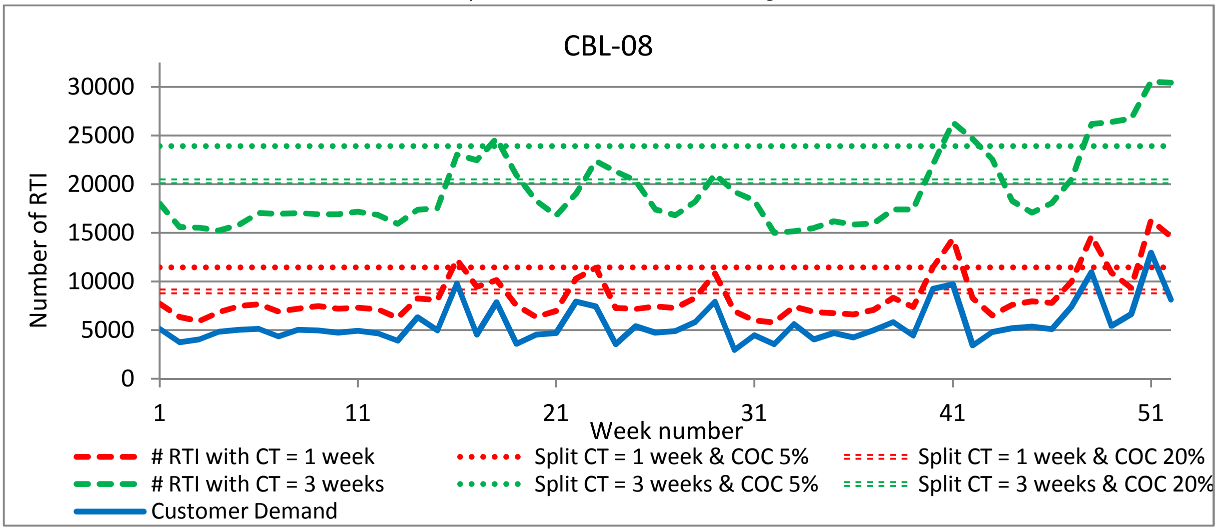

Figure 23: Split LTR en STR CBL-08

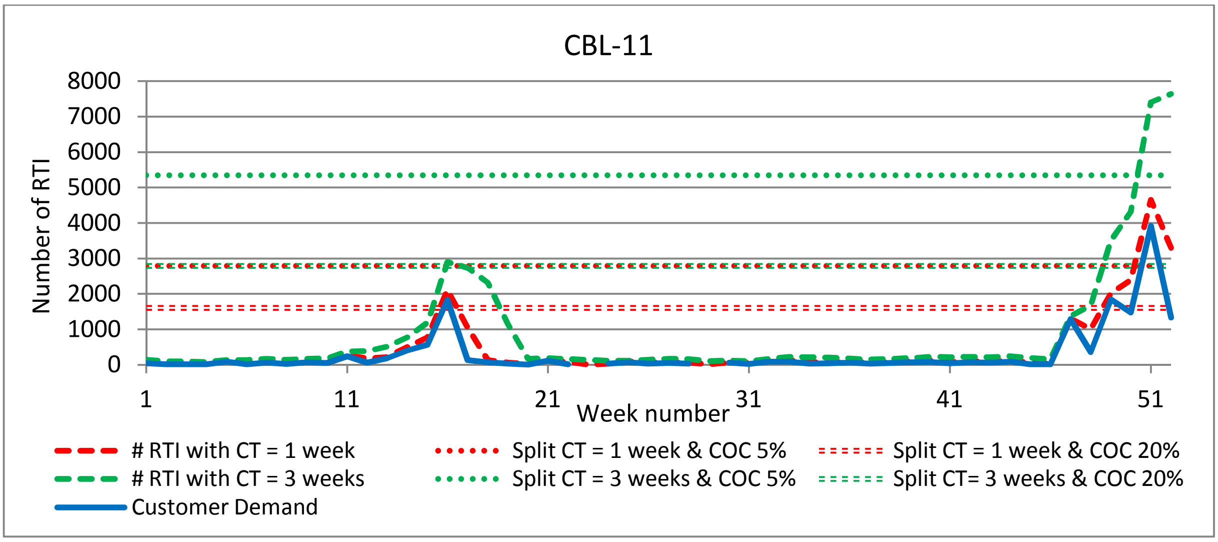

Figure 24: Split LTR en STR CBL-11

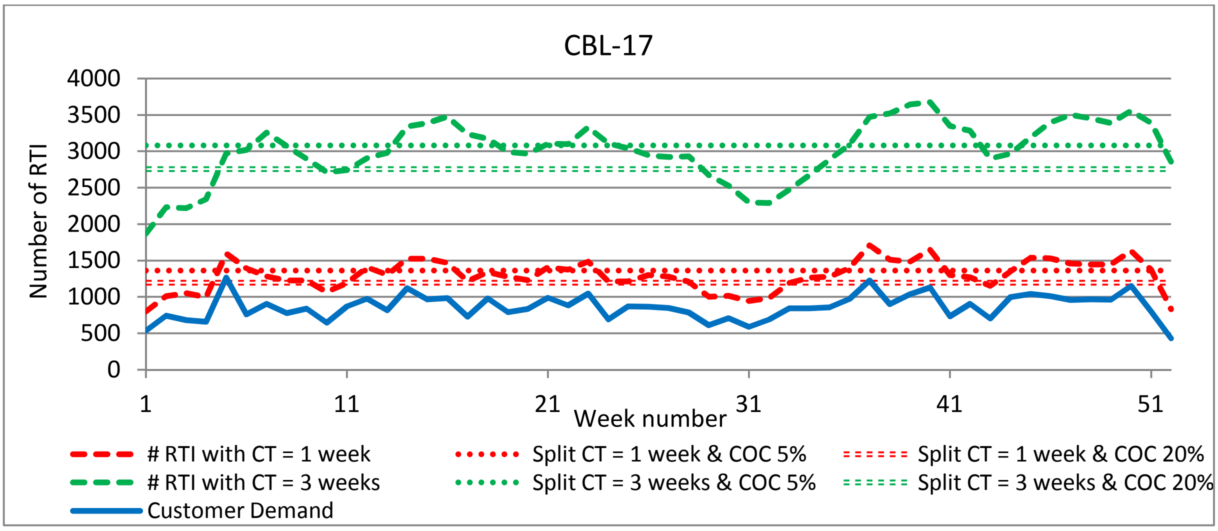

Figure 25: Split LTR en STR CBL-17

The demand pattern in Figure 24 shows two remarkable peaks. These peaks are caused due to the seasonal production around Easter, Christmas and during the summer (increase of internal demand).

As concluded before Johma does no longer use CBL-15, therefore a figure on this RTI-type does not provide extra useful information. It is logical that it would have been optimal to rent neither STR- or LTR-crates during 2011. The analysis on our last RTI-type, CBL-17 can be found in Figure 25.

Cost comparison

The current LTR-contracts are not in line with incurred demand for RTI. We use the highest LTR-levels that follow from our analysis (CT = 3 weeks and COC = 5%) and compare the accompanying costs with the costs calculated in Chapter 3. Table 6 provides an overview of the current RTI-contracts and the costs paid by Johma over 2011.

	# LTR-RTI	2011 LTR-costs	Storage costs	# STR-RTI	STR-costs	Total costs
CBL-07	16.335	€ 4.575	€ 2.219	0	€ -	€ 6.794
CBL-08	0	€ -	€ 955	2.050	€ 5.337	€ 6.292
CBL-11	20.000	€ 5.600	€ 4.237	0	€ -	€ 9.837
CBL-15	4.000	€ 1.120	€ 1.185	0	€ -	€ 2.305
CBL-17	2.000	€ 560	€ 1.642	0	€ -	€ 2.202
CBL-23	5.000	€ 1.400	€ -	5.400	€ 14.029	€ 15.429
						€ 42.859

Table 6: Rental costs 2011

	# LTR-RTI	Improved situation LTR-costs	Storage costs	# STR-RTI	STR-costs	Total costs
CBL-07	1.000	€ 300		40	€ 100	€ 400
CBL-08	24.000	€ 6.750		1.350	€ 3.500	€ 10.250
CBL-11	5.300	€ 1.500		230	€ 600	€ 2.100
CBL-15	0	€ -		0	€ -	€ -
CBL-17	3.000	€ 850		350	€ 900	€ 1.750
CBL-23	3.000	€ 850		270	€ 700	€ 1.550
			€ 5.000			**€ 21.050**

Table 7: Rental costs with current knowledge

The optimal LTR-levels depend on the cycle time and the COC, Table 7 provides the costs for the situation in which we rent the most LTR-RTI (and less STR-RTI), the lead time is three weeks and the COC is 5%. The amount STR-RTI is given as the average number of crates rented in a week. Estimation of the storage costs is given as well. We conclude that the proposed number of LTR-RTI creates a cost reduction of roughly 50%. The total number of crates is slightly higher, at 36.300 than our estimate of 30.000 at the beginning of Section 5.2. This difference arises due to fluctuation of demand.

Step-by-step plan to determine an optimal rental policy

It is not possible to improve the past, therefore we describe the steps taken in our analysis. This step-by-step plan can be adopted for rental policies in upcoming years and helps management to decide on the number of LTR-RTI to put in a contract and the budget to be reserved for RTI-management.

1. Clear the outstanding balances

Sound RTI-management and communication to customers and pool service during the year is necessary to improve the balances at Habé. In case RTI is no longer required by the production facility, this RTI should be collected at one of the customer locations. This creates the possibility to decrease current LTR- or STR-contracts now or in the future. In principle, Johma should strive all day round towards zero RTI-inventories at the customers. The RTI should keep moving.

2. Gather data

A forecast of future RTI-demand can be compiled by customer service (external demand) and production planning (internal demand). Next to the quantitative data, these departments can provide information to possible changes in customer requirements that cause an extra increase or decrease in RTI-demand.

3. Determine the required time to create/deplete a full-truckload

The internal and the external demand determine the time it takes to form a batch or full-truckload of RTI. The return volumes during the year can be calculated by adding the demand figures belonging to a certain period. In case the profiles, as in Figure 18, show a problematic situation, e.g. demand is relatively low and batching requires too much time, an extra amount of RTI should be reserved or smaller shipments are necessary to ensure an optimal rental policy.

4. Determine the proportional costs between LTR- and STR-RTI

To apply the rule of Kirby (1959) we need the proportional difference between LTR-costs and STR-costs. The decision on the COC-level (and the demand pattern) influences the optimal split between these two types of crates.

5. Determine the cycle time and the required work-in-process

The required work-in-process level can be calculated with Little's formula, we have to make an assumption on the expected cycle time during the year. In case this cycle time is expected to fluctuate during the year, this should be included as well. The total work-in-process can now be calculated by summing the total expected demand during the expected lead time.

6. Set the number of LTR- and STR-RTI

The rule of Kirby (1959) prescribes that Johma should rent as much LTR-RTI as the minimum amount of RTI required in a period during the year, plus an additional amount of (k-1)/k of the peaks. The factor k resembles the proportional cost difference determined in step 4. The remaining peaks (of size 1/k) can be covered with an amount of STR-RTI.

7. Cost comparison

The LTR-levels determined in step 6 and the expected peak demand fulfilled with STR-RTI involve rental costs and estimated storage costs. The total required budget for rental purposes should be established.

8. Contractual adjustments

In case the advised number of LTR-RTI deviates too much from current LTR-contracts, Johma should arrange a meeting with the representatives of Pool Service to discuss possible adjustments of current contracts. If Johma would like to decrease the number of LTR-RTI, they have to return the physical RTI. In case of an increase, the total amount of deposit paid goes up.

5.4 Conclusion

From Section 5.2 we can conclude that the presence of a deposit system made the relation between a delivery location and a pick-up location disappear. The criterion whether a supplier should be authorized to pick up the RTI, depends on the number of RTI delivered to all customers together. A problem arising from this system is that customers act as if they own the received RTI and suppliers prefer to collect RTI closest to their cleaning facility. On top of this, Figure 11 illustrates that the logistics service provider travels over a longer distance than would be required if we look at the different available locations of the Habé cleaning facilities.

Johma has not enough control over the amount of RTI they distributed among their supply chain. Section 5.2 shows that the rented pool of RTI seams to disappear while the yearly rental fee is still paid and more RTI is contracted to fulfill production demand. The figures on the yearly balances and transactions show there is no yearly strategy to determine the number of RTI to rent on a LTR-contract in order to avoid extra costs for STR. This causes multiple problems that come down to two central cases, which are:

- Too many LTR-crates which causes unnecessary rental costs, a high balance at the cleaning facility and a low incentive to monitor the specific RTI through the supply chain.
- Too few LTR-crates which causes a high uncertainty for the collection of RTI, because there is no contract to cover demand and high costs for STR of crates.

The variables that might have an effect on the configuration of the optimal rental policy presented in Section 5.3 are not equally important for Johma. The time to create/deplete a full-truckload has a minimal influence if the volumes of RTI transported from the cleaning facility to Johma represent the RTI necessary for production. In this way the inventory level at Johma is minimal and the RTI keeps moving through the different steps of the process, which minimizes the required number of RTI.

The proportions of LTR- versus STR-RTI depend on the cost differences between the (total) rental costs and the demand pattern. The decision on COC-level becomes more important for volatile demand patterns and less important in case of a stable demand. In both situations it is important to get more insight and control over the cycle time. One possibility to reduce the cycle time is to combine multiple types of RTI in one freight instead of waiting for a full-truckload pick-up. In this way, the calculated cost reduction of roughly 50%, can increase even more.

In the next chapter a model is presented that captures the problems encountered in this data analysis from a more general point of view by applying the discussed Inventory Routing Models from the literature study in Chapter 4.

Keep the “Hard Workers” moving!

6 Inventory Routing Model

The practical situation and its difficulties are made clear. In this chapter, we translate the specific problem instance of Johma to a more general problem, which is an instance of the Inventory Routing Problem (IRP). This problem is introduced step by step and relates to the discussed literature on IRPs of Chapter 4. We start with positioning the IRP with respect to capacity planning activities in an organization in Section 6.1. Section 6.2 presents a graphical representation of the discussed network of Johma and discusses the differences between the situation of Johma and the proposed model formulation. The detailed model formulation is discussed in Section 6.3 and the chapter ends with conclusions on the applicability of this model within Johma in Section 6.4.

6.1 Level of Analysis

The planning of resources and capacity is influenced on multiple aggregation levels. Strategic issues influence tactic decisions and operational activities. We discuss the three levels given in Figure 26 shortly, from which we analyze to what level of analysis the IRP presented in this chapter belongs.

Figure 26: Planning levels

Strategic level

The highest level of aggregation is the strategic level. Decisions on this level are generally made by directors or top management. In the situation of RTI-management within Johma these decisions concern the product/market mix and corporate objectives for the future. The choice on RTI-cycle model and the pricing structure for services delivered by external parties are typical strategic issues as well.

Tactic level

The implications of strategic decisions are translated to the tactical decision level. The long term capacity planning and RTI allocation are generally a concern for middle management. Decisions on the number of LTR-RTI and the size of RTI-storage capacity at the facility of Johma are included in the tactical hierarchical level.

Operational level

The execution procedures are part of the operational level. The employee concerned with this procedures, creates a detailed distribution planning based on the master production schedule and coordinates/solves possible unexpected situations. Usually the daily decision maker on RTI-transactions.

From these short descriptions it is clear that the IRP contributes to decision making on the tactical level. The proposed model balances rental and transportation costs in such a way that we can compare the cost-effects of different levels of LTR-RTI. Nevertheless, it is important to note that strategically decisions are treated as input parameters and solutions to operational issues are outside the scope of the IRP-model. A throughout explanation on the model and the assumptions is given in the next section.

6.2 Model Framework

The relations and possible interactions in the complex RTI environment are combined in Figure 27. A distinction is made between the internal environment of Johma and the external, uncontrollable environment in which the logistics service provider, the cleaning facility and pool service operate. There are three types of interactions necessary between these two environments; the exchange of (i) products ordered by the customers, (ii) the demand data for cleaned RTI, and (iii) the physical flow of cleaned RTI.

The external environment is much larger than pictured in Figure 27 due to all other suppliers and customers who participate in the RTI-pooling system. The external shipments are displayed in the figure with arrows that enter or leave the external environment of Johma from other suppliers or to, for example, other cleaning facilities. The stakeholder that tries to manage this complex continuous changing environment is Pool Service by means of a deposit system and a pool management system. In this pool management system, transactions between pool participants are registered and the outstanding balances with respect to the pool are updated. In the proposed model we assume that all customers of Johma participate in this pooling system and use the pool management application correctly. In this way all RTI-transactions are recorded, there is no RTI lost and next to that we assume that Johma knows where the RTI inventories are kept (the triangles at customer locations in Figure 27) at a certain moment.

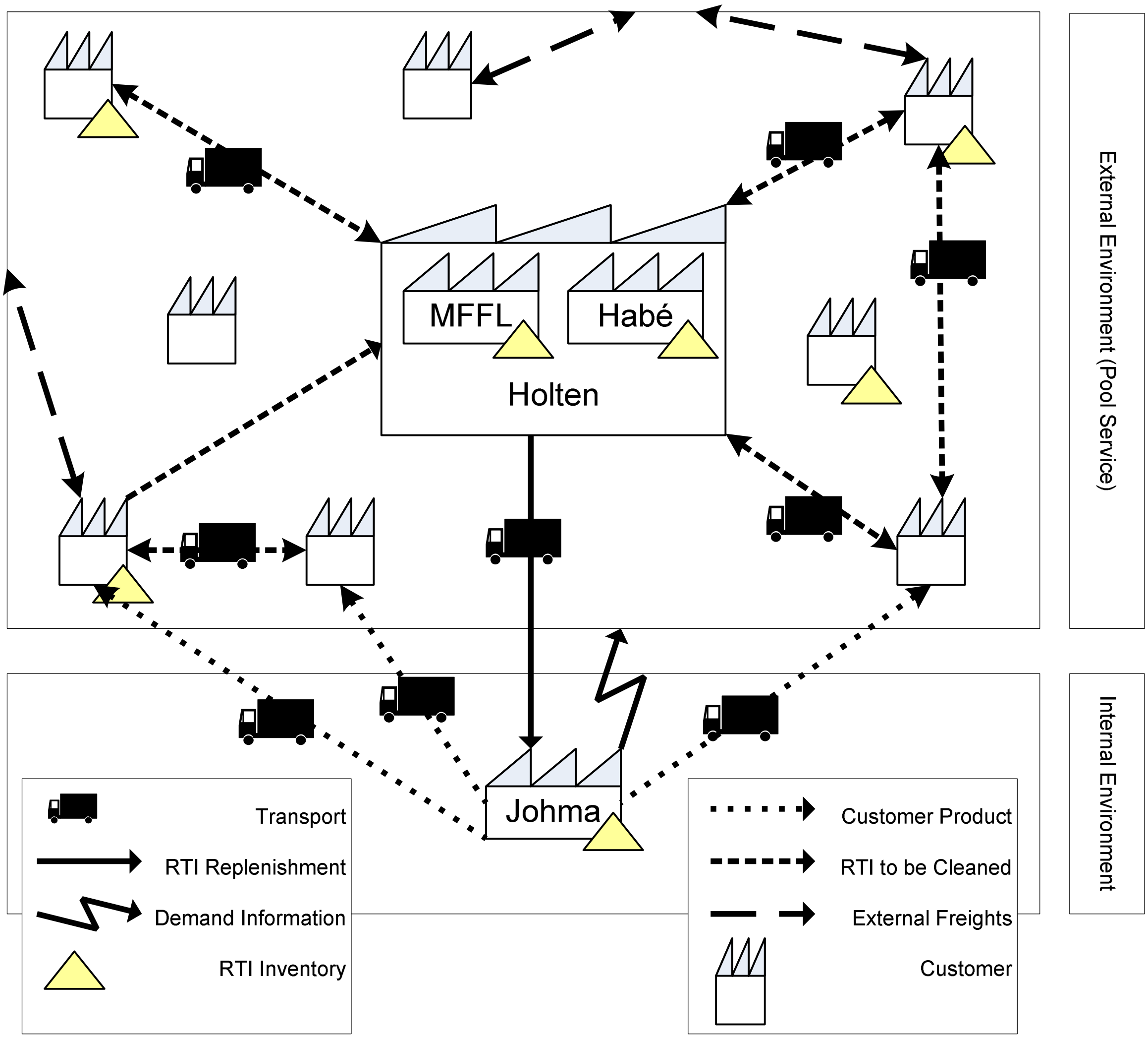

Figure 27: RTI-network of Johma

Information on the total number of items sent to all customers of Johma in a certain period is relevant because it resembles the increase in the outstanding balance of Johma, which indicates the amount of RTI available to be picked-up by MFFL. The contrary is true for the RTI collected at a customers location, transported to the cleaning facility and back to Johma; this causes a decrease in the outstanding balance of Johma and therefore less RTI remaining for collection at customer locations. In case there are not enough RTI available in the supply chain of Johma, there is an STR-opportunity at the cleaning facility to cover peak periods.

It is important to note that there is no explicit relation between the outstanding balance of Johma and a specific customer location, instead the outstanding balance relates to the sum over all customers together. In other words, it is common to bring RTI to customer A till D and pick-up RTI at customer E and F because they have a lot of inventory and/or are located close to the cleaning facility. These transactions are approved as long as the overall balances of Johma are positive. Note that in reality, as seen with CBL-08 in Section 5.2, it was possible to pick-up more RTI than allowed based on the LTR- plus STR-contracts. The number of crates in an LTR-contract is given as an input parameter that can be adapted to see the implications on the number of STR-crates and the corresponding costs. This creates the opportunity to balance the split between STR- and LTR-crates.

The cleaning facility of Habé, and the service provider MFFL, are both situated in Holten. These two parties closed an agreement to work more closely together in such a way that also their customers, for example Johma, realize savings. These savings are equal to the decrease in total transportation and rental costs. The holding costs are left out during the remaining part of this report because:

- Johma is not invoiced for holding costs at their customers;
- The holding costs at the cleaning facility are negligible and already influenced positively by minimizing the number of RTI;
- The holding cost structure is complex and not always in place, see Section 3.5.

To determine the course of action to benefit from the collaboration between MFFL and Habé, we present an instance of the Inventory Routing Problem. If we know the availabilities of RTI’s at all pick-up locations, and we know the distances between the locations and the external demand at the production facility, we can create a model that decreases total rental and transportation costs, while demand is fulfilled.

We study an instance of the IRP of which its basic form is introduced in Chapter 4. In the IRP, multiple capacitated trucks transport RTI from multiple suppliers of RTI, via a cleaning facility, to a production facility (i.e., a three-level m-to-1 distribution network) to meet the demand in each week for each RTI-type over a finite horizon of, for example, one year. It is a network of inbound logistic where the network consists of a depot, a production facility, a cleaning facility and N suppliers (the customers of Johma) of RTI, see Figure 28. The objective is to minimize the combination of transportation and rental costs (over the planning horizon). Shortages and backordering is not allowed because this may lead to excessive penalty costs at the production facility.

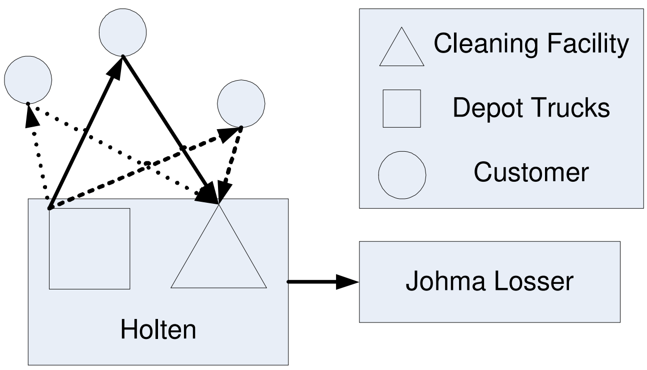

Figure 28: Three-level distribution network

The differences between our model and the practical situation of Johma are discussed previously, here we present the assumptions made on the practical elements that we include into the model:

1. The demand at the production facility of Johma is RTI-type specific, deterministic and given for every period.
2. If there are more RTIs collected and delivered at the production facility than there was demand for during that period, the inventory is carried forward to the next period.
3. An unlimited number of capacitated and identical vehicles are available at the logistics service provider. The number of vehicles used in a period may vary over time.
4. Travel times/distances between different locations are (deterministic) fixed and given.

5. The transportation cost consists of a fixed charge incurring for each trip plus a variable cost proportional to the travel distance between the involved customer and the cleaning facility.
6. The physical customer inventory changes according to a given forecast and is known throughout the planning horizon. The impact of demand by Johma and other suppliers is neglected.
7. The number of LTR-RTI dedicated to the supply chain of Johma is deterministic, fixed (for a year) and given.
8. The outstanding LTR-balances should be at least as high as the total quantity pick-up at the customers or STR-crates should be used from the cleaning facility.
9. Weekly rental costs are paid for the number of RTI in the supply chain of Johma, a part is fixed by the LTR-contracts and the other part is variable due to STR-possibilities.

The conclusions on the applicability of the model, which is given in Section 6.3, for the RTI-management within Johma are given in Section 6.4. We discuss for example the consequences of the differences between the modeled situation and Johma.

6.3 Model description

The model formulation that fits with the assumptions in the previous section is given after a qualitative introduction to the used variables by looking at an illustration of the modeled situation. The mathematical model consists of five parts; the formulation of indices, parameters and variables, the objective function and the formulated constraints. Each item is explained briefly.

Illustration of the situation

The mathematical formulation describes the situation depicted in Figure 29. Every period the customers of Johma receive a delivery of products, the inbound RTI or variable D. The inbound RTI flow is connected to the Demand incurred at the production facility, therefore also variable D. We assume a production lead time of two weeks, so every production demand incurred in period 1 is registered as inbound RTI in week 3.

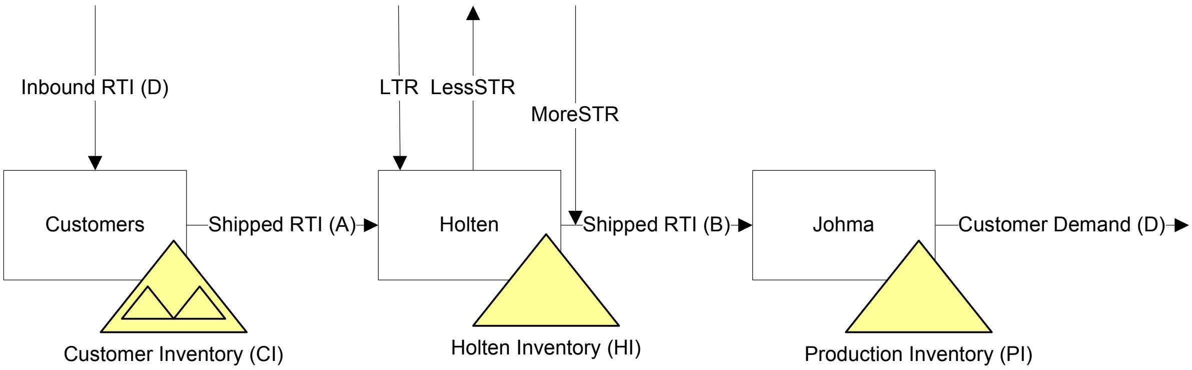

Figure 29: Model illustration

The inbound RTI raises the outstanding balance of Johma, but not automatically the physical inventory that is ready for pick-up at the customers. Due to an internal cycle time at, for example, the warehouse of the retailer, it is quite normal that the outstanding balance rises more than the Customer Inventory, or CI. The relation between the outstanding balance and the physical Customer Inventory is a bit more complex. The sum of the Customer Inventories among all customers together can be divided into two separate bins. The first resembles the amount of product that is dedicated for Johma, or as mentioned before, the outstanding balance. The second bin contains the remainder of the products, a surplus that can be collected by other pool participants. For this reason it is possible that the outstanding balance increases by D and the Customer Inventory declines due to a lot of shipments to other pool participants. The Demand, Inbound RTI and the physical Customer Inventory are modeled as given input parameters.

Every period, the inventory in Holten (HI) is checked and if there are not enough items present to fulfill demands from Johma, a truck is sent to transport RTI from the Customers Inventory to Holten (A). The total amount shipped can never exceed the total outstanding balance of Johma. In case there still is a shortage to transport RTI to Johma (B), this should be covered by renting additional STR-RTI. Also the contrary holds, in case there are more items shipped to Holten then there is demand for, the STR-balance decreases. Customer demand should always be fulfilled from the Production Inventory (PI) at Johma.

To determine the value of the objective function, we record the transportation movements and the number of (fixed) LTR and (variable) STR-RTI during the planning horizon.

Formulation

A mathematical formulation based on Moin et al. (2010) is given here. We first introduce the following notation.

<u>Indices</u>

$S = \{1,2,...,N\}$	a set of all customer locations
$R = \{1,2,3\}$	a set of all RTI-types
$\tau = \{0,1,...,T\}$	a set of all time periods

<u>Parameters</u>

cap	Fixed capacity (m^3) of a vehicle
f_1	Fixed cost component (trip-fee) for every shipment from Holten to the customer and back to Holten
f_2	Fixed cost component (trip-fee) for every shipment from Holten to Johma
v	Variable cost component per unit distance travelled
strc	Short-term-rental costs per week/RTI
ltrc	Long-term-rental costs per year/RTI
w_k	Product-volume (m^3) of RTI type k
d_{kt}	Production demand for RTI type k, at Johma, in week t
$inid_k$	Production demand for RTI type k, at Johma, a week before the planning horizon starts i.e. week t = -1
c_i	One way travel distance between Holten and customer i
ltr_k	Number of fixed LTR-RTI of type k on contract for the whole year
HI_{k0}	Inventory level of RTI type k at Holten at the beginning of week 1
PI_{k0}	Inventory level of RTI type k at Johma at the beginning of week 1
STR_{k0}	Number of STR-RTI of type k at the beginning of week 1
ci_{kit}	Physical Inventory level of RTI type k at customer location i at the end of week t (exogenous process discussed in Section 6.1 and in more detail in Section 7.2)

<u>Decision variables</u>

A_{kit}	Total amount shipped of RTI type k from customer i to Holten in week t
B_{kt}	Total amount shipped of RTI type k from Holten to Johma in week t
HI_{kt}	Inventory level of RTI type k at Holten at the end of week t, for t > 0
PI_{kt}	Inventory level of RTI type k at Johma at the end of week t, for t > 0
X_{it}	Number of times customer i is visited by a vehicle in week t
Y_t	Number of shipments between Holten and Johma in week t

RTI_{kt}	Amount of dedicated (outstanding balance) RTI type k at the end of week t (LTR and STR combined)
STR_{kt}	Number of RTI type k rented on a short-term-basis measured at the end of week t, for t > 0
$MoreSTR_{kt}$	Number of additional RTI of type k rented at Holten starting in week t
$LessSTR_{kt}$	Number of RTI type k handed in at Holten in week t

The mathematical formulation for our inventory routing problem is given as follows:

$$Z1 = \min v \times 2\sum_{i \in S} c_i \left(\sum_{t \in \tau} X_{it}\right) + f_1 \times \sum\sum_{t \in \tau\, i \in S} X_{it} + f_2 \times \sum_{t \in \tau} Y_t + strc \times \sum\sum_{k \in R\, t \in \tau} STR_{kt}$$

The objective function minimizes the transportation costs (travelled distance * variable costs per unit distance + fixed trip-fee) and rental costs (short term rental costs + long term rental costs). For the transportation planning it is not important to include the fixed LTR-costs. In the situation of Johma we also want to know how many LTR-RTI are necessary. In that case the fixed costs (see the formulation below) should be included as well.

$$Z2 = \min v \times 2\sum_{i \in S} c_i \left(\sum_{t \in \tau} X_{it}\right) + f_1 \times \sum\sum_{t \in \tau\, i \in S} X_{it} + f_2 \times \sum_{t \in \tau} Y_t + strc \times \sum\sum_{k \in R\, t \in \tau} STR_{kt} + ltrc \times \sum_{k \in R} LTR_k$$

Subject to

Constraint	Explanation	
$\mathbf{HI_{kt} = HI_{k,t-1} + \sum_{i \in S} A_{kit} - LessSTR_{kt} - B_{kt}\ , \forall k \in R, \forall t > 0 \in \tau}$	Inventory balance equation for all RTI type k at Holten in week t.	(1)
$\mathbf{PI_{kt} = PI_{k,t-1} + B_{kt} + MoreSTR_{kt} - d_{kt}\ , \forall k \in R, \forall t > 0 \in \tau}$	Inventory balance equation for all RTI type k at Johma in week t.	(2)
$\mathbf{\sum_{i \in S} A_{kit} \leq RTI_{k,t-1} - HI_{k,t-1} - PI_{k,t-1}\ , \forall k \in R, \forall t > 0 \in \tau}$	Makes it impossible to collect more RTI of type k in week t, than the amount dedicated to Johma still present at the customer locations.	(3)
$\mathbf{STR_{kt} = STR_{k,t-1} + MoreSTR_{kt} - LessSTR_{kt}\ , \forall k \in R, \forall t > 0 \in \tau}$	Inventory balances equation on the number of RTI type k rented on a Short-term-basis in week t.	(4)
$\mathbf{RTI_{kt} = RTI_{k,t-1} + d_{k,t-2} - d_{kt} + MoreSTR_{kt} - LessSTR_{kt}, \forall k \in R, \forall t > 1 \in \tau}$	Inventory balance equation for all RTI type k on the number of dedicated (outstanding balance) RTI in week t.	(5)
$\boldsymbol{RTI_{k1} = RTI_{k0} + inid_k - d_{k1} + MoreSTR_{k1} - Less\ STR_{k1}\ , \forall k \in R, t = 1}$	Initializing the variable denoting the dedicated (outstanding balance) RTI of type k in week 1.	(6)
$\boldsymbol{RTI_{k0} = LTR_k + STR_{k0} - d_{k0} - inid_k\ , \forall k \in R, t = 0}$	Initializing the variable denoting the dedicated (outstanding balance) RTI of type k in week 0.	(7)
$\mathbf{d_{kt} + d_{k,t-1} + RTI_{kt} = ltr_k + STR_{kt}\ , \forall k \in R, \forall t > 0 \in \tau}$	Creates a relationship between the total numbers of RTI of type k required in week t with the number of LTR- and STR-RTI.	(8)
$\mathbf{\sum_{k \in R} A_{kit} \times w_k \leq cap \times X_{it}\ , \forall i \in S, \forall t \in \tau}$	Capacity restriction on the transported volume of all RTI together with respect to the maximum capacity of the vehicle.	(9)
$\mathbf{\sum_{k \in R} (B_{kt} + MoreSTR_{kt}) \times w_k \leq cap \times Y_t\ , \forall t \in \tau}$	Capacity restriction on the transported volume of all RTI together with respect to the maximum capacity of the vehicle.	(10)

$A_{kit} < ci_{kit}, \forall k \in R, \forall i \in S, \forall t > 0 \in \tau$	Inventory equation on the total amount of all RTI type k available at customer i in week t.	(11)
$HI_{kt} \geq 0, \forall k \in R, \forall t > 0 \in \tau$	Ensures that the demand at Holten is completely fulfilled without backorders.	(12)
$PI_{kt} \geq 0, \forall k \in R, \forall t > 0 \in \tau$	Ensures that the demand at Johma is completely fulfilled without backorders.	(13)
$RTI_{kt} \geq 0, \forall k \in R, \forall t \in \tau$	Ensures that the outstanding balances are high enough to cover for the total quantity picked-up.	(14)
$STR_{kt} \geq 0, \forall k \in R, \forall t > 0 \in \tau$	Nonnegative constraint.	(15)
$A_{kit} \geq 0$ and integer $, \forall k \in R, \forall i \in S, \forall t \in \tau$	Nonnegative constraint.	(16)
$B_{kt} \geq 0$ and integer $, \forall k \in R, \forall t \in \tau$	Nonnegative constraint.	(17)
$X_{it} \geq 0$ and integer $, \forall i \in S, \forall t \in \tau$	Nonnegative constraint.	(18)
$Y_t \geq 0$ and integer $, \forall t \in \tau$	Nonnegative constraint.	(19)
$MoreSTR_{kt} \geq 0$ and integer$, \forall k \in R, \forall t \in \tau$	Nonnegative constraint.	(20)
$LessSTR_{kt} \geq 0$ and integer $, \forall k \in R, \forall t \in \tau$	Nonnegative constraint.	(21)

Section 3.1 shows that a full-truckload of RTI consists of 26 or 33 PPE, depending on the pallet-type. In practice a pallet is piled with only one type of RTI at the same time. If we include this requirement into the model described above, we need even more integer variables. To ensure solvability of the problem instances we excluded this set of restrictions and additional integer variables at first. We expect that the objective value of the presented model will be slightly lower than if we include these last restrictions. To check this, an alternative model formulation is discussed below.

We can include the fact that RTI is piled type by type on one pallet to simplify handling at the different locations. To solve this problem we need more integer decision variables. The following adjustments are required:

<u>Include Parameters</u>

PPE_k	Volume of the RTI of type k that can be piled on one IPP-pallet
C	Fixed capacity (number of PPE) of a vehicle

<u>Include Decision variables</u>

Z_{kit}	The number of PPE piled with RTI-type k, transported at a fright between a customer i and Holten in week t
Q_{kt}	The number of PPE piled with RTI-type k, transported at a fright between Holten and Johma in week t

The final step is to exclude restrictions (9) and (10) and introduce the six sets of restrictions below:

Constraint	Explanation	
$A_{kit} \leq Z_{kit} \times PPE_k, \forall i \in S, \forall k \in R, \forall t \in \tau$	Capacity restriction on the transport of PPE piled with only one RTI-type k in week t between customer i and Holten.	(i)
$\sum_{k \in R} Z_{kit} \leq CX_{it}, \forall i \in S, \forall t \in \tau$	Capacity restriction on the transport of a maximum number of PPE in one vehicle between the customer i and Holten in week t.	(ii)
$B_{kt} + MoreSTR_{kt} \leq Q_{kt} \times PPE_k, \forall k \in R, \forall t \in \tau$	Capacity restriction on the transport of PPE piled with only one RTI-type k in week t between Holten and Johma.	(iii)

$\sum_{k \in R} Q_{kt} \leq CY_t, \forall t \in \tau$	Capacity restriction on the transport of a maximum number of PPE in one vehicle. between Holten and Johma in week t.	(iv)
$Z_{kit} \geq 0$ *and integer*, $\forall k \in R, \forall i \in S, \forall t \in \tau$	Nonnegative constraint.	(v)
$Q_{kt} \geq 0$ *and integer*, $\forall k \in R, \forall t \in \tau$	Nonnegative constraint.	(vi)

6.4 Conclusions

The instance of an Inventory Routing Problem is formulated in this chapter. The IRP-solution contributes to decision making on the tactical level as we have seen in Section 6.1. The differences between the model and the practical situation are given in Section 6.2. The differences and assumptions referred to in this section, have consequences to the applicability of the model within Johma. It should be noted that the model does not solve the problematic misbalance between current LTR-contracts and current consumption pattern. Nevertheless, it is possible to estimate the cost-effects of certain future LTR-levels over the year.

The main issue to apply this model within Johma is the forecast of available RTI at the different customer locations. We modeled this effect as an exogenous process. In cooperation with Pool Service a better estimate of this process and/or even real time data on inventory levels would increase usefulness of the proposed model. If it is possible to increase the dependability of this data on customer behavior and the customer balances, the model can be used to determine the optimal number of LTR and for efficient (daily) decision-making in RTI-management within Johma.

The solution method to solve the mixed integer linear programming model is presented in the next chapter. This solution method includes the trade-off between inventory and transportation costs as well as the trade-off between the uses of LTR-crates versus STR-crates.

7 Solution Method

The solution method to the model presented in Chapter 6 is the subject for this chapter, in which we aim to illustrate the functionality of it. The translation to a Mixed Integer Linear Problem (MILP) code is subject of Section 7.1. The MILP-model requires a couple of input parameters; the data collection is discussed in Section 7.2. The results given in Section 7.3 consist of the experimental design and the objective values. In the last three sections of this research we present some tests on statistical significance of the results, make a comparison in decision variables between the current situation at Johma and the proposed change from Chapter 5 and we give conclusions.

7.1 Programming code

Mathematical programming is a collective term on selection of the best option from a set of alternatives (Dantzig, 2012). An optimization problem consists of finding the best (minimizing versus maximizing) possible value of some objective function given a specified domain which is created with restrictions. The code (see Appendix E) created in OMST LP SHELL on the MILP-model can be solved with CPLEX.

The model in Section 6.3 contains a lot of integer decision variables. For the values of X_{it} and Y_t it is important that these are integers because of their impact on the objective function and their relatively small sizes. The remaining decision variables are expected to be relatively large because they refer to the number of RTI. In the following, we rounded these variables to the closest integer value.

The code is divided into different parts; the indices are defined under sets, followed by the parameters and variables. The constraints and objective function determine the body of the program and we conclude with the data entered in the defined parameters. The next section elaborates on the data collection for these parameters before we jump to the results in Section 7.3.

7.2 Data collection

The last category of the MILP-formulation initializes the parameters defined earlier. These input parameters are chosen in such a way that it resembles the situation of Johma as close as possible. More information on these different data values and possible assumptions are treated below.

Production demand at Johma

The production demand is given for every week and every product-type separately. It is possible to run the model for multiple demand patterns to check, for example, the financial consequences of accepting new customer demand or a sudden change in requirements of secondary packages. We use the production data of 2011 on the RTI-types CBL-11, CBL-17 and CBL-23 from Chapter 5 for the situation of Johma. Only three RTI-types are considered because demand for the other types is expected to disappear, nevertheless the model can be easily extended.

Exogenous process at the customers

The demand and return patterns of the customers and suppliers who participate in the pooling model of Pool Service influence the available number of RTI that Johma can collect in a certain period. These processes are not modeled explicitly, but we refer to an exogenous process. De data that represent this exogenous process comes from a uniform probability distribution. As Figure

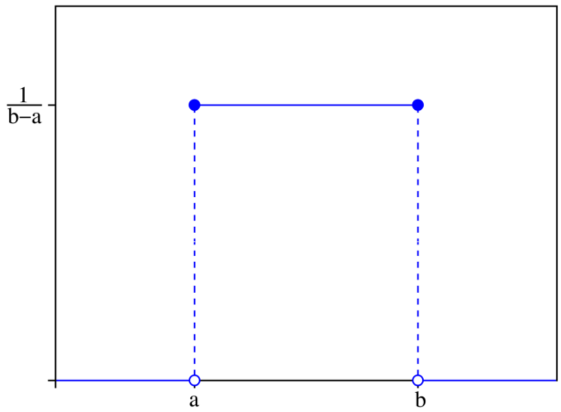

Figure 30: Uniform distribution

30 illustrates, every number drawn from this distribution function has a value between (a) 800 and (b) 1200 (20% increase or decrease from the mean 1000) (Wikipedia, 2012). These numbers are chosen intuitively, naturally this is not the situation in practice, due to large and small customer locations or locations without a certain RTI type at all. The input values represent the current number of RTI available for collection by Johma.

Inventory at Holten and Johma at the beginning of the planning horizon
The inventory level in Holten is set equal to two weeks of demand by Johma, i.e. a time supply of two weeks. For the initial levels of stock at the production facility of Johma we use current minimum balances given in Table 2 in Section 3.4. This was the minimum level of RTI at the production facility before a new order was placed and therefore an appropriate starting value to determine total costs over 2011.

Number of STR- and LTR-RTI at the beginning of the planning horizon
In case there are too few LTR-RTI available, an additional amount of STR-RTI is rented at the cleaning facility. For the initial levels of RTI we rely on the data given by the cleaning facility and the contractual information from Pool Service. The level of LTR-RTI are first set to the values hold actually by the available contracts with Pool Service and secondly to the levels suggested in Chapter 5. The costs of renting LTR-RTI should be added to the objective value found by the MILP-solver. The level of STR-RTI is set initially at 500 pieces for every RTI-type.

Vehicle capacity and product volumes
The capacity of a vehicle can be modeled in two ways (see experimental settings in Section 7.3). This first model can be solved in a relatively short time period but it does not represent the practical situation correct. This option does not include the fact that RTI is piled on a pallet by type. We just calculate the volumes of RTI and the total space in a truck. In the second model, we determine the number of PPE necessary to transport each RTI type between certain origins and destinations and from there we determine the optimal number of trucks to do this. The second options’ effect is contrary to the first, an increase in average running time due to more integer variables and the solution is more in line with the situation of Johma. The product volumes can be calculated with the numbers given in Appendix B. The truck volume is given. The number of PPE that fit in one truck is given as well, and the number of RTI piled on one pallet is given in Appendix C, Table 15.

Transportation and rental costs
Transportation of RTI costs currently €225,00 per freight, no matter the distance and carried amount of products. In the proposed model we refer to a fixed fee plus an additional distance based variable component, to decrease total kilometers travelled. We decided to use €1,00 for each kilometer and a fixed charge of €50,00 for freights between customer locations and Holten. These numbers resemble the current situation of Johma and MFFL best. The trip-fee between Holten and Johma is estimated at €150,00. The rental costs are given by the current contractual agreements as discussed in Section 5.3. The STR-RTI cost €0,05 per week and the LTR-RTI cost €0,28 a year (with a COC of 5%).

Travel distances
The pick-up locations visited in 2011 are considered as possible collection points; their one-way distance to the depot is calculated and given as an input variable.

The MILP-model is loaded with the described input parameters and solved for multiple runs with different customer inventory data. The experimental design and the objective values plus accompanying variables are presented and discussed in the next section.

7.3 Results

To draw conclusions on the results generated by the model, we have to know how trustworthy, for example, an objective value is. How sensitive is the output to the input parameters? The exogenous parameter, on the levels of physical inventory at the customer locations, is a stochastic process. This process is modeled as a series of given deterministic values (drawn from the probability distribution discussed in Section 7.2). To eliminate the effect of this specific collection of parameters we create multiple parameter-sets (with the same statistical characteristics) and solve multiple problem instances by changing the input parameters on available customer inventory. The average objective value of all solutions together can be used as a benchmark-value to other experiments. A confidence interval on the difference between the objective values is constructed to determine the effect of adding more integer values, as in the second model described in Section 6.3. We come back to this in the experimental design, given below.

Experimental design

The model presented in Chapter 6 can provide insight into the effects of a certain level of LTR-RTI contracted by Johma. The model is a simplification of the actual situation and we made assumptions on the elements that are included. Nevertheless we do expect an improvement of the objective function if we change the current levels of LTR-RTI on a contract to the calculated 'optimal' amounts from Chapter 5.

An aspect of the model in Section 6.3 is the method to calculate the optimal load for a shipment. The original model calculates the volume of each RTI transported and ensures the total volume of every truck is not exceeded. The fact that RTI is piled on a pallet in neglected due to the increase in required integer variables and thereby the computational complexity of the model. Whether this assumption in the original model is a valid one, is the second element of the experimental design.

Table 8 gives the four combinations of further analysis. Four different experiments are constructed to draw conclusions on the effect of a certain number of LTR-RTI and the consequences of neglecting the RTI being piled on a pallet.

Settings	# LTR-RTI	Vehicle Capacity
Experiment 1	Current	Volume
Experiment 2	Current	PPE
Experiment 3	Proposed	Volume
Experiment 4	Proposed	PPE

Table 8: Experimental settings

Objective values

The objective function of the model in Section 6.3 consists of the transportation plus STR-costs. The level of LTR-costs for the different settings is a constant value (that differs between the current and proposed situation) that can be added afterwards. Table 9 displays the total values of the different experiments, each run refers to a different set of input parameters on customer inventory (the exogenous process). We display the percentages of the total rental costs (versus the transportation costs) as well, from which we conclude that total rental costs are lower in the proposed situation.

By using the same series of input parameters, the different experimental results become paired observations. This creates the opportunity to compare the different experiments and perform a sensitivity analysis.

Total costs	Run 1	Run2	Run 3	Run 4	Run 5
Experiment 1	€126.045 (7,6%)	€126.020 (7,6%)	€125.992 (7,7%)	€126.017 (7,7%)	€126.031 (7,7%)
Experiment 2	€128.786 (8,2%)	€127.627 (8,1%)	€131.068 (7,7%)	€127.004 (7,9%)	€129.664 (7,6%)
Experiment 3	€120.204 (3,2%)	€120.312 (3,3%)	€120.283 (3,2%)	€120.168 (3,2%)	€120.307 (3,2%)
Experiment 4	€123.317 (4,4%)	€120.823 (3,2%)	€121.075 (3,4%)	€120.704 (3,3%)	€122.152 (3,5%)

Table 9: Total costs (LTR-costs included)

Sensitivity analysis

We would like to compare the objective values of the performed experiments. In this test we look for patterns and enough statistical evidence to accept that it is very unlikely that all results happened by accident. As a result we come up with a paired confidence interval which resembles the reliability of the tested parameters.

If n is sufficiently large, an approximate 100(1-α) percent confidence interval for the mean D is given by:

$$\bar{D} \mp t_{n-1,\alpha/2}\sqrt{\frac{s^2(n)}{n}}$$

With $t_{n-1,\alpha/2}$ (for 0 < α < 1) is the upper α/2 critical point for the t-distribution with n-1 degrees of freedom. The confidence level gives the interval that contains the true mean µ with probability 1-α.

<u>Experiment 1 – Experiment 3</u>

The results in Table 9 are used to construct a 95 % confidence interval for the difference in objective values between Experiment 1 and Experiment 3.

$$5.766 \mp 2{,}7764 \times \sqrt{\frac{5223}{5}} = [5.676, 5.856]$$

We conclude with 95% certainty that the average objective value for experiments of type 1 lies between €5.676 and €5.856 higher than the value of Experiment 3. This means that the proposed amount of LTR-RTI from Chapter 5 realizes a saving in transportation and rental costs (in this simplified situation of Johma).

The same procedure can be applied to conclude whether there is a difference between Experiment 1 and Experiment 2, or equivalently between the two model configurations.

<u>Experiment 1 – Experiment 2</u>

The results in Table 9 are used to construct a 95 % confidence interval for the difference in objective values between Experiment 1 and Experiment 2.

$$-2.809 \mp 2{,}7764 \times \sqrt{\frac{2646844}{5}} = [-4.829, -789]$$

We conclude with 95% certainty that the average objective value for experiments of type 1 lies between €4.829 and €789 lower than the value of Experiment 2. This result is conform the expectations, because the solutions of the model in Experiment 2 are a subset of the solutions of Experiment 1. The confidence interval can be improved if we increase the number of runs, n.

7.4 Comparison current and proposed situation

In Chapter 5 we described a method to determine the optimal number of LTR- and STR-RTI, we concluded with a proposition on the number of LTR-RTI required in 2011 for the situation of Johma. We saw in the previous section that this proposed number generates a saving if we solve the MILP-model as well. Due to the model assumptions and parameter choices the actual situation of Chapter 5 and the model situation differ from each other. Nevertheless, we can see where the difference in objective value between experiments 1 and 3 come from. What differences in decision variables cause it?

Figure 31 and Figure 32 show the loaded amounts of RTI each week in the different trucks between the customer locations and the cleaning facility in Holten. The bars indicate the number of RTI transported of a certain RTI-type for that specific week. Johma uses during the year 79 vehicles in the current situation (Figure 31) and 9 vehicles more in the proposed situation (Figure 32). This difference is caused by the decrease in the number of relatively cheap LTR-RTI in the proposed situation (with respect to the current situation), the average outstanding balance declines. This decrease causes a decline of the average utilization of a freight which makes the number of required shipments increases to 88.

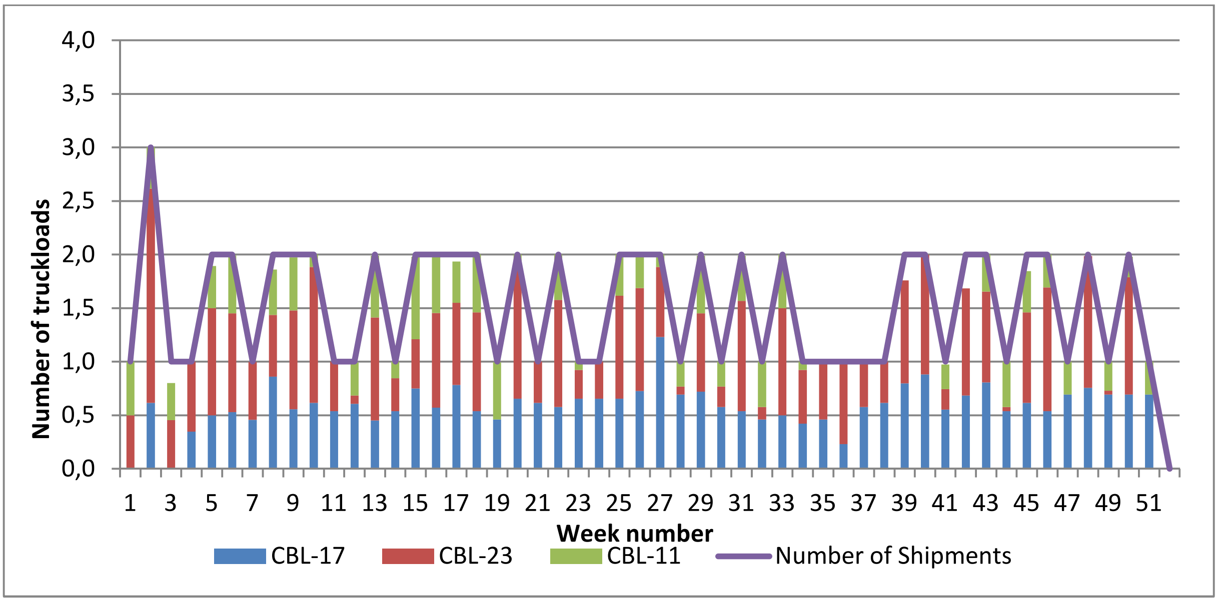

Figure 31: Truckloads between the customers and Holten - Current situation

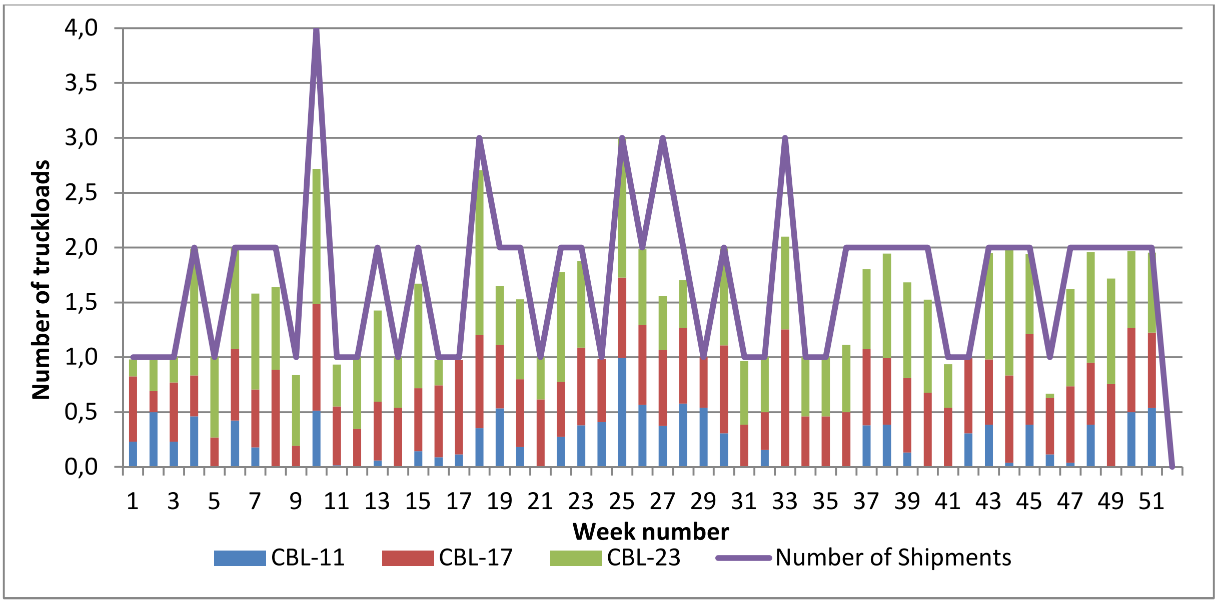

Figure 32: Truckloads between the customers and Holten - Proposed situation

The amounts of RTI shipped each week between the cleaning facility in Holten and the supplier Johma in Losser in the current and proposed situation differ if we look at their compilation, the number of freights is more or less equal (see figures in Appendix F). In the proposed situation we transport the RTI more in line with the production demand which causes a 40% decrease in Johma's inventory, see Figure 33 and Figure 34. Johma transports only RTI in case they expect demand in the near future. By this, the total inventory at Johma decreases in the proposed situation and the RTI keep moving through the supply chain of Johma to prevent interruptions and extra costs.

Pool Service aims to decrease the RTI-cycle times in order to create savings for participants, the model shows that the new balances can contribute to this goal. Next to this, the customers and suppliers should reserve less space for storage in their warehouses if total average amounts decline.

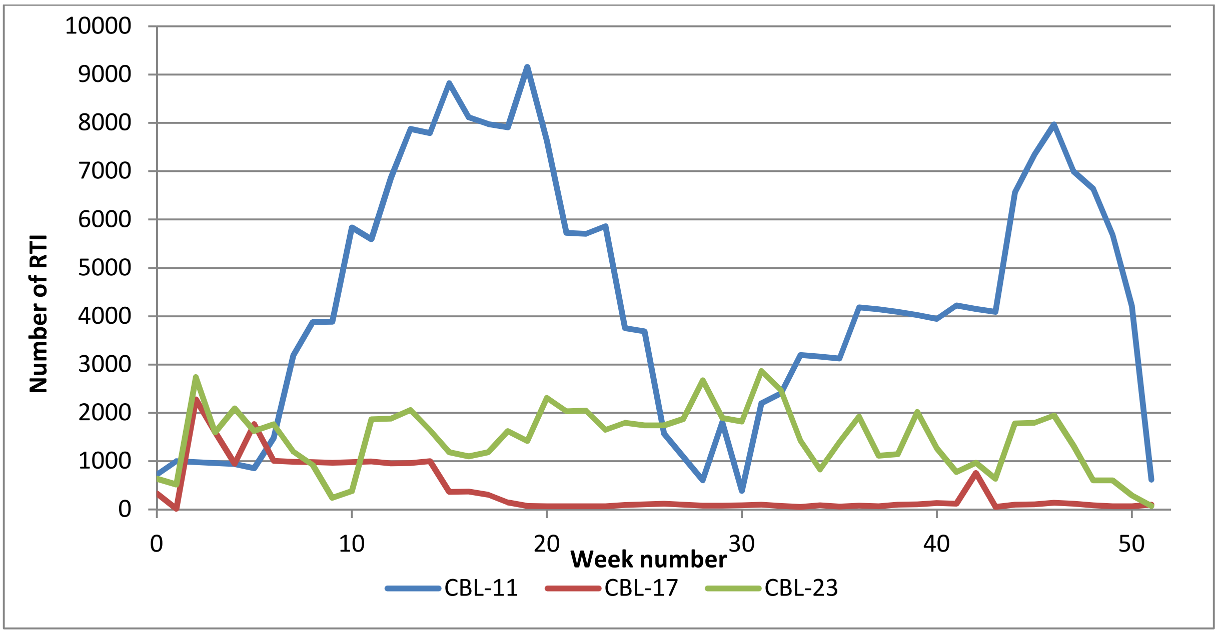

Figure 33: Johma's Inventory - Current situation

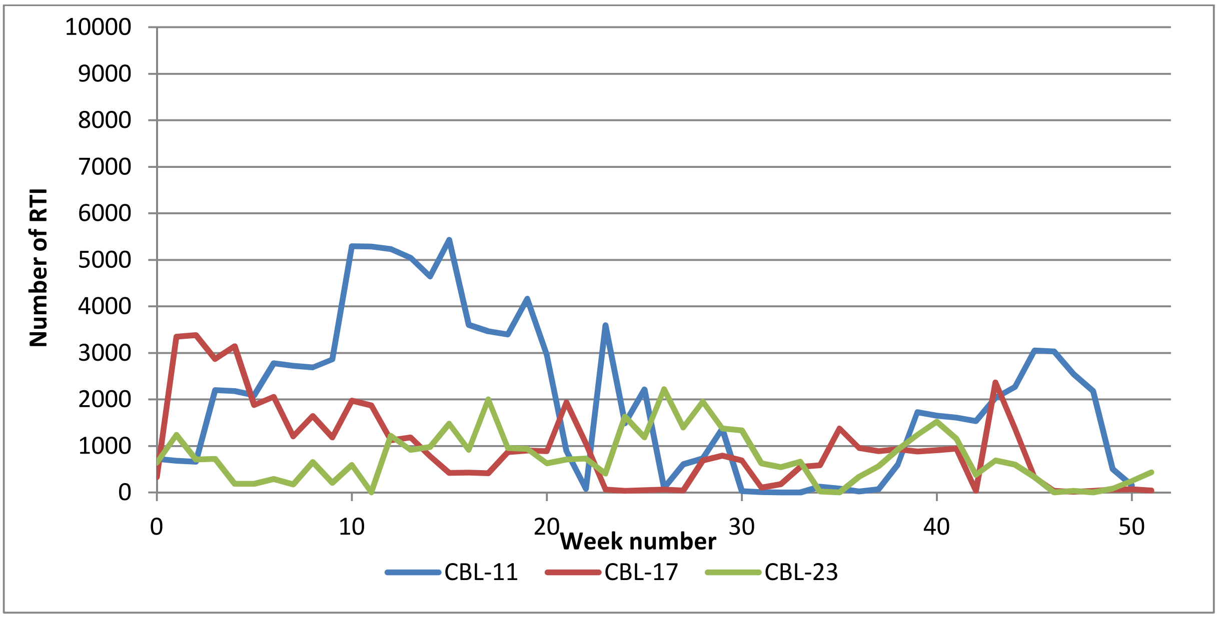

Figure 34: Johma's Inventory - Proposed situation

The MILP-model holds currently no restriction on the available storage space and/or storage costs at the customers, the cleaning facility and/or the supplier Johma. In case we would include these aspects, the model may come up with even lower inventory levels (at possible extra costs).

By adjusting the number of LTR-RTI we expect an effect on the number of STR-RTI requested by Johma. Figure 35 and Figure 36 show the STR-balances at Habé during the year. In the current situation we see a high demand for CBL-17 and almost zero demand for CBL-11 and CBL-23. We explain this by referring to the mismatch between the number of LTR-RTI and the demand pattern. In Figure 36 it is clear that with the proposed number of LTR, the short term rentals follow the peaks in demand for all types of RTI. Costs of LTR- and STR-RTI are balanced, as it should be.

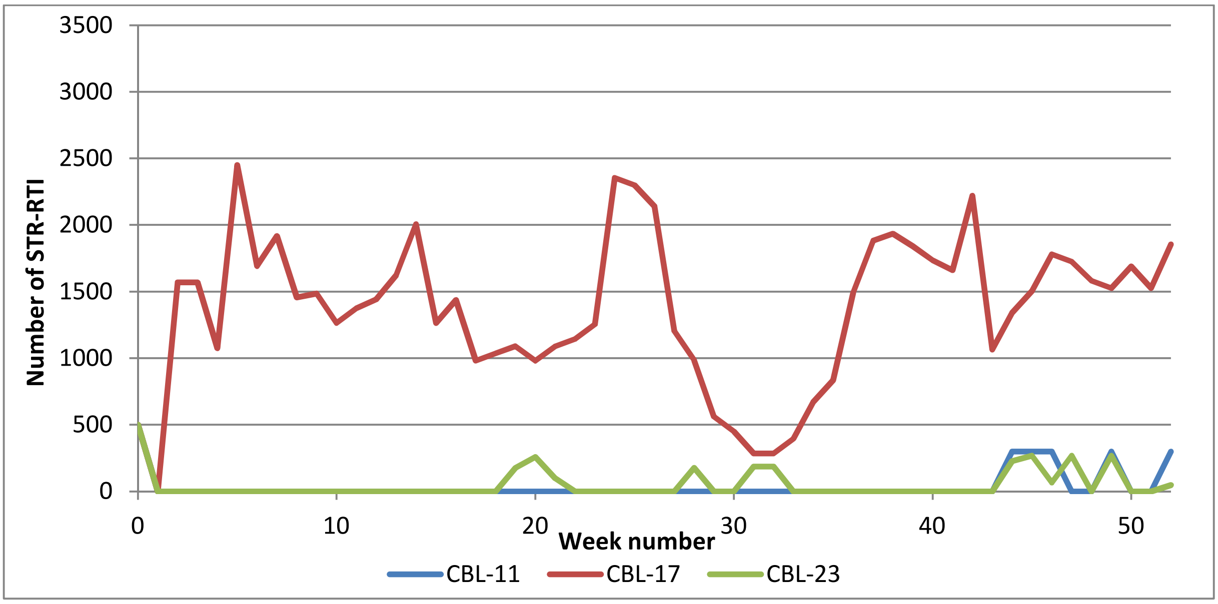

Figure 35: STR-RTI - Current situation

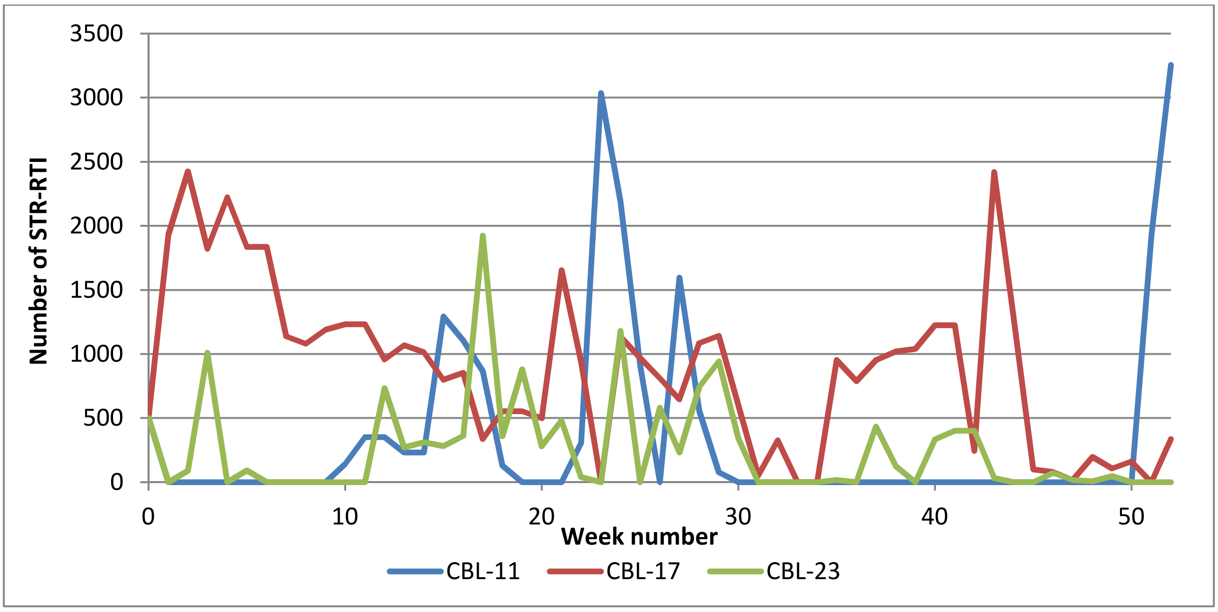

Figure 36: STR-RTI - Proposed situation

7.5 Conclusions

The solution method presented in this chapter consists of a MILP-formulation (details can be found in Appendix E) of which the data requirements and assumptions are discussed in Section 7.2.

Special attention should be given to the assumptions on the exogenous process at the customer locations. A uniform distribution on the interval of 800-1200 RTIs, representing the available amount at the customer locations for a given week, simplifies this effect drastically. In reality the level of inventory at a location is depending on the number of received RTI, the internal cycle time and the behavior and demand patterns of other suppliers requesting RTI. The exogenous process represents a complex environment. Further research is necessary to improve the input parameters that represent customer inventory levels, this would increase the validity of the model.

The MILP solution method has an undesirable effect on the practical usability of the solution. We solved multiple problem instances over a planning horizon of 52 weeks and entered the required data to support this. The gap between this model and reality comes from the extra information on future states of, for example, the available RTI at each location. The model decides on the decision variables for a certain week by including future effects, which are unknown in reality. For the long run and tactical decisions (see Section 6.1) to determination of the effect of a certain level of LTR-RTI, the model can create valuable insights but for operational decision making on shorter-time horizons we require more detailed information on, for example, the stochastic elements. An daily decision model is required. Given a certain level of RTI among the different locations and the expected demand patterns of Johma and other participants in the RTI-cycle model, the model should choose (with probability x) for a certain set of actions. In this way the planning department can rely on the model to manage the RTI transactions.

The sensitivity analysis shows the positive effect on the objective value if we revise the number of RTI on a LTR-contract from current levels to proposed levels. We concluded with 95% certainty that the we can realize savings between €5.676 and €5.856. The assumptions and differences on the practical situation of Johma make it impossible to compare the estimated savings directly to the estimated values from Chapter 5.

If we look at the decision variables of the solution on the current situation versus the proposed situation, we see the trade-off between rental costs and transportation costs and a 40% decrease in inventory levels. The objective value of the proposed situation is significantly lower. Nevertheless, the average truck utilization in the proposed solution between the customer locations and Johma decreased as an effect of the decrease in LTR-RTI. This is an obvious effect of balancing rental and transportation costs.

The important conclusion we draw from the statistical analysis and the decision variables of the two situations, is that the model creates solutions that fit the model assumptions accurately but there are differences with the actual situation of Johma.

8 Conclusions and recommendations

In the introduction of this research we mentioned the reason for starting up this research and the problem encountered by Johma:

Johma has limited insight in, and limited control over, the use of Returnable Transportation Items within the continuously changing Supply Chain. This causes a lack of control and more costs than legitimated.

Johma wants to increase control and make sure that they do not lag behind in the negotiations with stakeholders. To achieve this objective, we formulated the goal of this research as:

Developing methods for analysis, that contribute to an efficient use of Returnable Transportation Items along the Supply Chain of Johma. The acquired information can be used as input in the negotiations with different stakeholders.

8.1 Conclusions

To answer the main research question on how Johma should manage their Returnable Transportation Items through the supply chain in a cost effective way, we first answer some sub questions.

What about Returnable Transportation Items?
The RTI under consideration are used for secondary packaging of products by Johma and a lot of other suppliers. The total share of Johma in the total use of RTI in the Netherlands is limited to only 0,13%. A position that creates dependability on the behavior of other participants. With other participants we mean all organizations that joined the pool provider Pool Service.

How are Returnable Transportation Items used?
The RTI flow through the supply chain of Johma via different stakeholders. The products produced in the production facility in Losser are shipped to the customers (including the RTI) by MFFL. As soon as the RTI are delivered to the customers, the outstanding balances of Johma increase and MFFL may be contacted to come and collect a freight of RTI. This RTI still have to be cleaned at the cleaning facility. The cleaning facility of Habé is located in Holten, relatively close to Johma and therefore the best option. As soon as a new batch of RTI is required at the production facility, an order is placed at Habé and the (full truckload) amount is picked up by MFFL. In case there is not enough RTI present at the warehouse of Habé that belongs to Johma, there is a possibility to rent additional RTI at extra costs.

What costs are involved in RTI-management?
The costs on RTI usage can be subdivided into five categories, namely: cleaning, rental, storage, transportation and overhead costs. From data on 2011 we learned that Johma spent a total budget of €139.500 on these categories together. We are especially interested in the factors influencing the total costs. We identified three relationships among the cost factors in Chapter 3:

1. A trade-off between high truck utilization versus low inventory levels and thereby rental costs;
2. The COC influences the amount of LTR-costs;
3. The cost effect of the level of LTR-RTI versus STR-RTI.

What did we learn from literature?
In reverse logistics the products flow supply driven from many origins to one destination, in the situation of Johma we have to deal with a situation in which the return products flow demand driven. This is possible because Johma has the opportunity to rent additional STR-RTI from a variable pooling system at the cleaning facility in case of a shortage at the customer locations. The LTR-RTI belong to

a dynamic pool of crates, which means that the total amount of RTI is constant but the amount actually in use may fluctuate during the year.

The RTI cycle through the forward and reverse supply chains of multiple organizations with a lot of inventory locations. A decrease in total rental costs can be achieved if the total inventories decrease by keeping the RTI flowing through the different stages. Another saving possibility comes from Kirby (1959), who describes a method we can use to determine the optimal number of relatively cheap LTR-RTI to put on a contract. This brings up the opportunity to save on the costs for STR-RTI.

Minimizing the costs of transportation, storage and renting RTI is the overall goal of Inventory Routing Problems. The basic idea of the model of Lee et al. (2003) for an assembly plant in the automotive industry is used to formulate a model for Johma in Chapter 6.

What is important in the current situation?
Data analysis shows that the deposit system made the relationship between the delivery and pick-up location disappear. The overall balances of a supplier are leading if Pool Service authorizes a request for collecting a batch of RTI. The lack of information on the use of RTI causes a flaw in the number of LTR-RTI contracted by Johma. The theory of Kirby (1959) and some sensitivity analysis on the COC used to compute the LTR-costs gave insight in saving opportunities by adapting the LTR-contracts to levels that suit the current demand rates. A savings opportunity of an estimated 50% on the total costs of almost €43.000. The description of the method can be found in Chapter 5.

How should a decision support model on the efficient use of RTI look like?
The relationships analyzed in Chapter 5 are included into the model of Lee et al. (2003) in a mathematical formulation that can be found in Section 6.3. The objective of the model is to decrease total transportation and rental costs at a given number of LTR-RTI. Assumptions had to be made to generalize the situation of Johma. The biggest gap between the model and the situation of Johma comes from the lack of information on the inventory levels at customer locations. The limited influence of Johma in the Netherlands on the total dispersion of RTI among customers, made us assume that the inventory levels are given and unchanged by decisions of Johma in prior periods.

What did we learn from the output of this model?
The mathematical formulation is translated to a MILP-model that is solved for multiple problem instances. The runs of the model with the new level of LTR-RTI, found by the method of Kirby (1959), results in lower objective values. We concluded with 95% certainty that the we can realize savings between €5.676 and €5.856. This is in line with the expectations and endorses the method given in Chapter 5. Nevertheless, the model assumptions and parameter data make it impossible to compare this number directly against the savings estimated with the method of Kirby.

Next to this, we saw a decline of 40% in average inventory at Johma if we change the number of LTR-RTI to the proposed situation, a desirable situation to keep the RTI moving through the supply chain.

A undesirable effect involved in solving an MILP-model comes from the extra information 'known' by the model on future states which are not obvious in reality. For the long run and determination of the effect with a certain level of LTR-RTI, the model can create valuable insights but for actual decision making on shorter-time horizons we require more detail on stochastic processes. A simulation study in which it is possible to model certain probabilities for a reaction to an observed state can provide support in daily decision making.

8.2 Recommendations

RTI-management is no core-business activity and increasing control over RTI from the perspective of Johma is difficult. Not only caused by the limited share of Johma compared to other participants, but mostly because the RTI flow in the external environment, outside Johma’s direct control. If we combine this with the fact that not all customers participate into the pooling model, we recommend Johma to start active promoting the membership of Pool Service for all customer relations. To increase chances on success, Johma could work together with other suppliers and include Pool Service in this process. It is important to work together with more suppliers to increase total effects of efficient RTI usage. If all participants aim to decrease total cycle stock and thereby the cycle time, it is possible to create large savings for participating companies.

This research provides in a recommendations to improve RTI-management from the point of view that we would like to decrease total costs. We did not look for opportunities to eliminate the need for effective RTI-management. In Section 4.2 we discussed the different RTI cycle models; one type of a pooling model is called ‘one-way-rental’. The pool operator charges suppliers a variable price on a ‘per trip’ basis, with the operator responsible for collecting empty units after delivery. Johma can use this research to determine the required budget for continuation of the current way of working and start negotiation with, for example, Habé and MFFL (both 50% shareholder of the cleaning facility in Holten), on the costs of switching to a ‘one-way-rental’-system. Habé and MFFL should increase their knowledge of inventory levels and RTI-flows through the supply chain to help suppliers, like Johma.

Before such a system is implemented, Johma still has the obligation to return the proper amounts of RTI on LTR-contract to Pool Service, in order to change the contracts towards the proposed future RTI-levels. These LTR-levels should be evaluated yearly based on the expected long term demand-rates. By anticipating on fluctuations in future demand, Johma has more time to adapt contractual agreements or charge extra costs to the customers who cause the expected fluctuation. A yearly check on the contracts and forecasts and more awareness of important cost factors increases the insight of Johma and decreases total costs. Keeping the number of RTI, also known as “Hard Workers”, up to date decrease the cycle times and keeps them moving along the supply chain.

Keep the “Hard Workers” moving!

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Appendix A

Company Information

To formulate a good solution to the problem statement formulated in the Section 1.2 it is necessary to know in what context this problem has emerged and how Johma handles its RTI right now. Johma is the largest and well-known salad producing company in The Netherlands. In this Appendix we provide some historical background, discuss the strategy, the products and markets and look into more detail to the general production and logistical aspects.

Historical Background

Johan Schreur and his business partner Martin Schreur found Johma in 1968. The company name ‘Johma’ is based on their surnames. The company started really small in a garage located in Glanerbrug, near Enschede. After a period of growth, Johma moved in the early 70s to Losser.

The company is sold for the first time in 1984. Since then its structure and ownership have changed almost continuously. In 2003 Johma became part of Uniq plc, an English company registered at the stock exchange. Due to losses of the Uniq group, Uniq decided to sell Johma Salades, Uniq Sandwiches and the former sister party of Johma (from Belgium), Hamal to Gilde Equity Management Benelux. From the end of 2009 until May 2012, Gilde is the biggest shareholder of Johma Salades. Recently, Johma is bought by AAC Capital Partners.

The Gilde group participated in several food-producing companies, e.g., in Bakker Bart, De Banketgroep, and as mentioned Hamal Signature. At the end of 2010, Gilde decided to split up Johma Signature (Johma Salades en Johma Sandwiches) and sell Johma Sandwiches to Convenience Food Europe. Johma Salades could focus in this way more on its core activity, producing salads for the Dutch and German market. Unfortunately, Nadler, Johma’s customer from Germany started producing salads in-house. With the loss of the German market another new reorganization was necessary and around 70 people lost their job.

Since this last intense reorganization, the management of Johma is striving to turn Johma again into a stable and profitable organization on the long term as part of AAC Capital Partners. Starting point is their strategic vision on the company. The starting point of the next subparagraph.

Strategy, Products and Markets

As can be concluded from the historical background of Johma a lot has been changed in the last decennium. This includes the vision, mission and strategy of Johma. The current mission is formulated recently, in 2011, as:

“We make everyone enjoy the most delicious salads!”

Accompanying this mission, four core values for the organization and its employees are specified, i.e.:

- *Craftsmanship* - Acquiring and using specialists’ knowledge to increase product quality and deliver unique results in an efficient and effective way.
- *Neighborliness* - Colleague friendliness, (company) loyalty and supporting each other.
- *Competitiveness* - Continuously improving all processes and striving for the best performance delivery by every employee.
- *Customer is King* - Any product’s design, sale, production, distribution and marketing activity should have one central focus at the core of all decision-making: the internal/external customer (Wine Australia, 2012).

Each core value throws light on another aspect of quality. This, by Porter defined, quality-oriented differentiation strategy turned Johma into the overall market leader in the Dutch salad market with an average market share of 21,8% in 2011 (Daft, 2005). Johma’s production facility is located in Losser and produces over 300 different Stock Keeping Units (SKU’s), which generated an annual sales volume of € 65 million in 2011.

Johma employs about 150 fixed employees, during periods of peak demand additional personnel are hired at the in-house employment agency. Seasonality in demand for Johma’s products is caused due to weather conditions and/or holidays, the variations in restricted storage life of products, and the number of customers. These factors make it hard to produce accurately on forecast. Nevertheless it is very important that shortages and obsoletes are minimized, because lost sales and waste, deplete the already relatively low profit (margin) even further.

Johma’s customers can be divided in to two categories, namely: retail and foodservice. The supermarkets belong to the retail customers, and are delivered by Johma through different distribution centers. The foodservice customers can be further segmented in to catering, train- and fuel-stations, convenience shops (domestic caterers) and other institutions (like hospitals).

At the beginning of 2012 Johma signed a new contract with a supermarket from Germany. This contract concerns mainly products destined for the Dutch market and a relative small part for the German market. When Johma was part of Uniq it produced for the German market as well, but due to reorganizations and quality issues, this position got lost. As part of the overall strategy, Johma searches for new possibilities to re-enter the German market. The new contract resembles this ambition and makes Johma’s overall performance very important.

Now we know in which environment Johma operates, the next step is to look at the company in a little bit more detail. What are the main processes within Johma?

The Internal Processes

This paragraph treats every phase of the (production) process, starting with a customer order until actual delivery takes place. Figure 37 provides a graphical representation of the production process.

Customer-order

As the title of the department already indicates, ‘customer service’ is in contact with the direct customers of Johma. They compose a forecast for each customer that is based on historical information, special offers and known orders. Customer service enters this forecast in the Enterprise Resource Planning-system, Infor ERP_{LX}.

Planning

The planning department consists of multiple employees. The finished goods planner(s) translate the forecast into a production demand that satisfies the capacity restrictions and current inventory. The definite Master Production Schedule is translated into shop orders and used as an input for the Materials Requirement Planning that generates a certain need for Raw Materials and Packages. The call-off planner contacts subsequently the suppliers and/or Cold store (a nearby chilled warehouse in Hengelo that is used as a buffer inventory location) for Raw Materials that are not available in Losser based on the planned production/demand forecast.

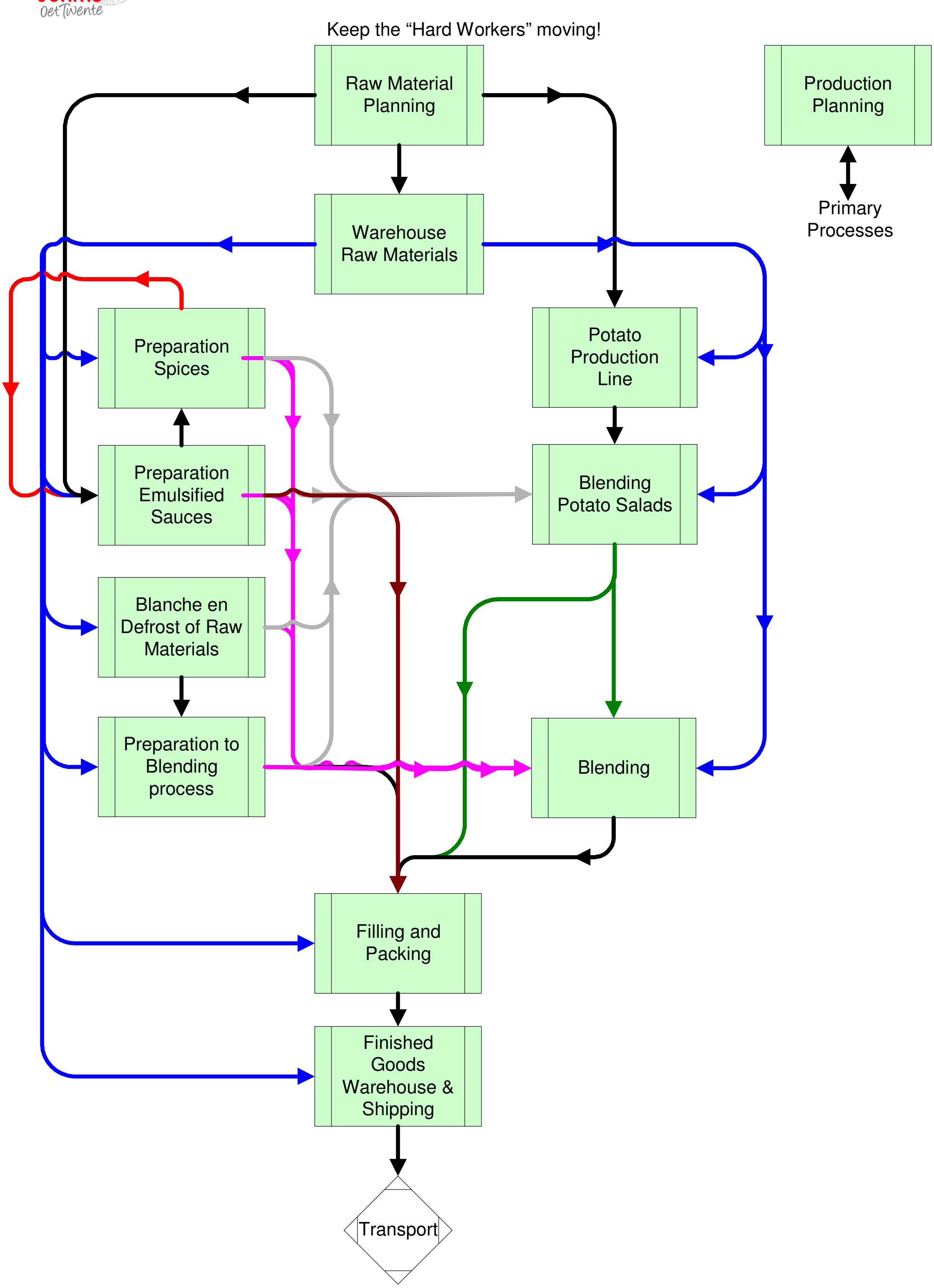


Figure 37 Flow chart of production process

Suppliers

Johma uses over 1000 different Raw Materials and Packages which are delivered by x different suppliers. The purchasing department closes contracts, which consists of agreements on price, quality, type of products, minimum order quantity, and delivery time blocks. Johma started implementing a Vendor Management Inventory-system in which the supplier is entitled to determine when they deliver a certain quantity as long as the physical inventory is between set boundaries.

Raw Material-warehouse

Johma has two internal warehouses, one for Raw Materials and Packages and one for Finished Goods. The logistics service provider of the supplier delivers the products (Raw Materials and Packages) to the Raw Material warehouse. The products are registered into the Warehouse Management System. They stay there until the Blending department makes a request for Raw Materials, the Fill-and Pack up section requires Packages, the Hot Kitchen requests Vegetables that require pre-cooking, when the Cold Kitchen produces Emulsified Sauces or when Spices have to be prepared.

Potato production line

Johma has one type of Raw Material that is treated differently, this are the potatoes. Different farmers deliver (on-order) truckloads, directly to the buffer spaces in front of the Potato production line. This production line is used to produce mashed potatoes, chunks or slices, depending on the demand for these intermediary products.

Blending

The Blending department blends the different ingredients (mostly) into funnels of 600 kg. These ingredients can be categorized into the outputs of the potato production line, spices, Johma-made sauces, pre-cooked vegetables, and others. The Blending department works according a Pull mechanism and therefore reacts to requests from the Fill and Pack up department that work according a schedule released by the scheduler.

Fill- and Pack up

The funnels are transferred to the Fill and Pack up department, where the salad is filled up and labeled on one of the x automated production lines. The separate bins are combined in plastic reusable crates, carton boxes or just blank and subsequently piled on a pallet.

Finished Goods-warehouse

All pallets with finished products are stored in the Finished Goods-warehouse. Meanwhile, the customer orders, entered by Customer Service, are visible for order picking. These orders consist of whole pallets and/or separate packages. The deliveries are picked and put ready for shipment.

Shipping

There is a fixed time-schedule of trucks, from Müller Fresh Food Logistics (MFFL), arriving at Johma. A truck is connected to one of the docks and loaded by an employee of Johma. The driver receives the administrative papers and leaves (directly or via a distribution center) to the customer. The orders are registered as they leave Johma and billed in the ERP system.

Customers

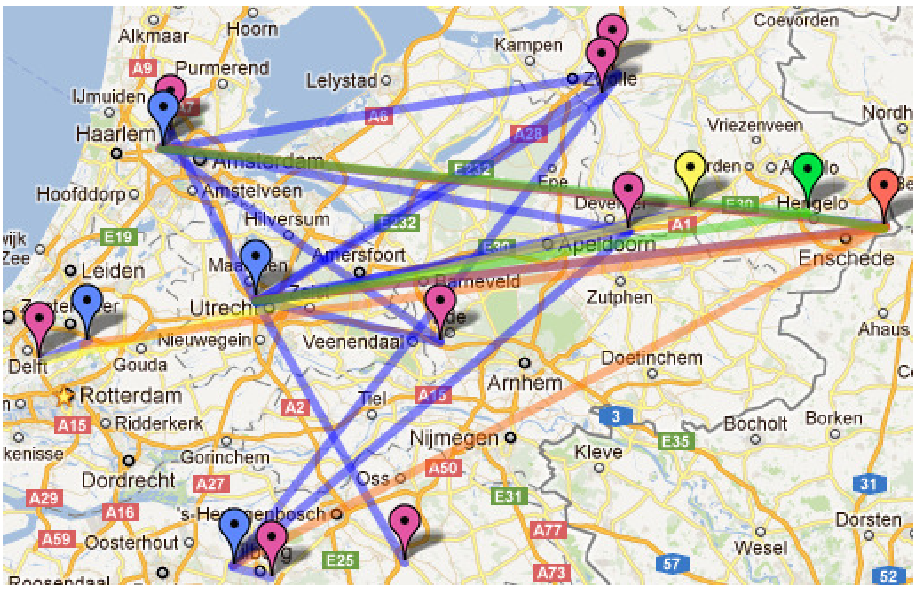
Most customers have certain pre-specified block-times for inbound deliveries. MFFL takes these times into account, delivers the goods and the customer performs a check. The financial department takes care of invoicing the delivered products and RTI (deposit money). The customer locations (including distribution centers) who received crates during 2011; are displayed in Figure 38.

Figure 38 RTI customers of Johma in 2011

RTI are valuable and reusable and therefore included in the Reverse Logistics part of the supply chain. This part of the logistical processes is important due to the scope of this research and therefore discussed separately in the next paragraph. Nevertheless, this process is interrelated and subject to the forward supply chain.

External process

Figure 39 shows the full-truckload transport movements (reverse logistics) between retail customers (large demand), the cleaning facilities of Habé, Johma (Losser and Cold store) and the warehouse of MFFL. This shows that there is no direct link between certain customers and a specific nearby cleaning facility.



Pink = retail customer

Blue = Habé cleaning facility

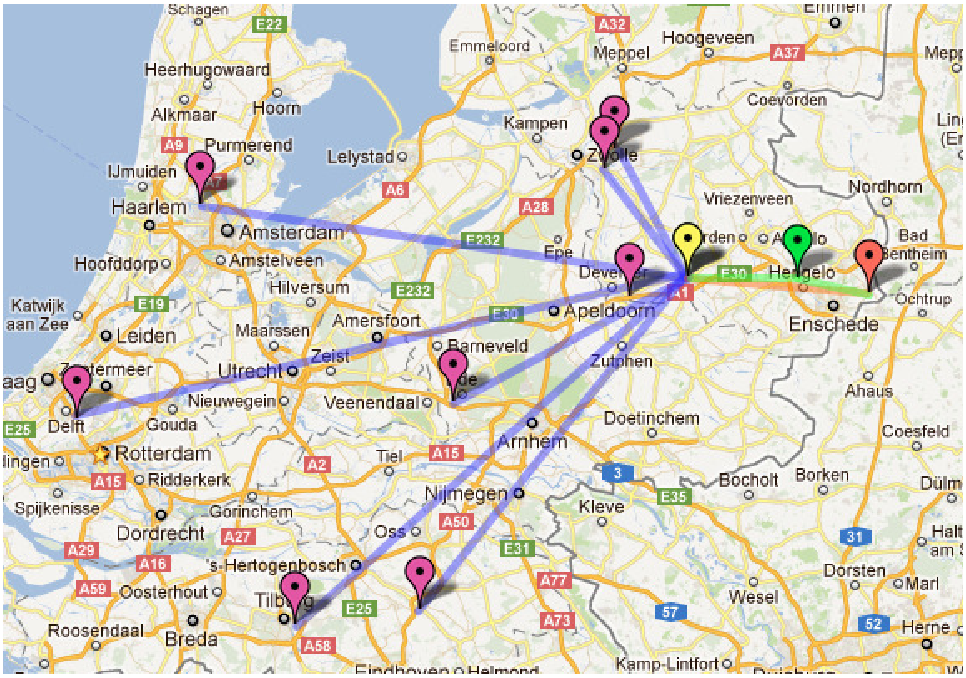
Yellow = warehouse of MFFL

Green = Johma Cold store

Orange = Johma Losser

Figure 39 Full-truckload RTI return flow 01-2011 t/m 47-2011

Up to week 48-2011 there were 4 Habé locations used by Johma, located in Amsterdam, Bleiswijk, Tilburg and Utrecht. This situation changed with the opening of the new location in Holten. This facility is located next to the warehouse of MFFL and MFFL is a 50% shareholder of this new accommodation. MFFL promised Johma that this opening is an interesting competitive advantage due to the reverse logistics on CBL-crates. MFFL is currently searching for possibilities to create the situation as presented in Figure 40.



Pink = retail customer

Yellow = warehouse of MFFL & Habé cleaning facility Holten

Green = Johma Cold store

Orange = Johma Losser

Figure 40 Full-truckload flow including Habé Holten

Section 5.2 gives the symbolic representation of Figure 39 and Figure 40 during 2011. In the first situation, Johma had a balance on CBL-crates at each cleaning facility separately. If the new situation will be in place, there is only one balance remaining, the balance of Holton.

Appendix B

Returnable Transportation Items Characteristics

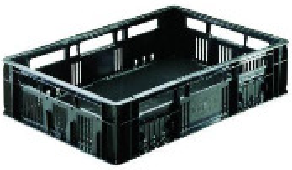
Foto	Type	Afmeting (LxBxH)	Volume (ltr)	Massa (kg)	Vormgeving
	CBL 07	60 x 40 x 7,6 cm EAN 8714303000002	16	1,08	kleur: antraciet bevat ventilatiegleuven
	CBL 08	30 x 40 x 7,6 cm EAN 8714303000064	7,5	0,58	kleur: antraciet bevat ventilatiegleuven
	CBL 11	60 x 40 x 11,5 cm EAN 8714303000019	24	1,32	kleur: antraciet bevat ventilatiegleuven
	CBL 15	30 x 40 x 15,3 cm EAN 8714303000040	15	0,82	kleur: antraciet bevat ventilatiegleuven
	CBL 17	60 x 40 x 16,7 cm EAN 8714303000026	34	1,67	kleur: antraciet bevat ventilatiegleuven
	CBL 23	60 x 40 x 23,0 cm EAN 8714303000033	47	2,00	kleur: antraciet bevat ventilatiegleuven

Figure 41: RTI characteristics
(Habé Centrale Retourencentra B.V., 2011)

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Appendix C

Expenditure and background data on RTI-management

As mentioned the retailers have joined a pool service for plastic RTI-crates. These crates are provided by the Centraal Bureau Levensmiddelenhandel (CBL) and are therefore called CBL-crates.

Cleaning Costs

CBL type	01/2011-07/2011	# of RTI	07/2011-12/2011	# of RTI	Total costs
CBL-07	€0,1019	3.250	€0,1041	1.750	€513,35
CBL-08	€0,0787	136.250	€0,0815	145.750	€22.601,50
CBL-11	€0,1042	20.720	€0,1083	10.400	€3.285,34
CBL-15	€0,0996	0	€0,1005	0	€0,00
CBL-17	€0,1065	22.517	€0,1159	26.422	€5.460,37
CBL-23	€0,1100	24.128	€0,1212	20.608	€5.151,77
		206.865		204.930	€37.012,33

Table 10: Cleaning costs

Long term rental

CBL type	# of RTI	Deposit per crate	Total Deposit	Yearly Pool-fee per crate	Yearly fee
CBL-07	16335	€4,54	€74.160,90	€0,20	€3.267,00
CBL-08	n/a	n/a	n/a	n/a	n/a
CBL-11	20000	€2,35	€47.000,00	€0,09	€1.800,00
CBL-15	4000	€2,25	€9.000,00	€0,06	€240,00
CBL-17	2000	€2,95	€5.900,00	€0,06	€120,00
CBL-23	5000	€3,24	€16.200,00	€0,09	€450,00
			€152.260,90		€5.877,00

Table 11: LTR costs

These are the numbers stated in the contracts. In practice Johma pays a standard pool fee for each type of RTI of €0,12. The yearly paid fee is therefore €5.680,20 and slightly lower than may be expected based on the available documentation.

CBL-type	#	Contract number	Contract date	Remark
CBL-07	1350	WD00044853	28-1-2008	Reduction on 801489
CBL-07	14985	801031	28-10-1997	
CBL-11	20000	803031	21-5-2002	
CBL-15	**4000**	WD00044844	28-1-2008	Currently not in use, remaining inventory: **5000** crates
CBL-17	2000	WD00044845	28-1-2008	
CBL-23	5000	802841	15-1-2002	

Table 12: Current LTR-contracts

Short term rental

The costs are given for using a STR-crate during one week. The total costs during 2011 are given.

CBL type	Rental fee per week	Average # crates per week	Total costs
CBL-07	€0,05	0	€0,00
CBL-08	€0,05	2.053	€5.337,80
CBL-11	€0,05	0	€0,00
CBL-15	€0,05	0	€0,00
CBL-17	€0,05	0	€0,00
CBL-23	€0,05	5.396	€14.029,60
			€19.367,40

Table 13: STR-costs

Storage costs

CBL type	Storage costs per PPE/week	Average # of PPE per week	Total costs
CBL-07	€0,53	81	€2.219,10
CBL-08	€0,53	35	€955,59
CBL-11	€0,53	154	€4.237,88
CBL-15	€0,53	43	€1.185,08
CBL-17	€0,53	60	€1.642,47
CBL-23	€0,53	0	€0,00
		Discount	€-773,80
		Total costs	€9.466,33

Table 14: Storage costs

Transportation costs first half year 2011

CBL-type	per layer	# of layers	#per freight	Price per freight	Remarks
CBL-07	5	25	3250	€268,13	
CBL-08	10	25	6500	€536,25	
CBL-11	5	16	2080	€171,60	
CBL-15	10	12	3120	€257,40	No longer used by Johma
CBL-17	5	11	1430	€117,98	
CBL-23	4	8	1056	€87,12	Transported on EURO pallets

Table 15: Transportation costs 1st semester

Transportation costs second half year 2011

CBL type	# of RTI	# of freights	Average utilization	Total costs
CBL-07	1.750	1	54%	€225,00
CBL-08	145.750	23	97%	€5.175,00
CBL-11	10.400	5	100%	€1.125,00
CBL-15	n/a	n/a	n/a	n/a
CBL-17	26.422	18,5	100%	€4.162,50
CBL-23	20.608	19.5	100%	€4.387,50
		67		€15.075,00

Table 16: Transportation costs 2nd semester

Appendix D

Contractual agreements Cleaning facility Habé and Johma

Availability:

- Habé cleaning facilities guarantees a 100% availability of RTI if Johma orders according to the principle of 'RTI ordered today is required for tomorrow's production'.
- Habé cleaning facilities guarantees, in case of shortages of RTI in the supply chain of Johma, the possibility to use inventories of Habé. Habé guarantees a 100% availability of possible unplanned peak demand with a maximum of 50% of average RTI demanded by Johma. The pick-up locations are tuned accordingly.

Cleaning of crates:

- Habé cleaning facilities guarantees a 99% service level of already accepted orders of clean RTI.

Administrative bookings:

- Johma has the possibility to transfer positive RTI balances from one Habé location to another as long as the unbalance is not larger than 10% of average RTI-flow. Habé cleaning facilities guarantees a 99% service level of completion of orders within 24 working hours.

Rental of crates:

- Johma has the opportunity to rent additional RTI to cover peak demands via Habé cleaning facilities. Habé guarantees a 100% availability of accepted orders at the agreed pick-up location.

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Appendix E

//MILP-Model on RTI-management of Johma

SETS

//here you find the indices of sets
//the data of the sets can be found under SETSDATA

i in CustomerLocations;	//Every customer location is denoted by i, i = 1...9 (Customer 9 is a dummy customer, where RTI is not available for pick-up)
k in ProductTypes;	//Every RTI type is denoted by k, k = 1...3
t,tt,ttt in TimePeriod;	//Every period (week) is denoted by t, t = 1...52

PARAMETERS

//here you find the parameter-definitions
//the parameters use the set-indices declared above under SETS

VehicleCapacityVol;	//Fixed capacity (m3) of a vehicle
// VehicleCapacityPPE;	//Fixed capacity (number of PPE) of a vehicle
FixedTransportationCost1;	//Fixed cost component (trip-fee) for every shipment from Holten to the customer and back to Holten
FixedTransportationCost2;	//Fixed cost component (trip-fee) for every shipment from Holten to Johma
VariableTransportationCost;	//Variable cost component per unit distance travelled
STRCost;	//Short-term-rental costs per week/RTI
LTRCost;	//Long-term-rental costs per year/RTI
ProductVolume(k);	//Product-volume of RTI type k
ProductionDemand(k,t);	//Production demand at Johma for RTI type k in week t
TravelDistance(i);	//One-way travel distance between Johma and customer i
NumberOfLTR(k);	//Number of fixed LTR-RTI of type k on contract for the whole year
HoltInvStart(k);	//Initial inventory level of RTI type k at Holten at the beginning of week 1
SuppInvStart(k);	//Initial inventory level of RTI type k at Johma at the beginning of week 1
NumSTRStart(k);	//Initial number of STR-RTI of type k at the beginning of week 1
IniProdDem(k);	//Production demand in week -1
// PPE(k);	//Volume of RTI type k that can be piled on one IPP-pallet
CustomerInv(k,i,t);	//Inventory level of RTI type k at customer location i at the end of week t

VARIABLES

//here you find the variable-definitions
//the variables also use the set-indices declared above under SETS

ShipAmountA(k,i,t):[0,inf];	//Total amount shipped of RTI type k from customer i to Holten in week t (continuous values)
ShipAmountB(k,t):[0,inf];	//Total amount shipped of RTI type k from Holten to Johma in week t (continuous values)
HoltenInv(k,t):[0,inf];	//Inventory level of RTI type k at Holten at the end of week t, for t>0 (continuous values)

```
SupplierInv(k,t):[0,inf];            //Inventory level of RTI type k at Johma at the end of week t,
                                     for t>0 (continuous values)
NumberOfShipsX(i,t):{0,inf};         //Number of times customer i is visited by a vehicle in week t
                                     (integer values)
NumberOfShipsY(t):{0,inf};           //Number of shipments between Holten and Johma in week t
                                     (integer values)
OutstandBalance(k,t):[0,inf];        //Amount of dedicated (outstanding balance) RTI type k at the
                                     end of week t (LTR and STR combined) (continuous values)
NumberOfSTR(k,t):[0,inf];            //Number of RTI of type k rented on a short-term-basis
                                     measured at the end of week t, for t>0 (continuous values)
MoreSTR(k,t):[0,inf];                //Number of additional RTI of type k rented at Holten starting
                                     in week t (continuous values)
LessSTR(k,t):[0,inf];                //Number of RTI type k handed in at Holten in week t
                                     (continuous values)
// NumPiledPPEA(k,i,t):{0,inf};      //Number of PPE piled with RTI type k shipped from customer
                                     i to Holten in week t (integer values)
// NumPiledPPEB(k,t):{0,inf};        //Number of PPE piled with RTI type k shipped from Holten to
                                     Johma in week t (integer values)
```

<u>CONSTRAINTS</u>

```
//here you find the problem restrictions
//Initializing the variable denoting the inventory level of RTI type k at Holten at the beginning of week 1
 IniHoltInv((k,t)|(ord(t)=1)):
   HoltenInv(k,t) = HoltInvStart(k);

//Inventory balance equation for all RTI type k at Holten in week t, for t>0
 InvBalanceH(k,t,tt|(ord(tt)=ord(t)-1) AND (ord(t)>1)):
    HoltenInv(k,t) = HoltenInv(k,tt) + SUM[(i),ShipAmountA(k,i,t)] - ShipAmountB(k,t) - LessSTR(k,t);

//Initializing the variable denoting the inventory level of RTY type k at Johma at the beginning of week
1
 IniSuppInv((k,t)|ord(t)=1):
   SupplierInv(k,t) = SuppInvStart(k);

//Inventory balance equation for all RTI type k at Johma in week t, for t>0
 InvBalanceS(k,t,tt|ord(tt)=(ord(t)-1) AND (ord(t)>1)):
   SupplierInv(k,t) = SupplierInv(k,tt) + ShipAmountB(k,t) + MoreSTR(k,t) - ProductionDemand(k,t);

//Makes it impossible to collect more RTI of type k in week t, for t>0, than the amount dedicated to
Johma still present at the customers inventory
 MaxPickCust(k,t,tt|(ord(tt)=ord(t)-1) AND (ord(t)>1)):
    SUM[(i), ShipAmountA(k,i,t)] <= OutstandBalance(k,tt) - HoltenInv(k,tt) - SupplierInv(k,tt);

//Initializing the variable denoting the number of STR-RTI of type k in week 0
 IniNumSTR((k,t)|(ord(t)=1)):
    NumberOfSTR(k,t) = NumSTRStart(k);

//Inventory balance equation on the number of RTI type k rented on a short-term basis in week t, for
t>0
 STRBalance(k,t,tt|ord(tt)=(ord(t)-1) AND (ord(t)>1)):
    NumberOfSTR(k,t) = NumberOfSTR(k,tt) + MoreSTR(k,t) - LessSTR(k,t);
```

```
//Initializing the variable denoting the dedicated (outstanding balance) RTI of type k in week 0
  IniOutBal((k,t)|(ord(t)=1)):
    OutstandBalance(k,t) = NumberOfLTR(k) + NumSTRStart(k) - ProductionDemand(k,t) - IniProdDem(k);

//Initializing the variable denoting the dedicated (outstanding balance) RTI of type k in week 1
  IniOutInvBa2((k,t,tt)|(ord(tt)=ord(t)-1) AND (ord(t)=2)):
    OutstandBalance(k,t) = OutstandBalance(k,tt) + IniProdDem(k) - ProductionDemand(k,t) + MoreSTR(k,t) - LessSTR(k,t);

//Inventory balance equation for all RTI type k on the number of dedicated (outstanding balance) RTI in week t for t>1
  OutInvBaN(k,t,tt,ttt|(ord(tt)=ord(t)-1) AND (ord(ttt)=ord(t)-2) AND (ord(t)>2)):
    OutstandBalance(k,t) = OutstandBalance(k,tt) + ProductionDemand(k,ttt) - ProductionDemand(k,t) + MoreSTR(k,t) - LessSTR(k,t);

//Creates a relationship between the total number of RTI of type k required in week t with the number of LTR- and STR-RTI
  LTRvsSTR(k,t,tt|ord(tt)=(ord(t)-1) AND (ord(t)>1)):
    ProductionDemand(k,t) + ProductionDemand(k,tt) + OutstandBalance(k,t) = NumberOfLTR(k) + NumberOfSTR(k,t);

//Capacity restriction on the transported volume of all RTI together with respect to the maximum capacity of the vehicle (between the customers and Holten)
  TruckCapX(i,t):
    SUM[(k), ShipAmountA(k,i,t) * ProductVolume(k)] <= VehicleCapacityVol * NumberOfShipsX(i,t);

//Capacity restriction on the transported volume of all RTI together with respect to the maximum capacity of the vehicle (between Holten and Johma)
  TruckCapY(t):
    SUM[(k), (ShipAmountB(k,t) + MoreSTR(k,t)) * ProductVolume(k)] <= VehicleCapacityVol * NumberOfShipsY(t);

//Capacity restriction on the transport of PPE piled with only one RTI type k in week t between the customer i and Holten
//  PPECapX(k,i,t):
//     ShipAmountA(k,i,t) <= NumPiledPPEA(k,i,t) * PPE(k);

//Capacity restriction on the transport of a maximum number of PPE in one vehicle between customer i and Holten in week t
//  TruckCapX(i,t):
//     SUM[(k), NumPiledPPEA(k,i,t)] <= VehicleCapacityPPE * NumberofShipsX(i,t);

//Capacity restriction on the transport of PPE piled with only one RTI type k in week t between Holten and Johma
//  PPECapY(k,t):
//     ShipAmountB(k,t) + MoreSTR(k,t) <= NumPiledPPEB(k,t) * PPE(k);

//Capacity restriction on the transport of a maximum number of PPE in one vehicle between Holten and Johma in week t
//  TruckCapY(t):
```

```
//      SUM[(k), NumPiledPPEB(k,t)] <= VehicleCapacityPPE * NumberofShipsY(t);

//Inventory balance equation for the total amount of every RTI type k available at customer i in week t
  CustInv(k,i,t):
      ShipAmountA(k,i,t) < CustomerInv(k,i,t);
```

MINIMIZE

```
//here you find the objective function, we try to minimize the function below.
//The objective function minimizes the transportation costs (fixed trip fee + variable costs per unit distance) and the STR-costs. The LTR-costs are not included because these are fixed for the year
  VariableTransportationCost*2*SUM[(i),TravelDistance(i)*SUM[(t),NumberOfShipsX(i,t)]]+
  FixedTransportationCost1*SUM[(i,t),NumberOfShipsX(i,t)]+
  FixedTransportationCost2*SUM[(i,t),NumberOfShipsY(t)]+
  STRCost*SUM[(k,t),NumberOfSTR(k,t)];    // + LTRCost*SUM[(k),NumberOfLTR(k)];
```

SETSDATA

```
//here you find the data for the sets that were defined above
  CustomerLocations:  {i1..i9};          // There are 9 customer locations considered
  ProductTypes:{k1,k2,k3};               // There are three RTI-types considered: CBL-11, CBL-17 and CBL-23
  TimePeriod:{t0..t52};                  // The model is solved for one year consisting of 52 weeks
```

PARAMETERSDATA

```
//here you find the data for the PARAMETERS that were defined for all applicable indices
  IniProdDem(k):
  HoltInvStart(k):
  SuppInvStart(k):
  NumSTRStart(k):
  VehicleCapacityVol:
//VehicleCapacityPPE:
//PPE(k):
  FixedTransportationCost1:
  FixedTransportationCost2:
  VariableTransportationCost:
  STRCost:
  LTRCost:
  ProductVolume(k):
  ProductionDemand(k,t):
  TravelDistance(i):
  NumberOfLTR(k):
//NumberOfLTR(k):
  CustomerInv(k,i,t):
```

Appendix F

Figure 42 and Figure 43 show the loaded amounts of RTI shipped each week between the cleaning facility in Holten and the supplier Johma in Losser. The main difference is the compilation of each freight. In the proposed situation we transport the RTI more in line with the production demand which causes a decrease in Johma's inventory, see Figure 33 and Figure 34 as well.

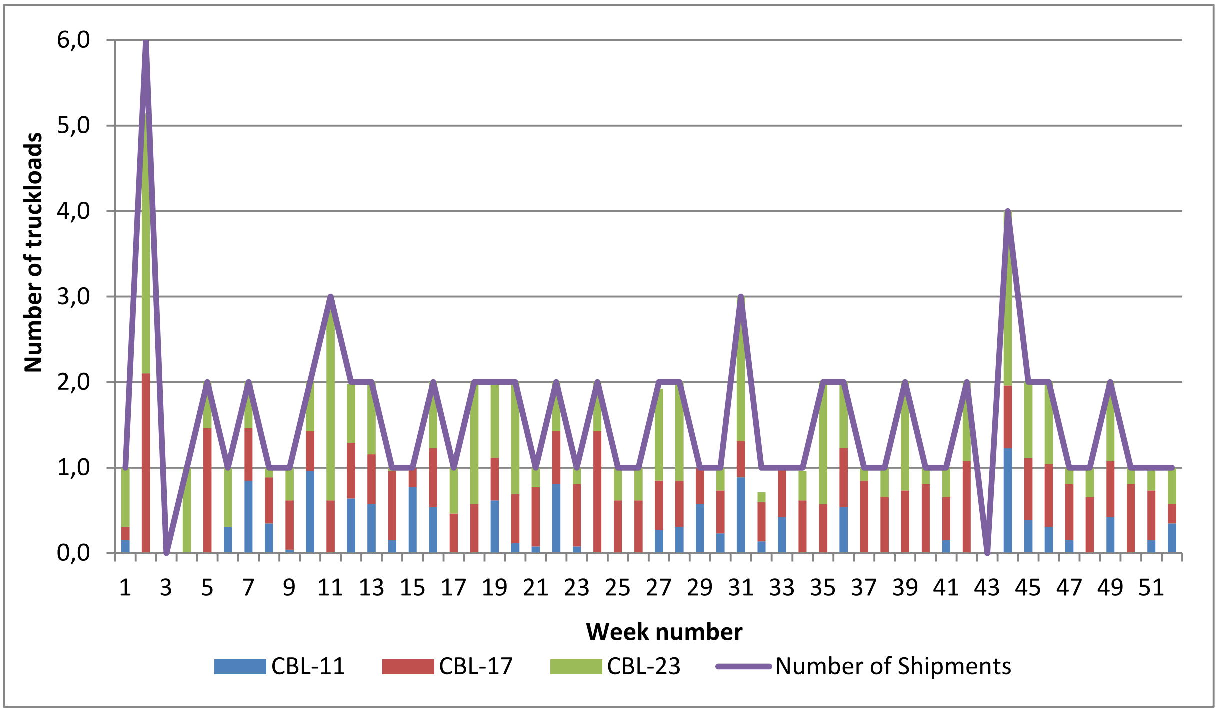

Figure 42: Truckloads between Holten and Johma - Current situation

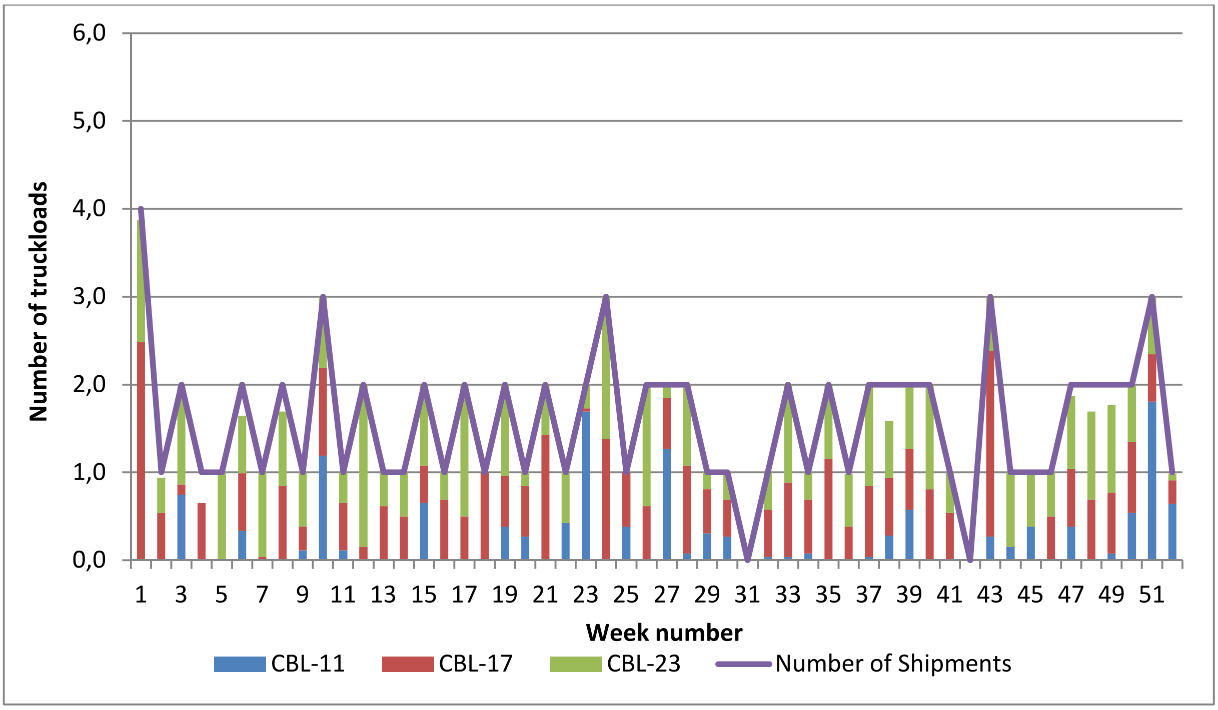

Figure 43: Truckloads between Holten and Johma - Proposed situation

Keep the “Hard Workers” moving!

Keep the “Hard Workers” moving!