MASTER

The value of radio frequency identification (RFID) technology for managing pools of returnable transport items

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The Value of Radio Frequency Identification (RFID) Technology for Managing Pools of Returnable Transport Items

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I ABSTRACT

Limited asset visibility is a key problem in the management of returnable transport items (RTIs). One way of increasing asset visibility is radio frequency identification (RFID) technology. However, RFID requires high investment cost and intense efforts for implementation. In this study, we investigate the value of increase in asset visibility and improvement opportunities provided by RFID technology for the management of RTI pools in a closed-loop supply chain setting both considering its costs and benefits. We present a comprehensive list of potential benefits and costs of using RFID technology for managing pools of RTIs which is obtained through extensive literature search. In the quantitative part of our study, the results regarding the value of using RFID technology obtained with simulation models for a case study are included.

II PREFACE

This document presents my master thesis study in the double degree Master of Science program between Industrial Engineering Department of Middle East Technical University (Ankara/Turkey), and OPAC research group in Industrial Engineering and Innovation Sciences Department of Eindhoven University of Technology. This master thesis study was started in Eindhoven with a company project and continued in Ankara with theoretical work on the case studied during the company project. In total, this study carried on almost one year with hard work.

To be continued with acknowledgements.

III. EXECUTIVE SUMMARY

To be completed after the revision.

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1. INTRODUCTION

1.1. Introduction to the Management of RTI Pools

According to International Organization for Standardization (ISO), RTIs are defined as all means to assemble goods for transportation, storage, handling and product protection in the supply chain which are returned for further usage, including for example pallets with and without cash deposits as well as all forms of reusable crates, trays, boxes, roll pallets, barrels, trolleys, pallet collars and lids (ISO, 2005). They are key elements for efficient logistics operations and the protection of goods during transport, storage and handling (Ilic et al., 2009). They offer significant benefits over traditional single use packaging (Johansson and Hellström, 2007). Firms have been adopting RTIs

- For operational benefits such as improved protection and security of products, improved working environments, more efficient handling, etc. (Witt, 1999; Maloney, 2001; Twede and Clarke, 2004); and
- For government regulations requiring to reduce packaging waste (Livingstone and Sparks, 1994; Kroon and Vrijens, 1995).

The supply chain management of RTIs includes the management of both forward channel and reverse channel. Forward channel refers to the development, production, distribution and delivery of products and services to the end users (Karaer and Lee, 2007). Moreover, reverse channel refers to the collection of returns, reuse, recycling, remanufacturing, and disposal of products. Specifically, it refers to the collection of returns and the reuse of transport items in a supply chain of RTIs (Karaer and Lee, 2007). The combination of forward and reverse channel is referred as the “closed-loop supply chain” (Flapper et al., 2005).

RTI management is challenging since it requires accurate counting, reporting and shared information among organizations (Twede and Clarke, 2004). Current RTI management processes are based on estimates about where, when and how RTIs are utilized, because it is often unknown where the individual RTIs are and in what condition they are in at any specific point in time. This limited visibility constitutes the key problem in RTI management (Ilic et al., 2009). Due to limited visibility, organizations feel less responsible for the proper management of RTIs. Consequently, high lost rates, breakages and unavailability of RTIs bring unnecessary costs (Ilic et al., 2009).

RTIs are often managed with limited visibility or control, although they are often of high value, vulnerable to theft or misplacement, and critical for production and distribution (McKerrow, 1996; Twede, 1999; Witt, 2000). Due to these characteristics of RTIs, the management of RTI fleets is expected to suffer without systems which keep track of individual RTIs and present timely and relevant information on their whereabouts. Tracking systems are needed to manage and control where and how RTIs are moving, and to reconcile RTI supply with demand (Johansson and Hellström, 2007).

One way of tracking assets and increasing asset visibility is RFID technology. This means RFID can be utilized as a tool to assist in RTI management. However, RFID requires high investments cost and intense efforts for implementation. In this respect, our goal is to find out the value of increased asset visibility with RFID for management of RTIs in a closed-loop supply chain both considering its costs and benefits. (For more information about RFID technology, see Appendix A)

RTI pool operator, manufacturer and retailer are key RTI stakeholders. The following figure (Ilic et al., 2009) shows the domain boundaries of these key stakeholders which describe their responsibilities and interests in the RTI management process. It also denotes the minimum set of points for the setup of RFID readers (i.e. a set of three inbound RFID read points (denoted with squares) or a set of three outbound RFID read points (denoted with circles)) for any form of automation using RFID (Ilic et al., 2009).

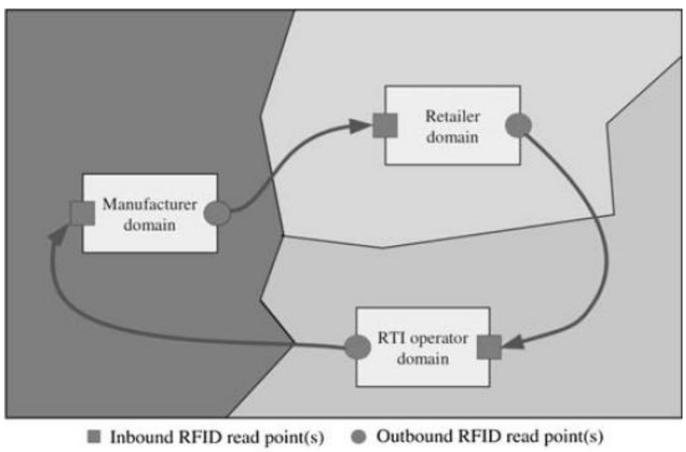

Figure 1.1: The three domains of responsibility and interest for RTI management

1.2. RFID Technology

This section provides general knowledge about RFID. It starts with mentioning current opinions about the use of RFID technology in subsection 1.2.1. After, the application areas of this technology are illustrated in subsection 1.2.2. The technical details of RFID technology can be found in Appendix A. Appendix B presents the comparison of this technology with and older one, barcoding. In addition, Appendix C presents the disadvantages and advantages of RFID technology for the interested readers.

1.2.1. The Potential of RFID Technology

According to Ustundag and Tanyas (2009), RFID is regarded as a promising technology for the optimization of supply chain processes since it improves manufacturing and retail operations from forecasting demand to planning, managing inventory, and distribution. As indicated by Tzeng et al. (2008), owing to its "MOST" (mobility, organizational, systems and technologies) characteristics, RFID has received considerable attention and is considered to be the next wave of the IT revolution. Heinrich (2005) pointed out that RFID is likely to be among the most exciting and fastest-growing technologies in terms of scope of application in the next generation of business intelligence. Curtin et al. (2007) states that the emergence of RFID is expected to drastically affect a number of industries and impact their strategic management. Several recent studies have indicated that investing in RFID technology is promising and an excellent long-term capital investment (Karkkainen, 2003; Kumar and Budin, 2006; Regattieri et al., 2007). The Economist (2003) defined RFID as "The Best Thing Since the Bar-Code". AMR Research's Lundstrom (2003) proclaimed that "RFID Will Be Bigger Than Y2K".

Ngai et al. (2008-a) state that RFID has become a new and exciting area of technological development, and is receiving increasing amounts of attention. As indicated by Heim et al. (2009) RFID technologies today are reaching cost and functionality levels, making them practical for many service applications. According to Ustundag and Tanyas (2009), as costs in the semiconductor industry decrease and data communication standards improve, the use of RFID technology has increased. Industry analyst IDTechEx forecasts strong growth over the next decade both in RFID tag sales and in the breadth of application sectors. Total RFID market is expected to grow from over $5 billion in 2008 to over $25 billion in 2017 (Das and Harrop, 2008; Sheng et al., 2008).The number of RFID tags sold annually doubled from around one billion tags in 2006 to 2.16 billion tags in 2008, with most tags being passive RFID (Das and Harrop, 2008).

1.2.2. The Application Areas of RFID

As stated by Fosso Wamba et al. (2008), RFID technology has received a great deal of attention over the last few years, with a ''boom'' in early 2003 due to (i) recent key developments in microprocessors and (ii) demands by Wal-Mart and the US Department of Defense (US DOD) that major suppliers should adopt and implement the technology by the beginning of 2005 (Srivastava, 2004). Heim et al. points out that large retailers like Wal-Mart and Target drove much of the early development and adoption of RFID by mandating their suppliers to deploy RFID. The interest in RFID is highlighted by the many recent white papers published by technology providers (e.g., Intermec, 2006; Texas Instruments, 2004), consulting firms (e.g., Bearing- Point, 2004; Accenture, 2005), infrastructure providers (e.g., HP, 2005; Sun Microsystems, 2004), enterprise software providers (e.g., SAP, 2005), and solution providers (e.g., IBM, 2003)

As stated by Ngai et al (2008b), RFID technology has been widely applied in many industries, including the airline industry (Wyld et al., 2005; O'Connor, 2006), cattle industry (Mennecke and Townsend, 2005), construction (Jaseiskis and Ei-Misalami, 2003; Song et al., 2006), logistics (Ngai et al., 2007b), healthcare (Collins, 2005), and manufacturing (Swedberg, 2006). Tzeng et al. (2008) pointed out that its applications are not a new phenomenon. The British Royal Air Force (RAF) used RFID-like technology in World War II to distinguish between enemy and friendly aircraft (Asif and Mandviwalla, 2005). Most recently, it is gaining importance and popularity in many areas such as marathon races, airline luggage tracking, electronic security keys, toll collection and asset tracking, etc. (Angeles, 2005; Ericson, 2004; Karkkainen, 2003; Srivastava, 2004) and is considered to be the next revolution in supply-chain management (Srivastava, 2004) and the healthcare industry (Ericson, 2004).

According to Heim et al. (2009), many service sectors are also deploying RFID applications. Examples can be found among hospitals and health care providers, airlines and transportation services, postal services, libraries, veterinarian services, banking, and government services (Das &Harrop, 2008). They also state that large consumer-packaged goods manufacturers (e.g., The Gillette Co., Procter & Gamble, Johnson & Johnson) and logistics service providers (e.g., United Parcel Service, DHL) also have experimented with RFID (Sliwa, 2002; Vijayan & Brewin, 2003). These companies hope RFID will increase customer demand and enhance inventory visibility and allow them to optimize production planning, order fulfillment, pricing, consumer promotions, and trade promotion expenditures (Overby, Charron, & Chaskey, 2002; Bennewitz, Bess, Breuer, & O'Neill, 2004; Lawrie, Metcalfe, Takahashi, Overby, & Kinikin, 2004; Schwartz, 2005). These early RFID applications presented valuable information about perishable goods, thefts, security, event synchronization, delivery history, and new product success (Songini, 2006).

1.3. The Problem Choice

Our aim is to investigate the value of increase in asset visibility provided by RFID technology for the management of RTI pools in a closed-loop supply chain setting. Our general research question can be stated as follows:

What is the added value of using RFID technology for the management of an RTI pool in a closed-loop supply chain setting when both the costs and the benefits of RFID technology are considered?

The following two subsections explain the importance of our problem both in practice and in current literature and how our problem choice is positioned in the current literature, respectively.

1.3.1. The Importance of the Problem

According to Lee (2007), RFID deployment has made a moderate progress until today despite of the optimism that high numbers of white papers, reports and trade articles about the value that RFID can bring. Several companies are still at pilot stage and high hopes for value realization have not been attained. This current situation gives rise to the question of whether RFID’s potential value is a hype or not. Lee and Ozer (2007) state that a credibility gap has emerged due to this current situation. They argue that concrete quantification of benefits is necessary instead of guesses and rough estimates in order to close this credibility gap.

Dutta et al. (2007) point out that very few companies would implement a new technology such as RFID based on pure faith. Rather, they would prefer to perform value assessment studies, tests or experiments, and benchmarking. Therefore, there is a need for research on value assessment exercises as well as on modeling the economics of RFID systems in order to guide their planning and implementation. Particularly, this need makes our problem important for practice.

As stated by Johansson and Hellström (2007), RTIs have increasingly been introduced in various industries. This means our problem can be widely seen in practice. Some examples of RTIs include beer kegs, special reusable containers for shipping glasses, large wooden bobbins of cables, cylinders for liquid gases. Johansson and Hellström (2007) also indicated that RTIs are often high value and an RTI fleet is often characterized with a significant initial capital investment and shrinkage which brings considerable operating cost. Asset visibility is expected to be more important for higher value assets since it can provide higher cost savings and eventually higher benefits. In case of high shrinkage rates, the importance of asset visibility is also expected to increase. In a survey of 233 enterprises in consumer-oriented industries undertaken by the Aberdeen Group (2004), one quarter of the respondents report that they lose more than 10 per cent of their RTI fleet annually, with 10 per cent of the respondents losing more than 15 per cent. Studies have shown that visibility of where and how RTI are moving may save firms detention and demurrage charges for third-party-owned assets by as much as 80 per cent (Angeles, 2005). Therefore, it is worthwhile to explore the potential value that can be realized by asset visibility.

1.3.2. Filling a Gap in the Literature

As stated by Ngai et al. (2008), RFID is an exciting area for research due to its relative novelty and exploding growth. According to past publication rates, they predict substantial development in this area in the future, with a significant increase in research and published literature. In addition, Dutta et al. (2007) indicate that there are numerous white papers, reports and trade articles on the value that RFID can provide. However, they also indicate that measuring the value of RFID has several challenges and it is not clear if the value claims performed in the literature are actually sound (Dutta et al., 2007). Therefore, reliable value quantification examples are required in the literature in order to show whether RFID is profitable or not and in what conditions.

According to comprehensive review in Lee and Ozer (2007), many of the industry reports and white papers indicate what is obvious with lack of much quantification. For instance, there are many reports stating that RFID can decrease inventory and improve customer service. However, they do not provide details of how, nor did they give more specifics or quantification. Concrete quantification is needed instead of available guesses and rough estimates (Lee and Ozer, 2007). In addition, Johansson and Hellström (2007) also states that most of the research on asset tracking and asset visibility has focused on potential benefits and has been largely theoretically explorative (Shayan and Ghotb, 2000; Luedtke and White, 2004).

1.4. Organization of the Report

To be completed after revision.

2. LITERATURE STUDY

In this chapter, an overview of the relevant literature is provided. Section 2.1 introduces the current status and contemporary trends of RFID research. Section 2.2 presents the related academic studies about the value of information, the added value of RFID, and the value of asset visibility. By added value, we mean the additional value that RFID brings in monetary terms; in order words, it is the benefits of using RFID after its costs are subtracted. Section 2.3 mentions the relevant studies on the RTI pool management and the closed-loop supply chain of RTIs.

2.1. The Current Status and Contemporary Trends of RFID Research

According to Ngai et al. (2008a), it is essential to understand the current status of RFID research and to examine contemporary trends in the research domain for the sake of continuation of advancement of knowledge in this area. Additionally, they also stated that it is vital to determine the principal concerns of current RFID research, whether technological, application related, or security related. Therefore, we found it suitable to start with discussing an academic literature review on RFID research which can give a more comprehensive idea about the current status of this research area.

Ngai et al. (2008a) present an academic literature review of 85 academic journal papers that were published on RFID subject between 1995 and 2005. These studies are divided into four main categories according to their main focus. These categories are technological issues, application areas, policy and security issues, and other issues. The purpose of review and classification is to help the creation and accumulation of knowledge in this area. Specifically, the objectives of the paper are stated by the authors as follows:

1. Develop a classification framework that is based on theory and informed by existing RFID research.
2. Use the classification framework to summarize what is known about RFID research.
3. Review and analyze the RFID literature with respect to both the quantitative developments that have been made and the qualitative issues that have been raised in a manner that is useful to both researchers and practitioners.
4. Guide future research so that the interests of RFID researchers can be matched with the needs of practitioners.

According to this review, the applications of RFID are many and varied as they span 14 different industries. In most cases of RFID studies on retailing, the articles present a general view of RFID use in retail and supply chains or mention the potential of using RFID technology, the perceived benefits, effects and challenges for retailers, how consumers are likely to react to the technology and the market drivers in the grocery industry for RFID implementation (Eckfeldt, 2005; Karkkainen, 2003; Jones et al., 2005; Prater et al., 2005).

Ngai et al. (2008a) also discuss the future research questions and directions. They believe that future research effort is needed to offer useful guiding principles for practitioners for the process of RFID system design, development, implementation and evaluation. Many different research directions are advised. However, the three future research directions are the ones interest us the most. These are as stated as by Ngai et al. (2008a) as follows:

- The economic performance of RFID systems in terms of their ‘‘cradle to grave’’ cost. This includes the costs of designing, developing, maintaining, controlling, and updating the systems.
- The formulation of detailed technical and economic decision rules to guide practitioners to choose the appropriate RFID system for implementation.
- The impact of RFID systems on companies and organizations in various industrial situations and the creation of business models for the adoption of RFID

It is found important for production and operations management, information technology and information systems researchers to make sure that future research directions are managerially useful with an emphasis on studies including design, implementation and deployment of RFID technology. Here, the words of John Williams, director of the MIT Auto-ID Labs should be noted: ‘‘there is simply an enormous amount of applied research that needs to be done to move RFID forward and realize the dream of creating the ‘‘internet of things.’’

2.2. The Added Value of RFID and Asset Visibility

Johansson and Hellström (2007) propose a framework of the potential benefits of asset visibility on costs associated with RTI systems. They base the foundation of this framework on the general tracking and visibility literature. With the help of this framework, they explore the effect of asset visibility on the management of RTI systems by performing a combined case and simulation study. The case study is conducted to identify and understand how an existing RTI system is managed. It shows that a tracking system with inadequate data analyzing and reporting capabilities provides limited visibility. It is about a company (The Arla Foods Group) which distributes its fresh products directly to retail outlets in RTI (roll containers). It has experienced difficulties in managing and controlling RTI. Besides, it loses a large number of RTI annually. It estimates that approximately 10 percent of its RTI are lost annually as a result of misplacement and theft. The information about how many RTI are in circulation or in stock at various points in the supply chain is unknown. On the other hand, in the simulation study three scenarios are developed:

- Operation of the system without a tracking system
- Operation of the system based on the collected data from the tracking system
- Operation of the system when asset visibility is accompanied by proper management actions

In the mentioned tracking system, there are three different identification locations to gather data about container locations and a single transaction contains ID of the container, its location, customer ID, or route number, along with a date and a time stamp. As a result of this simulation study, the appropriate fleet size can be calculated and insights into the effects of changes in different parameter values such as cycle times, demand, etc. have on the system are gained. It suggests that the investment cost in RTI and total costs can be reduced significantly (52% and 34% respectively in the Arla case) if asset visibility is accompanied with the proper managerial actions. The authors emphasize that asset visibility for RTI systems is not sufficient; rather it requires proper actions and continuous management attention so as to gain savings. They also emphasize the importance of shrinkage and its impact on the operating costs of an RTI system. According to them, the findings are likely to be valid for other systems with high RTI shrinkage where a central organization supplies RTI without deposits or rental charges.

Ilic et al. (2009) explores the impact of increased asset visibility on the RTI management processes. They define the key problem in RTI management as the reality that it is often unknown the location and condition of individual RTIs at any specific point in time. They argue that RTI visibility together with a proper management approach is needed to improve process efficiency and RTI control. They present the potential benefits of visibility at different points in a closed-loop supply chain of reusable pallets. They estimate the decrease in trip fee (the fee for an RTI to make one cycle) with improved visibility.

According to Thoroe et al. (2009), the benefits of the use of RFID technology for tracking RTIs have so far hardly been undertaken from a theoretical perspective. In order to help to fill this gap, they analyze the impact of RFID on RTI management using a deterministic inventory model. Their model misses some important aspects of both the use of RFID technology (e.g. the setup cost of RFID) and RTI management (e.g. stochasticity of losses). With their deterministic inventory model, they make suggestions for the batch sizes and frequency of the procurement of new RTIs and the refurbishment process.

Leung et al. offers a tool for quantifying the business value of RFID for different participants in a manufacturing-retail supply chain in order to enable the development of business cases to support the decision whether or when to adopt the technology. Their tool consists of two parts which are linked to each other, namely a business value model and a business process model. They classify the benefits of RFID as direct and indirect. Their business value model calculates the direct benefits. On the other hand, their business process model calculates indirect benefits which may be overlooked with traditional return on investment analysis.

Thiesse and Fleisch (2008) analyze practical benefits of location information provided by real-time location systems (RTLSs) in complex manufacturing processes. This analysis is based on the case example of an RFID-based RTLS implementation which combines the flexibility of manual production processes with high level of visibility and control of conventional automation technologies in a semiconductor fabrication facility. The main goals of the project are decreased cycle times, prevention of handling faults and reduction of non-value-adding activities by making entire production process visible and thus controllable with the help of RTLS. Therefore, authors examine the value of RTLS information on the location of physical objects in a production system to the problem of efficient scheduling with a simplified simulation model capturing the main characteristics of the real manufacturing process. With this simulation model, they experiment on the RTLS-enabled dispatching rules that they propose and compare them with conventional rules that do not make use of any location information. The results show that the use of RTLS technology offers new levels of process visibility and control in comparison to conventional material-tracking systems. It also offers both significant improvements with regard to process performance indicators such as cycle time, machine utilization, etc. and opportunity to develop novel dispatching rules considering real-time information on logistic processes on the shop floor.

According to Dutta et al. (2007), the ability of RFID –as with any new technology– to deliver business value depends not just on technical factors, but also on economic and organizational ones. Their objective is to identify selected research issues arising from these factors themselves and their interaction. Hence, there dimensions of the value proposition of RFID are examined and areas for further research are proposed. The first dimension is the architecture of RFID implementations in which the focus is on issues that would be relevant to management in adopting this technology and obtaining business value from it. The second dimension is measurement issues related to value assessment. Value can be derived from three issues, namely labor cost savings, reduction in shrinkage and higher visibility. There are three means to estimate the value added by these three issues:

- Time and motion studies based on controlled tests
- Live (or pilot) experiments
- Experts' subjective judgment obtained by a survey instrument

Academic research on assessing the value of RFID mainly utilizes three categories as tools, namely empirical-based research (field studies), simulation and analytical operations-research models. The third and last dimension focuses on incentives for achieving diffusion through the entire supply chain.

As indicated in Van Dalen et al. (2008), the Heineken Group started the Chip in Crate pilot at the Brand brewery in April 2000. The objective of the project is to measure total circulation time of Brand crates through returnable packaging materials (RPM) logistic chain. For the calculations of optimum amount of RPM, the measurement results of the project are used as input. Existing information about storage duration of crates at the brewery (based on daily counts of full and empty RPM) is complemented by the Chip in Crate information. The united information sources give information about total circulation times and about the time crates spend in the market. This information is necessary for both long-term decisions about RPM investments and for short-term forecasts of RPM returns to the brewery. Besides, it gives Heineken the opportunity to initiate efforts o control the return of RPM. The resulting information shows that the return pattern of empty crates is S-shaped and it can be conveniently used to forecast RPM returns in a specific week. An investment model based on the Chip in Crate data suggests that implementation of the project brings a saving opportunity between 5 and 10 million Euro for RPM worldwide, which makes the Chip in Crate project to be appreciated as a highly successful experiment.

Van Dalen et al. (2008) states that Heineken chose to use the read-only chip to keep the process simple and affordable. The chips were baked into the crates. These chips can only be observed with scanning. Therefore, reading the information from the chips was performed crate by crate. The scanners were placed alongside the production belt. Chips carry information regarding tag numbers which are uniquely linked with individual chips in crates, the dates and times at which they passed the scanners. Samples are drawn from chips in crates in order to check whether chips are still functioning and whether the data output is correct. It was observed that all chips function properly. However, it was also observed that the performance of the scanners at the production belt is less satisfactory since occasionally no chips are registered while passing the scanners.

According to Ustundag and Tanyas (2009), several researchers have examined the impact of RFID technology on inventory and supply chain management. Generally, the research studies have mainly interested in the inventory function and the effect of considering inventory discrepancies. Thus, literature having an analytical assessment of RFID technology is quite limited. On the other hand, there are some studies focusing on cost-benefit analysis of RFID implementation. According to Ustundag and Tanyas (2009), several RFID researchers concentrating on inventory management handled the impact of inventory errors on supply chain performance and examined how reducing inventory inaccuracy with RFID technology affects performance factors. Besides, they note that most studies in this area have used the simulation method to determine the impact of inventory inaccuracy on supply chain performance.

Ustundag and Tanyas (2009) performs a simulation study to calculate the expected benefits of an integrated RFID system on a three-echelon supply chain gained by means of performance increases in efficiency, accuracy, visibility and security level. This study fills a gap in the literature by examining the effect of product value, lead time and demand uncertainty on the benefits of RFID integrated supply chain in terms of cost factors at the echelon level using a simulation model. It is shown that the factors of product value and demand uncertainty have significant influence on the expected benefits of integrated RFID systems. As the product value increases, total supply chain cost saving increases and as the demand uncertainty increases, total supply chain cost savings decreases. Additionally, simulation study reveals that each member of supply chain does not benefit equally from RFID integration.

Kok et al. (2008) determine an inventory policy by considering shrinkage and the impact of RFID technology. The situation with RFID is compared with the one without RFID in terms of costs. As a result, an exact analytical expression is derived for the break-even prices of an RFID tag. Using these expressions in a full factorial design, it is shown that these break-even prices closely linked to the value of the lost items, the shrinkage fraction, and the remaining shrinkage after implementation. Additionally, a simple rough-cut approximation for the determination of the maximum amount of money that a manager should be willing to invest in RFID technology is offered. It should be noted that, fixed investment costs are not taken into account in this study and they are left for potential future research.

Bottani and Rizzi (2008) quantitatively assess the impact of RFID technology and electroic product code (EPC) system on the main processes of the Fast Moving Consumer Goods (FMCG) supply chain. The impact of these technologies on the FMCG industry was quantified on a three-echelon supply chain composed of manufacturers, distributors and retailers. Firstly, a questionnaire survey is conducted and both quantitative and qualitative data about logistics process of each supply chain player is collected. Then, a quantitative feasibility study which includes the costs and benefits of such technologies is performed to quantify the economical profitability of the implementation and to justify technology investments. This study reveals that RFID and EPC implementation is still not profitable for all echelons. Although RFID adoption with pallet level tagging gives positive revenues for all supply chain players, case level tagging produced negative economic results especially for manufacturers. Additionally, the break even prices for RFID tags are estimated.

Heim et al. (2009) investigates how customer value may be affected by deploying RFID technologies within service environments. Although business articles points out operational cost savings and improved inventory management as key benefits of RFID deployment, this study shows that customers will recognize far more value from RFID applications that these key benefits. Firstly, a conceptual framework of service RFID applications derived from three potential user groups involved in an RFID-enabled service process: customers, service firms, and suppliers (Lee et al., 2008) is developed. The framework is used to structure a value-focused thinking study (Keeney, 1992, 1999) to identify a list of RFID value dimensions. After, how the proposed RFID value dimensions relate to the framework structure is investigated. In short, the study analyzes qualitative survey responses on the value gained from RFID to identify a broad list of value objectives —benefits and drawbacks—associated with RFID service applications. This article contributes to academic literature by identifying a broad set of value dimensions related with RFID applications, and additionally, by this means constructing a foundation for subsequent empirical study of RFID in service applications. As a practical contribution, service managers can use the developed framework and empirical findings to aid in design and improvement of service operations.

According to Karaer and Lee (2007), most of the articles about inventory management with reverse channel dynamics that they have seen focus on finding the optimal inventory policy regarding reverse channel by addressing possible correlation between demand and return streams and possible negativity of net demand. They concentrate on the major challenges of the reverse channel dynamics with the assumption of full visibility in the whole system. Different from those studies, to Karaer and Lee (2007) focuses on the benefit of information and visibility in the reverse channel pipeline in coordination with the regular product procurement, with some practical assumptions regarding reverse channel dynamics.

Karaer and Lee (2007) examine the inventory decisions of a manufacturer who has ample production capacity and also uses returned products to satisfy customer demand. Therefore, the focus is the coordination of the reverse and forward chain at the distribution center of a manufacturer. Among the product returns classes, namely end of life, end of use, reusable items, and commercial returns (Krikke, le Blanc, and van de Velde 2004), the concern of the study is commercial returns. All commercial returns enter an evaluation process to make decision of disposal, direct selling, or rework according to a predetermined procedure. They quantify the value of information and visibility on the reverse channel for the manufacturer by making comparisons among following three approaches:

1. *Naive approach:* The naive manufacturer neither has visibility on his reverse channel nor utilizes general characteristics of the return flow in his inventory management.
2. *Enlightened Approach:* The enlightened manufacturer knows the statistical characteristics of the return flow. Although he is aware of the reverse channel (i.e., the pipeline of negative demands in the reverse channel); he does not have visibility on it.
3. *Full Visibility:* The manufacturer has full visibility on his reverse supply chain, i.e., he can monitor the number of products at every step of the chain. However, he cannot foresee beforehand exactly how many units out of the returned products batch will be disposed of, reworked, or sold as is.

For quantifying, Karaer and Lee (2007) use a basic model with many simplifying assumptions (e.g. constant production and rework time, no capacity constraints in production and rework etc). As a result, they find the value of visibility increases with the comparative length of the reverse channel and volume, volatility, and usability of returns. Besides, the smarter the manufacturer, the less benefit visibility brings to the system. Most important part for us is that they quantify the visibility savings of (RFID) in the reverse channel as a candidate enabler technology for visibility and show that RFID can also have benefits to the reverse channel.

Langer et al. (2007) investigates the benefits of RFID with a field study with GENCO, a third party logistic company. It deployed RFID technology in the outbound logistics operations of one of its return centers. Its purpose was to improve warehouse operational accuracy and quality of material flow, enhance customer responsiveness and diminish shipment errors. It placed the

RFID tags containing information regarding the pallet, its contents, order details, etc. on the pallets. Besides, each forklift was equipped with a reader and a screen in order to ensure correct loading onto trucks and locate lost pallets within the facility more easily. In order to assess the impact of RFID on customer claims, authors conducted statistical analyses. They estimated a profit model by using the claims as dependent variable and RFID, transaction intensity- specific parameters, shipment characteristic variables, and buyer-specific parameters as explanatory variables. Therefore, they confirmed that the RFID implementation had a significant impact on the accuracy of GENCO's outbound logistics process and RFID was a key factor that contributed to the positive results. Following its deployment, the number of claims fell substantially due to reduction in errors in loading, etc. as well as acting as a deterrent to fraudulent claims. Additionally, Langer et al. (2007) emphasizes that GENCO barcoded all of its outgoing shipments, however this provided no benefits due to technical (e.g. problems in reading) and human limitations.

2.3. The RTI Pool Management

There are early studies related with the management of RTIs. Kelle and Silver (1989a) examine the forecasting the returns of reusable containers which is important to give the decision of new container acquisition. They propose four methods each of which requires a different amount of information to forecast the net demand, i.e. the demand minus the returns. They compare these methods on a wide range of empirical data gathered from industry. They conclude that the use of additional information improves the performance and the most of the benefit is related to the identification and tracking of individual containers.

Kelle and Silver (1989b) propose a stochastic mathematical model of optimal purchasing based on net demand with a chance constraint for target service level. They conclude that this stochastic problem is equivalent to the usual dynamic lot-sizing problem which can be exactly solved by Wagner-Whitin dynamic programming algorithm.

Goh and Varaprasad (1986) study on container life-cycle characteristics including parameters such as trippage (the number of trips made by a container in its lifetime), trip duration, loss rate and expected useful life. They also describe a data analysis and modeling approach to find out the needed parameters. They argue that accurate estimation of life cycle parameters is required for pricing a product, effective inventory and ad production control, financial control and accounting for losses.

Lange and Semal (2009) consider the management of the return flows of empty logistics containers that accumulate at customer's sites and must be brought back to the factories. They try to answer the following questions raised by the management of return flows with a strategic perspective:

1. To which factory should each customer return the containers?
2. At which frequency should they be returned?
3. How many containers are needed in the network?

Castillo and Cochran (1996) also deals with the subject of reusable containers, however they are also interested in optimizing production planning and transportation of containers throughout the system. They try to address three interrelated decision sets which are stated in their paper as follows:
(1) Production planning: what products should be made, in what lines, and for how long?
(2) Product distribution: how much of each product should be distributed to each depot and during which shifts?
(3) Return of containers: from which depots should containers be returned to each plant and in which shifts, and how many of each type of container is needed?

Castillo and Cochran (1996) model the reusable bottle production and distribution operations of a large soft-drink producer. The paper uses hierarchical models to assist decision making with referring to Hax and Meal (1975). In order to form the overall optimization system, two types of operational research models are combined. A framework and a mathematical formulation for process control and material management in reusable-container industries depending on optimization and difference equation simulation techniques are proposed. Improvements have resulted in significant market gains for the soft-drink producer after the proposed models were implemented.

For more information related with reusable asset management including

- RTI use cases (wooden pallet management, plastic pallet management, keg management, etc.), and
- RTI models (closed-loop and open-loop circulation)

we refer the reader to Bowman et al (2009).

3. THE VALUE OF USING RFID TECHNOLOGY IN A CLOSED-LOOP SUPPLY CHAIN OF RTIS

Both benefits and costs of RFID should be determined in order to assess the value of using RFID technology. In the section 3.1, the benefits of RFID technology were explored in detail. In the section following this, namely the section 3.2, the costs of RFID technology were analyzed.

3.1. The Potential Benefits of Using RFID Technology in a Closed-Loop Supply Chain of RTIs

In general, RFID is seen as an enabling technology that a company can adopt to enhance asset visibility and improve operations, like improving receiving and picking accuracies, and reducing human errors (Ngai et al., 2007). The four benefit factors of RFID technology is defined as operational efficiency, accuracy, visibility, and security (Singer, 2003). Though beginning as a tool to achieve operational efficiency, some practitioners believe that RFID could become the next major weapon for organizations to gain strategic competitive advantage (Tzeng et al., 2008).

RFID is expected to bring various benefits changing according to its application setting, which makes right focus essential. Our focus is on the benefits of RFID technology in a closed-loop supply chain setting in which RTIs are in use. In the literature, the following benefits related with our focus have been found:

1. RFID provides timely information of manufacturer's actual RTI stock. Therefore, the manufacturer's replenishment process and stocks can be optimized based on the actual RTI stock (Ilic et al., 2009).

2. The flow of RTIs in the supply chain becomes more predictable with asset visibility (Ilic et al., 2009). Uncertainty in quantity, quality and timing of returns is decreased (Karaer and Lee, 2007). Increased visibility of return process can be seen as similar to having advanced negative demand information since inventory in the return channel can be seen as future negative demands (Lee and Ozer, 2007). In that sense, more accurate forecasting methods can be used for returns and replenishment process can be improved with better return forecasts. Therefore, increased visibility allows more proactive decisions (Dutta et al., 2007). This can help to reduce buffer stocks and stockouts.

3. The unique identification of each RTI can guarantee clear accountability of each of the RTIs and can help in assessing the number of outstanding RTIs kept by each stakeholder accurately (Ilic et al., 2009). RFID provides an accurate reading of the quantity of stocks in the system, avoiding the problem of inventory discrepancies due to shrinkage, misplacement and transaction errors (Dutta et al., 2007). This eventually brings inventory reduction and decrease in stock outs (Lee and Ozer, 2007).

4. With unique serial identification associated with the RTISs, it is possible to trace the source of the damaged pallets to the originator. As a result, it is expected that RTI damages are decreased (Ilic et al., 2009).

5. With the help of track and trace capability, it is also possible to identify any systematic losses (including theft (Dutta et al., 2007)) within the supply chain (Ilic et al., 2009). As a result, it is expected that RTI losses are decreased.

6. With the help of track and trace capability, it is also possible to identify slow moving locations and excessive holding areas in the supply chain. Cycle time can be decreased and rotation rate can be increased with the determination of slow moving locations and taking action when possible. Cycle time and rotation rate can be further improved with elimination of delays due to manual data acquisition processes, etc.

7. The accurate recording of inventory by quantity and by location can help in making use of the contents that RTIs are filled before they are outdated especially when they are perishable items (Dutta et al., 2007). RFID can create value in the presence of important concerns of food and drug industries like counterfeit prevention, facilitation of product recall and traceability (Lee and Ozer, 2007).

8. The lifetime information and repair history can be kept for individual RTIs. As a result, RTI maintenance decisions and corresponding actions can be automated and speeded up. Such efficiency can provide quicker update of the usable RTI stock count and thus help to minimize buffer stocks or emergency purchases (Ilic et al., 2009). Besides, RFID enables automatic handling of preventive maintenance and disposal of RTIs which have exceeded their best-use-before dates. Improved maintenance brings extended use life of RTIs (Johansson and Hellström, 2007).

   With the repair history of all fleet, which type of repair is done with which frequency can be found out. Most vulnerable parts of the RTI can be determined. This information can be used for improvement of the RTI design, if possible.

9. The availability of dynamic RTI stock and movement data, the load utilizations of the delivery vehicles can be improved. It also helps in avoiding or at least decreasing emergency deliveries (Ilic et al., 2009). In addition, where to collect is also known in case of such emergencies.

10. Due to automatic RTI identification and notification upon reaching a drop point, the collection of RTIs from drop points (customer locations) can be better scheduled.

Collection route optimization is also possible (Ilic et al., 2009). Besides, RFID brings decrease in or elimination of erroneous shipments since RFID readers placed on gates or forklifts can scan the shipments and give signals in case of errors (Johansson and Hellström, 2007).

11. Labor savings can be achieved in the receiving operations or inventory audits since multiple RFID tags can be scanned together without manually scanning the objects one by one (Dutta et al., 2007). RTIs can be counted and found in an efficient manner when necessary due to automatic read count and identification (Ilic et al., 2009). RFID enables automatic sorting, handling, and cleaning procedures, which also brings labor cost savings (Johansson and Hellström, 2007). In addition, costly data acquisition processes like extraction data from invoices, etc. can be avoided (Ilic et al., 2009).

12. Asset visibility brings cycle time reduction, increase in rotation rate, damage and lost reduction. Therefore, investment in RTI fleet can be decreased with minimal sizing and configuration of RTI fleet through asset visibility (Johansson and Hellström, 2007; Frazelle, 2002).

13. Several flexible billing models can be made possible. For example, the end user can be charged for each damaged and lost RTI within his domain of responsibility. In addition, deposit charging can be also possible due to automatic identification of RTIs (Ilic et al., 2009).

14. RFID can decrease information asymmetries and incentive problems arising between parties. Two main source of information asymmetry for a supply chain are costs and forecasts (Lee and Ozer, 2007).

15. RFID systems make it possible to use a more systemic view of managing the production function and indeed business organization as a whole. By systemic, it is meant that the production function is seen as a structured collection of technical and organization components that interact with the operating environment and react to changing conditions. (Dutta et al., 2007)
16. Any data errors due to manual data entry can be eliminated (Ilic et al., 2009).

The first 12 benefits can be directly related to RTI management operations since we are able to establish the link between them and some operational characteristics of a closed-loop supply chain like cycle time, fleet size, etc. As a result, we are able to quantify these benefits. On the other hand, we have decided not to quantify the benefits 13-16 for the following reasons:

Benefit 13: There are various billing models and the formula of system wide costs of a closed-loop supply chain can greatly differ between one billing model to another. It is possible to build a different cost formula for each billing model. However, this option results in a cost formula depended on the billing model. We do not want this to happen, since our aim is not to deal with billing models in detail.

Benefit 14: There can be countless different situations of information asymmetries arising between different parties of the supply chain. Likewise 13^{th} benefit, it is not possible to make generalizations for quantification of this benefit.

Benefit 15: It is not possible for us to establish a clear link between this benefit and operational characteristics since there is not a clear and single way that this benefit can create a change in supply chain. In other words, it is not clear how systemic view can help us to make improvements in which parts of the supply chain.

Benefit 16: It is not possible to quantify this benefit without knowing the consequences of errors in manual data entry. These consequences can be countless. Therefore, it is not possible to make generalizations for quantification of this benefit.

3.2. The Potential Costs of Using RFID Technology

The costs of an RFID application should be analyzed with the following cost classification:

1. Setup costs: Initial investment cost of RFID implementation incurred only one time
2. Periodic costs: The costs that can be attributed to the application of RFID that are incurred periodically

The cost items belonging to each class are listed below. It is important to note that one item can be included to both classes.

3.2.1. Setup Costs

1. Training costs: The cost for training the employees which are going to use RFID technology
2. Administration costs: The cost of labor devoted to administering the implementation of RFID technology. This can include the fee for consultancy taken for RFID implementation.
3. Installation cost: The cost for setting up the necessary working environment for an RFID application
4. Tag costs: This cost item covers both purchasing and placing RFID tags.
5. Software costs: The cost for purchasing the necessary software including construction of a database in which RFID data can be stored, software for readers, etc.
6. Hardware costs: The cost for purchasing the necessary hardware including readers, personal computers to access to the database, etc.

7. Other costs: The costs attributable to the RFID implementation and cannot be included one of the above cost items

3.2.2. Periodic Costs

1. Administration costs: The cost of labor devoted to the operations necessary for RFID application. For example, using manual readers to scan the shipments should be included in this cost item.\
2. Tag maintenance costs: This cost item covers the cost of replacing damaged and fallen tags.
3. Software maintenance costs: The maintenance cost for keeping the software (including the database) up to date and running. For example, if there is a periodic fee for using the database, this should be included in this cost item.
4. Hardware maintenance costs: The maintenance cost for keeping the hardware up to date and running. This also includes renewal of hardware which becomes obsolete.
5. Other costs: The costs attributable to the RFID application and cannot be included one of the above cost items.

In addition to the known cost items, there can be unexpected costs which can be attributable to the RFID deployment. If there are such costs, they should be included in the cost item 'other'.

4. THE QUANTIFICATION OF THE ADDED VALUE OF USING RFID TECHNOLOGY

In section 4.1, firstly the links between the listed benefits in section 3.1 and the operational characteristics of a CLSC were established. With the help of these links, we found out how and which operational characteristics can be affected with RFID implementation. As a final step in section 4.2, we quantified the change in operational characteristics due to RFID technology. Here, it should be noted that by operational characteristics we meant the variables which can give some indication about the operational efficiency of a supply chain like cycle time, fleet size, inventory level, etc. In section 4.2, a formula to quantify the total cost introduced by RFID implementation was developed for the costs items listed in section 3.2. Finally, the formula for the added value of RFID was given in section 4.3.

4.1. The Quantification of the Potential Benefits of Using RFID Technology

Lee and Ozer (2007) (Lee and Ozer, 2007) argue that ground-up approaches are needed to obtain a better assessment of the value of RFID. According to them, the best approach is to start with the most fundamental operational characteristics and observe how the technology initiates a chain of improvements and accordingly values (Lee and Ozer, 2007). Therefore, analytical models connecting underlying operational characteristics to control decisions, and finally performance measures needed to be developed (Dutta et al., 2007). Such operational models can describe the way that RFID affects the operation of processes. With such a description, the quantification of RFID’s impact can be accurately performed (Dutta et al., 2007).

The Operational Characteristics

Table 4.1 shows how and which operational characteristics of a closed-loop supply chain of RTIs are affected with RFID technology. It also shows the links between the benefits (the benefits 1-12) chosen for quantification in section 3.1 and operational characteristics. This table constitutes a framework for quantification of these chosen benefits. The 1st column of this table shows the number of the benefit in our benefit list given in the section 3.1. The 2nd column answers the question of what RFID technology makes possible. For example, RFID makes tracking and tracing RTIs possible, which brings several benefits which can be found in Table 4.1. The 3rd column of this table shows the yield of what is given in the 2nd column. For example, timely information of actual RTI stock brings replenishment process improvement/optimization (as it is given in the row for the benefit 1). Finally, the last column shows the final results of the benefits in terms of some operational characteristics.

Table 4.1: The benefits related to asset visibility

Benefit	What does RFID make possible?	What does this bring?	What is/are final important outcome(s)?
1	Timely information of actual RTI stock	- Replenishment process improvement/optimization - Improvement/optimization in/of stock levels	- Decrease in new RTI purchases - Inventory reduction - Increase in vehicle utilization - Decrease in emergency shipments - Increase in RTI availability - Decrease in stockouts/lost sales/backorders
2	Increased visibility of return process	- More predictable return flow(s) - More accurate return forecasting	- Decrease in new RTI purchases - Inventory reduction - Increase in vehicle utilization - Decrease in emergency shipments - Increase in RTI availability - Decrease in stockouts/lost sales/backorders
3	Unique identification of RTIs Track and trace capability	- Clear accountability of stocks - Decrease in inventory discrepancies	- Inventory reduction - Decrease in stockouts - Decrease in new RTI purchases
4	Unique identification of RTIs Track and trace capability	- Tracing source(s) of damages	- Decrease in damage - Increase in RTI availability - Decrease in new RTI purchases
5	Unique identification of RTIs Track and trace capability	- Tracing source(s) of systematic losses/ thefts	- Decrease lost/stolen containers - Increase in RTI availability - Decrease in new RTI purchases

6	Unique identification of RTIs Track and trace capability	- Identification of slow moving locations/operations - Identification of excessive holding areas	- Cycle time reduction Increase in RTI availability - Increase in rotation rate Decrease in the RTI fleet size
7	Unique identification of RTIs Track and trace capability	- Tracing lifetime information of the RTI contents - Facilitation of product recall - Counterfeit prevention	- Decrease in the amount of outdated RTI contents - Decrease in penalty cost of outdated RTI contents reaching the end user
8	Storing RTI lifetime information Storing RTI repair history	- Automatic handling of preventive maintenance - Ensuring disposal of RTIs completing their lifetime - Repair frequency information of the RTI fleet - Improvement opportunities in the RTI design	- Extended lifetime of RTIs - Decrease in new RTI purchases - Decrease in the RTI damages - Decrease in penalties of outdated RTIs
9	The availability of dynamic RTI stock and movement data	- Better scheduling of the RTI shipments - Information about where to collect RTIs in case of emergencies	- Decrease in emergency shipments - Increase in vehicle utilization
10	Automatic RTI identification and notification	- Better scheduled RTI collection - Collection route optimization	- Decrease in erroneous shipments - Decrease in the transportation cost - Cycle time reduction - Increase in rotation rate
11	Automatic read and count	- More easier inventory audit - Elimination of manual data acquisition processes - Automatic sorting	- Decrease in labor cost - Cycle time reduction
12	Asset visibility	- Improvement opportunities for the sizing and configuration of the RTI fleet	- Decrease in the RTI fleet size - Decrease in the RTI fleet investment

Although all of the listed operational characteristics in Table 4.1 are expected to change with the use of RFID technology, not all of them have a direct effect on the total cost. For example, the availability of RTIs to satisfy the demand for empty RTIs is expected to increase with the use of RFID technology; however this does not directly influence cost. Due to increase in availability, we expect decrease in lost sales which has a direct effect on penalty cost. This means, increase in the availability influence cost through the decrease in lost sales.

These changes in operational characteristics are expected to (directly or indirectly) bring changes in the following cost items. The operational characteristic having a direct affect on cost items are written in bold in the following set of cost formulas. The superscript *i* differentiates between the time before (*i*=1) and after (*i*=2) the use of RFID technology.

$$TC^{i}_{administration} = c_{labor}\boldsymbol{H^{i}_{RTI\ management}} \quad (4.1)$$

$$TC^{i}_{inventory} = h_e\boldsymbol{E^{i}} + h_f\boldsymbol{F^{i}} \quad (4.2)$$

$$TC^{i}_{new} = K_{order}\boldsymbol{N^{i}_{order}} + c_{new}\boldsymbol{N^{i}_{new}} \quad (4.3)$$

$$TC^{i}_{penalty} = c_{penalty}\boldsymbol{L^{i}} \quad (4.4)$$

$$TC^{i}_{preparing} = \boldsymbol{c^{i}_{sorting}}\boldsymbol{R^{i}} + c_{repair}\boldsymbol{r^{i}_{repair}}\boldsymbol{R^{i}} + c_{dispose}\boldsymbol{r^{i}_{disposal}}\boldsymbol{R^{i}} + c_{cleaning}(1 - \boldsymbol{r^{i}_{disposal}})\boldsymbol{R^{i}} \quad (4.5)$$

$$TC^{i}_{transportation} = \boldsymbol{c^{e,i}_{transportation}}X + \boldsymbol{c^{f,i}_{transportation}}Y \quad (4.6)$$

or $TC^{i}_{transportation} = \sum_{x,y} c^{trip}_{xy}\,\boldsymbol{T^{i}_{xy}}$ (4.7)

Where,

$c_{cleaning}$: The unit cleaning cost for RTIs

$c_{dispose}$: The unit disposal cost for RTIs

c_{labor}: The unit labor cost for RTI pool management

$c_{penalty}$: The penalty cost for one unit of lost sales

c_{repair}: The cost for repairing one RTI

$c_{sorting}$: The unit sorting and checking for damage cost for RTIs

$c^{e}_{transportation}$: The unit transportation cost for an empty RTI from end users to distribution centers

$c^{f}_{transportation}$: The unit transportation cost for a full RTI from distribution centers to end users

c^{trip}_{xy}: The fixed trip cost of a truck for the transportation from location x to location y

E: The average empty RTI inventory level in the whole close-loop supply chain

F: The average full RTI inventory level in the whole close-loop supply chain

h_e: Inventory holding cost of one empty RTI for one period

h_f: Inventory holding cost of one full RTI for one period

$H_{RTI\ management}$: Total amount of administrative labor hours spent in RTI management operations
K_{order}: The fixed order cost of new RTI orders
L: Total number of lost sales occurred in stock out occasions in the planning horizon
N_{new}: The amount new RTI purchases in the planning horizon ($N_{new} = \sum_{t=0}^{T} N_t$)
N_{order}: The number of new RTI orders in the planning horizon
R: Total amount of RTIs entered preparing for reuse operation in the planning horizon
$r_{disposal}$: The disposal rate ($r_{disposal} = \frac{RTI\ disposals}{RTI\ returns}$)
r_{repair}: The repair rate ($r_{repair} = \frac{Repaired\ RTIs}{RTI\ returns}$)
T_{xy}: Total number of truck trips made between location x and y in the planning horizon
$TC_{administration}$: The total administration cost for RTI pool management (including administration for new RTI purchases, planning RTI shipments, taking action in case of low level of returns, etc.)
$TC_{inventory}$: The total inventory holding cost
$TC_{new,}$: The total cost of new RTI purchases
$TC_{penalty}$: The total penalty cost of lost sales
$TC_{preparing}$: The total cost of preparing for reuse operation of RTIs
$TC_{transportation}$: The total transportation cost
X: The total amount of transported empty RTIs in the planning horizon
Y: The total amount of transported full RTIs in the planning horizon

The total value of the benefits of RFID is the decrease in the total cost:

$$TB_{RFID} = TC^1 - TC^2 \tag{4.8}$$

Where

- TB_{RFID} is the total benefit of RFID, and
- $$TC^i = TC^i_{administration} + TC^i_{inventory} + TC^i_{new} + TC^i_{penalty} + TC^i_{preparing} + TC^i_{transportation} \tag{4.9}$$

$$\begin{aligned} TB_{RFID} = {} & (TC^1_{administration} - TC^2_{administration}) \\ & + (TC^1_{inventory} - TC^2_{inventory}) \\ & + (TC^1_{new} - TC^2_{new}) \\ & + (TC^1_{penalty} - TC^2_{penalty}) \\ & + (TC^1_{preparing} - TC^2_{preparing}) \\ & + (TC^1_{transportation} - TC^2_{transportation}) \end{aligned} \tag{4.10}$$

Since the demand is assumed to stay the same for before and after the use of RFID technology, we expect that the total amount of empty RTIs (after prepared for reuse) sent to the filling/loading facility should be the same. Therefore,
$\left(1 - r^1_{disposal}\right)R^1 = \left(1 - r^2_{disposal}\right)R^2$

As a result, the last term of $TC^i_{preparing}$ will be the same both before and after the use of RFID technology and cancel each other.

In conclusion, total cost saving of RFID can be found with the following equation:

$$\begin{aligned} TB_{RFID} &= \left[c_{labor}\left(\boldsymbol{H^1_{RTI\,management}} - \boldsymbol{H^2_{RTI\,management}}\right)\right] \\ &+\left[h_e(\boldsymbol{E^1} - \boldsymbol{E^2}) + h_f(\boldsymbol{F^1} - \boldsymbol{F^2})\right] \\ &+\left[K_{order}(\boldsymbol{N^1_{order}} - \boldsymbol{N^2_{order}}) + c_{new}(\boldsymbol{N^1_{new}} - \boldsymbol{N^2_{new}})\right] \\ &+\left[c_{penalty}(\boldsymbol{L^1} - \boldsymbol{L^2})\right] \\ &+\left[(\boldsymbol{c^1_{sorting}R^1} - \boldsymbol{c^2_{sorting}R^2}) + c_{repair}(\boldsymbol{r^1_{repair}R^1} - \boldsymbol{r^2_{repair}R^2}) \right. \\ &\qquad \left. + c_{dispose}\left(\boldsymbol{r^1_{disposal}R^1} - \boldsymbol{r^2_{disposal}R^2}\right)\right] \\ &+\left[(\boldsymbol{c^{e,1}_{transportation}} - \boldsymbol{c^{e,2}_{transportation}})X + (\boldsymbol{c^{f,1}_{transportation}} - \boldsymbol{c^{f,2}_{transportation}})Y\right] \end{aligned} \tag{4.11}$$

The last term can be changed with
$TC^1_{transportation} - TC^1_{transportation} = \sum_{x,y} c^{trip}_{xy}\, T^1_{xy} - \sum_{x,y} c^{trip}_{xy}$.

4.2. The Quantification of the Potential Costs of Using RFID Technology
The following assumptions were used in this quantification.

- There is no salvage value of any item purchased for RFID application.
- All the costs of RFID can be separated from the costs of any other activities. For example, if the database stores non-RFID data which is used for an operation not affected by RFID (e.g. marketing), it is possible to separate the database cost related with RFID application.

Notation
TC_{RFID}: Total cost of the RFID application
SC: Total setup cost of the RFID application
PC: Total periodic costs of the RFID application in the planning horizon
PC_t: Total periodic costs of the RFID application in period t
T: The number of periods in the planning horizon
$r_{interest}$: The interest rate reflecting the cost of tying up capital, etc.

Superscripts for denoting the cost items:

- tra: Training cost
- adm: Administration cost
- ins: Installation cost
- tag: Tag (maintenance) cost
- sw: Software (maintenance) cost
- hw: Hardware (maintenance)costs
- oth: Other costs

Formulas

$$TC_{RFID} = SC + \sum_t PC_t \qquad \text{without discounting} \qquad (4.12)$$

$$TC_{RFID} = SC + \sum_t \frac{PC_t}{(1+r)^t} \qquad \text{with discounting} \qquad (4.13)$$

where

$$SC = SC^{tra} + SC^{adm} + SC^{ins} + SC^{tag} + SC^{sw} + SC^{hw} + SC^{oth} \qquad (4.14)$$

$$PC_t = PC_t^{adm} + PC_t^{tag} + PC_t^{sw} + PC_t^{hw} + PC_t^{oth} \quad for\ t = 0,1,2 \ldots, T \qquad (4.15)$$

4.3. The Added Value of Using RFID Technology

The added value of RFID is equal to its benefits which are cost savings introduced by RFID minus the cost for RFID implementation.

$$Added\ value\ of\ RFID = TB_{RFID} - TC_{RFID} \qquad (4.16)$$

The RFID application can be considered as profitable if the following condition is satisfied:

$$Added\ value\ of\ RFID \geq \pi_{profit} TC_{RFID} \qquad (4.17)$$

where

π_{profit} is the profit margin determined by the organization which initializes the RFID application.

5. CASE STUDY

5.1. Problem Owners

CHEP is a third party logistic provider which issues, collects, conditions and reissues more than 300 million pallets and containers from a global network of service centers, helping manufacturers and growers transport their products to distributors and retailers. It is the global leader in pallet and container pooling services serving many of the world's largest companies. It handles pallet and container supply chain logistics for customers in the consumer goods, produce, meat, home improvement, beverage, raw materials, petro-chemical and automotive industries by combining superior technology, decades of experience and an unmatched asset base. As a result, it provides a valuable service to over 345,000 customers in 46 countries. (Rf. Official website of CHEP: www.chep.com, 2010)

Pooling necessitates a closed loop supply chain of pallets and containers which has mainly four steps: (Rf. Official website of CHEP: www.chep.com, 2009)

1. CHEP issues ready-to-use pallets and containers to the manufacturers for use and movement thorough the supply chain.
2. After receiving empty pallets and containers from CHEP, manufacturers load their products and ship full ones.
3. The receiving retailer or distributor unloads the goods at the end of supply chain. After, the empty pallets are returned to or collected by CHEP.
4. CHEP inspects and conditions all returned pallets and containers to make them ready-to-use.

In our case, Company A fills RTIs with its product and ships full RTIs to the end user facilities of Company B. The owner of the RTIs is Company A. After being emptied in one of the end users, empty RTIs are collected in a facility in which the RTIs are cleaned and repaired if necessary. After, they are shipped to the manufacturing facility of Company A. All this constitutes a closed loop supply chain for RTIs. The role of CHEP here is to consult Company A on the management of RTIs pool with the help of RFID technology. Currently, Company A has troubles regarding RTI returns. The speed of return is slow (or not fast enough), which brings difficulties in meeting the RTI demand of the manufacturing facility of Company A. In order to help Company A, CHEP started an RFID application in this closed loop supply chain for a better RTI pool management. Our role is to find out the value of RFID technology for managing pools of RTIs.

The answers of the following questions were unknown before the use of RFID technology since the RTIs did not have unique identity numbers and there were no tracking and tracing. (Rf. CHEP RFID services presentation for Company A, 2009)

- How many RTIs are there in this closed loop supply chain in total?
- What is the actual cycle time of RTIs?

- Where do excess holding periods occur in supply chain?
- How many RTIs get lost periodically?
- At what points do RTIs get lost?
- What are the benefits associated with improved RTI pool management?

In summary, the size of the RTI pool, actual cycle time, the points and the amounts of RTI damage/lost/theft in the supply chain were unknown, which were making the RTI pool management harder. Because of this reason, RFID technology was implemented in order to estimate unknown parameters. In general, the accurate estimation of these life cycle parameters is required for pricing a product, effective inventory and ad production control, financial control and accounting for losses (Goh and Varaprasad, 1986).

To conclude, the concern of this project iss the core business of CHEP as it can be understood from this section. Besides, this is a pilot project for RFID, and if it turns out to be successful, there will be an opportunity of its worldwide application in different companies which have the similar complaints with Company A. Because of this reasons, this project is important for CHEP both for its current business with Company A and for its long term business opportunities.

5.2. The Closed-Loop Supply Chain of RTIs

Figure 5.1 demonstrates the closed loop supply chain of RTIs. The journey of an RTI starts with purchasing. A newly purchased RTI (denoted by dotted arrow entering the stock point 1) is brought to the production facility in which it is going to be filled. Firstly, it enters the stock of empty and clean RTIs which are waiting to be filled (the stock point 1). After the filling operation, it enters the stock of full RTIs (the stock point 2). After waiting in this stock, it is shipped one of the distribution centers (the transportation 1). The distribution center delivers it (from the stock point 3 to the stock point 4) to the one of the facilities of end users in which it is going to be emptied (the transportation 2). When it is emptied in a facility of an end user, it enters to the empty RTI stock of this facility (the stock point 5). After waiting in this stock, it is collected and brought to one of the distribution centers again (the transportation 3). When it arrives in the distribution center, it is placed at (one of) the stock point(s) for returned RTIs (the stock point 6). After, it is shipped (to the stock point 7) to the facility of preparing for reuse (the transportation 4). In this facility, it is checked to determine whether it has a damage or not and if the damage is repairable or not. If it has a non-repairable damage, it is disposed. Otherwise, it is prepared for reuse after repairing if necessary. Following to preparing for reuse operation, it enters the stock of ready-for-reuse RTIs (the stock point 8). From this stock, it is transported to the facility in which it is going to be filled (the transportation 5). After this transportation, it completes its first cycle and continues to its next cycle with filling again. It continues cycling until it is lost at one of the stages of the closed-loop supply chain or is disposed due to a non-repairable damage (denoted by dashed arrows).

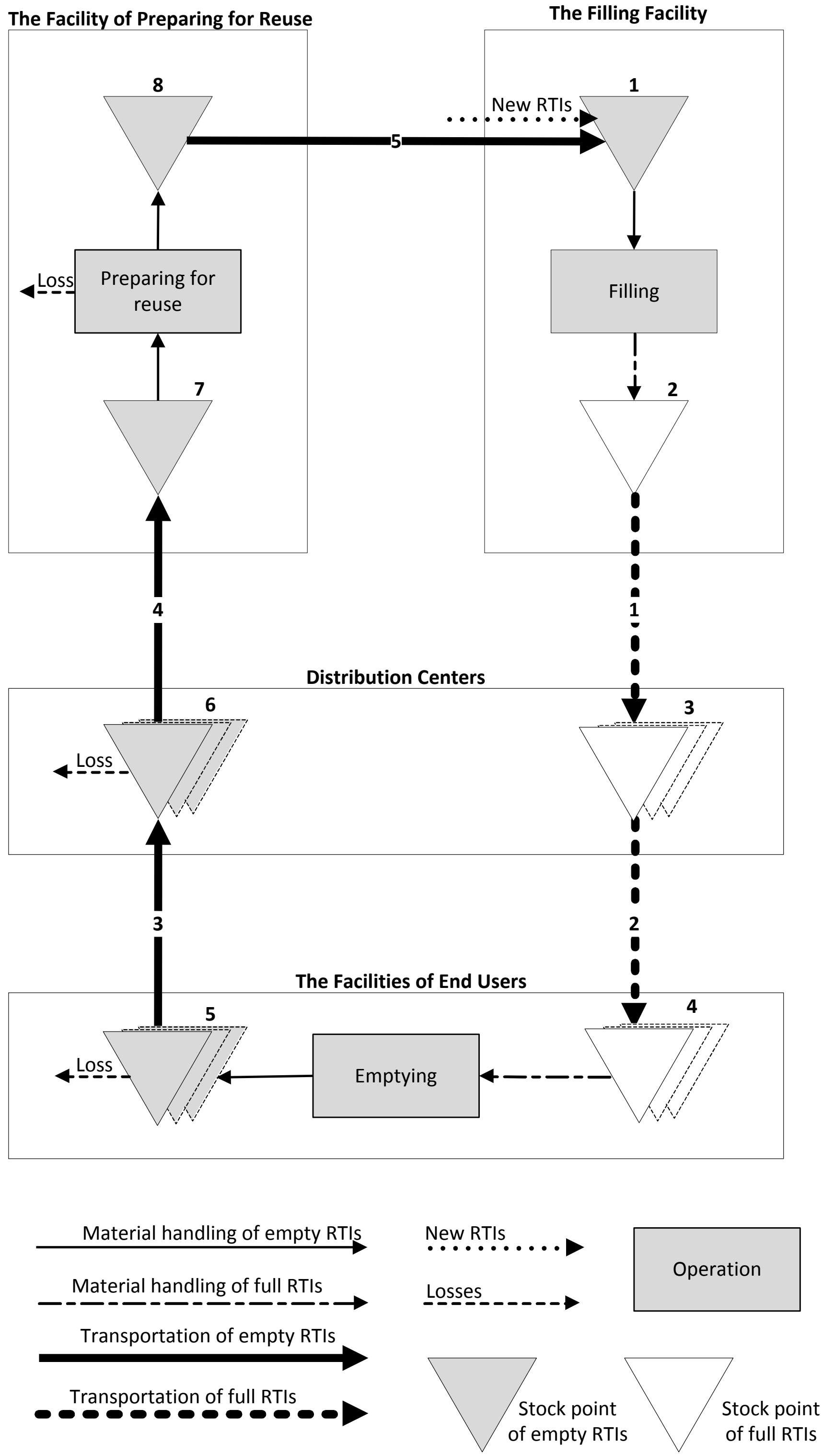

Figure 5.1: The closed-loop supply chain of RTIs

5.3. The Application of RFID Technology

In order to help Company A, CHEP started an RFID application in this closed loop supply chain. CHEP is a leader in all aspects of RFID – from customer trials and testing to global compliance and technology (Rf. Official website of CHEP: www.chep.com, 2009). RFID technology has been fully implemented with three shipment scanning points since September 2009. These three scan points are as follows: (Rf. Meeting with Floris Kleijn, September 2009)

- Just before shipping filled RTIs from Company A
- Just after receiving empty RTIs in the facility for cleaning and repair
- Just before shipping empty RTIs from cleaning facility to Company A

Besides, scanning has been also performed in the facility for cleaning and repair in order to record repair history of RTIs. The following figure shows the currently used scan points in the supply chain.

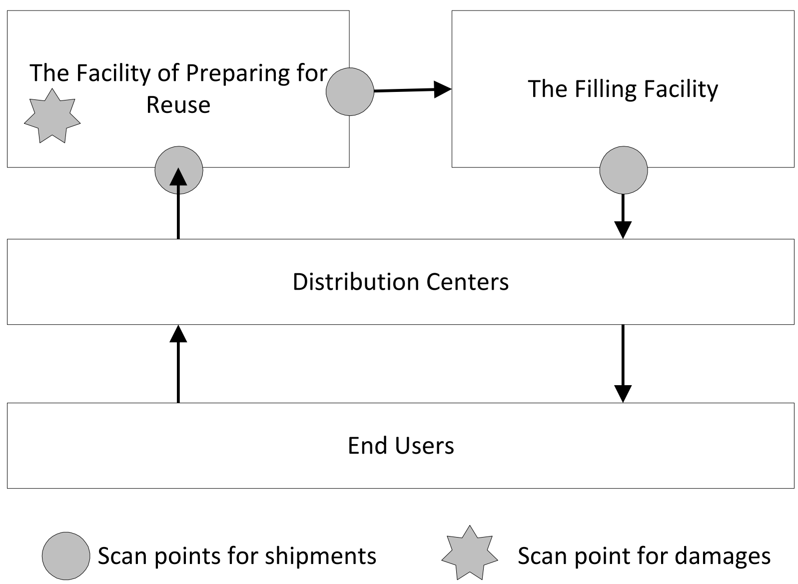

Figure 5.2: RFID scan points

5.4. The Potential Benefits of Using RFID Technology for the Chosen Case

From the list of benefits given in chapter 3, the following benefits were found to be the most relevant with our case after the discussion with Floris Kleijn (2009) who is the supervisor of the pilot project.

2. The flow of RTIs in the supply chain becomes more predictable with asset visibility (Ilic et al., 2009). Uncertainty in quantity, quality and timing of returns is decreased (Karaer and Lee, 2007). More accurate forecasting methods can be used for returns and replenishment process can be improved with better return forecasts.

4. With unique serial identification associated with the RTISs, it is possible to trace the source of the damaged pallets to the originator. As a result, it is expected that RTI damages are decreased (Ilic et al., 2009).

5. With the help of track and trace capability, it is also possible to identify any systematic losses (including theft (Dutta et al., 2007)) within the supply chain (Ilic et al., 2009). As a result, it is expected that RTI losses are decreased.

6. With the help of track and trace capability, it is also possible to identify slow moving locations and excessive holding areas in the supply chain. Cycle time can be decreased and rotation rate can be increased with the determination of slow moving locations and taking action when possible.

9. Currently, emergency deliveries occur since the return flow is slow. The decrease in damages, and losses as well as the identification of slow moving location can help to increase the speed of return flow. Therefore, RFID can help in avoiding or at least decreasing emergency deliveries between the facility of preparing for reuse and the filling facility.

12. Asset visibility brings cycle time reduction, increase in rotation rate, damage and lost reduction. Therefore, investment in RTI fleet can be decreased with minimal sizing of RTI fleet through asset visibility (Johansson and Hellström, 2007; Frazelle, 2002).

We have decided to quantify all of these benefits except the benefit 2 in this master thesis study. The quantification of benefit 2 can be a topic of a master thesis study alone under the title advance supply information.

5.5. Work Has Been Done So Far

This pilot project has been started with RFID implementation. The goal of CHEP was to ensure that the pilot project went live and has been continuing for a long time. This could be achieved by making the potential value of RFID real. Therefore, the ultimate step that the pilot project should reach was the realization of value. Figure 5.3 shows the path for value realization starting with RFID implementation as a first step. In order to reach the ultimate step of value realization, there were questions to be answered at every step. These questions were written in word balloons in Figure 5.3. Studies have been conducted related with all of the questions during the case study. Therefore, Figure 5.3 was drawn by us in order to summarize what we have done in this pilot project. In the end, we have achieved to turn the pilot project into a long-term RFID application.

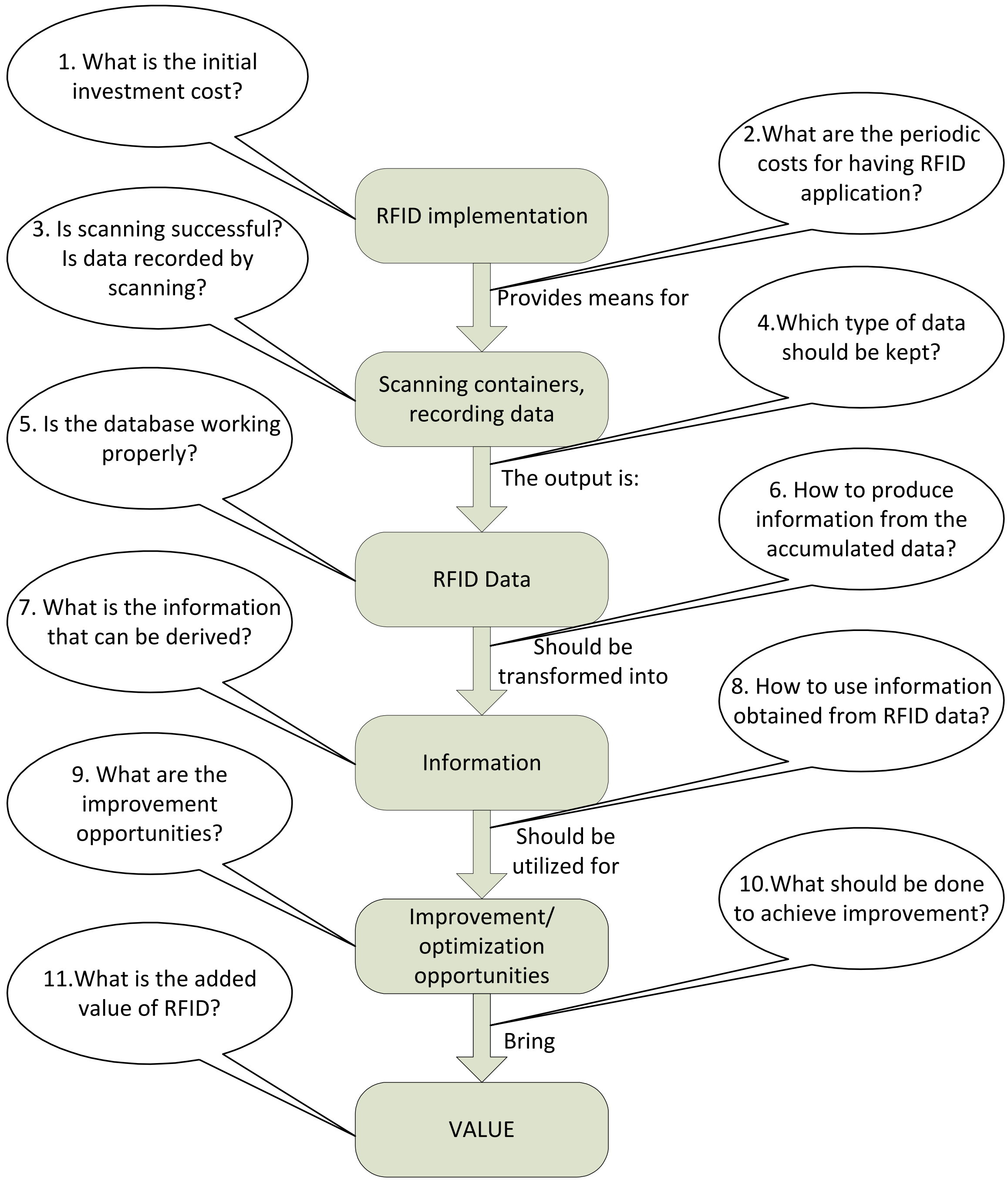

Figure 5.3: The path for value realization

6. PROPOSED APPROACH

6.1. Introduction

Our aim was to explore the value of using RFID technology on RTI pool management for cases similar to our case study. For this purpose, we were required to investigate the situations both with and without the use of RFID technology. In both situations, the manager of the RTI pool may or may not have optimization effort. As a result, there exists four ways to manage an RTI pool. These ways are summarized in Figure 6.1. Atali et al. (2006) did a similar summary for the ways to manage an inventory system under inventory inaccuracy.

		VISIBILITY	
		Without (No use of RFID technology)	With (RFID-enabled)
OPTIMIZATION EFFORT	Without	Situation 0: Ignorant situation	Situation 2: Situation of not fully utilizing RFID
	With	Situation 1: Optimal situation without RFID	Situation 3: Optimal situation with RFID

Figure 6.1: Four situations in RTI pool management

Situation 0 refers to the way of RTI management in which both a possible optimization opportunity and a possible means for visibility (RFID) are ignored. Therefore, this situation is referred as *ignorant situation*. The initial situation of our case can be considered as *ignorant situation*. *Situation 1* refers to the management way when possible optimization opportunities are exploited in the absence of RFID technology. *Situation 2* is the RTI management way when RFID technology is applied; however there is no effort to make any improvement with the additional information provided by this technology. Since such a way of management is impractical and irrational, we do not deal with *Situation 2*. Finally, *Situation 3* refers to the way of management when possible optimization opportunities are utilized in the presence of RFID technology and the additional information and visibility that it provides. With the aim of being fair, we found it is best to compare *Situation 1* and *Situation 3* in order to reach to true impact of using RFID technology.

6.2. Main Steps of Proposed Approach

In order to find out the true impact of using RFID technology, the following main steps should be completed:

1. Modeling *Situation 1*: For this step, we needed to find the optimal way of RTI management in the absence of RFID technology in the best possible way.
2. Modeling *Situation 3*: For this step, we needed to find the optimal way of RTI management in the presence of RFID technology in the best possible way. This modeling should be done assuming that
   - RFID data is transformed into useful information and this additional information is used in order to find out
     - The sources of damages,
     - The sources of systematic losses, and
     - Slow moving locations and excessive holding areas.
   - Action is taken in order to diminish the sources of damages, the sources of systematic losses, slow moving locations and excessive holding areas.
3. Comparing *Situation 1* and *Situation 3.*

At strategic level, RTI management requires the design of the CLSC including the locations and the numbers of facilities that serve to the end users as well as the structure of collection and distribution. At tactical level, RTI management requires deciding on the pool size which determines the level of capital investment. At operational level, it is necessary to decide on quantity and timing of new RTI purchases in order to sustain the RTI pool as some RTIs are never returned and some are disposed due to non-repairable damages. Besides, emergency shipments should be organized at operational level when there are not enough empty RTIs to fulfill the demand of full RTIs. These decisions should be made according to a prescribed service level of satisfying the demand of full RTIs.

In our study, strategic level decisions were taken as given. Our aim was to deal with the following tactical and operational level decisions:

- The size of the RTI pool
- The determination of quantity and timing of new RTI purchases
- The decision of emergency shipments

There were other decisions at tactical and operation levels like the lot sizes of transportation, preparing for reuse operation, etc. These decisions were taken as given because our focus in only on the decisions that RFID can have an impact and the RTI manager can have an effect on.

6.3. The CLSC to Be Modeled

Before starting with modeling of *Situation 1* and *Situation 3*, we needed to determine the specifications of the CLSC to be modeled and additionally do some simplifying assumptions.

In our case study, we could reach the detailed information only about the operations of the manufacturer. There was not enough reliable information about the operations of the distributor and end users. It was not clearly known how distribution and collection operations are carried out between DCs and end users. Because of these reasons, we modeled the part of the CLSC that involves DCs and end users as a *black box*. Related with this *black box*, we only observed the deliveries of full RTIs to DCs, the receipts of empty RTI returns from DCs at the manufacturer and the level of empty RTI stock at DCs when there is a need of emergency shipment by contacting with them. In addition, we combined the preparing for reuse facility and the filling facility as if it was a single facility since the distance between them (takes 1 hour with trucks) is negligible when modeling is done at day level. As a result, we came up with the CLSC shown in Figure 6.2.

In our case study, we have observed that the manufacturer rarely needs to ship RTI returns from DCs emergently. These emergency shipments help the manufacturer to increase RTI availability for the filling operation because it reduces the time that empty RTIs need to wait at DCs to form a full truck load of RTI returns. On the other hand, they result in dispute between the manufacturer and DCs because they require additional effort of DCs. There can be cases that it is not possible to make an emergency shipment because DCs are reluctant to cooperate with the manufacturer for such shipments. Because of these reasons, we have modeled the CLSC with considering two possible settings related with emergency shipments of empty and dirty RTIs from DCs. These settings are as follows:

1. Emergency shipment is not allowed by DCs.
2. Emergency shipment is allowed by DCs and the manufacturer can decide whether or not to make emergency shipments.

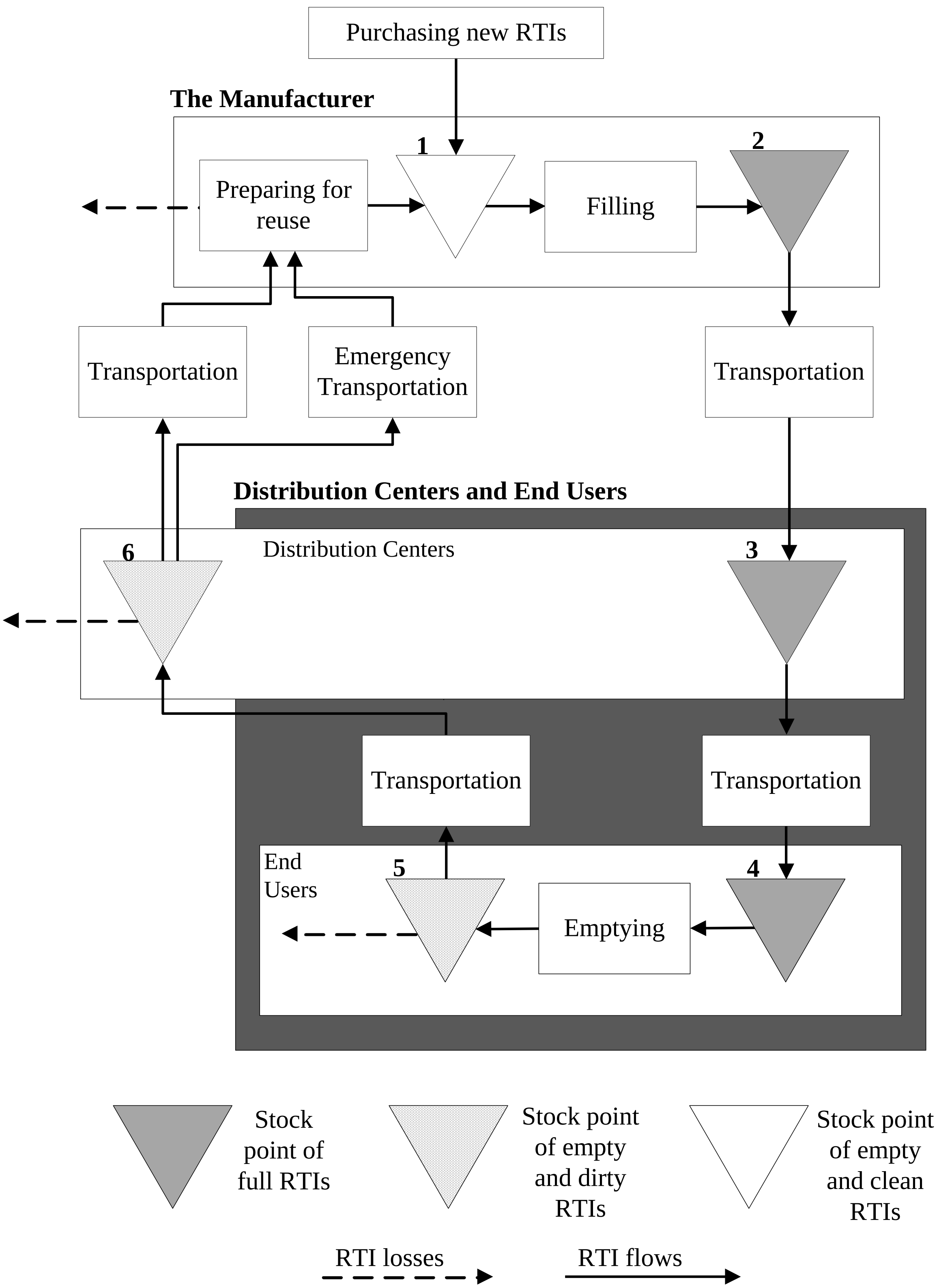

Figure 6.2: The simplified version of CLSC of RTIs

The CLSC was assumed to have the following specifications:

- There is a single manufacturer. Its aim is to minimize undiscounted total cost of RTI pool management.
- The manufacturer produces various products. Only one of them is under consideration.
- The manufacturer sells the product under consideration in a single type of RTI.
- All RTIs in the pool are identical and interchangeable.
- The manufacturer is the owner of the RTI pool.
- RTIs can be damaged; however they do not deteriorate. As a result, there is no useful lifetime limit for RTIs.
- Possible causes of RTI losses are disposals due to non-repairable damages and never being returned.
- The quantity and timing of new RTI orders are determined by the manufacturer according to the demand of the filling operation, on hand stock of reusable empty RTIs and the expected RTI returns.
- The purchasing of new RTIs is carried out according to periodic (weekly) review.
- The decisions regarding new RTI purchases are given so as to there will be no need for the emergency shipments of empty returns from DCs when emergency shipment is allowed. The emergency shipments bring additional transportation cost and planning effort to the manufacturer. Besides, they result in dispute with DCs because they require additional effort of DCs at each occasion of contacting with DCs for their planning. Most importantly, the manufacturer does not want to take the risk regarding empty RTI availability. When the manufacturer needs to make an emergency shipment, it is not certain that there will be enough empty RTIs at DCs to satisfy the need.
- The purchasing of new RTIs is carried out according to the target service level of 99% fill rate (type 2 service level) for satisfying the demand of filling operation.
- The inventory policy of the manufacturer for empty RTI stock is order-point, order quantity (s, Q) policy. In this policy, a fixed order quantity Q is ordered whenever the inventory position drops to the reorder point s or lower.
- There is no limit for the order quantities of new RTI purchases.
- There is a minimum order quantity of new RTI purchases.
- There is a positive fixed ordering cost of new RTI purchases. This is the cost of transportation from the supplier of RTIs to the manufacturer.
- There is a positive, fixed and known lead time (the time between order and delivery) for new RTI purchases. It does not depend on order quantity.
- The unit price of new RTIs is constant and known. It does not depend on order quantity (no quantity discounts), the time of ordering (no promotion periods), etc.
- The price of new RTI purchases is paid when they are delivered to the manufacturer.
- A newly purchased RTI is ready for use. Therefore, it enters empty and clean RTI stock at the manufacturer.

- The manufacturer holds three kinds of RTI stock, namely returns stock (empty and dirty RTIs returned from DCs), empty and clean RTI stock (ready to enter filling operation), and full RTI stock.
- There is no storage space restriction for the empty and full RTIs stock at the manufacturer.
- The manufacturer is responsible for the preparing for reuse and the filling operations.
- Only prepared for reuse RTIs (at the empty and clean RTI stock of the manufacturer) can enter the filling operation.
- The production of ingredients is decoupled from the filling operation. There is always enough substance to fill the RTIs.
- Only the lack of RTIs can interrupt the filling operation.
- The filling operation has abundant capacity.
- The filling operation is carried out according to periodic (weekly) review.
- Once a week, the filling lot size is determined according to the on hand full RTI stock and demand forecasts. After determining the filling lot size, the filling operation is performed.
- The inventory policy of the manufacturer for its full RTI stock is periodic-review, order-up-to-level (R, S) policy. The systems under this inventory policy are also known as replenishment cycle system. Its control procedure is that every R units of time enough is ordered to increase the inventory position to the level S.
- If emergency shipment is allowed, the time between the determination of filling lot size and the start of the filling operation is enough to make an emergency shipment if it is found to be necessary. Otherwise, if emergency shipment is not allowed, the filling operation is started just after the determination of the filling lot size.
- If the level of on hand empty and clean RTI stock is less than the need of the filling operation (the filling lot size) at the start of the filling operation, it is started and all of the RTIs at the empty and clean RTI stock are filled.
- There is a positive and fixed lead time for the filling operation.
- The setup cost and time of the filling operation are negligible.
- The filling operation is always successful.
- RTIs which leave the filling operation enter full RTI stock and wait for demand arrivals from DCs if there is no backorders of full RTIs. Otherwise, if there is a backorder of full RTIs, RTIs leaving the filling operation are sent immediately to satisfy the outstanding backorders.
- The target service level for satisfying full RTI demand is 95% fill rate (type 2 service level).
- There are 3 DCs demanding for full RTIs.
- The demand for full RTIs is stationary.
- Unsatisfied demand is backordered.

- When more than one DC have a backorder, firstly the DC having the maximum level of backorders is satisfied. If the level of backorders are equal, backorders are satisfied according to the following rationing policy:

  Priority of DC-1 > Priority of DC-2 > Priority of DC-3
- The manufacturer aims to fulfill a determined type 2 service level (fill rate) for satisfying the demand of full RTIs.
- The demand interarrival time and the distributions of the order quantities of DCs are known and different between DCs.
- There is no upper or lower limit for the order quantities of DCs given in total in a time period.
- The size of each order can be from a set of possible order sizes with finite size. Each possible order size has a discrete probability to be given by a DC.
- RTIs are distributed to the end users through DCs. There is no direct shipment from the manufacturer to the end users.
- RTIs are collected from the end users through DCs. There is no direct shipment from the end users to the manufacturer.
- Once an RTI is sent to a DC, it is distributed to and collected from an end user by the same DC. In addition, it is brought back to the manufacturer by the same DC.
- It is not possible to combine full RTI shipments to DCs.
- The transportation cost of the full RTI shipments from the manufacturer to the DCs is in the responsibility of the DCs.
- Each DC returns empty RTIs when their returns stock is enough to fill a truck completely. In other words, every ordinary shipment of returns from DCs has full truck load.
- The transportation between the manufacturer and a DC has a positive and fixed lead time regardless of whether the truck carries full RTIs or empty RTI returns.
- When the level of empty RTI stock at the manufacturer is lower than the need of the filling operation, the manufacturer decides whether or not to do emergency shipments according to the amount of empty RTI shortage if emergency shipment is allowed.
- The emergency shipments are started immediately after the decision of them is given.
- It is not possible to combine emergency shipments of different DCs. The emergency shipment of a DC cannot wait a truck coming from another DC since emergency shipments are started immediately after their decision is given.
- When the amount of empty RTI shortage is enough to make an emergency shipment, i.e. when it is greater than a threshold value, the manufacturer contacts with DCs. The aim of contact is to find out whether or not a shipment of returns is on the way and the amount of the returns stock at DCs.
  - If there is not any shipment of returns on the way, the manufacturer makes the emergency shipment from the DC having the maximum level of returns stock if its level is worth to make an emergency shipment, i.e. if its level is greater than

the minimum amount of emergency shipment. If the manufacturer decides to make an emergency shipment, it recalculates the amount of empty RTI shortage by considering the amount of emergency shipment. After, it makes necessary number of emergency shipments as long as the recalculated amount of empty RTI shortage and the level of returns stock at the DCs is enough to make an emergency shipment.

  - If there is a shipment of returns on the way, the manufacturer recalculates the amount of empty RTI shortage by considering the total amount of RTI returns on the way. If the amount of shortage is not still greater than the threshold value, the manufacturer does not make an emergency shipment. Otherwise, it makes the emergency shipment from the DC having maximum level of returns stock if its level is worth to make an emergency shipment. In that case, it recalculates the amount of empty RTI shortage by considering the amount of emergency shipment. After, it makes necessary number of emergency shipments as long as the recalculated amount of empty RTI shortage and the level of returns stock at the DCs is enough to make an emergency shipment.

- When the amount of empty RTI shortage is enough to make an emergency shipment (after including the RTI returns which are currently on the way to the manufacturer, if there are any) and there is more than one DC having equal levels of returns stock which worth to do an emergency shipment, emergency shipment(s) should be carried out according to the preference ranking DC-1 > DC-2 > DC-3.
- The cost of the ordinary shipments is in the responsibility of DCs. On the other hand, the cost of the emergency shipments is in the responsibility of the manufacturer.
- The transportation time is the same for both ordinary and emergency shipments.
- Transportation is done with identical trucks having the same capacities for carrying empty RTIs and same capacities for carrying full RTIs. The truck capacity for carrying empty RTIs is larger than the same for full RTIs due to the fact that there is a legal weight limit for truck loads.
- It is not possible to combine the shipments of empty RTI returns from DCs.
- The RTIs returned by DCs are sent to the preparing for reuse operation immediately.
- The condition of RTIs when they are returned from DCs has a general discrete distribution with three different outcomes and a known probability mass function. They can be undamaged, reparably damaged or non-reparably damaged.
- The preparing for reuse operation has abundant capacity.
- There is a positive and fixed lead time for the preparing for reuse operation.
- The setup cost and time of the preparing for reuse operation are negligible.
- In the preparing for reuse operation, RTIs are checked for their damages, cleaned and repaired if necessary and possible.
- RTIs entering the preparing for reuse operation are firstly checked to determine:
  - Whether they have a damage or not, and

    - If they have a damage, whether it is repairable or not.
- The returned RTIs having non-repairable damages are disposed immediately.
- Returned RTIs having repairable damages are repaired at a fixed unit repair cost.
- Repair is always successful and repaired RTIs become as good as new.
- Cleaning is always successful. Once cleaned, an RTI cannot be dirty again before being used again.
- A returned RTI can be non-reparably damaged, reparably damaged or undamaged with a known and fixed discrete probability.
- An RTI cannot be damaged or lost at the site of manufacturer.
- An RTI may be never returned after it is sent one of DCs. This probability of never being returned, i.e. being lost in the field, has a binomial distribution.
- The RTI losses in preparing for reuse operation as well as at the stock points 5 and 6 are not negligible. The total of these losses constitutes RTI shrinkage.

We were only interested in the costs which are in the responsibility of the manufacturer. These were the following cost items:
- Purchasing cost of RTIs (including fixed purchasing cost and unit price of RTIs)
- The cost of preparing for reuse (including cleaning, checking, repair, and disposal)
- Transportation cost of emergency shipments
- The cost of labor devoted to planning of operations related with RTI pool
- The penalty cost of backorders
- Inventory holding cost (the cost of capital tied to RTI pool and on hand full RTI stock)
- Material handling cost at the manufacturer site

Among the above cost items, some of them are (almost) fixed costs, i.e. they do not seem to be (significantly) changed with an improvement in RTI pool management. These costs are the cost of cleaning and checking RTI returns, the cost of labor devoted to planning of operations related with RTI pool, the inventory holding cost of full RTIs and material handling cost at the manufacturer site. Besides, the penalty cost of backorders is not expected to change significantly given a determined a service level for satisfying full RTIs. In addition, some of the cost items are small enough to be considered as negligible (e.g. disposal cost). When all of these cost items were removed, we were left with the following cost list which includes the cost items that we needed to take into consideration:
- Purchasing cost of RTIs (including fixed purchasing cost and unit price of RTIs)
- The cost of repair
- Transportation cost of emergency shipments
- Inventory holding cost (the cost of capital expended for RTI pool)

6.4. Performance Measures of the CLSC

We needed to determine the performance measures that can help to evaluate the solutions of the models for *Situation 1* and *Situation 3* and to compare the situations with each other. The life-cycle characteristics of reusable containers given by Goh and Varaprasad (1986) as well as the lists of RTI key performance indicators and RTI management metrics given by Bowman et al. (2009) guided us to come up with the presented list of performance measures. In addition, we used the insight that we gained during our case study.

The list of performance measures was as follows:

- Total RTI pool management cost (including the cost items in the final cost list in Section 6.3)
- The average cycle time (trip duration)
- The trippage (total number of cycles completed by an RTI in its lifetime)
- The average useful lifetime of RTIs
- The average pool size (total number of RTIs in circulation in the CLSC)
- The rate of new RTI replenishment
- The service level for satisfying the empty RTI need of filling operation
- The service level for satisfying the full RTI demand of DCs
- The average time that RTIs spend in the field (i.e. the duration between the time that an RTI leaves the manufacturer and the time that it comes back to there)

6.5. Problem Context

For the case in which the emergency shipment is not allowed, the optimization model which aims to minimize total undiscounted RTI pool management cost of the manufacturer is given below. The optimization model was written according to the specifications of the CLSC given in section 6.3. Since the RTIs returned by DCs are sent to the preparing for reuse operation immediately, the level of returns stock at the manufacturer is zero, and the amount of RTIs sent to preparing for reuse operation is equal to the amount of returns from DCs. This means that the level of returns stock at the manufacturer and the amount of RTIs sent to the preparing for reuse operation are not decision variables.

Indexes

e denotes the empty and clean RTI stocks.

f denotes the full RTI stocks.

i denotes DCs with $i = 1,2,3$.

m denotes the manufacturer.

t denotes the time periods with $t = 0,1,2, \ldots, N$.

Decision Variables

B_{it}: The amount of outstanding full RTI backorders to DC i in period t
F_t: The number of RTIs filled in period t
I_{mt}^{e}: The level of empty and clean RTI stock at the manufacturer in period t
I_{mt}^{f}: The level of full RTI stock at the manufacturer in period t
Q_t: The amount of new RTI orders given in period t
z: The objective function value giving total cost of RTI pool management
$\delta(Q_t)$: The number of shipments required to transport Q_t amount of new RTIs to the manufacturer
β: The average fill rate for satisfying full RTIs demand of DCs in the planning horizon

Parameters

$c_{holding}$: The cost of holding an RTI in the pool
c_{new}: The unit cost of purchasing new RTIs
c_{repair}: The unit cost of repair
$c_{transportation}$: The unit transportation cost of a shipment
D_{it}: The amount of full RTI demand of DC i in period t
FTL_e: The full truck load (capacity of a truck) for empty RTIs
I_{m0}^{f}: On hand full RTI stock at the manufacturer at the beginning of planning horizon
I_{m0}^{e}: On hand empty and clean RTI stock at the manufacturer at the beginning of planning horizon
ln: The lead time for new RTI orders
N: The number of periods in the planning horizon
p_r: The probability that an RTI needs repair in the preparing for reuse operation
p_d: The probability that an RTI is disposed due to a non-repairable damage in the preparing for reuse operation
PS^0: The initial pool size
R_{imt}: The amount of empty RTI returns from DC i to the manufacturer in period t with regular shipments
U_t: The number of RTIs prepared for reuse in period t
β_{target}: The prescribed fill rate for satisfying full RTIs demand of DCs

$Minimize$ expected $total\ cost$:

$$z = \sum_t (c_{new}\, Q_t + c_{transportation}\, \delta(Q_t)) + \sum_i \sum_t c_{repair}\, p_r R_{imt} + c_{holding} [\, \sum_t (N - t - ln) Q_t + N(PS^0)] \quad (6.1)$$

$Subject\ to$:

$$I_{m,t-1}^{e} + Q_{t-ln} + U_t - F_t = I_{mt}^{e} \qquad for\ t = 1,2,\dots,N \quad (6.2)$$

$$I^f_{m,t-1} + F_t - \sum_i D_{it} = I^f_{mt} - \sum_i B_{it} \qquad for\ t = 1,2,\dots,N \qquad (6.3)$$
$$U_t = (1 - p_d)\sum_i R_{imt} \qquad for\ t = 0,1,2,\dots,N \qquad (6.4)$$
$$FTL_e\delta(Q_t) \le Q_t \qquad for\ t = 0,1,2,\dots,N \qquad (6.5)$$

$$\beta = 1 - \frac{\sum_i \sum_t B_{it}}{\sum_i \sum_t D_{it}} \qquad (6.6)$$
$$\beta \ge \beta_{target} \qquad (6.7)$$

$$B_{it},\ F_t,\ I^e_{mt},\ I^f_{mt}, Q_t, \beta, \delta(Q_t) \ge 0 \qquad for\ t = 0,1,2,\dots,N \qquad (6.8)$$
$$\delta(Q_t) \text{ is integer} \qquad for\ t = 0,1,2,\dots,N \qquad (6.9)$$

The objective function is minimizing total expected cost of RTI pool management. It includes the terms of the purchasing cost of new RTIs, the cost of repair, and the cost of capital spent on the RTI pool, respectively. The equations 6.2 and 6.3 are inventory balance equations for the empty and clean RTI stock and the full RTI stock at the manufacturer, respectively. Equation 6.4 indicates that the number of RTIs prepared for reuse in period t is equal to total amount of empty RTI returns from DCs after the non-reparably damaged ones are disposed. Equation 6.4 ensures the truck capacity constraint for shipping the purchased RTIs to the manufacturer. Equation 6.6 calculates the fill rate and Equation 6.7 ensures that the calculated fill rate is greater than or equal to target fill rate.

This optimization model is an example of non-linear programming (NLP). This is obvious when D_{it}'s derived from Equation 6.3 and this derived formula is written in place of D_{it}'s in Equation 6.6. Besides, it is stochastic since it involves stochastic parameters such as D_{it}, p_d, p_d, and R_{imt}. As a result, the objective function can only give expected total cost. This optimization model can be solved by a mixed integer linear programming solver by

- Taking average or forecasted values for the stochastic parameters, and
- Equating all B_{it}'s to zero, which makes fill rate equals to 100%.

In brief, it may be possible to estimate the total cost of RTI pool management. However, this was not enough for our purposes for the following reasons and it was required to find a better way to deal with our problem:

1. There are many other performance measures to look at for RTI pool management as mentioned in section 6.4. Total cost is just one of them.
2. Solving the optimization model with average values is expected to result in missing the effect of variability of parameters on optimal solution. For example, the time that an RTI spends in the field may have high variability and decreasing this variability may have significant impact on performance measures.
3. Finding the total cost given the initial pool size is not enough to find the optimal way of RTI pool management, because pool size is considered as a decision variable. The

optimization model should be solved with the possible levels of pool size in order to find the optimal value. This may necessitate complete enumeration which is not a preferred method since it may require enormous computational effort.

The CLSC to be modeled is a complex and dynamic system for Lesyna (1999). Rather than only dealing with a single decision like the amount of new RTI orders, considering the whole CLSC within the scope of this study introduces complexity. The complexity arises because there are various rules and logic that must be followed for example for giving the decision of emergency shipments. Such rules can be easily modeled with a discrete event simulation (DES) model, although it is impractical to implement them in an LP (Lesyna, 1999). On the other hand, the CLSC has various dynamic features since stock levels are fluctuating and RTIs cycle constantly. For such dynamic systems, working with the average values are of little value and likely to be misleading (Lesyna, 1999). We were also interested in the minimum and maximum levels as well as the reduction in variances of some parameters.

In conclusion, it was found more suitable to construct a DES model and then try to solve the optimization problem with the help of DES. Two simulation models (one for the situations in which emergency shipment is not allowed and one for the opposite situations) were constructed with the help of Arena. Next, the constructed simulation models were embedded into OptQuest which is Arena's simulation optimization solver engine. The details of the simulation models can be found in Chapter 7. They ensure the constraints other than the ones for target service level. OptQuest ensures the target service level and searches for optimal solution in terms of total cost by changing the initial pool size. The details of the simulation optimization model can be found in Chapter 8. The decision rules related with the determination of timing and quantity of RTIs entering to the filling operation and new RTI purchases were inserted into the simulation models. The timing and quantity of RTIs entering to the filling operation should be determined according to order up to level of full RTI stock and once a week according to our problem definition. This order up to level was found in a straightforward way in Chapter 7. On the other hand, the decision of the timing and quantity of new RTI purchases was not straightforward. In the next section, we discussed this decision. We have concluded that the timing and quantity of new RTI purchases should be determined according to (s, Q) inventory policy. We added this conclusion to our problem definition.

6.6. New RTIs Purchasing Decision

Our approach was to determine the quantities of new RTI orders by netting the demand against the returns of empty RTIs. This approach was referred to as reducing the problem to a traditional setting in practice by Fleischmann et al. (1997). Kelle and Silver (1989) have a fundamental study about optimal purchasing policy of new RTIs. In this study, they considered a purchasing

policy in which only the net demand (the number of RTIs to be filled minus the returns) was considered.
Minner and Lindner (1997) studied lot sizing decisions for reverse logistics processes where demand can be satisfied with two supply sources, namely manufacturing or remanufacturing. They discussed that a netting approach can be used when one of the setup costs associated with manufacturing or remanufacturing is negligible and processing rates of both of the supply sources are infinite. In our problem, we have also two supply sources, namely the returns and the new purchases. According to the logic of Minner and Lindner (1997), our problem reduces to the determination of the order quantities of new RTIs with a net demand rate considering fixed cost of new RTI purchases. In this reduced problem, the returns should be prepared for reuse as they received. Actually, this is just the case in our problem.

Van der Laan et al. (2004) described this approach as "naive netting" and they argued that the returns process was not taken into account explicitly with this approach. However, they indicated that when there is high correlation between returns and demand, this approach works and gives fair results. In our case, a full RTI sent to satisfy demand is always returned to the manufacturer after being emptied if it is not lost in the field. As a result, the returns are a function of the demands.

Kelle and Silver (1989) formulated the optimal purchasing problem as a stochastic problem by considering the demand and the returns as random and with a chance constraint of prescribed high service level. They proved that "this stochastic problem of optimal purchasing of RTIs is equivalent to the usual dynamic lot-sizing problem having an optimal solution.

Empty RTI stock at the manufacturer should be checked based on periodic review. Since the demand of empty containers only happens once in a week (on the day of filling operation), it is pointless to consider continuous review for this stock level. Besides, a rolling schedule should be applied because of the reason that both the demand and the returns are stochastic, which results in the forecasts different than the actual.

Since we were looking for the best possible way of RTI management, we needed to use a lot-sizing algorithm that guarantees to produce fair results. For this, Kelle and Silver (1989) advises us to use Wagner- Whitin algorithm. However, Blackburn and Millen (1980) have shown that Silver Meal heuristic may perform better than Wagner-Whitin algorithm in terms of cost performance in a rolling schedule environment. On the other hand, Vargas (2008) discussed that an order-point, order-up-to or (s,S) inventory policy provides optimal solution for the cases when one is only interested in the decision for the first period in the planning horizon. Besides, he also indicated that such a policy is more suitable for inventory stocking.

The purchasing decision in our specified problem situation has the following properties:

- Non-zero and constant transportation cost per shipment
- Capacity limit of shipments (***FTL of Empty RTIs***)
- Non-zero and constant inventory holding cost (the cost of capital tied to the RTI pool)
- Non-zero and constant price of new RTIs
- Non-zero and constant lead time for new RTI orders
- Stochastic returns of empty RTIs and full RTI demand
- Stationary full RTI demand

Since we have stationary full RTI demand with a given ***Probability of Loss***, it appeared that the forecasted net demand for future periods appears to be the same. Considering the properties of our purchasing decision and the above discussions, we have found that it is best to order new RTIs when the on hand empty RTI stock level drops below ***Reorder Point for Purchasing*** with a fixed ***Purchasing Lot Size*** which is found with the help of economic order quantity (EOQ) model.

Reorder Point for Purchasing is calculated according to the following set of formulas given by Kelle and Silver (1989a):

$$E(R_L) = P \times E(D_L) \tag{6.10}$$
$$V(R_L) = [P^2 \times V(D_L)] + [P \times (1-P) \times E(D_L)] \tag{6.11}$$
$$E(ND_L) = E(D_L) - E(R_L) = (1-P) \times E(D_L) \tag{6.12}$$
$$V(ND_L) = [(1-P)^2 \times V(D_L)] + [P \times (1-P) \times E(D_L)] \tag{6.13}$$
$$P = 1 - p_{loss} \tag{6.14}$$
$$p_{loss} = p_{field\ loss} + p_{disposal} \times \left(1 - p_{field\ loss}\right) \tag{6.15}$$
$$\boldsymbol{Reorder\ Point\ for\ Purchasing} = E(ND_L) + \left(k_p \times \sqrt{V(ND_L)}\right) \tag{6.16}$$

where

- $E(D_L)$ is the expected lead time full RTI demand.
- $E(R_L)$ is the expected lead time RTI reuses.
- $V(D_L)$ is the variance of lead time full RTI demand.
- $V(R_L)$ is the variance of lead time reuses.
- $E(ND_L)$ is the expected lead time net full RTI demand.
- $V(ND_L)$ is the variance of lead time net full RTI demand.
- P is the probability that an RTI sent to the field can be reused again.
- p_{loss} is the probability that an RTI is lost because of never being returned, and disposed due to a non-repairable damage.
- k_p is the safety factor for purchasing.

Purchasing Lot Size should be found with the help of EOQ model. However, the classic EOQ formula should be modified since there is a capacity limit of shipments and unit transportation per shipment. Below, the notation and the formulas explaining how to find ***Purchasing Lot Size*** is given.

Notation:

$c_{holding}$: The inventory holding cost per empty RTI per year

c_{new}: The unit price of new RTIs

$c_{transportation}$: The unit transportation cost of a shipment

FTL_e: Full truck load (the capacity of trucks) for empty RTIs

n: The number of transportations needed to ship Q amount of new RTIs

ND: The annual net demand rate

Q: The number of new RTIs to be purchased in a single order

$Y(Q)$: The function giving the unit cost of RTI purchasing when an amount of Q RTIs are ordered

$\delta(Q_t)$: The function giving the number of transportations needed to ship Q amount of new RTIs

Formulas:

$$Unit\ inventory\ holding\ cost = \frac{c_{holding} \times Q}{2(ND)} \tag{6.17}$$

$$Unit\ transportation\ cost = \frac{\delta(Q) \times c_{transportation}}{Q} \quad \text{where} \quad \delta(Q) = \left\lceil Q/_{FTL_e} \right\rceil \tag{6.18}$$

$$Y(Q) = \frac{c_{holding} \times Q}{2(ND)} + \frac{\delta(Q) \times c_{transportation}}{Q} + c_{new} \tag{6.19}$$

where

$$\delta(Q_t) = \begin{cases} n, & \text{for } (n-1)FTL_e < Q \leq (n)FTL_e \text{ and } n = 1, 2, 3, \ldots \\ 0, & \text{for } Q = 0 \end{cases} \tag{6.20}$$

As a result, for $Q > 0$:

$$Y_n(Q) = \frac{c_{holding} \times Q}{2(ND)} + \frac{n \times c_{transportation}}{Q} + c_{new} \text{ for } \quad (n-1)FTL_e < Q \leq (n)FTL_e \tag{6.21}$$

$$\frac{dY_n(Q)}{dQ} = \frac{c_{holding}}{2(ND)} - \frac{n \times c_{transportation}}{Q^2} \tag{6.22}$$

$$\frac{d^2Y_n(Q)}{dQ^2} = \frac{n \times c_{transportation}}{Q^3} \tag{6.23}$$

$\frac{d^2 Y_n(Q)}{dQ^2} > 0$ for $Q > 0$

As a result, it is possible to find the Q value which gives minimum $Y_n(Q)$ for each n. Let's denote the Q value giving the minimum $dY_n(Q)$ in interval $(n-1)FTL_e < Q \leq (n)FTL_e$ with Q^{n*}.

Q^{n*}can be found as follows:

$$\frac{dY_n(Q)}{dQ} = 0 \qquad (6.24)$$

$$\frac{c_{holding}}{2(ND)} - \frac{n \times c_{transportation}}{Q^2} = 0 \qquad (6.25)$$

Lets denote the Q value giving $dY_n(Q) = 0$ with $Q^{n'}$.

$$Q^{n'} = \sqrt{\frac{2 \times n \times c_{transportation} \times ND}{c_{holding}}} \qquad (6.26)$$

$$Q^{n*} = \begin{cases} Q^{n'}, & \text{if } (n-1)FTL_e < Q^{n'} \leq (n)FTL_e \\ (n-1)FTL_e + 1, & \text{if } Q^{n'} \leq (n-1)FTL_e \\ Q^{n'} > (n)FTL_e, & \text{if } Q^{n*} = (n)FTL_e \end{cases} \qquad (6.27)$$

In conclusion, Q^* is the ***Purchasing Lot Size*** that we aimed to find out. Let's denote the Q value giving the minimum $dY(Q)$ with Q^*. Then, Q^* is the Q value giving the minimum $Y_n(Q)$ value among the set of Q^{n*}s.

7. SIMULATION STUDY

This chapter starts with the detailed explanation of the simulation models which were utilized in simulation optimization. Simulation models have various parameters; therefore it was required to do a comprehensive input analysis to find out the values of the parameters. In section 7.2, the results of this analysis for the set of parameters which are not influenced by the use of RFID technology were presented. In section 7.3, the run parameters of the simulation models were investigated. The details on the verification and validation of the simulation models were given in section 7.4 and 7.5, respectively.

7.1. Simulation Modeling

Arena is utilized for the simulation modeling. It is the simulation package built on SIMAN which is a general purpose simulation language. Our simulation model is

- Stochastic, i.e. it has inputs and outputs which are random variables;
- Dynamic, i.e. there is a time dimension and the system state changes over time;
- Discrete, i.e. the system state changes at discrete points in time.

The time unit in our simulation study is day. A month and a year are assumed to have 30 and 360 days, respectively. The CLSC is modeled according to the specifications given in section 6.3. Two varieties of the simulation model are developed for the same CLSC. In the 1st one, emergency shipment is not an option. In the 2nd one, it is an option exactly like in our case study. With the help of these varieties, the impact of the emergency shipment option on CLSC performance can be investigated and managerial insights can be drawn.

The elements of the simulation study are given in subsection 7.1.1. Additionally, the simulation model is explained with several flow charts in subsection 7.1.2. The notation used in the simulation study is written in bold and italic letters.

7.1.1. The Elements of the Simulation Study

Main elements of the simulation study are entities, events, input parameters, variables, and performance measures. Entities, input parameters and variables are given in subsection 7.1.1.1, 7.1.1.2 and 7.1.1.3, respectively. Events are not listed explicitly, because they can be understood from subsection 7.1.3. The performance measures have already been given in section 6.4.

7.1.1.1. The Entities

Entities are objects of interest or components of the system which flow through the system throughout a simulation run. There are 4 types of entities in the simulation model. These are ***RTIs***, ***Demand***, ***Periodic Review*** and ***Report***. They are listed in the next paragraph with their attributes, if they have any. Attributes represent the characteristics of entities and they move with entities. An entity can have more attributes than the ones written here. However, only a subset of possible attributes for an entity which served to the purpose of finding out the required performance measures was used in the simulation model.

1. ***RTIs*** represent the RTIs flow through the CLSC. Their attributes are as follows:
   - ***Assigned DC*** represents the DC to which RTI is lastly sent.
   - ***Cleanness*** indicates whether RTI is ***Clean*** or ***Dirty***.
   - ***Condition*** indicates whether RTI has no damage (***Undamaged***), a repairable damage (***Reparably Damaged***) or a non-repairable damage (***Non-Reparably Damaged***).
   - ***Cycle Time Attribute*** records the duration that an RTI completes a whole cycle, i.e. the duration between two consecutive times that an RTI enters the empty and clean RTI stock at the manufacturer.
   - ***Emptying Duration*** indicates the duration between the time that an RTI arrives at its ***Assigned DC*** and it comes back to the same DC from one of the end users.
   - ***Fullness*** indicates whether RTI is ***Empty*** or ***Full***.
   - ***Number of Rotations*** records how many times an RTI has completed a whole cycle so far.
   - ***Time to Enter CLSC*** records the entrance time of RTI to the CLSC in order to keep statistics of useful lifetime of RTIs. It is the value of the simulation clock when the related entity is created.
   - ***Time to Enter Empty RTI Stock*** records the last entrance time of RTI to the empty and clean RTI stock. This is required to calculate ***Cycle Time Attribute***.
   - ***Time to Enter Field*** records the last entrance time of RTI to the field in order to keep statistics of ***Time Spent in the Field*** of RTIs.

2. ***Demand***, represent the demand arrivals. Its attributes are as follows:
   - ***Demand Interarrival Time*** indicates the time between two consecutive orders of a DC.
   - ***Demand Owner*** indicates the DC from which the full RTI demand arrives
   - ***Demand Size*** indicates the number of RTIs in the coming full RTI order.

3. ***Periodic Review*** represents the component of the system in which periodic decisions like the determination of filling lot size are given.

4. ***Report*** ensures the calculation of some performance measures just before a simulation replication ends. It also helps to keep the record of ***Pool Size*** just before the ***Warm up Period*** ends. This is required to calculate ***Total Cost of RTI Pool Management*** accurately, because the value of ***Pool Size*** just before the ***Warm up Period*** ends is the actual starting value of ***Pool Size***.

7.1.1.2. The Input Parameters

The input parameters are listed below.

- ***Annual RFID Fee*** is the fee annually paid to the supplier of RFID technology by the manufacturer for its service of RFID technology.
- ***Demand Interarrival Time Distribution*** is the distribution of ***Demand Interarrival Time*** of a DC.
- ***Demand Size Distribution*** is the distribution of ***Demand Size***, i.e. the quantity demanded in a single order by a DC.
- ***Emergency Shipment Threshold*** determines the minimum level of empty RTI shortage at the manufacturer that is worth to do an emergency shipment.
- ***Emptying Duration Distribution*** is the distribution of ***Emptying Duration***. It changes according to the DCs.
- ***FTL of Empty RTIs*** is the full truck load for empty RTIs, i.e. the maximum number of empty RTIs that can be loaded into a truck.
- ***FTL of Full RTIs*** is the full truck load for full RTIs.
- ***Initial Distribution of RTI Pool*** is the distribution of the RTI pool in the CLSC at the start of the simulation run.
- ***Initial Pool Size*** is the pool size at the start of the simulation run. This is entered into the simulation model as a parameter; however it is a decision variable that RTI pool manager should determine.
- ***Lead Time of Filling*** is the time that the filling operation takes.
- ***Lead Time of Preparing for Reuse*** is the time that the preparing for reuse operation takes.
- ***Lead Time of Transportation*** is the time that transportation of RTIs between the manufacturer and a DC takes.
- ***Minimum Emergency Shipment Lot Size*** determines the minimum returns stock level at a DC which is worth to do an emergency shipment.
- ***Minimum Emptying Duration*** is the assumed minimum ***Emptying Duration*** that can happen in real life.
- ***New RTIs Purchasing Lead Time*** is the duration between the time when the order of new RTIs is given and the time of order delivery to the manufacturer.
- ***Order up to Level of Full RTI Stock*** is the order up to level of full RTI stock which is required to determine ***Filling Lot Size***.
- ***Probability of Disposal*** is the probability that an RTI is disposed due to a non-repairable damage after it returns to the manufacturer.
- ***Probability of Field Loss*** is the probability that an RTI is lost in the field, i.e. that an RTI has never been returned from the field.
- ***Probability of Loss*** is the probability that an RTI is lost (due to a non-repairable damage or never being returned) once it is sent to the DCs.

- ***Probability of Reuse*** is the probability that an RTI can be reused again once it is sent to DCs. It can be calculated with the formula ***Probability of Reuse*** = 1−***Probability of Loss***.
- ***Probability of Repair*** is the probability that an RTI requires repair due to a repairable damage after it returns to the manufacturer.
- ***Purchasing Lot Size*** is the lot size of purchasing which is required to determine how large new RTI replenishments should be.
- ***Reorder Point for Purchasing*** is the reorder point of empty RTI inventory position required to determine the timing of new RTI replenishments.
- ***Review Period for Filling*** is the length of review period for checking full RTI stock and determining filling lot size accordingly.
- ***Review Period for Purchasing*** is the length of review period for checking the need of new RTIs to maintain or increase the pool size.
- ***RTI Condition Distribution*** is the distribution of the condition of RTIs (undamaged, having repairable or non-repairable damage) when they are returned to the manufacturer. This is the combination of ***The Probability of Disposal*** and ***The Probability of Repair***.
- ***Safety Factor for Empty RTI Stock*** is the safety factor determined for empty and clean RTI stock according to the service level target of satisfying the need of filling operation.
- ***Safety Factor for Full RTI Stock*** is the safety factor determined for full RTI stock according to the service level target of satisfying the demand coming from DCs.
- ***Time to Action*** is the time required for the implementation of RFID technology, the accumulation of RFID data and finally taking action to reduce problems in the CLSC.
- ***Time to Activate Filling Decision*** is the duration between the time when the filling lot size is determined and the time of operating filling line. It is an enough time to give emergency shipment decision (if it is an option), make the emergency shipment and prepare emergently shipped RTIs for reuse.
- ***Unit Repair Cost*** is the cost of repairing (including both spare part and labor cost) an RTI having a repairable damage.
- ***Unit RTI Holding Cost*** is the capital holding cost of an RTI for a year.
- ***Unit RTI Price*** is the price for purchasing a new RTI.
- ***Unit Transportation Cost*** is the transportation cost per shipment.

The simulation model includes the following demand parameters. Below, lead time refers to ***New RTIs Purchasing Lead Time***.

- ***Expected Daily Full RTI Demand***
- ***Expected Lead Time Full RTI Demand***
- ***Expected Weekly Full RTI Demand***
- ***Std. Dev. of Weekly Full RTI Demand***
- ***Variance of Lead Time Full RTI Demand***

In addition to these, the following net demand parameters required to calculate ***Reorder Point for Purchasing***:

- ***Expected Lead Time Net RTI Demand*** is the net RTI demand (the demand of the filling operation minus the amount of usable returns) in ***New RTIs Purchasing Lead Time***
- ***Variance of Lead Time Net RTI Demand*** is the net RTI demand (the demand of the filling operation minus the amount of usable returns) in ***New RTIs Purchasing Lead Time***

It should be also noted that the simulation model has run parameters, namely ***Replication Length***, ***Warm up Period*** and ***Number of Replications***. These were presented in section 7.3.

7.1.1.3. The Variables

The main variables of the simulation model are listed below. They are clarified in order to help the understanding of the flowcharts of the simulation model given in section 7.1.2. The calculations of some of them are explained in these flowcharts.

- ***Actual Starting Pool Size*** is the value of ***Pool Size*** recorded at the end of ***Warm up Period***.
- ***Cycle Time*** is the name of the variable tallies the time of cycles completed by RTIs when they enter to the empty and clean RTI stock at the manufacturer.
- ***Empty RTI Backorders*** is the number of RTIs that is failed to be sent to the filling operation in order to satisfy ***Filling Lot Size***.
- ***Empty RTI Inventory Position*** is the inventory position of empty and clean RTI stock of the manufacturer.
- ***Filling Lot Size*** is the filling lot size determined according to the on hand full RTI stock and ***Full RTI Backorders (All)*** and ***Order up to Level of Full RTI Stock***.
- ***Fill Rate for Empty RTIs*** is the proportion of the need of the filling operation directly satisfied from on hand empty and clean RTI stock.
- ***Fill Rate for Full RTIs*** is the proportion of full RTI demand directly satisfied from on hand full RTI stock.
- ***Full RTI Backorders (All)*** shows the number of backorders of all DCs. It is updated when a demand is backordered and when a backorder is satisfied.
- ***Full RTI Backorders (DC i)*** stands for the number of backorders of DC *i*. It is updated when a demand of DC *i* is backordered and when a backorder of DC *i* is satisfied.
- ***Lack of Empty RTIs*** stands for the difference between the empty and clean RTI need of the filling operation (***Filling Lot Size***) and ***RTIs on Hand***, exactly when the decision of ***Filling Lot Size*** is given. This is required for the simulation model with emergency shipment option.
- ***Lifetime*** is the name of the variable tallies the total useful lifetime of an RTI before it leaves the system.
- ***New RTI Replenishment Rate*** is the rate of new RTI purchases with respect to time.

- ***Number of Contacts with DCs*** is the number of times that the manufacturer contact with DCs in order to obtainer required information for emergency shipment decision.
- ***Number of Emergency Shipments*** counts the number of emergency shipments made.
- ***Number of Empty RTI Stockouts*** is the number of empty RTI stockout situations. Such stockout situations happen when on hand empty and clean RTI stock is less than the determined filling lot size just before the starting operation of filling line.
- ***Number of Full RTI Stockouts*** is the number of full RTI stockout situations. Such stockout situations happen when on hand full RTI stock is not enough to completely satisfy the order quantity of the demand arrival.
- ***Number of New RTI Shipments*** is the accumulated value of ***Required Number of Shipments***.
- ***Number of Periods*** is the number of periods passed during ***Warm up Period*** and ***Replication Length***.
- ***Number of RTI Disposals*** counts the number of RTIs disposed due to a non-repairable damage.
- ***Number of RTI Field Losses*** counts the number of RTIs lost in the field, i.e. RTIs that have never been returned from the field.
- ***Number of RTI Repairs*** counts the number of repaired RTIs.
- ***Number of RTI Returns*** counts the number of RTIs returned from DCs.
- ***Pool Size*** is the size of the RTI pool.
- ***Quantity to Fill*** is the number of RTIs entering into the filling operation.
- ***Quantity to Purchase*** is the order quantity of new RTI purchases.
- ***Quantity to Send*** is the number of RTIs send to the demanding DC after a demand arrival.
- ***Required Number of Shipments*** is the number of shipments enough to transport ***Quantity to Purchase*** amount of new RTIs
- ***RFID Data Entries*** counts the number of shipment entries that are recorded.
- ***RTIs on Hand*** stands for the number of RTIs that can be ready to enter filling operation just before the operation of filling line starts.
- ***Time Spent in the Field*** is used to keep statistics of the time that RTIs spent in the field.
- ***Total Demand*** is total amount of full RTIs demanded by all DCs since the start of the simulation run.
- ***Total Number of Purchased New RTIs*** counts the number of purchased RTIs excluding the initial RTI pool.
- ***Trippage*** is the name of the variable tallies total number of cycles completed by an RTI in its lifetime before it leaves the system.
- ***TNOW*** shows the value of simulation clock. It is an interval variable kept by Arena.

The simulation model also find outs the following cost values:

- ***Total Cost of RFID Technology***
- ***Total Emergency Shipment Cost***
- ***Total Purchasing Cost***
- ***Total Repair Cost***
- ***Total RTI Pool Holding Cost***
- ***Total RTI Pool Management Cost***

There are two options to initialize the value of a variable, namely initializing with system (at the start of the simulation run) and with statistics (at the end of ***Warm up Period***). The variables related with recording statistics like ***Trippage***, ***Fill Rate for Full RTIs***, etc. and the variables that need to account for only the time after ***Warm up Period*** like ***Number of New RTI Shipments***, ***Total Number of Purchased RTIs***, etc. were initialized with statistics. On the other hand, the variables which are the elements of the system state like ***Empty RTI Backorders***, ***Filling Lot Size***, etc. were initialized with system.

7.1.2. The Detailed Explanation of Simulation Model

The main structure of the simulation model is shown in Figure 7.1. A simulation run starts with the creation of the initial pool and the distribution of this initial pool to the main stock points. Among this stock points returns stock at the manufacturer is not included since RTIs arriving at the manufacturer directly enter preparing for reuse operation without waiting.

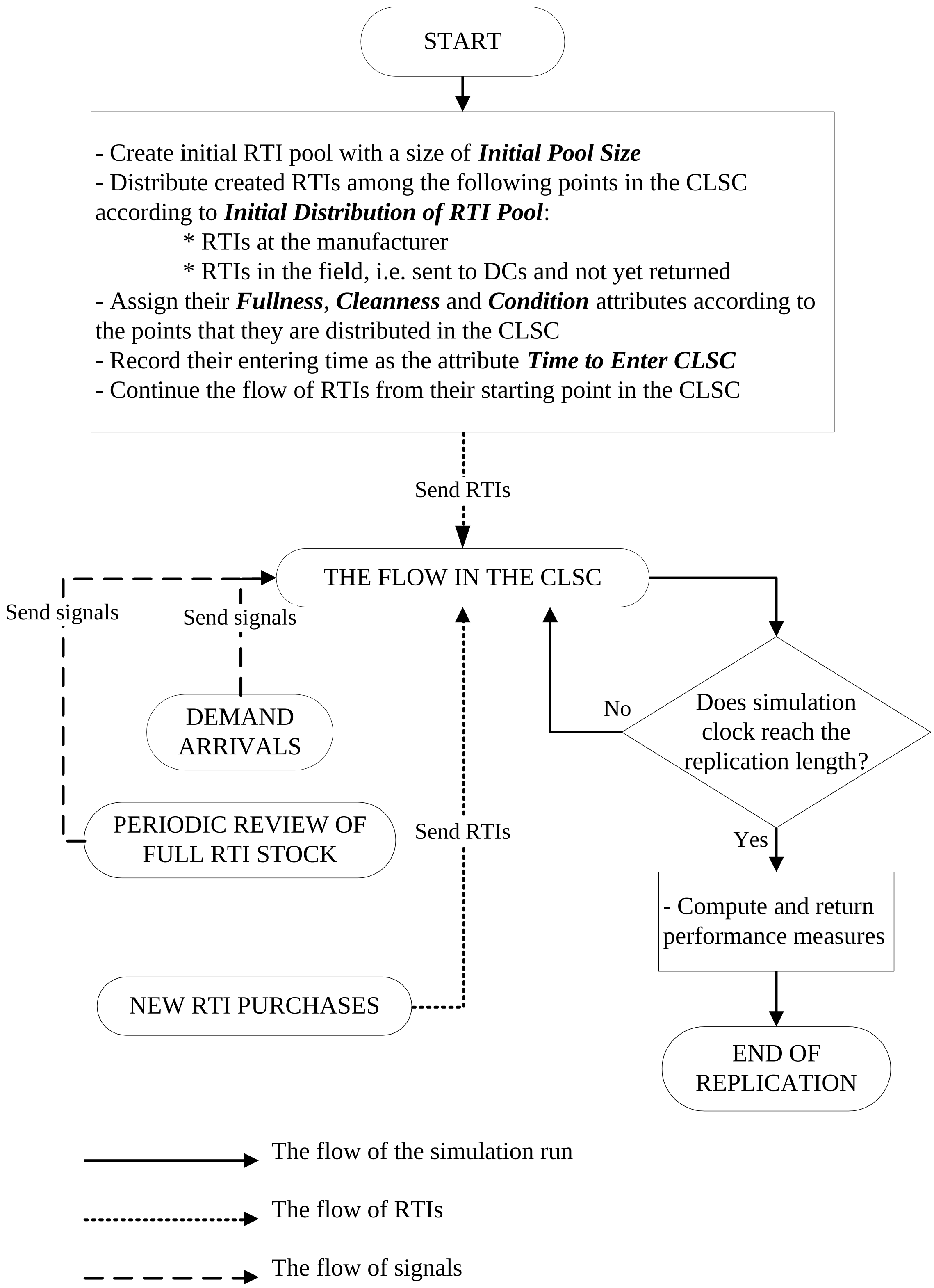

Figure 7.1. The main structure of the simulation model

After the initialization of RTI pool, created RTIs continue their flows through the CLSC starting with the points that they are initially distributed. They enter to the filling operation with a batch size of ***Quantity to Fill*** after they receive a signal indicating that the operation starts in the filling line. Similarly, they also wait for a signal to be sent to DCs. This signal indicates demand arrivals. As simulation clock advances, the decisions of new RTI purchases are given. Accordingly, newly purchased RTIs are created and entered to CLSC after they are delayed by ***New RTIs Purchasing Lead Time.***

A simulation replication reaches its end when the simulation clock reaches ***Replication Length***. A simulation run reaches its end when it completes a desired number of replications. When the simulation run ends, Arena returns summary statistics based on collected records and calculates desired performance measures. The output includes the summary statistics of the following performance measures:

- Average cycle time (with the help of ***Cycle Time Attribute*** and ***Cycle Time***)
- Average trippage (with the help of ***Number of Rotations*** and ***Trippage***)
- Average useful lifetime of RTIs (with the help of ***Time to Enter CLSC*** and ***Lifetime***)
- Pool size (with the help of ***Pool Size***)
- Type 2 (β) service level (fill rate) for satisfying the empty RTI need of filling operation (with the help of ***Fill Rate for Empty RTIs***)
- Type 2 (β) service level (fill rate) for satisfying the full RTI demand directly from on hand full RTI stock (with the help of ***Fill Rate for Full RTIs***)
- Average time that RTIs spend in the field (with the help of ***Time Spent in the Field***)

In addition, Arena calculates and returns the following performance measures at the end of simulation run:

- ***Total Cost of RTI Pool Management***
- The rate of new RTI replenishment with respect to time

  New RTI Replenishment Rate (7.1)

  = ***Total Number of Purchased RTIs***/ (***Replication Length−Warm up Period***)

At the end of simulation replication ***Total Cost of RTI Pool Management*** is calculated with the following cost formulas:

Total Cost of RTI Pool Management (7.2)

= ***Total Cost of RFID Technology + Total Emergency Shipment Cost***

+ Total Purchasing Cost + Total Repair Cost + Total RTI Pool Holding Cost

Total Cost of RFID Technology (7.3)

= ***Annual RFID Fee***

× ((***Replication Length−Warm up Period***)/360 + 12 × ***Time to Action***)

Total Emergency Shipment Cost (7.4)

= ***Unit Transportation Cost*** × ***Number of Emergency Shipments***

Total Purchasing Cost (7.5)

= Unit RTI Price × (***Actual Starting Pool Size*** + ***Total Number of Purchased New RTIs***) + ***Unit Transportation Cost*** × (Required number of shipments to transport ***Actual Starting Pool Size*** + ***Number of New RTI Shipments***)

Total Repair Cost = Unit Repair Cost × ***Number of Repairs*** (7.6)

Total RTI Pool Holding Cost (7.7)

= Total RTI Pool Holding Cost (accumulated until ***Replication Length***)
+ Unit RTI Holding Cost × (***Actual Starting Pool Size*** ×
((***Replication Length***− ***Warm up Period***)/360))

During the simulation replication, ***Total RTI Pool Holding Cost*** is updated in each purchasing period as follows:

Total RTI Pool Holding Cost (7.8)

= Total RTI Pool Holding Cost (its value at ***TNOW***) **+**
Unit RTI Holding Cost × (***Purchasing Lot Size***× ((***Replication Length***− ***TNOW*** − ***New RTIs Purchasing Lead Time***)/360))

The part of the simulation model involving the circulation of RTIs in the CLSC (***THE FLOW IN THE CLSC***) is shown in Figure 7.2 and 7.3. The flow of RTIs is described starting with the empty and clean RTI stock at the manufacturer. The variable ***Quantity to Fill*** is determined in ***PERIODIC REVIEW OF FULL RTI STOCK*** and communicated via signals to ***THE FLOW IN THE CLSC***. Similarly, the variable ***Quantity to Send*** is determined in ***DEMAND ARRIVALS*** and communicated via signals to ***THE FLOW IN THE CLSC***.

THE FLOW IN THE CLSC calls two modules during the simulation run. The 1st one is ***SATISFY BACKORDERS***. The flowchart of this module is shown in Figure 7.4. The aim of this module is to send full RTIs firstly to satisfy backorders (without entering to the full RTI stock) once they leave the filling operation, when there is any outstanding backorder. When the number of outstanding backorders (***Full RTI Backorders (All)***) or the amount of full RTIs to satisfy the outstanding backorders reaches zero, ***SATISFY BACKORDERS*** returns to ***THE FLOW IN THE CLSC*** to start sending the full RTIs to DCs to satisfy backorders. The 2nd module is ***RTI SHRINKAGE***. The flowchart of this module is shown in Figure 7.5. This module serves the purposes of firstly keeping the statistics of RTIs which become shrinkage. Secondly, it disposes these RTIs from the simulation model in order to remove them from the CLSC.

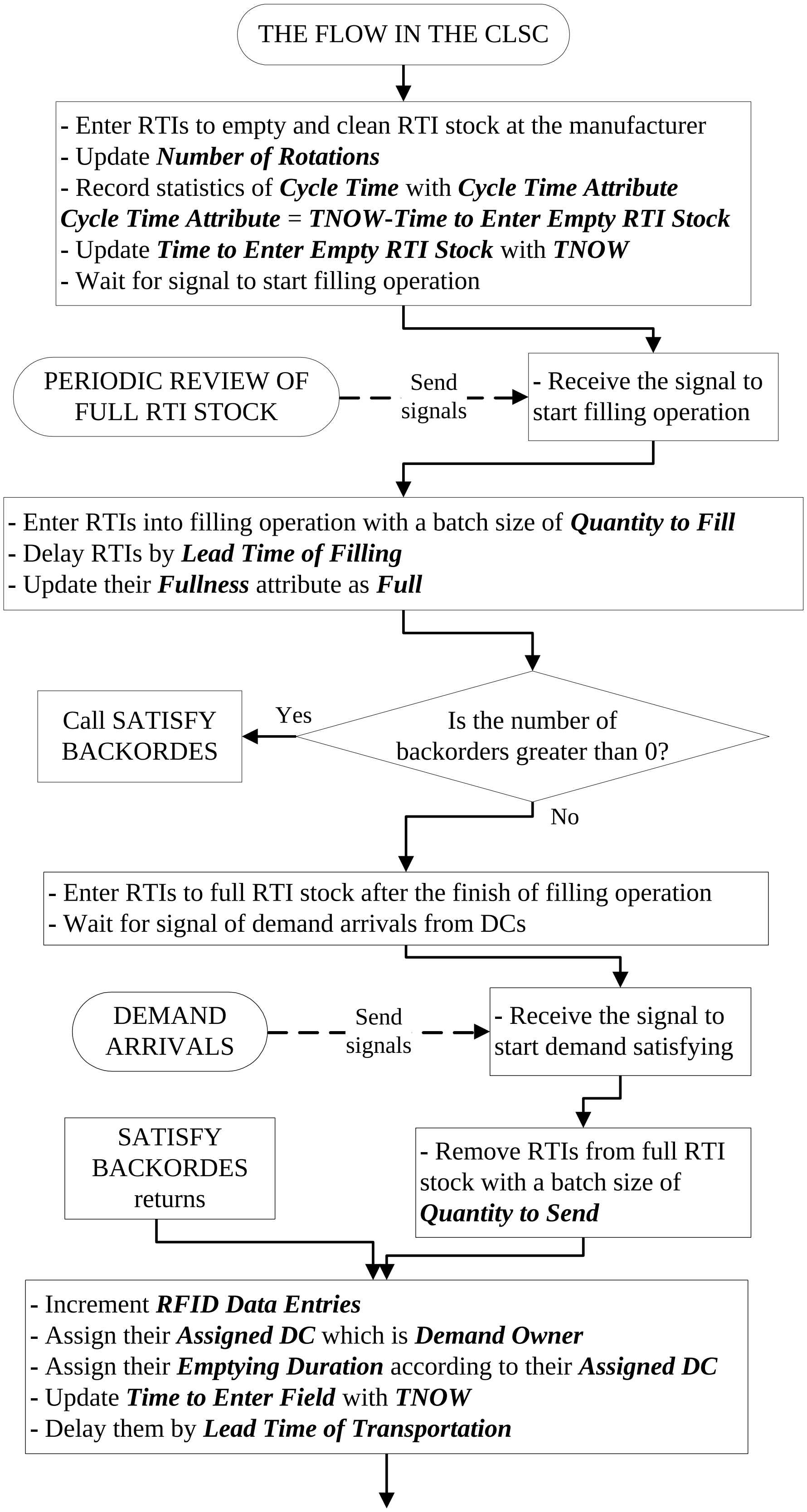

Figure 7.2: The flow in the CLSC – part 1

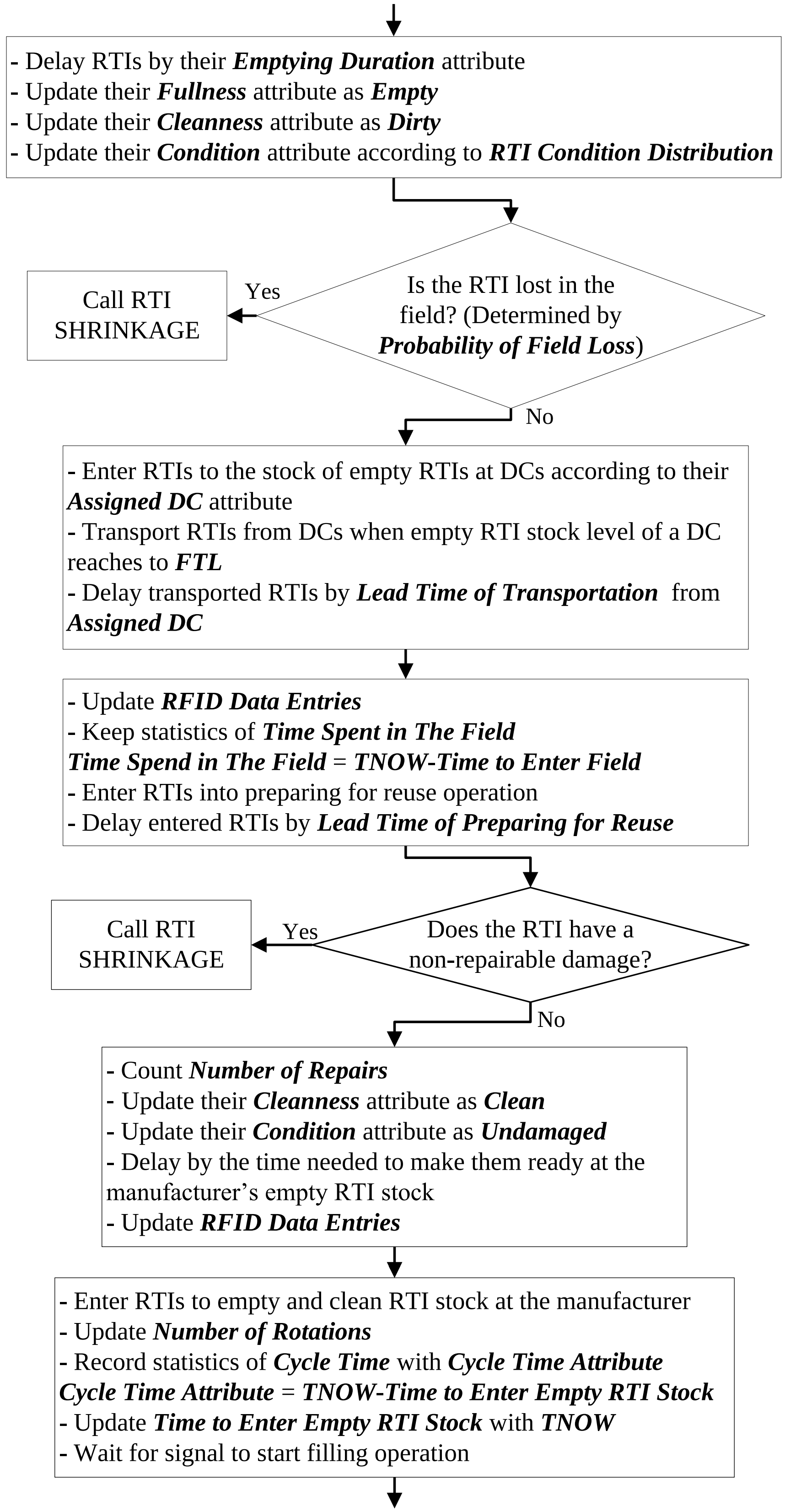

Figure 7.3: The flow in the CLSC – part 2

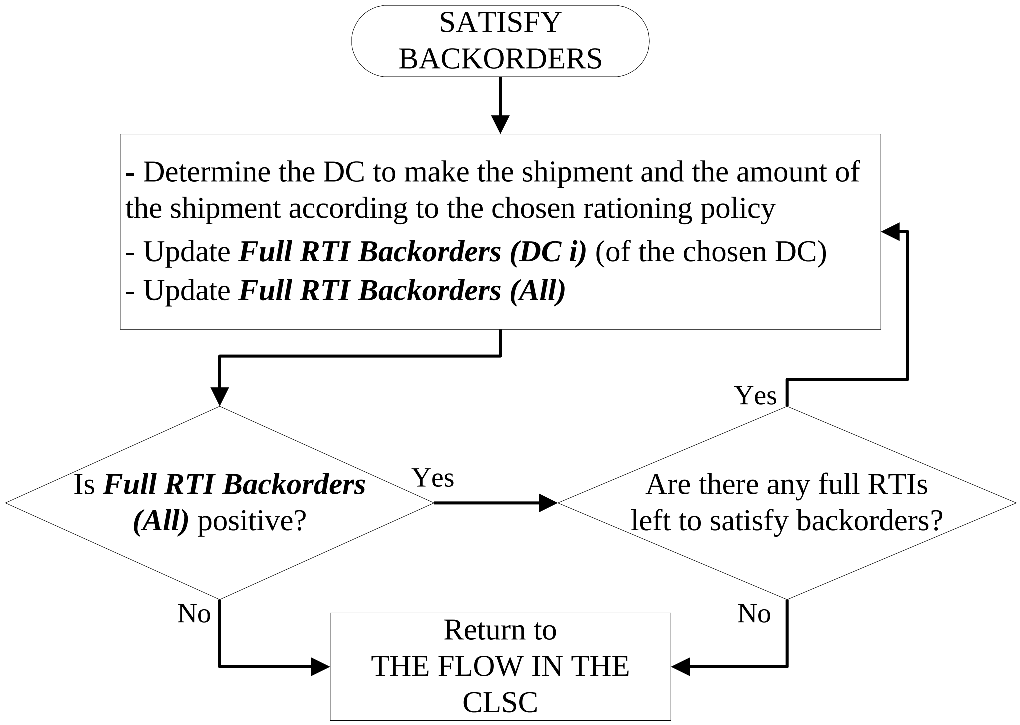

Figure 7.4: ***SATISFY BACKORDERS*** module of the simulation model

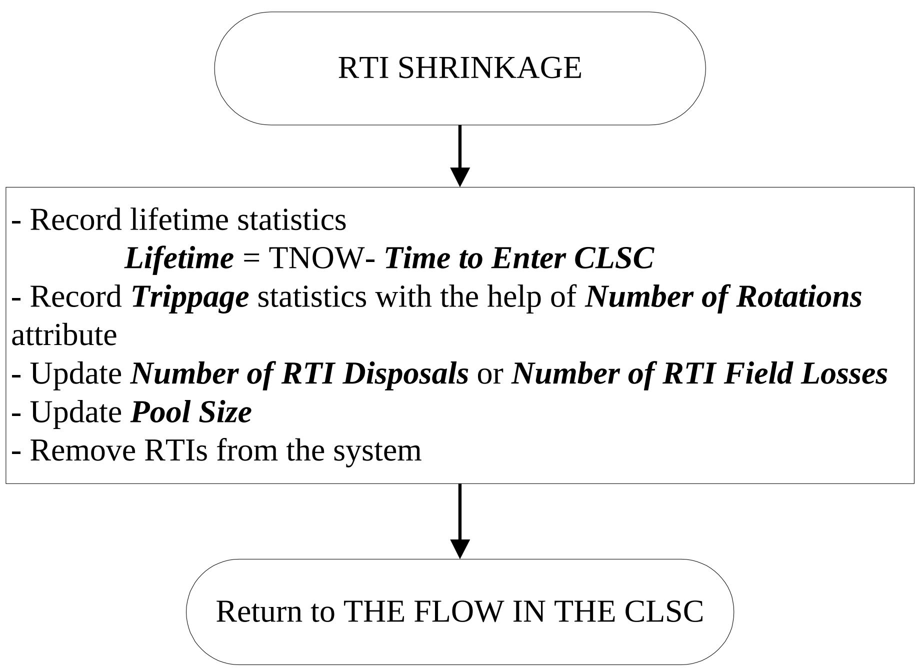

Figure 7.5: ***RTI SHRINKAGE*** module of the simulation model

DEMAND ARRIVAL part of the simulation model is demonstrated in Figure 7.6. This part determines ***Quantity to Send***. When there are enough full RTIs on hand to satisfy all of the incoming demand, ***Quantity to Send*** equals to ***Demand Size*** of the incoming demand. Otherwise, ***Quantity to Send*** equals to the level of full RTI stock because this is the maximum number of RTIs that can be sent to the demanding DC.

PERIODIC REVIEW OF FULL RTI STOCK part of the simulation model is demonstrated in Figure 7.7-7.9. These figures are drawn for the cases when the emergency shipment is not useful (Figure 7.7) and when it is useful (Figures 7.8-7.9) respectively. ***Order up to Level of Full RTI Stock*** and ***Filling Lot Size*** are calculated as follows:

For both of the models:

Order up to Level of Full RTI Stock = ***Expected Weekly Full RTI Demand*** +
(***Safety Factor for Full RTI Stock*** × ***Std. Dev. of Weekly Full RTI Demand***) (7.9)

For the model of the case when the emergency shipment is not useful:
Filling Lot Size = Maximum {0, ***Order up to Level of Full RTI Stock***
– On hand full RTI stock level **+*Full RTI Backorders (All)***} (7.10)

For the model of the case when the emergency shipment is an option:

Filling Lot Size = Maximum {0, ***Order up to Level of Full RTI Stock***
– On hand full RTI stock level **+*Full RTI Backorders (All)***
+ (***Time to Activate Filling Decision***× ***Expected Daily Full RTI Demand***)} (7.11)

For the case when emergency shipment is an option, ***RTIs on Hand*** is calculated as follows:

RTIs on Hand **=** On hand empty and clean RTI stock level
+ (The number of RTIs in preparing for reuse operation × (1 **–*Probability of Disposal***))
+ The number of RTIs coming from preparing for reuse operation
+ The number of RTIs on order expected to arrive at the manufacturer before the filling operation starts (7.12)

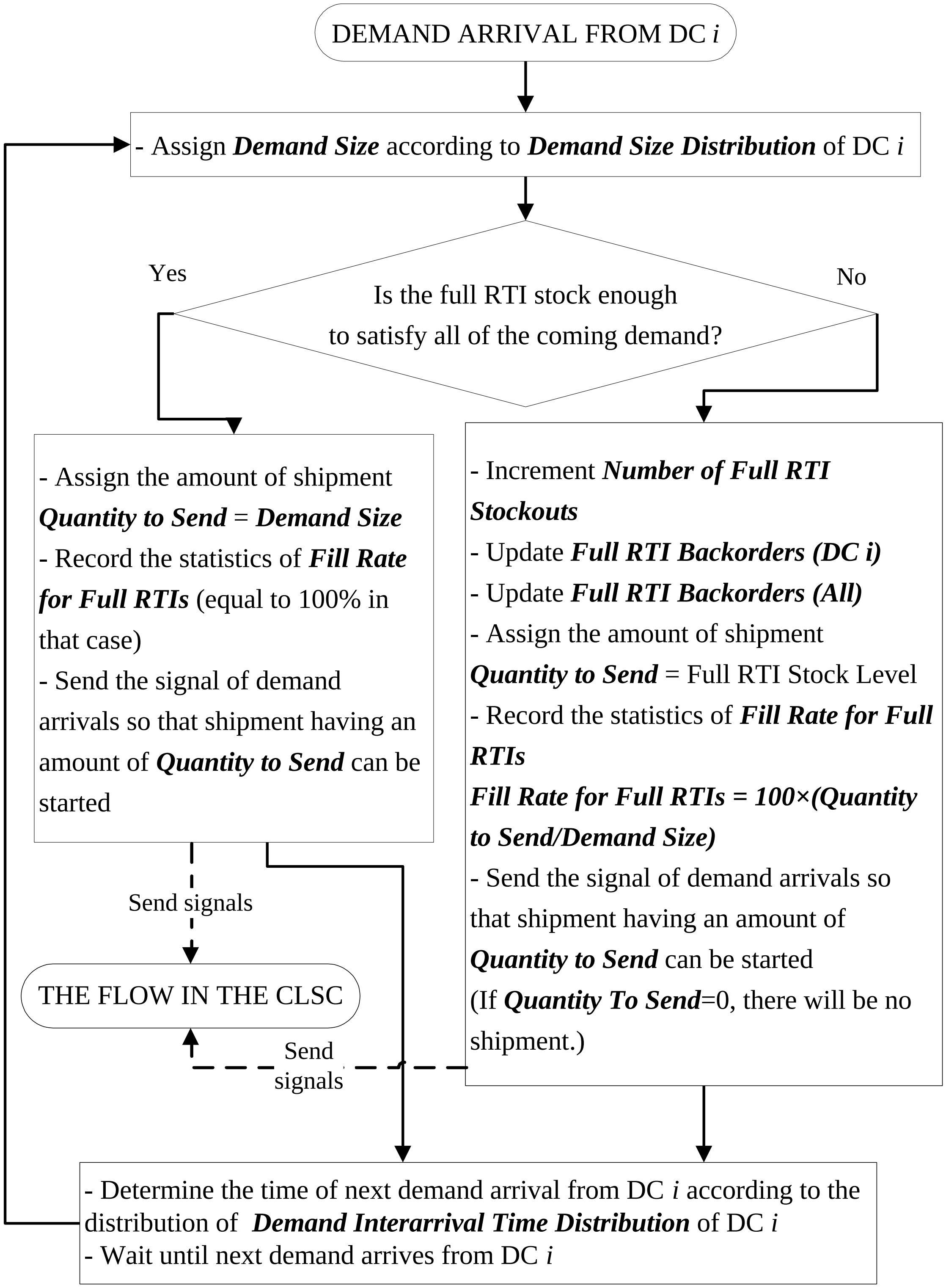

Figure 7.6: ***DEMAND ARRIVALS*** part of the simulation model

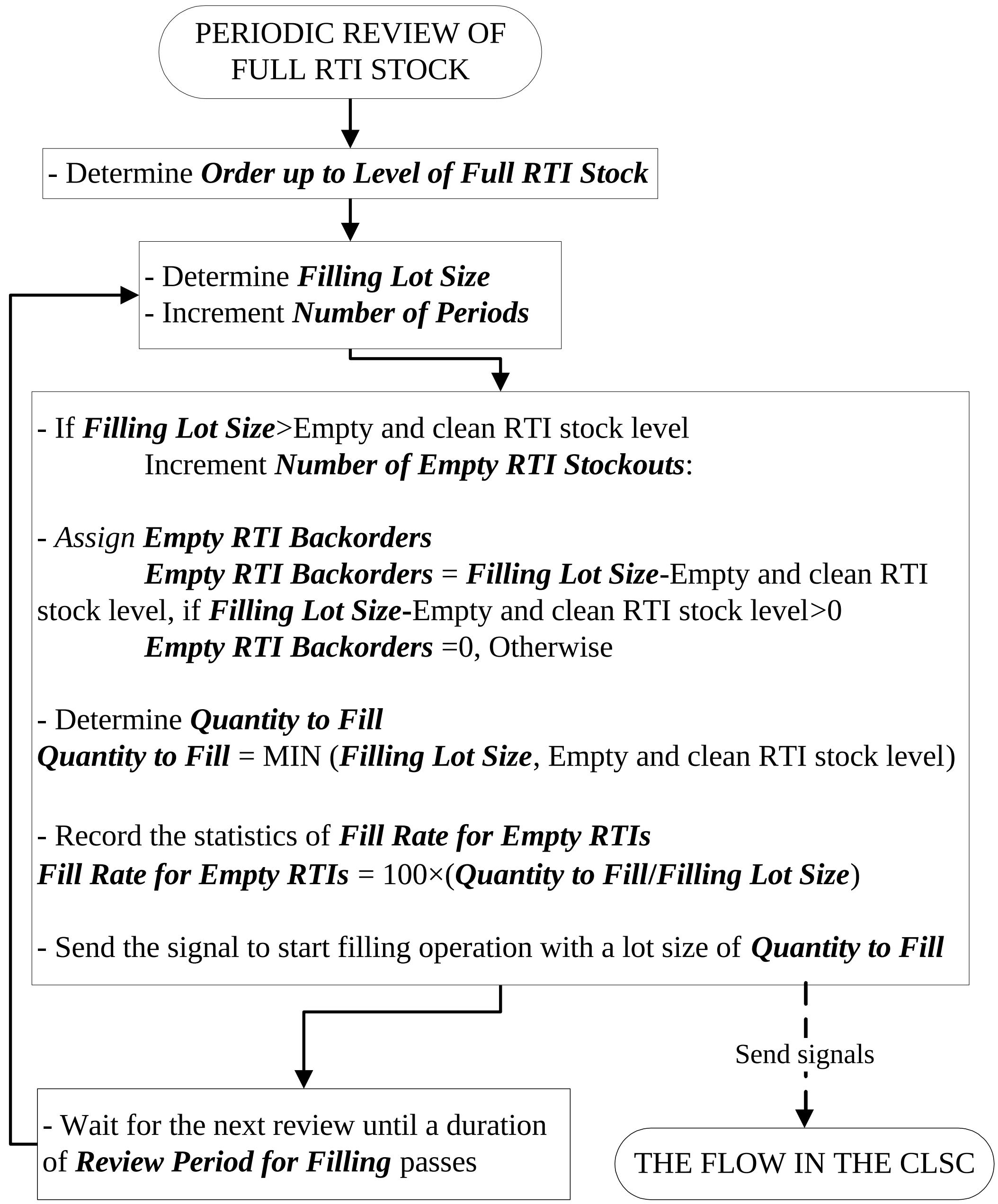

Figure 7.7: ***PERIODIC REVIEW OF FULL RTI STOCK*** part of the simulation model when emergency shipment is not useful

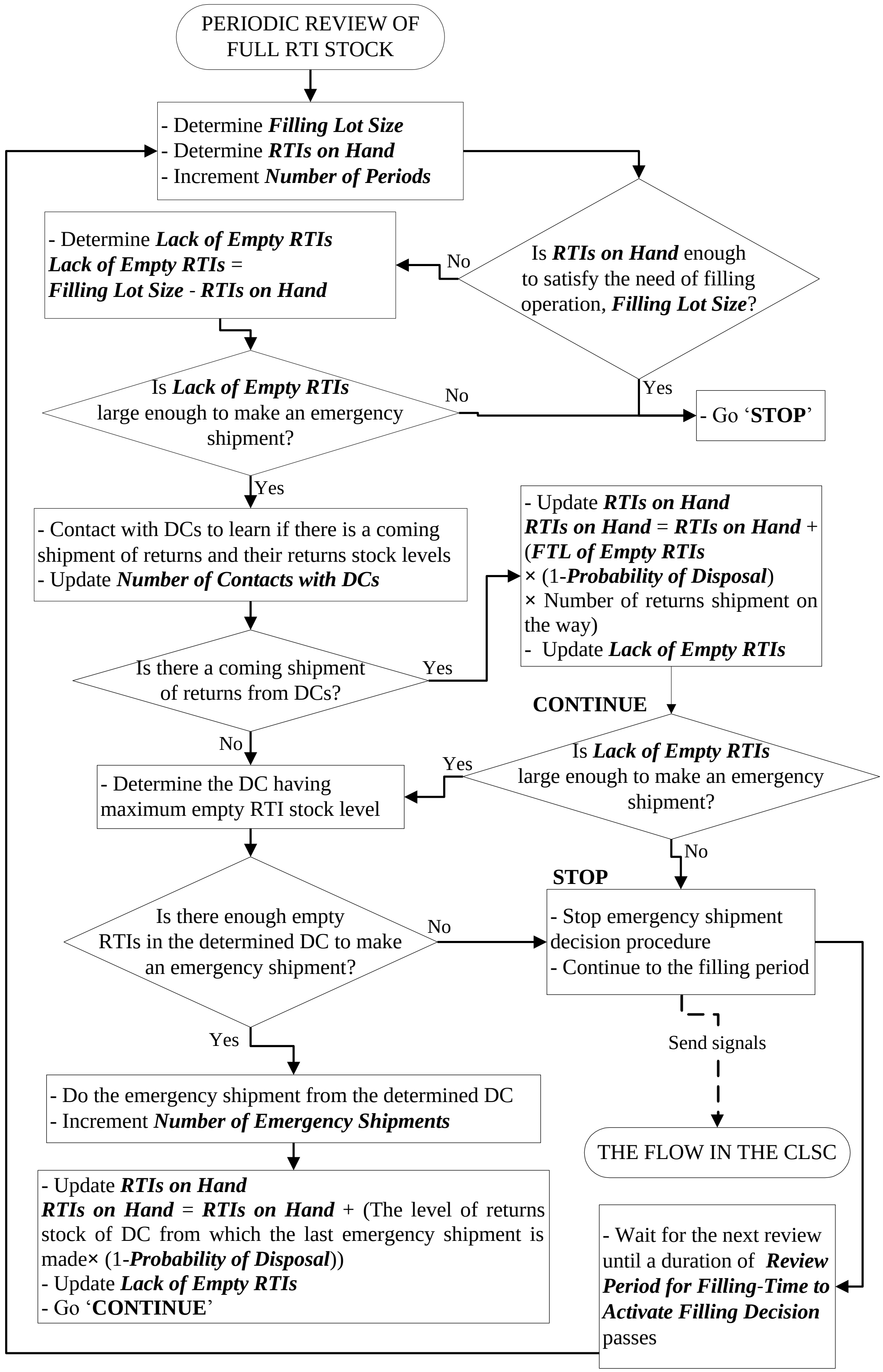

Figure 7.8: ***PERIODIC REVIEW OF FULL RTI STOCK*** part of the simulation model when emergency shipment can be useful

STOP

- Stop emergency shipment decision procedure

- Wait for the time of filling operation until a duration of ***Time to Activate Filling Decision*** passes

- If ***Filling Lot Size***>Empty and clean RTI stock level
  Increment ***Number of Empty RTI Stockouts***:

- *Assign* ***Empty RTI Backorders***
  Empty RTI Backorders = ***Filling Lot Size***-Empty and clean RTI stock level, if ***Filling Lot Size-***Empty and clean RTI stock level>0

  Empty RTI Backorders =0, Otherwise

- Determine ***Quantity to Fill***
Quantity to Fill = MIN (***Filling Lot Size***, Empty and clean RTI stock level)

- Record the statistics of ***Fill Rate for Empty RTIs***
Fill Rate for Empty RTIs = 100×(***Quantity to Fill/Filling Lot Size***)

- Send the signal to start filling operation with a lot size of ***Quantity to Fill***

Figure 7.9: 'STOP' part of the ***PERIODIC REVIEW OF FULL RTI STOCK*** which is shown in Figure 7.8

NEW RTI PURCHASES part of the simulation model is demonstrated in Figure 7.10. In this part, ***Quantity to Purchase*** is determined. After, new RTIs are ordered and send to ***THE FLOW IN THE CLSC*** after the duration of ***New RTI Purchasing Lead Time*** passes.

This part of the model starts with calculating ***Expected Lead Time Net RTI Demand, Variance of Lead Time Net RTI Demand*** and then ***Reorder Point for Purchasing***. Required formulas were already given in section 6.6. These parameters are calculated once and the same values are used until the end of simulation replication. ***Purchasing Lot Size*** is also required for this part. This should be calculated with the related formulas given in section 6.6 and entered as a parameter to the simulation model.

In each period, ***Empty RTIs Inventory Position*** is calculated and compared with ***Reorder Point for Purchasing***. When ***Empty RTIs Inventory Position*** drops at or below ***Reorder Point for Purchasing***, a replenishment order should be given with a size enough to make ***Empty RTIs Inventory Position*** larger than ***Reorder Point for Purchasing***. If a replenishment order having a size of ***Purchasing Lot Size*** is not enough, then its size should be the minimum multiples of ***Purchasing Lot Size*** which is enough to increase ***Empty RTIs Inventory Position*** above ***Reorder Point for Purchasing. Empty RTIs Inventory Position***, ***Quantity to Purchase and Required Number of Shipments*** are found with the formulas given below

Empty RTI Inventory Position = On hand empty and clean RTI stock level
+ (The number of RTIs in preparing for reuse operation × (1 − ***Probability of Disposal***))
+ The number of RTIs coming from preparing for reuse operation
+ The number of RTIs on order
− ***Empty RTI Backorders*** ` (7.13)

Let ***Q"*** be calculated as follows:

Q" = (***Reorder Point for Purchasing*** − ***Empty RTIs Inventory Position)/Purchasing Lot Size*** (7.14)

$$\textbf{\textit{Quantity to Purchase}} = \begin{cases} 0, & \text{if } Q'' < 0 \\ \textbf{\textit{Purchasing Lot Size}}, & \text{if } Q'' = 0 \\ \lceil Q'' \rceil \times \textbf{\textit{Purchasing Lot Size}}, & \text{if } Q'' > 0 \end{cases} \quad (7.15)$$

$$\textbf{\textit{Required Number of Shipments}} = \left\lceil \frac{\textbf{\textit{Quantity to Purchase}}}{\textbf{\textit{FTL of Empty RTIs}}} \right\rceil \quad (7.16)$$

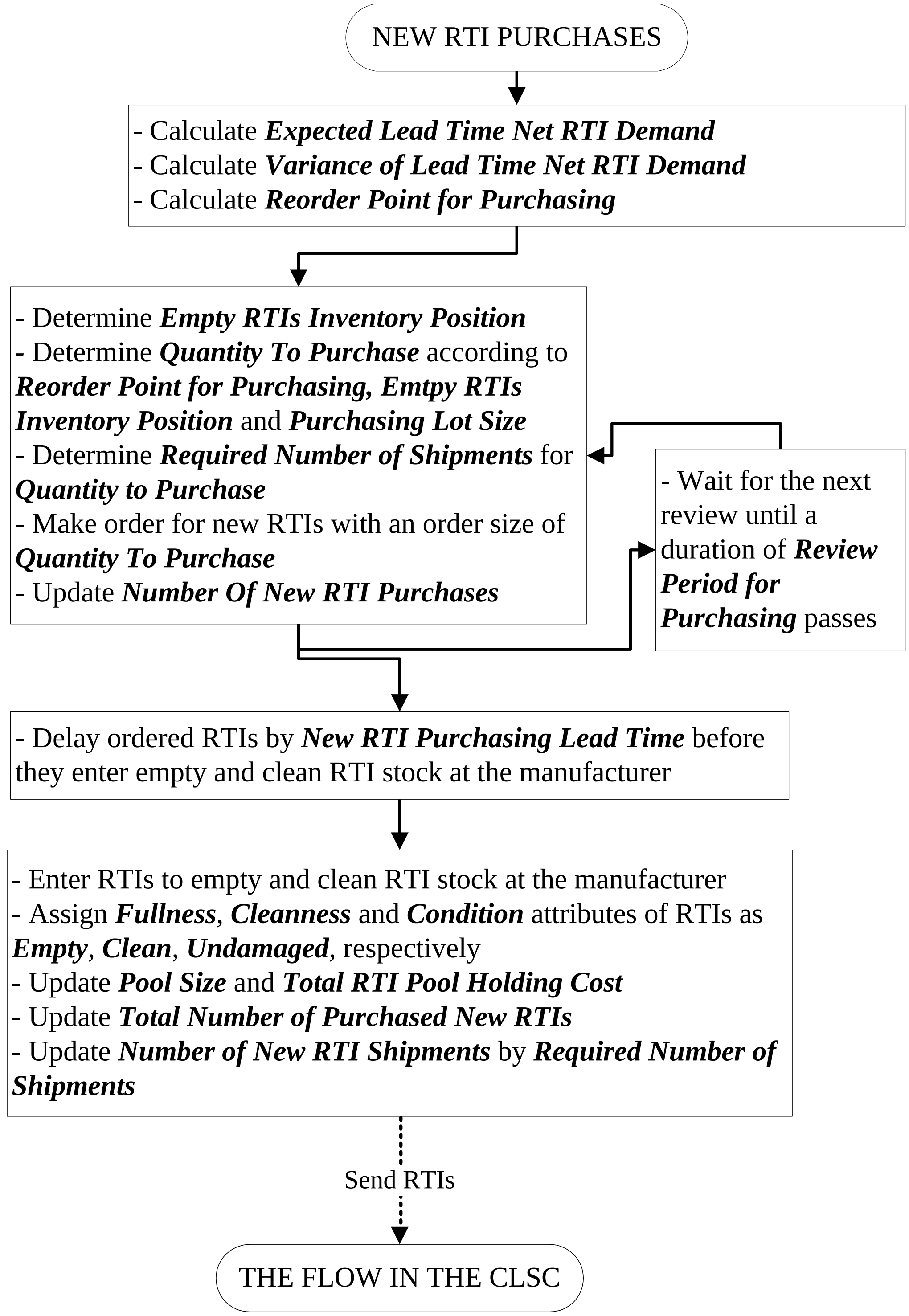

Figure 7.10: ***NEW RTI PURCHASES*** part of the simulation model

7.2. Input Analysis

It is possible to divide the parameters that are needed as inputs of the simulation model into two groups. The 1st group of parameters does not change with respect to the use of RFID technology. On the other hand, the values of the parameters in the 2nd group change directly or indirectly with respect to the use of RFID technology. The parameters having values directly affected by the use of this technology were used to construct scenarios for experimental analysis. As a result, the values of parameters in the 2nd group are expected to change between scenarios. Because of this reason, they were analyzed in Section 9.2. The parameters that were analyzed in this section have values fixed in each scenario that was developed.

7.2.1. The Inputs Related with the Initialization of Simulation Run

At the start of each simulation run, the RTI pool should be distributed among the stock points of the CLSC. Once the RTI pool is created, each RTI should be sent to a part of the CLSC according to a probability. Using the RFID data, it is found that on average approximately 60% of RTI pool is held in the field and 40% of RTI pool is held by the manufacturer. In addition to this finding, the following assumptions are made regarding the initial state of the distribution of RTI pool in order to make a valid estimation for ***Initial Distribution of RTI Pool***.

1. There are no RTIs in transportation
2. There are no RTIs in the processes of filling and preparing for reuse.
3. There are no RTIs on order.
4. The manufacturer holds all of its RTIs as empty.
5. The probability that an RTI is lastly sent to a DC is proportional to its average daily full RTI demand rate.

In the next period following to the start of the simulation run, ***Filling Lot Size*** is determined by taking into account that the full RTI stock is empty. Therefore, the effect of the 4th assumption is expected to disappear as simulation clock advances. This makes the 4th assumption suitable although it seems to be unrealistic. The 5th assumption suggests that the probability that an RTI in the field is assigned to a DC is proportional to its average daily full RTI demand rate. The CDF of the initial place of RTIs is given in Figure 7.11. Besides, the CDF of the distribution of RTIs in the field among three DCs is given in Figure 7.12. These two CDFs together determine the ***Initial Distribution of RTI Pool***.

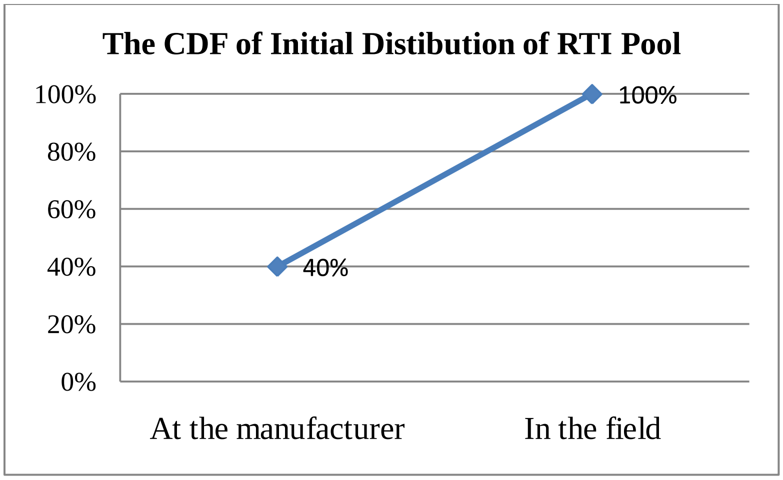

Figure 7.11: The CDF of the initial place of RTIs at the start of simulation run

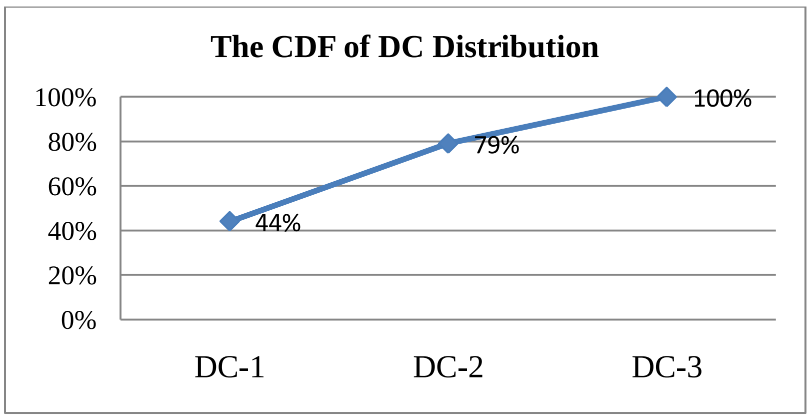

Figure 7.12: The CDF of the distribution of RTIs in the field among three DCs

7.2.2. The Inputs Related with Purchasing New RTIs

Review Period for Purchasing is 1 week. Besides, ***New RTIs Purchasing Lead Time*** is 8 weeks. The values of ***Purchasing Lot Size*** and ***Reorder Point for Purchasing*** depend on the size of net demand, and accordingly ***Probability of Field Loss*** and ***Probability of Disposal***. As a result, their values change between scenarios. They are given in section 9.2.

7.2.3. The Inputs Related with Filling

Review Period for Filling is 1 week. ***Lead Time of Filling*** is 1 day. ***Time to Activate Filling Decision*** is 4 days, which is the just enough time to give emergency shipment decision (if it is an option), make the emergency shipment, prepare emergently shipped RTIs for reuse and make them ready at the empty and clean RTI stock. ***Order up to Level of Full RTI Stock*** is calculated according to Equation 7.8**.** Assuming weekly full RTI demand is normally distributed, ***Safety factor for Full RTI Stock*** is chosen as 1.65 because of the desired service level is 95% fill rate.

Order up to Level of Full RTI Stock = Expected Weekly Full RTI Demand +
(***Safety Factor for Full RTI Stock*** × ***Std. Dev. of Weekly Full RTI Demand***) (7.8)

Order up to Level of Full RTI Stock $= 786 + (1.65 \times 106) \cong 961$

7.2.4. The Inputs Related with Full RTI Demand

The quantity demanded in a single order can take values of 20, 40 and 60. The CDF of ***Demand Size*** for each DC can be seen in the following figures.

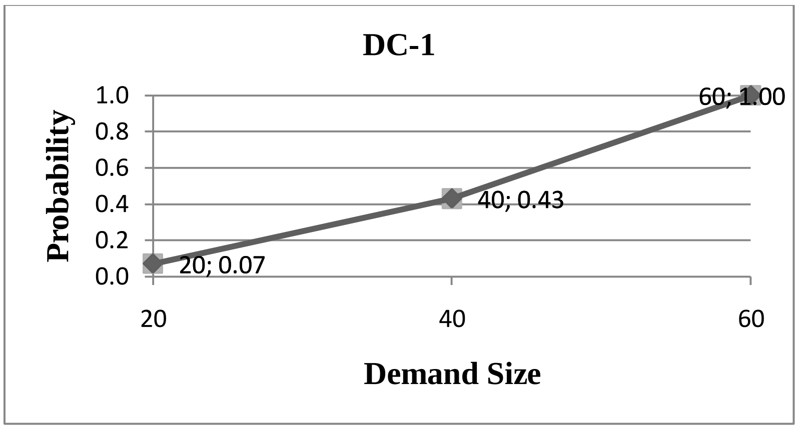

Figure 7.13: The CDF of ***Demand Size*** of DC-1

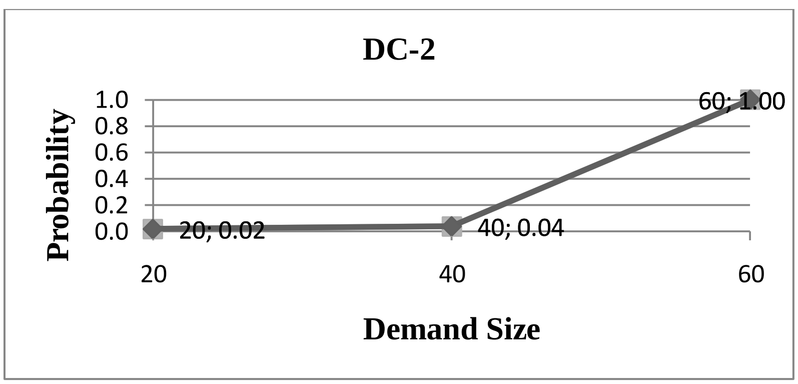

Figure 7.14: The CDF of ***Demand Size*** of DC-2

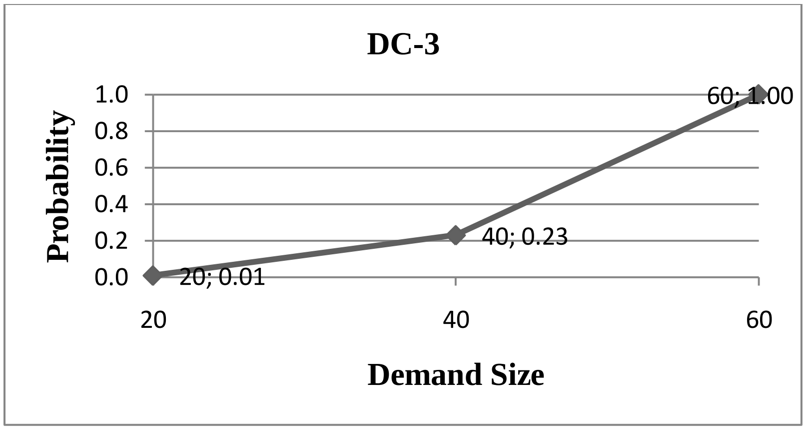

Figure 7.15: The CDF of ***Demand Size*** of DC-3

In order to find the distribution of ***Demand Interarrival Time***, Arena Input Analyzer is used. All possible continuous probability distributions, namely beta, erlang, exponential, gamma, lognormal, normal, triangular, uniform and weibull distributions, are tested with this software. It gives the best fitted distribution (in days) for each DC as follows:

- For DC-1, ***Demand Interarrival Time*** $= -0.5 + 6 \times BETA(8.3, 23.5)$ where 8.3 and 23.5 are the shape parameters of the beta distribution typically denoted as α and β, respectively.
- For DC-2, ***Demand Interarrival Time*** $= -0.5 + LOGNORMAL(1.98, 1.07)$ where 1.98 and 1.07 are the mean and the standard deviation of the random variable's natural logarithm, respectively.
- For DC-3, ***Demand Interarrival Time*** $= -0.5 + ERLANG(0.396, 7)$ where 0.396 and 7 are exponential mean and erlang shape parameter, respectively.

A set of demand data is generated by utilizing the distributions of ***Demand Size*** and ***Demand Interarrival Time*** given for three DCs in order to find out the distribution of total (arriving from all DCs) full RTI demand observed by the manufacturer. A simulation model is developed to generate a demand data covering a year with the help of Arena. The experiment and model frames of this simulation model can be seen in Appendix D. From the generated data, we obtain data sets of total daily and weekly full RTI demand observed by the manufacturer. These data sets are analyzed with Arena Input Analyzer in order to find the best fitted distributions. As a result, it is found out that weekly demand is normally distributed with a mean of 786 and a standard deviation of 106. In addition, daily demand is normally distributed with a mean of 103 and a standard deviation of 59.

7.2.5. The Inputs Related with Transportation

Lead Time of Transportation is 1 day regardless of the DC. ***FTL of Full RTIs*** is 60 and ***FTL of Empty RTIs*** is 380.

Both ***Emergency Shipment Threshold*** and ***Minimum Emergency Shipment Lot Size*** are half of ***FTL of Empty RTIs***. They are taken as equal because the reasoning behind the determination of those levels is similar. ***Lack of Empty RTIs*** should be larger than ***Emergency Shipment Threshold***. Otherwise, it is assumed that it is not worthwhile to increase the empty RTI stock level at the manufacturer with an emergency shipment. The maximum level of empty RTI stock among DCs should be larger than ***Minimum Emergency Shipment***. Otherwise, it is assumed that it is not worthwhile to do an emergency shipment due to its additional cost and planning effort.

7.2.6. The Inputs Related with Preparing for Reuse

Lead Time of Preparing for Reuse is 1 day. In addition, it takes 1 day to make the prepared for reuse RTIs ready at the empty and clean RTI stock.

7.2.7. The Inputs Related with Cost Items

Cost related inputs are shown in Table 7.1. Unit capital cost is found by assuming that the opportunity cost of capital is 15% of its value for a year. Unit transportation cost is valid for both emergency shipments and the shipments of new RTIs.

Table 7.1: The values of cost related inputs of the simulation model

Cost Item	Value
Unit RTI Holding Cost	€ 18
Unit RTI Price	€ 120
Unit Repair Cost	€ 50
Unit Transportation Cost	€ 500
Annual RFID Fee	€ 100,000

7.3. Simulation Run Parameters

As it was mentioned before, there are 3 run parameters for a simulation study namely ***Warm up Period, Replication Length*** and ***Number of Replications***. These parameters were studied in sections 7.3.1 and 7.3.2. They were determined by considering the capability of the simulation models to produce fair and unbiased results as well as the run time. The simulation run time was crucial in our study because the simulation models were prepared to be embedded in a simulation optimization tool which requires many simulation runs in order to find the optimal solution.

Trial runs showed us that the simulation run time was large due to the high number of entities representing RTIs in the system. In order to obtain a reasonable simulation run time, a solution can be scaling the RTI pool by using entities representing more than one RTI and adjusting the input parameters accordingly. The decision of scaling is expected to affect the choice of simulation run parameters. Because of this reason, we found suitable to discuss this in section 7.3.3 under this title.

7.3.1 Warm up Period and Replication Length

It was assumed that once RFID is set in place, it can be used for 3 years. When ***Time to Action*** is taken as 12 months, usable lifetime of RFID remains 2 years. Since we want to simulate the usable lifetime of RFID after ***Time to Action***, ***Replication Length*** should be ***Warm up Period*** + 2 years.

The initial conditions of the simulation mostly do not characterize the steady state of the system. This problem is called ‘initial transient’ or ‘initial bias’. In order to minimize this, we selected the initial conditions close to steady state as much as possible. However, initial bias cannot be eliminated with the selection of initial conditions. We needed to truncate some initial observations because they are the ones responsible most of the initial bias.

We run the simulation model in which the emergency shipment is not an option without initializing the statistics and the system state with 50 replications each having a length of 100 days. Since we chose not to initialize the statistics and the system state at the beginning of each replication, the values of performance measures in i^{th} replication gave the evaluation of the observations accumulated until the simulation clock reaches 100*i* days since the start of the run. Figure 7.16-7.20 show the change of some performance measures with respect to simulation time without truncating any initial observations. From these figures, it can be concluded that ***Cycle Time***, ***Fill Rate for Full RTIs*** and ***Pool Size*** reach steady state very quickly compared to ***Trippage*** and ***Lifetime***. ***Trippage*** and ***Lifetime*** requires much longer time than the others to reach the steady state.

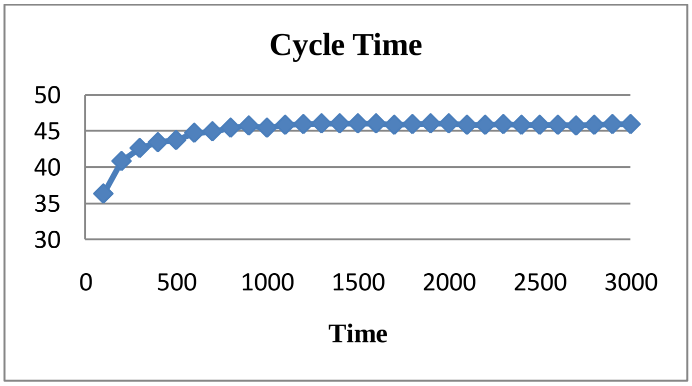

Figure 7.16: The change of average ***Cycle Time*** with respect to simulation time

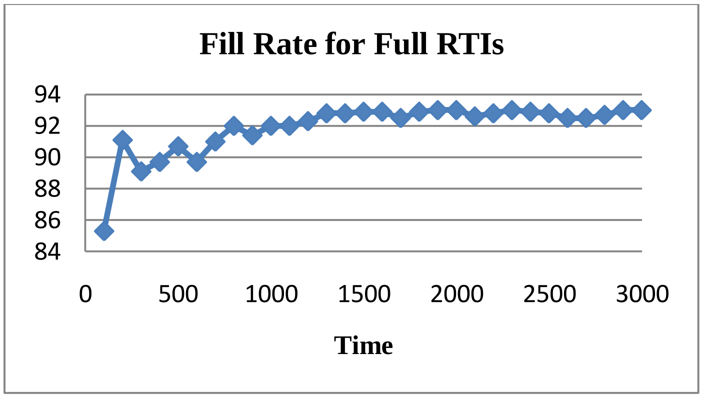

Figure 7.17: The change of average ***Fill Rate for Full RTIs*** with respect to the simulation time

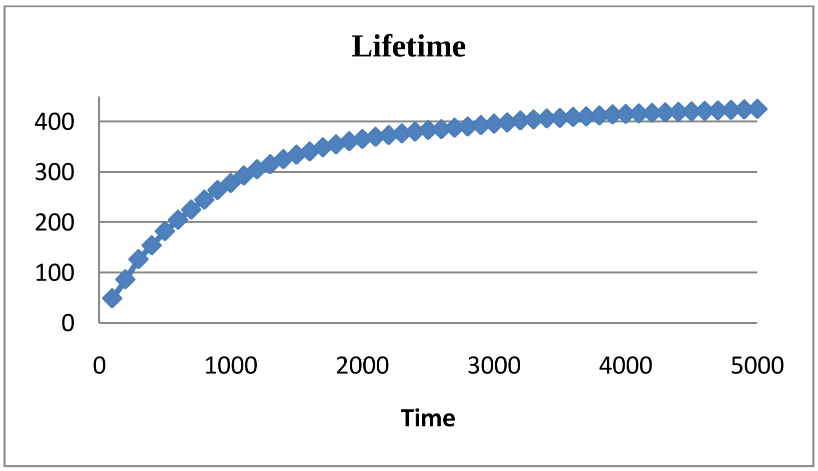

Figure 7.18: The change of average ***Lifetime*** with respect to the simulation time

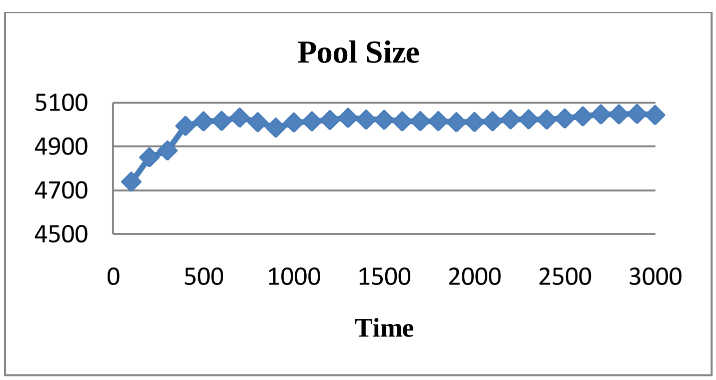

Figure 7.19: The change of average ***Pool Size*** with respect to the simulation time

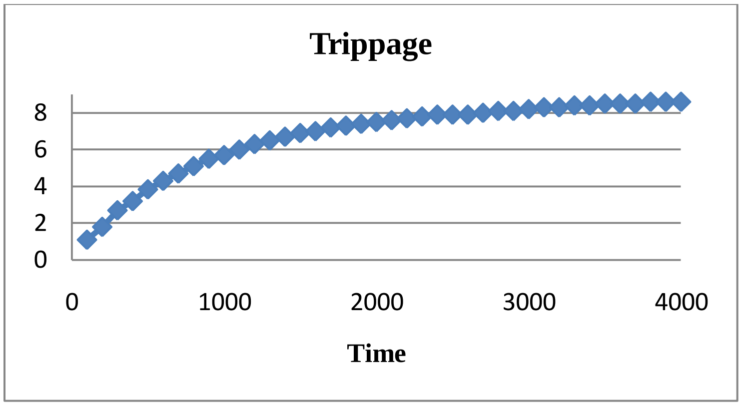

Figure 7.20: The change of average ***Trippage*** with respect to the simulation time

At this point, we considered the following 3 options in order to find ***Warm up Period.***

1. Determining ***Warm up Period*** long enough so that the effect of initial bias becomes negligible at the end of ***Warm up Period***.

2. Reducing initial bias by assigning initial values to ***Number of Rotations*** and ***Time to Enter CLSC*** by using ***Probability of Field Loss***, ***Probability of Disposal*** and the steady state value of ***Cycle Time*** as follows:

$$\textbf{\textit{Number of Rotations}} = \begin{cases} 0 & \text{with probability } p_f \\ \text{n} & \text{with probability } p_d(1-p_f)\,(1-p_f)^{\,n-1} + p_f(1-p_l)^{\,n} \end{cases} \quad (7.17)$$

$$\textbf{\textit{Time to Enter CLSC}} = \begin{cases} 0 & \text{with probability } p_f \\ -n \times CT^{ss} & \text{with probability } p_d(1-p_f)\,(1-p_f)^{\,n-1} + p_f(1-p_l)^{\,n} \end{cases} \quad (7.18)$$

where

$n = 1,2,3 \ldots$
p_d: ***Probability of Disposal***
p_f: ***Probability of Field Loss***
p_l: ***Probability of Loss*** ($p_l = p_f + p_d(1 - p_f)$)
CT^{ss}: The steady state value of average ***Cycle Time***

3. Estimating the average values of ***Lifetime*** and ***Trippage*** with the below formulas and determining ***Warm up Period*** with respect to other variables which reach steady state more quickly. The idea behind the formulas belongs to Goh and Varaprasad (1983).
Trippage = E[***Number of Rotations***] (7.19)
Lifetime = ***Cycle Time*** × ***Trippage*** (7.20)

Although the simulation run times of 2nd and 3rd options are better than the same of 1st one, it was found suitable to use the 1st option because of the following reasons:

- Removing the initial bias of the distribution of RTIs throughout the supply chain is also important to obtain fair results. As a result, a high ***Warm up Period*** is preferable to a smaller one.
- The estimation of ***Lifetime*** in 2nd and 3rd option is questionable because it should be the exact multiples of ***Trippage***. In our model, an RTI can be lost both in the field and in the preparing for reuse process without completing the last cycle in its lifetime. This means an RTI can be lost without completing its last trip.

The RTIs created at the start of the run are the responsible of the initial bias because their attributes ***Number of Rotations*** and ***Time to Enter CLSC*** are zero. Therefore, minimum required ***Warm up Period*** should cover a period during which the most of the RTIs created at the start of the simulation run are disposed. It is expected to change with respect to ***Probability of Disposal*** and ***Probability of Field Loss***, and ***Emptying Duration***.

Firstly, the simulation model without emergency shipments was run for the scenario without RFID in the less problematic case (See Chapter 9 for more details about developed scenarios.) with one replication having a ***Replication Length*** of 100,000 days and a ***Warm up Period*** of 50,000 days. We run the simulation model long enough so that the impact of initial bias vanishes and we could find the steady state value of ***Lifetime*** for this scenario. We chose the model without emergency shipment, because it is expected to reach steady state less quickly than the model with emergency shipment given the parameters ***Probability of Disposal*** and ***Probability of Field Loss***, and ***Emptying Duration***. The reason of this expectation is the fact that RTIs are expected to circulate faster due to emergency shipments. After finding the steady state values of ***Lifetime***, we searched for ***Warm up Period*** which gives ***Lifetime*** at its steady state value. It turned out to be that ***Warm up Period*** was around 3000 days, which increased the run time significantly.

For the sake of obtaining reasonable run time, we decided to scale 20 RTIs to one entity. In that case, we observed that a ***Warm up Period*** of 3000 days was enough to remove initial bias for all scenarios.

7.3.2. Number of Replications

The precision of an output value can be controlled by determining ***Number of Replications***. Let,

- CT_{ij} be the observation i in replication j where $i = 1,2,\dots,m$ and $j = 1,2,\dots,n$.
- $\overline{CT_j}$ be the replication averages of ***Cycle Time*** observations and $\overline{CT_j} = \frac{1}{m}\sum_i^m CT_{ij}$ for $j = 1,2,\dots,n$.

CT_{ij}'s for $i = 1,2, \dots, m$ for the same j (for the same replication) are expected to be dependent. On the other hand, $\overline{CT_j}$ for $j = 1,2, \dots, n$ are independent, since the system state and statistics are initialized at the start of each replication and different random numbers are used in each replication. It is also approximately normally distributed by Central Limit Theorem provided that m is not too small, because CT_j is the average of m observations. For a ***Replication Length*** of 3720 days, m is around 3500. We chose to make this analysis with ***Cycle Time*** due to its high number of observations because m should not be small.

We had $\overline{CT_j}$ iif and approximately normally distributed. Half length for $(1-\alpha)\%$ confidence interval can be found with the following formula:

$Half\ length = t_{n-1,1-\alpha/2} \frac{s}{\sqrt{n}}$ where s is the sample standard deviation. (7.21)

We run the simulation model without emergency shipments (for the scenario without RFID in the less problematic case) with a ***Replication Length*** of 3720 days and a ***Warm up Period*** of 3000 days for $n = 5$ replications. We used the scaled version as it was discussed in section 7.3.3. Table 7.2 shows the values of $\overline{CT_j}$ for $n = 5$ replications, $\overline{\overline{CT_j}}$ which is the average of $\overline{CT_j}$s, and s.

Table 7.2: The sample of average ***Cycle Time*** for 5 replications and sample statistics

$\overline{CT_1}$	46.14
$\overline{CT_2}$	46.16
$\overline{CT_3}$	46.56
$\overline{CT_4}$	47.30
$\overline{CT_5}$	47.70
$\boldsymbol{\overline{\overline{CT_j}}}$	**46.77**
$\boldsymbol{s}$	**0.70**

If want a relative precision of 5%, $\frac{Half\ length}{\overline{\overline{CT_j}}} \leq 0.05$ should be. According to Table 7.2, $Half\ length = 2.776 \frac{0.70}{\sqrt{5}} = 0.87$ and $\frac{Half\ length}{\overline{\overline{CT_j}}} \cong 0.02$ which is less than 0.05 where $t_{n-1,1-\alpha/2}$=2.776 for $n = 5$ and $\alpha = 0.05$. As a result, ***Number of Replications*** of 5 is enough to have a relative precision of 5%.

In order to be sure, we also did the same analysis to ***Lifetime***. Although the number of observations for ***Lifetime*** was not as much as the same for ***Cycle Time***, it was not small. It was around 400 for the same simulation run that was obtained for the analysis of ***Cycle Time***. . Table 7.3 shows the values of $\overline{LT_j}$ for $n = 5$ replications, $\overline{\overline{LT_j}}$ which is the average of $\overline{LT_j}$s (the average value of ***Lifetime*** in replication j.

Table 7.3: The sample of average ***Lifetime*** for 5 replications and sample statistics

$\overline{LT_1}$	464.9
$\overline{LT_2}$	491.2
$\overline{LT_3}$	488.6
$\overline{LT_4}$	514.9
$\overline{LT_5}$	491.2
$\overline{\overline{\boldsymbol{LT_J}}}$	**490.1**
$\boldsymbol{s}$	**17.70**

According to Table 7.3, $Half\ length = 2.776\frac{17.70}{\sqrt{5}} = 21.97$ and $\frac{Half\ length}{\overline{\overline{CT_J}}} \cong 0.045$ which is less than 0.05 where $t_{n-1,1-\alpha/2}$=2.776 for $n = 5$ and $\alpha = 0.05$. As a result, again ***Number of Replications*** of 5 was found to be enough to have a relative precision of 5%.

7.3.3. Scaling Decision

It is possible to decrease the simulation run time by allowing entities to represent more than one RTI. The decision of representing n RTIs with one entity results in RTIs circulating in the CLSC in groups of n.This decision requires the following adjustments in the input parameters:

1. The following parameters should be divided by n:
   - ***Demand Size***
   - ***Expected Daily Full RTI Demand***
   - ***Expected Lead Time Full RTI Demand***
   - ***Expected Weekly Full RTI Demand***
   - ***Emergency Shipment Threshold***
   - ***Minimum Emergency Shipment Lot Size***
   - ***FTL of Full RTIs***
   - ***Initial Pool Size***
   - ***Purchasing Lot Size***
   - ***Std. Dev. of Weekly Full RTI Demand***

Adjusting these parameters is enough because once they are adjusted, the other parameters which are calculated with a subset of these parameters like ***Reorder Point for Purchasing*** and ***Order up to Level of Full RTI Stock*** by the simulation models becomes adjusted accordingly. In addition, ***Variance of Lead Time Full RTI Demand*** should be divided by n^2. If X is an independent random variable normally distributed with mean μ, and variance σ^2, then X/n is also be normally distributed with mean μ/n, and variance σ^2/n^2 provided that n is a constant.

2. The following parameters should be multiplied by n in order to calculate ***Total RTI Pool Management Cost*** correctly:
    - ***Unit Repair Cost***
    - ***Unit RTI Holding Cost***.
    - ***Unit RTI Price***

We run the simulation models with and without emergency shipments

- For the case without RFID in the less problematic case (See Chapter 9 for more details about developed scenarios.),
- With 10 replications (more than the decided ***Number of Replications*** to increase the precision) each having a ***Warm up Period*** of 3000 days and a ***Replication Length*** of 3720 days, and
- For n=1 (no scaling), n=10 and n=20,

in order to see the impact of scaling decision on performance measures. The following two tables show the obtained results. The 'Output Values' columns show the average values of performance measures for 10 replications. The percentage values under '% Change' columns are the proportion of the difference between the results with and without scaling to the result without scaling. The values under this column were calculated after making the readjustments if necessary. For example, ***Pool Size*** value for the scaling with n=20 was multiplied with 20.

Table 7.4: The change of performance measures with respect to scaling decision for the simulation model with emergency shipment

	No Scaling – Output values	**Scaled with 1:10**		**Scaled with 1:20**	
		Output Values	**% Change**	**Output Values**	**% Change**
Cycle Time (days)	45.9	46.6	1%	46.8	2%
Lifetime (days)	470.6	476.4	1%	482.4	2%
Trippage (days)	9.8	9.8	0%	9.9	0%
Pool Size	5029	508.6	1%	256.7	2%
Fill Rate for Empty RTIs	96.2	96.9	1%	97.6	1%
Fill Rate for Full RTIs	93.9	94.8	1%	94.9	1%
New RTIs Replenishment Rate (RTIs/day)	10.9	1.1	-2%	0.5	0%
Time Spent in the Field (days)	32.4	32.3	0%	32.0	-1%
Total Cost of RTI Pool Management (€)	2,230,900	2,236,600	0%	2,262,000	1%
Run Time (minutes)	9.68	1.48	-85%	0.95	-90%

Table 7.5: The change of performance measures with respect to scaling decision for the simulation model with emergency shipment

	No Scaling	Scaled with 1:10		Scaled with 1:20	
		Output Values	**% Change**	**Output Values**	**% Change**
Cycle Time (days)	45.6	46.7	2%	46.8	3%
Lifetime (days)	465.8	476.4	2%	463.5	0%
Trippage (days)	9.7	9.8	1%	9.5	-2%
Pool Size	5046.8	513.6	2%	256.68	2%
Fill Rate for Empty RTIs	98.2	98.8	1%	98.9	1%
Fill Rate for Full RTIs	94.3	95.0	1%	94.6	0%
New RTIs Replenishment Rate (RTIs/day)	11.0	1.06	-4%	0.54	-2%
Time Spent in the Field (days)	32.3	32.3	0%	32.1	-1%
Total Cost of RTI Pool Management (€)	2,269,000	2,241,700	-1%	2,249,400	-1%
Run Time (minutes)	11.4	1.5	-87%	0.97	-91%

From the results in these two tables, it can be concluded that scaling does not affect performance measures significantly while reducing the run time significantly. As a result, we decided to adapt scaling with n=20 in our experimental analysis.

7.4. The Verification of Simulation Models

Verification is about answering the question “Did we do the things right?”. In other words, verification is questioning whether or not the conceptual simulation model is correctly translated into Arena and the simulation model runs as intended. In this section, we presented how our simulation models were verified.

7.4.1 Tracing the Operation of Simulation Models

We firstly started with a simple model, and then added the details until we reached the final simulation model of the whole CLSC. At each time that simulation models were modified, they were debugged with Arena’s run controller. ‘Set Trace’ command was used in order to trace the flows of every entity in the system. This debugging was repeated with a small number of RTI pool size in order to not to be distracted by the enormous number of entities while tracing. The errors were found out and immediately corrected, if they were any. After each correction, debugging was restarted. It was made certain that the entities were flow in the system as intended and the formulas were correct. In the end, we ensured that the conceptual simulation model was correctly translated into Arena.

7.4.2 The Consistency Check for the Outputs of Simulation Models

In this section, we presented an example to the consistency check that was performed for the final version of the simulation models. In this example, we run both of the models with the run parameters determined in section 7.3. We have used the scenario of 'without RFID' for the less problematic case. The details of scenarios can be found in Chapter 9.

We started the consistency check by balancing the number of ***RTIs*** at the end of simulation run. The number of ***RTIs*** in the system should be equal to the number of ***RTIs*** that have entered to the system after the number of ***RTIs*** that have left the system is deducted from this number.

Pool Size = ***Actual Starting Pool Size***
+ ***Total Number of Purchased RTIs***
−***Number of RTI Disposals***
−***Number of RTI Field Losses*** (7.22)

The final value of Pool Size should equal to the total amount of RTIs distributed among the parts of the CLSC.

Pool Size = The empty and clean RTI stock level at the manufacturer
+ The number of RTIs in the filling operation
+ The full RTI stock level at the manufacturer
+ The RTIs in transportation (including emergency if it is useful) between the manufacturer and DCs
+ The RTIs that were sent to DCs and have not returned to DCs
+ The empty RTI stocks at DCs
+ The number of RTIs in the preparing for reuse operation
+ The number of RTIs in carrying from the preparing for reuse operation (7.23)

At the start of each replication, the pool created with ***Initial Pool Size***, should be distributed according to ***Initial Distribution of RTI Pool.*** As a result, the following equations should hold:

Initial Pool Size = Initial number of RTIs that are sent to the empty and clean RTI stock
+ Initial number of RTIs that are sent to the field (7.24)

Initial number of RTIs that are sent to the empty and clean RTI stock (7.25)
≈ The probability that an RTI is sent to this stock point × ***Initial Pool Size***

Initial number of RTIs that are sent to the field (7.26)
≈ The probability that an RTI is sent to this part of the CLSC × ***Initial Pool Size***

The final (and also average) value of ***Full RTI Backorders (All)*** should be the total of final (and also average) values of ***Full RTI Backorders (DC i)*** variables. In other words, the following equation should hold:

Full RTI Backorders (All) = ***Full RTI Backorders (DC-1)***
+ ***Full RTI Backorders (DC-2)***
+***Full RTI Backorders (DC-3)*** (7.27)

In addition, the following equations and inequalities were also checked. They were presented to give the idea of how the simulation models were verified by checking if there were any inconsistencies in the outputs. This is not the exhaustive list.

- Total number of demand arrivals from DCs = Number of observations for the statistics variable ***Fill Rate for Full RTIs***
- ***Number of Periods*** = Number of observations of for the statistics variable ***Fill Rate for Empty RTIs***
- ***Total Demand*** / ((***Replication Length*** – ***Warmup Period***) ≈ ***Expected Daily Full RTI Demand***
- The maximum empty RTI stock levels at DCs should be equal to ***FTL of Empty RTIs***.
- The number of emergency shipments at one week cannot be greater than 3, since there are 3 DCs.
- Once the returns arrive at the manufacturer, they are immediately entered to the preparing for reuse operation without waiting. Therefore, the waiting time at the returns stock and the maximum level of returns stock at the manufacturer should be zero.
- If there is a backorder, the full RTIs leaving the filling operation are directly sent to satisfy outstanding backorders without waiting at the manufacturer. If the final value of ***Full RTI Backorders (All)*** is greater than zero, then the minimum value of waiting time in full RTI stock should not be zero because the full RTIs that are send to satisfy backorders do not enter the full RTI stock.
- ***Number of RTI Disposals***
  ≈ (1− ***Probability of Field Loss***) × ***Probability of Disposal*** × ***Total Demand***
- ***Number of RTI Field Losses*** ≈ ***Probability of Field Loss*** × ***Total Demand***
- ***Number of RTI Repairs***
  ≈ (1− ***Probability of Field Loss***) × ***Probability of Repair*** × ***Total Demand***
- ***Number of RTI Returns*** ≈ (1− ***Probability of Field Loss***) × ***Total Demand***
- Average value of ***Trippage*** ≈ E[***Number of Rotations***] which can be found with Equation 7.17.
- Average value of ***Lifetime*** ≈ Average value of ***Trippage*** × Average value of ***Cycle Time***
- Average number of RTIs in preparing for reuse operation
  ≈ (***Number of RTI Returns*** × ***Lead Time of Preparing For Reuse***)/(***Replication Length*** − ***Warm up Period***)
- ***Number of RTI Returns*** ≈ (1− ***Probability of Field Loss***) × ***Total Demand***

- The daily rate of new RTI replenishment should be close to the daily loss rate:
  ***Total Number of Purchased RTIs*/ (*Replication Length−Warm up Period*)**
  = *Expected Daily Full RTI Demand* × (*Probability of Loss*)

7.4.3. Extreme Value Check

This check was performed in order to see whether or not the simulation models provide plausible outputs to extreme and unlikely combination of levels of parameters. The simulation runs were conducted with the input parameters found in section 7.3. The scenario without the use of RFID technology in the less problematic case was used for the runs. The results of 15 extreme cases were checked and compared with the results of the original scenario. In all of the checks, the simulation models provided expected results. As a result, we could conclude that the simulation models seemed to be working and providing correct results.

1. Zero Demand Rate

Since there is zero demand, no RTIs are sent to the field after warm up period. The number of observations of these variables are zero. Because of this reason, the output of the simulation models give no values for ***Cycle Time***, ***Lifetime***, ***Trippage***, ***Time Spent in the Field*** and ***Fill Rate for Full RTIs***. ***Fill Rate for Empty RTIs*** is 100% because the empty and clean RTI stock does not fail to satisfy the complete need of the filling operation which is always zero. Most of the RTIs initally sent to the field return to the manufacturer. However, some of them stuck in the DCs because the empty RTI stock levels at DCs stay at a level less than ***FTL of Empty RTIs***. Since a small part of the initial RTI pool is lost or disposed, ***Actual Starting Pool Size*** is less than ***Initial Pool Size***. After the completion of warm up period, there are no losses because there are no RTIs sent to the field. As expected, ***New RTI Replenishment Rate*** and ***Number of Emergency Shipments*** (of the model with emergency shipments) is zero. Total Cost of RTI Pool Management only includes ***Total Purchasing Cost*** and ***Total RTI Pool Holding Cost*** of the ***Actual Starting Pool Size***.

2. Very High Demand Rate

For this check, ***Demand Size*** for each demand arrival was taken as 600. ***Order up to Level of Full RTI Stock*** and ***Reorder Point for Purchasing*** were not adjusted according to the high demand rate. If we had adjusted, this check would have looked like reversing the scaling without updating cost parameters. In this scenario, average ***Cycle Time*** decreases approximately 25% due to decreases in waiting times at stock points, especially at empty RTI stocks of DCs and at full RTI stock at the manufacturer. Average ***Cycle Time*** also decreases due to the high level of backorders because RTIs sent to satisfy backorders do not enter and wait at full RTI stock. Since empty RTIs wait less at DCs for FTL shipments, average ***Time Spent in the Field*** also decreases. average ***Pool Size*** and ***Total Cost of RTI Pool Management*** increases greately due to high ***New RTI Replenishment Rate*** (around 120 RTIs per day). ***Fill Rate for Full RTIs*** is less than 0.5% despite of high ***New RTI Replenishment Rate*** because ***Order up to Level of Full RTI Stock*** is not adjusted. Average ***Trippage*** stays at the same level given the same ***Probability of Disposal*** and ***Probability of Field Loss***. On the other hand, average ***Lifetime*** decreases due to the decrease in average ***Cycle Time***. According to the output of the model with emergency shipments, ***Number of Emergency Shipments*** increased approximately 800%.

3. No Purchasing

It was assumed that giving orders for new RTIs is not allowed after warm up period. The final value of ***Pool Size*** is much more smaller than ***Actual Starting Pool Size***. Average ***Fill Rate for Full RTIs*** is around 25% and 22% for the models with and without emergengency shipments, respectively. For both of the models, the maximum ***Fill Rate for Full RTIs*** is 100%. On the other hand, the minimum of the same is 0% since ***Pool Size*** decreases greately towards to end of run. ***Full RTI Backorders (All)*** increases greatly and has a very large final value. ***Total Number of Purchased RTIs*** is a positive small number because RTIs on order at the end of warm up period arrive later. ***Total RTI Pool Management Cost*** decreases 50% because our total cost formula does not contain penalty cost as well as ***Total Purchasing Cost*** and ***Total RTI Pool Holding Cost*** decreases greately. For the model with emergency shipments, ***Number of Emergency Shipments*** is 750% higher than the case when ordering new RTIs is allowed.

4. Very Large *Purchasing Lot Size*

It was assumed that new RTIs can only be purchased with a lot size of 10 times ***Purchasing Lot Size*** after the end of warm up period. Two of the prominent changes in the outputs are the increases in average empty RTI stock level and waiting time of RTIs at that stock point. ***Cycle Time*** also increases due to the increase in waiting time at empty and clean RTI stock. Average ***Pool Size*** increases by 32% and 35% for the models with and without emergency shipments. Although ***Total Purchasing Cost*** does not increase significantly, ***Total RTI Pool Holding Cost*** increases in both models. For the model with emergency shipments, average ***Number of Emergency Shipments*** is close to zero.

5. Breakdown at Filling Operation

It was assumed that a breakdown at the filling line occurs at the end of warm up period and it takes 3 months to repair it. Until repair, it is not possible to fill any RTIs. The outputs show that the maximum level of ***Full RTI Backorders (All)*** increases enormously to a level close to expected full RTI demand of 3 months. The minimum level of ***Fill Rate for Full RTIs*** is zero as expected. The average level of ***Fill Rate for Full RTIs*** decrease by 12 for both of the models. In addition, average ***Cycle Time*** more than doubles for both of the models due to high waiting time before the filling operation.

6. Zero *Emptying Duration*

In this check, it is assumed that RTIs arrived at DCs immediately are emptied and entered to the empty RTI stock of DCs. In order to do this check, both ***Minimum Emptying Duration*** and

Emptying Duration for all DCs were taken as zero. The outputs of the simulation models showed that average ***Cycle Time*** decreases greately (approximately %50) due to the huge decrease in average ***Time Spent in the Field***. As a result, average ***Lifetime*** also decreases given the same level of average ***Trippage***. The most prominent change is in average ***Pool Size*** with an approximately 55% decrease for both of the models.

7. Very Large *Emptying Duration*

It was assumed that ***Emptying Duration*** takes a very high and fixed number, 150 days, at the end of warm up period. The outputs of the simulation models showed that average ***Cycle Time*** increases approximately 60%. Since the return of RTIs takes more time than usual, both ***Fill Rate for Empty RTIs*** and ***Fill Rate for Full RTIs*** decreases. Average ***Time Spent in the Field*** approximately triples. In addition, ***New RTI Replenishment Rate*** more than doubles in order to increase ***Pool Size*** and to cope with the new level of ***Emptying Duration***.

Although we expected that average ***Trippage*** stays approcximately the same and average ***Lifetime*** increases (due to increase in average ***Cycle Time***), both of them seems to be decreasing according to the outputs. The reason of this is that the determined ***Replication Length*** is not enough for this variables to reach their new steady state values after the change of ***Emptying Duration*** at the end of warm up period.

8. No Waiting for *FTL of Empty RTIs*

In this case, empty RTIs arriving at DCs are assumed to be transported one by one without waiting at DCs. It is expected that the empty RTI stock levels of DCs and the waiting times at these stock points become zero. According to the outputs, the average values of ***Cycle Time***, ***Lifetime*** and ***Time Spent in the Field*** decreases. At the end of warm up period, ***Pool Size*** is less than ***Initial Pool Size*** due to decrease in ***Cycle Time***. In the time period after warm up, average ***Pool Size*** is less than the one of original scenario. On the other hand, ***New RTI Replenishment Rate*** (which is measured after warm up period until the end of run) is close to the one of original scenario as expected since ***Probability of Disposal*** and ***Probability of Field Loss*** stays the same. It should be also noted that ***Number of Emergency Shipments*** is zero as expected for the model with emergency shipment because there is no empty RTI stock at DCs.

9. Very Large *Emergency Shipment Threshold* and *Minimum Emergency Shipment*

This check was firstly performed with a ***Emergency Shipment Threshold*** which is three times of the original one without changing ***Minimum Emergency Shipment***. ***Number of Contacts with DCs*** greatly decreases as expected. As a result, ***Number of Emergency Shipments*** also greatly decreases. Indeed, we observed only one emergency shipment in 5 replications.

This check was secondly performed with a ***Minimum Emergency Shipment*** which is larger than ***FTL of Empty RTIs***. This check gives no significant difference in ***Number of Contacts with***

DCs. However, ***Number of Emergency Shipments*** is given as zero for all replications as expected.

10. Zero *Emergency Shipment Threshold* and *Minimum Emergency Shipment*

This check was firstly performed with zero ***Emergency Shipment Threshold***. The output of the simulation model shows that ***Number of Contacts with DCs*** approximately doubles. In addition, ***Number of Emergency Shipments*** more than quadruples compared to the original scenario.

This check was secondly performed with a ***Minimum Emergency Shipment*** equal to 1. The average of ***Number of Contacts with DCs*** for 5 replications, turns out to be very close to the same of the original scenario. The same conclusion can be made for ***Number of Emergency Shipments***. Although sounds improbable, this result is expected because ***Number of Contacts with DCs*** limits ***Number of Emergency Shipments***. It is not possible to make an emergency shipment without contacting. Besides, after contacting with DCs, the manufacturer may learn that there is a shipment of empty RTIs on the way and decide not to make any emergency shipments.

11. Zero *Probability of Field Loss*

According to the outputs of the simulation models, ***Number of RTI Field Losses*** equals to zero. In addition ***New RTI Replenishment Rate*** and ***Total Purchasing Cost*** decrease. On the other hand, average values of ***Lifetime*** and ***Trippage*** increases, as expected.

12. Zero *Probability of Disposal*

The results similar to the case of zero ***Probability of Field Loss***. ***Number of RTI Disposals*** equals to zero. In addition ***New RTI Replenishment Rate*** and ***Total Purchasing Cost*** decrease. On the other hand, average values of ***Lifetime*** and ***Trippage*** increases, as expected.

13. Zero *Probability of Repair*

Number of Repairs and ***Total Repair Cost*** equal to zero. As a result, ***Total RTI Pool Management Cost*** decreases. There is no other change in the outputs mainly because it was assumed that repairing does not affect ***Lead Time of Preparing for Reuse***.

14. Zero *Initial Pool Size*

Initial Pool Size was entered as zero in this check. The results seem to be almost the same with the results of the original scenario. This is an expected outcome, because until the end of warm up period new RTIs are purchased as well as both the distribution and the size of the pool reach their steady states. Indeed, ***Actual Starting Pool Size*** is at a level close to average ***Pool Size*** for the period after warm up.

15. Very Large *Initial Pool Size*

Initial Pool Size was taken as 20 times as the same of original scenario. The most prominent change is ***New RTIs Replenishment Rate*** is zero and ***Total RTI Pool Holding Cost*** greately increases (more than 600%).

7.5. The Validation of The Simulation Models

Validation is about answering the question “Did we do the right thing?”. It is the process of resolving whether or not the conceptual model is a correct representation of the system by taking the objectives of the study into account. According to Irobi et al. (2001), the validation of conceptual models is questioning that the assumptions underlying the conceptual models are correct and they reasonably represent the problem for a given purpose. The simulations models were validated by using the methods face validity, internal validity and degenerate tests. These methods were explained in detail in sections 7.5.1-7.5.3.

7.5.1. Face Validity

Face validity is described by Irobi et al. (2001) by asking people familiar with the system if the logic used in the conceptual model is correct and whether or not input-output relationship is reasonable. The correctness of the conceptual model of the CLSC was discussed in detail in several meetings. These discussions were made in the light of the observations provided by our case study, the knowledge of similar cases and theoretical knowledge. Input-output relationship was found reasonable when the outputs of the simulation models were compared with the ones of the CLSC of our case study.

7.5.2. Internal Validity

According to Sargent (2003), a large amount of stochastic variability may be a sign of lack of consistency and may result in questionable results. He suggests that several replications (runs) of the simulation model should be performed to determine the extent of internal stochastic variability of the model.

We checked the internal validity of both of the simulation models by running them with 50 replications with a ***Replication Length*** of 3000 days, a ***Warm up Period*** of 3720 days, and using the scale ratio 1:20. The input combination belongs to the scenario without the use of RFID technology in the less problematic case. The details of the scenarios can be found in Chapter 9.

The results of the simulation runs can be found in Tables 7.6-7.7. The column named ‘Average’ shows the average of 50 replication averages. The columns named ‘Minimum’ and ‘Maximum’ shows the minimum and maximum of 50 replication averages. From these tables, it can be concluded that there is not a large amount of stochastic variability in each of the performance measures. The maximum ratio of half-width to average is less than 5%.

Table 7.6: The values of performance measures provided by the simulation model without emergency shipments

	Average	**Half-width**	**Minimum**	**Maximum**	**Half-width/ Average**
Cycle Time (days)	46.9	0.2	45.8	48.6	0.4%
Lifetime (days)	479.8	6.6	432.2	534.5	1.4%
Trippage (days)	9.8	0.1	8.8	10.8	1.3%
Pool Size	5155.6	217.6	4962.2	5377.0	4.2%
Fill Rate for Empty RTIs	97.6	0.3	94.9	99.4	0.3%
Fill Rate for Full RTIs	94.9	0.4	90.9	97.0	0.4%
New RTIs Replenishment Rate (RTIs/day)	10.7	0.2	9.0	12.7	2.0%
Time Spent in the Field (days)	32.1	0.1	31.7	32.5	0.2%
Total Cost of RTI Pool Management (€)	2,243,600	17,415	2,109,600	2,354,900	0.8%

Table 7.7: The values of performance measures provided by the simulation model without emergency shipments

	Average	**Half-width**	**Minimum**	**Maximum**	**Half-width /Average**
Cycle Time (days)	46.8	0.2	45.5	48.1	0.4%
Lifetime (days)	478.9	7.7	429.6	542.3	1.6%
Trippage (days)	9.8	0.2	8.8	11.1	1.5%
Pool Size	5153.0	18.0	5026.4	5324.8	0.3%
Fill Rate for Empty RTIs	98.9	0.1	97.5	99.6	0.1%
Fill Rate for Full RTIs	94.4	0.3	90.9	96.3	0.4%
New RTIs Replenishment Rate (RTIs/day)	10.8	0.2	9.5	12.1	1.5%
Time Spent in the Field (days)	32.1	0.1	31.6	32.5	0.2%
Total Cost of RTI Pool Management (€)	2,256,000	17,671	2,112,200	2,379,300	0.8%

7.5.3. Degenerate Tests

The degeneracy of the simulation model's behaviors were also tested by suitable choice of input parameters in order to answer whether or not the results change reasonable. An example to degeneracy tests was given by Irobi et al. (2001) as testing whether or not average number in the queue of a single server continue to increase with respect to time when the arrival rate is larger than the service rate.

We designed several degenerate tests and we observed that the simulation models gave expected results. Some examples to these tests include increasing/decreasing ***Demand Size***, increasing/decreasing ***Emptying Duration***, decreasing/increasing ***FTL of Empty RTIs***, etc.

8. SIMULATION OPTIMIZATON STUDY

This chapter starts with a brief introduction to simulation optimization in section 8.1. Section 8.2 presents the main features of the software used for this study. We explained the optimization model used in this study in section 8.3. In section 8.4, the lower and upper bounds for the decision variable of the optimization model were found. The simulation optimization model was verified and validated in section 8.5.

8.1. Introduction to Simulation Optimization

Simulation optimization was defined by Ólafsson and Kim (2002) as an optimization where the performance measure is the output of a simulation model and the problem setting includes the common optimization elements, namely decision variables, objective function and constraints. According to them, simulation optimization is a product of the need for a more exploratory process since a simple evaluation of performance is often insufficient.

Fu (2001a) has provided some examples of simulation optimization in manufacturing systems, supply chains and inventory control systems. Fu (2001b) discussed two important parts of simulation optimization, namely generating candidate solutions and estimating their objective function value. Fu (2001a) summarized the techniques used in simulation optimization into the following main categories.

1. Statistical procedures (such as ranking and selection procedures, etc.)
2. Metaheuristics (such as simulated annealing, tabu search, genetic algorithms, etc.)
3. Stochastic optimization (such as random search, stochastic approximation, etc.)
4. Others (such as ordinal optimization, sample path optimization, etc.)

There are several survey papers that discuss foundations, theoretical developments and applications of these techniques in the literature (Meketon, 1987; Jacobson and Schruben, 1989; Safizadeh, 1990; Azadivar, 1992; Fu,1994; Andradóttir, 1998; Swisher et al., 2000; Tekin and Sabuncuoglu, 2004).

8.2. Introduction to OptQuest

According to Law (2002), the availability of faster PCs and improved heuristic optimization search techniques lead to integration of optimization packages into simulation packages. He also indicated that "the goal of an optimization package is to orchestrate the simulation configurations, so that a system configuration is eventually obtained that provides and optimal or near optimal solution". Simulation configurations are particular settings of the decision variables. Law and Kelton (2000) listed the available software routines for performing this optimization.

OptQuest is one of the available routines for simulation optimization. Fu (2001a) described it as a stand-alone optimization routine that can be bundled with simulation environments such as

Arena and Crystal Ball. Its algorithm uses a combination of strategies based on scatter search and tabu search as well as neural networks for screening out candidate solutions that likely to be poor (Fu, 2001a). More detail about its algorithm can be found in Fu (2001a), Glover et al. (1999) and user's guide of OptQuest.

In OptQuest, it is possible to separate optimization procedure from simulation model. The optimization procedure uses the outputs of the simulation model to evaluate the results of the values of decision variables that were entered into the simulation model as inputs. According to both this evaluation and the evaluation of past results, the optimization procedure decides on a new set of values for decision variables as inputs to the simulation model. This relationship can be seen in Figure 8.1. The optimization procedure executes a special "non-monotonic search" in which the successively generated values of decision variables result in changing evaluations. Not all of these evaluations are improving; however the procedure seeks for a highly efficient path to the best solutions. This process continues until a terminating criterion is reached.

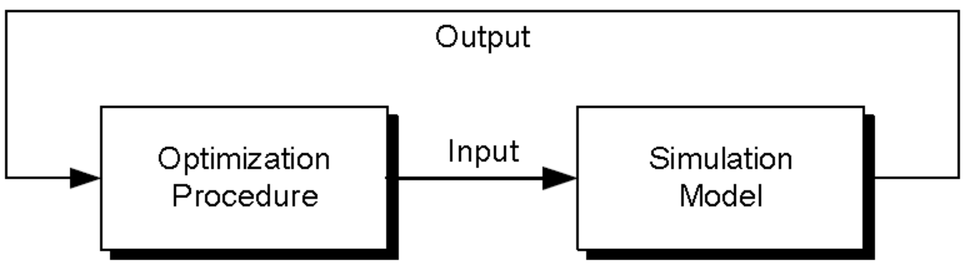

Figure 8.1: Coordination between optimization and simulation

8.3. The Simulation Optimization Model

Controls of OptQuest are the variables that OptQuest can meaningfully manipulate to affect the performance of a simulated system. In other words, controls are the decision variables. Responses are outputs from the simulation model and they are required to write the objective function and the constraints. For both of the simulation models, there is only one control which is ***Initial Pool Size***. On the other hand, the responses are ***Total Cost of RTI Pool Management*** and ***Fill Rate for Full RTIs***.

The optimization model can be written for both of the simulation model as follows:

Minimize ***Total Cost of RTI Pool Management*** (8.1)

Subject to ***Fill Rate for Full RTIs*** ≥ 95% (8.2)

By changing ***Initial Pool Size*** (8.3)

OptQuest requires the following for the control variable ***Initial Pool Size***:

- Lower and upper bounds to search optimal ***Initial Pool Size*** within specified interval
- Suggested value to start the search
- A discrete step size to continue search

How to find the lower and upper bounds were explained in the next section. Suggested value must be within the interval specified by these bounds. The average of these bounds can be taken as a suggested value. Step size, upper and lower bound determine the number of candidate solutions. As a result, they affect the run time required to search the solution set. Step size should be determined considering the length of specified interval and run time. Besides, it must be positive multiples of 20, since we decided to use scaling 20 RTIs to one entity. Considering the results of the next section and the observations of run time in trial runs, we decided to use the step size as 1 which corresponds to 20 RTIs. Number of simulations per one simulation run was selected to be the half of the difference between the lower and upper bounds so that one of the two solutions in the solution space can be checked. The bounds, suggested value and the number of simulations were provided in Appendix E.

At the end of a run, OptQuest returns ***Initial Pool Size*** that gives best ***Total Cost of RTI Pool Management*** for a ***Fill Rate for Full RTIs*** greater than 95%. In order to find out the values of other performance measures, the simulation model should be run with ***Initial Pool Size*** of best solution.

8.4. The Bounds for Initial Pool Size

As suggested by Lange and Semal (2010), the lower bound for pool size of RTIs can be found with the assumption of 'perfect coordination'. That is, a DC sends its RTIs to the manufacturer when it has reached its lot size ***FTL of Empty RTIs***. On the other side, the manufacturer receives this lot size exactly when needed, at the time when its inventory has just dropped to zero. Since Lange and Semal (2010) considered a network including only customers and factories, their assumption of perfect coordination only included the relationship between these parties. We needed to broaden their 'perfect coordination' assumption in order to include the relationship between DCs and end users. As a result, it was assumed that DCs do not hold full RTI inventory because they immediately distribute what they receive from the manufacturer to end users. In addition, it was also assumed that an end user receive a full RTI exactly when needed, at the time its only RTI has just emptied. In the notion of perfect coordination, we also assumed that there are no losses.

$$
\begin{aligned}
PS_{LB} = {} & The\ average\ number\ of\ RTIs\ in\ DCs \\
& + The\ average\ number\ of\ RTIs\ at\ the\ manufacturer \\
& + The\ average\ number\ of\ RTIs\ at\ end\ users
\end{aligned}
\tag{8.4}
$$

$$PS_{LB} = 3\frac{FTL_e}{2} + \sum_i \left(\frac{FTL_e}{2} \times \frac{d_i}{\sum_i d_i}\right) + Number\ of\ end\ users \quad (8.5)$$

where
PS_{LB}: The lower bound of the pool size
FTL_e: The full truck load (capacity of a truck) for empty RTIs
d_i: The average demand rate of DC i

The inventory varies at DCs from 0 to FTL_e. As a result, average inventory at each DC is $FTL_e/2$. In order to calculate the number of RTIs at the manufacturer, let us assume the manufacturer has no RTIs left and just receives the lot size FTL_e sent by DC i. It will consume the received RTIs at the speed $\sum_i d_i$. During this time, its average inventory will be $FTL_e/2$. Since the $d_i/\sum_i d_i$ represents the portion of time the manufacturer consumes the RTIs sent by DC i, the average inventory at the manufacturer is given by the 2nd term in equation 8.5. Since the lot sizes of all DCs equal to FTL_e, this term reduces to $FTL_e/2$. In conclusion, PS_{LB}=2260 given that FTL_e=380 and the assumed number of end users is 1,500.

The upper bound for pool size of RTIs can be found by summing up the maximum levels of all stock points in the CLSC. The maximum levels were found with the following assumptions. These assumptions may not be found realistic. However, the important point here was to find an upper bound for pool size which was better than taking infinity and at the same time surely greater than the optimal pool size.

- The maximum level of empty RTI stock at the manufacturer was assumed to be the total of ***Reorder Point for Purchasing*** and ***Purchasing Lot Size.*** We assumed that this stock level hit ***Reorder Point for Purchasing***, so that an order of new RTIs having a lot size of ***Purchasing Lot Size*** was given and the level of this stock was at ***Reorder Point for Purchasing*** when the order arrived.
- The maximum possible level of full RTI stock at the manufacturer is ***Order up to Level of Full RTI Stock***.
- The maximum level of full RTI stock at DCs was assumed to be enough to satisfy one week's full RTI demand.
- The maximum number of RTIs per end user was assumed to be 2. One should be half-full and the other one should be empty or full.
- The maximum level of empty RTI stock level of DCs is FTL_e.

Reorder Point for Purchasing and ***Purchasing Lot Size*** change with respect to ***Probability of Loss***. ***Probability of Loss*** changes with respect to the use of RFID technology and the extent of improvement that it brings. As a result, upper bound of pool size is expected to change between scenarios developed in Chapter 9. Table 8.1 shows the upper bounds of pool size for developed scenarios. The details of scenarios can be found in Chapter 9.

Table 8.1. The upper bound of pool size for different scenarios

	Without RFID	With RFID			
		Pessimistic	Neutral	Optimistic	Very Optimistic
The less problematic case	7085	7006	6848	6642	6406
The more problematic case	8569	8357	7921	7471	7006

8.5. Verification and Validation of the Simulation Optimization Model

The simulation optimization model was verified with extreme value check. The results of extreme value checks can be found in section 8.5.1. On the other hand, the model was validated with degenerate tests. The results of degenerate tests can be found in 8.5.2. Verification and validation were already defined in sections 7.4 and 7.5, respectively.

8.5.1. Extreme Value Check

This check was performed in order to see whether or not the optimization simulation model provides plausible outputs to extreme and unlikely combination of levels of parameters. The scenario without the use of RFID technology in the less problematic case was used for the runs. We could only develop two extreme cases with target level of ***Fill Rate for Full RTIs***, which is the only input of the optimization procedure of the simulation optimization model. In addition, we observed that ***Total RTI Pool Management Cost*** is largely affected by ***Pool Size***. Pool Size is expected to change with respect to ***Probability of Field Loss***, ***Probability of Disposal***, and ***Emptying Duration***. As a result, we developed 4 additional extreme cases with these parameters. The results of 6 extreme cases were checked and compared with the results of the original scenario giving best ***Total RTI Pool Management Cost*** as €2,205,460 and average ***Pool Size*** of 5150. The simulation optimization model provided expected results for in all extreme cases. As a result, we could conclude that the simulation optimization seemed to be working and providing correct results.

1. Target *Fill Rate for Full RTIs* of 1%

We updated the constraint given with equation 8.2 as follows:

$$\textbf{\textit{Fill Rate for Full RTIs}} \geq 1\% \qquad (8.6)$$

As expected, all tested ***Initial Pool Size*** values within the bounds given in section 8.4 were found to be feasible solutions. The best found solution gave an ***Initial Pool Size*** of 3800. We run the simulation model with this input and found that ***Fill Rate for Full RTIs*** was 94%. It was not close to 1% because the decision rules for the timing and quantity of replenishments of the full and empty RTI stocks at the manufacturer were modeled according to the target service levels.

2. Target *Fill Rate for Full RTIs* of 99%

We updated the constraint given with equation 8.2 as follows:

$$\textbf{\textit{Fill Rate for Full RTIs}} \geq 99\% \qquad (8.7)$$

As expected, all tested solutions of ***Initial Pool Size*** within the bounds given in section 8.4 were found to be infeasible. This was expected because the decision rule for the timing and quantity of replenishments of the full RTI stock at the manufacturer were modeled according to the target service level of 95%.

3. No Losses

We solved the simulation optimization model with zero ***Probability of Disposal*** and zero ***Probability of Field Loss***. The best found solution gave ***Total RTI Pool Management Cost*** about €1,460,000. We run the simulation model with the best found ***Initial Pool Size*** and found that average ***Pool Size*** is about 5500. As RTIs are lost in the CLSC, it is required to sustain the losses by new RTI replenishment. When the losses are zero, this does not mean that average Pool Size should decrease extensively. Rather, this means that new RTI replenishments should decrease and as a result ***Total RTI Pool Management Cost*** should decrease.

4. Very High Losses

We solved the simulation optimization model with taking both ***Probability of Disposal*** and ***Probability of Field Loss*** 0.5. The best found solution gave ***Total RTI Pool Management Cost*** about €9,000,000. We run the simulation model with the best found ***Initial Pool Size*** and found that average ***Pool Size*** is about 6000.

5. Zero *Emptying Duration*

We solved the simulation optimization model with zero ***Emptying Duration*** and zero ***Minimum Emptying Duration*** by assuming that RTIs are immediately emptied when they reach DCs. The best found solution gave average ***Total RTI Pool Management Cost*** about €1,700,000 over 5 replications. We run the simulation model with the best found ***Initial Pool Size*** and found that average ***Pool Size*** is about 2300. The decrease in average ***Pool Size*** was expected due to decrease in average ***Cycle Time***. In addition, smaller average ***Pool Size*** brought less cost, as expected.

6. Very Large *Emptying Duration*

We solved the simulation optimization model with a very large ***Emptying Duration***, which is 150 days for all DCs. The best found solution gave ***Total RTI Pool Management Cost*** about €4,500,000. We run the simulation model with the best found ***Initial Pool Size*** and found that average ***Pool Size*** is about 19,000. The high increase in average ***Pool Size*** was expected due to high increase in average ***Cycle Time***. In addition, larger average ***Pool Size*** brought higher cost, as expected.

8.5.2. Degenerate Tests

The degeneracy of the simulation optimization model's behavior was also tested by suitable choice of input parameters in order to answer whether or not the results change reasonable. We used the parameters changing with the use of RFID technology and the extent of improvement that it brings, namely ***Probability of Disposal***, ***Probability of Field Loss*** and ***Emptying Duration*** in these tests. The reason of this parameter choice was to ensure the validity of simulation optimization model to provide fair results in experimental analysis with the developed scenarios. We observed that the change in ***Total RTI Pool Management Cost*** with respect to these parameters was all as expected. The experimental study in Chapter 10 represents examples for such tests. Because of this reason, we found it was unnecessary to give any results here.

9. SCENARIO ANALYSIS

It is discussed before that our aim is to compare the best situations without and with the use of RFID technology in order to find out to true impact of using this technology. With the aim of making this comparison, we firstly need to develop scenarios for the situation of the CLSC without the use of this technology. A scenario is composed of the set of parameters directly changing with the use of RFID technology, namely ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage*** and the distributions of ***Emptying Duration*** for all DCs. Secondly, we need to develop scenarios which present the possible situations that the CLSC becomes with the use of RFID technology given the situation of the CLSC before it. These two steps are explained in section 9.1. Next, in section 9.2, the inputs required for the simulation models and changing with respect to the developed scenarios are analyzed.

9.1. Scenario Developing

We developed the first scenario for the situation of the CLSC before the use of RFID technology partly based on our case study. This scenario is party based on our case study due to some limitations of available data related with ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage***. As a result, estimate values for these parameters were used for this scenario. On the other hand, the distributions of ***Emptying Duration*** were found out by using the RFID data.

The second scenario for the situation of the CLSC before the use of RFID technology was developed to reveal the impact of RFID technology for a situation of the CLSC much worse than the situation described with the first scenario in terms of the parameters changing with the use of this technology. For the second scenario, it was assumed that ***Probability of Field Loss***, ***Probability of Disposal***, ***Probability of Repairable Damage***, and the coefficient of variation (CV) of ***Emptying Duration*** are the triples of their values used in the first scenario. The first and the second scenario are named as *the less problematic case* and *the more problematic case*, respectively. The parameter values for both of these cases can be seen in Table 9.1. This table gives the distributions of ***Emptying Duration*** for all DCs as normal which is denoted as $NORM(\mu,\sigma)$.

Table 9.1: The set of input values (changing directly with the use of RFID technology) for the less and the more problematic cases

	The Less Problematic Case	**The More Problematic Case**
Probability of Field Loss	0.05	0.15
Probability of Disposal	0.05	0.15
Probability of Repairable Damage	0.10	0.30
Emptying Duration of DC-1	NORM(21.5,10.5)	NORM(21.5,31.5)
Emptying Duration of DC-2	NORM(22.5,12.7)	NORM(22.5,38.1)
Emptying Duration of DC-3	NORM(25.9,16.0)	NORM(25.9,48.0)

For each of the cases, namely the less and the more problematic cases, the situation of the CLSC after the use of RFID technology is expected to differ with respect to the extent of the improvement. Therefore, we developed 4 scenarios for each of the two cases, namely pessimistic, neutral, optimistic and very optimistic, which present possible extents of the improvement. The extent of the improvement presented by these 4 scenarios can be seen in Table 9.2. The percentage values given in the rows of ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage*** are the percentages of expected decreases in these inputs. In addition, the values given in the row of ***Emptying Duration*** show the maximum percentiles that should be taken into account when finding the distribution of ***Emptying Duration*** with the use of RFID technology. More detailed explanation was given in the next section.

Table 9.2: The extent of improvements with the use of RFID technology for both the less and the more problematic cases

	With RFID			
	Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
Probability of Field Loss	10%	30%	50%	70%
Probability of Disposal	10%	30%	50%	70%
Probability of Repairable Damage	10%	30%	50%	70%
Emptying Duration	95^{th} Percentile	85^{th} Percentile	75^{th} Percentile	65^{th} Percentile

In summary, there are $2 \times 5 \times 2 = 20$ scenarios to experiment with, because there are

- 2 cases, namely the less problematic case and the more problematic case;
- 5 scenarios, 1 of them presents the situation without the use of RFID technology, 4 of them presents a subset of possible situations with the use of RFID technology; and

- 2 possible options regarding emergency shipment, namely emergency shipments are allowed and not allowed.

9.2 Input Analysis for Scenarios

This section gives the inputs of the simulation study whose values change with respect to the developed scenarios. It should be noted here that the values of input parameters were calculated with respect to the distinctions between

- Without and with the use of RFID technology, and
- The less and the more problematic cases.

The option of emergency shipment does not affect the value of the parameters.

9.2.1. Inputs Related with Shrinkage and Repairable Damage

The values of ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage*** in the pessimistic, neutral, optimistic and very optimistic scenarios developed for the less and the more problematic cases are shown in Table 9.3 and 9.4, respectively. The values under the columns of "with RFID'' were calculated based on the improvement percentages given in Table 9.2

Table 9.3: The values of ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage*** for the scenarios of the less problematic case

	Without RFID	**With RFID**			
		Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
Probability of Field Loss	0.05	0.045	0.035	0.025	0.015
Probability of Disposal	0.05	0.045	0.035	0.025	0.015
Probability of Repairable Damage	0.10	0.090	0.070	0.050	0.030

Table 9.4: The values of ***Probability of Field Loss***, ***Probability of Disposal***, and ***Probability of Repairable Damage*** for the scenarios of the more problematic case

	Without RFID	With RFID			
		Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
Probability of Field Loss	0.15	0.135	0.105	0.075	0.045
Probability of Disposal	0.15	0.135	0.105	0.075	0.045
Probability of Repairable Damage	0.30	0.270	0.210	0.150	0.090

9.2.2. The Inputs Related with Emptying Duration

The data gathered with RFID technology makes possible to reach the distribution of time that an RTI spends in the field. i.e. the duration between the time that an RTI leaves the manufacturer and the time it returns back. The distribution of time that RTI spends in the field is expected to change with respect to the DC that it is sent to. The main reasons for this are the facts that the demand rates of DCs are different (which especially changes the waiting time at DCs) and how DCs are operated may show differences.

With the help of available RFID data, we found out the distribution of time spent in the field for each DC. Since there were the missing scans of shipments and the missing reads during the scan of shipments, RFID data contained some inconsistent entries. Because of this reason, we did not use the raw data. Rather, we used the data after cleaning inconsistent entries. In Appendix F, it was explained how the data was cleaned.

The sets of cleaned data of time spent in the field for all DCs were analyzed with ARENA Input Analyzer. Since the distribution of ***Time Spent in the Field*** has a long right tail, no distribution (among beta, erlang, exponential, gamma, lognormal, normal, triangular, uniform and weibull distributions) was found to be fitted well. The chi-square test gives p-values less than 0.005 for all of the mentioned distributions. We chose to fit normal distribution in order to utilize the property of this distribution stating that if X_1, X_2 are two independent random variables normally distributed with means μ_1, μ_2 and standard deviations σ_1, σ_2, then their linear combination is also be normally distributed. This property was required because what we needed to find out as input to our simulation model from these analyzed data was the distribution of ***Emptying Duration***. ***Emptying Duration*** is the duration between the time that an RTI leaves the manufacturer and the time that it comes back to the DC that it is lastly sent to. Finding out the distribution of ***Emptying Duration*** was required in order to be able to model the shipments of

RTIs from DCs in ***FTL of Empty RTIs***. Normal distribution fitting has given the mean and standard deviation values as shown in Table 9.5.

Table 9.5: The parameters of the normal distribution of ***Time Spent in the Field***

	Mean (days)	**Standard deviation (days)**
DC-1	27.3	10.3
DC-2	29.3	12.4
DC-3	35.6	15.4

In order to find out the distribution of ***Emptying Duration***, we needed to make estimation for the time difference between ***Time Spent in the Field*** and ***Emptying Duration***. The details of how this estimation was made can be found in Appendix G. We fitted normal distribution to this time difference. As a result, we estimated that ***Emptying Duration*** is normally distributed with the parameters (changing with respect to the DC that RTI is sent to) given in Table 9.6.

Table 9.6: The parameters of the normal distribution of ***Emptying Duration***

	Mean (days)	**Standard deviation (days)**
DC-1	21.5	10.5
DC-2	22.5	12.7
DC-3	25.9	16.0

The fitted normal distributions produce random values and they are symmetric around their means. Therefore, it may happen that they give unrealistic values for ***Emptying Duration***. For example, it is possible to produce an ***Emptying Duration*** of 3 days with any normal distribution given in Table 9.6, although it is not possible to happen in real life. Therefore, it was required to truncate the fitted normal distributions with ***Minimum Emptying Duration***. ***Minimum Emptying Duration*** was assumed to be the minimum of ***Emptying Duration*** that can happen in real life. Table 9.7 shows how it was calculated.

Table 9.7: The calculation of ***Minimum Emptying Duration***

Activity	**Minimum Assumed Duration (days)**
Waiting time at DC (full)	1
Transportation to end user	1
Waiting time at end user (full)	1
Emptying at end user	1
Waiting time at end user (empty)	1
Transportation from end user	1
TOTAL	**6**

In order to find the distribution of for all developed scenarios, the following steps were conducted:

1. ***Emptying Duration*** data were generated with each normal distribution given in Table 9.6 for the less problematic case. For the more problematic case, the same normal distributions were used after their CV values were tripled, i.e. the standard deviation values were multiplied by 3. Data were generated with the help of ARENA in order to obtain a data set including 5000 data points each of which greater than or equal to ***Minimum Emptying Duration***. The model and experiment frames of this ARENA model can be found in Appendix H.

2. Generated data were sorted. Next, for each scenario regarding the use of RFID technology, a smaller data set was obtained by only including the data points smaller than a certain percentile (as given in Table 9.2) of the whole data set. The smaller data sets had the number of data points given in Table 9.8.

Table 9.8: The number of data points in the data set obtained with respect to a percentile value

Scenario	**Percentile**	**The Number of Data Points**
Pessimistic	95^{th} Percentile	4750
Neutral	85^{th} Percentile	4250
Optimistic	75^{th} Percentile	3750
Very Optimistic	65^{th} Percentile	3250

3. The whole data set and the smaller data sets were analyzed with Arena Input Analyzer. It was found they were best fitted to the beta distribution among all possible continuous probability distributions, namely beta, erlang, exponential, gamma, lognormal, normal, triangular, uniform and weibull distributions, which can be tested with this software. The equations for the distributions of ***Emptying Duration*** with and without the use of RFID technology for the less and the more problematic cases can be found in Table 9.9, Table 9.10, and Table 9.11.

Table 9.9: The distribution of ***Emptying Duration*** without the use of RFID technology for the less and the more problematic cases

	The Less Problematic Case	**The More Problematic Case**
DC-1	6 + 53 * BETA(1.98, 4.16)	6 + 128 * BETA(1.39, 4.15)
DC-2	6 + 60 * BETA(1.74, 3.83)	6 + 146 * BETA(1.18, 3.46)
DC-3	6 + 79 * BETA(1.79, 4.30)	6 + 203 * BETA(1.33, 4.34)

Table 9.10: The distribution of ***Emptying Duration*** with the use of RFID technology for the less problematic case

	With RFID			
	Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
DC-1	6 + 34 * BETA(1.56, 1.75)	6 + 28 * BETA(1.49, 1.4)	6 + 24 * BETA(1.43, 1.21)	6 + 21 * BETA(1.42, 1.15)
DC-2	6 + 39 * BETA(1.45, 1.79)	6 + 31 * BETA(1.39, 1.39)	6 + 26 * BETA(1.33, 1.16)	6 + 23 * BETA(1.35, 1.17)
DC-3	6 + 48 * BETA(1.4, 1.71)	6 + 39 * BETA(1.39, 1.43)	6 + 32 * BETA(1.28, 1.1)	6 + 28 * BETA(1.28, 1.07)

Table 9.11: The distribution of ***Emptying Duration*** with the use of RFID technology for the more problematic case

	With RFID			
	Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
DC-1	6 + 74 * BETA(1.17, 1.75)	6 + 56 * BETA(1.11, 1.3)	6 + 47 * BETA(1.12, 1.22)	6 + 40 * BETA(1.13, 1.2)
DC-2	6 + 86 * BETA(1.03, 1.59)	6 + 66 * BETA(1.02, 1.3)	6 + 54 * BETA(1.02, 1.2)	6 + 45 * BETA(1.05, 1.17)
DC-3	6 + 111 * BETA(1.09, 1.69)	6 + 84 * BETA(1.08, 1.34)	6 + 69 * BETA(1.09, 1.24)	6 + 57 * BETA(1.12, 1.19)

9.2.3. The Inputs Related with Purchasing of New RTIs

Reorder Point for Purchasing for the scenarios of the less and the more problematic cases were calculated according to the formulas given in section 6.6. The values of required parameters, namely ***Expected Lead Time Full RTI Demand*** and ***Variance of Lead Time Full RTI Demand***, for these formulas were already given in section 6.6. Table 9.12 and 9.13 gives the values of the related parameters in the calculation of ***Reorder Point for Purchasing*** and the values of ***Reorder Point for Purchasing*** for the scenarios of the less and the more problematic cases, respectively.

Table 9.12: The calculation of ***Reorder Point for Purchasing*** without and with the use of RFID technology for the less problematic case

	Without RFID	**With RFID**			
		Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
Probability of Field Loss	0.05	0.045	0.035	0.025	0.015
Probability of Disposal	0.05	0.045	0.035	0.025	0.015
Probability of Loss	0.0975	0.0880	0.0688	0.0494	0.0298
Probability of Reuse	0.9025	0.9120	0.9312	0.9506	0.9702
Expected Lead Time Full RTI Demand	6,288	6,288	6,288	6,288	6,288
Variance of Lead Time Full RTI Demand	719,104	719,104	719,104	719,104	719,104
Expected Lead Time Reuses	5,674.9	5,734.8	5,855.5	5,977.5	6,100.8
Variance of Lead Time Reuses	586,268.0	598,647.7	623,995.3	650,140.7	677,100.5
Expected Lead Time Net RTI Demand	613.1	553.2	432.5	310.5	187.2
Variance of Lead Time Net RTI Demand	7,389.3	6,070.1	3,804.1	2,048.2	819.2
Reorder Point for Purchasing	**813**	**734**	**576**	**415**	**254**

Table 9.13: The calculation of ***Reorder Point for Purchasing*** without and with the use of RFID technology for the more problematic case

	Without RFID	With RFID			
		Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
Probability of Field Loss	0.15	0.135	0.105	0.075	0.045
Probability of Disposal	0.15	0.135	0.105	0.075	0.045
Probability of Loss	0.2775	0.2518	0.1990	0.1444	0.0880
Probability of Reuse	0.7225	0.7482	0.8010	0.8556	0.9120
Expected Lead Time Full RTI Demand	6,288	6,288	6,288	6,288	6,288
Variance of Lead Time Full RTI Demand	719,104	719,104	719,104	719,104	719,104
Expected Lead Time Reuses	4,543.1	4,704.8	5,036.8	5,380.2	5,734.8
Variance of Lead Time Reuses	376,637.5	403,768.2	462,408.9	527,228.6	598,647.7
Expected Lead Time Net RTI Demand	1,744.9	1,583.2	1,251.2	907.8	553.2
Variance of Lead Time Net RTI Demand	56,636.2	46,769.0	29,472.3	15,765.9	6,070.1
Reorder Point for Purchasing	**2,297**	**2,085**	**1,649**	**1,199**	**734**

Purchasing Lot Size for the scenarios of the less and the more problematic cases were found according to modified EOQ method which is given in section 6.6. The values of required parameters, namely ***Unit RTI Price***, ***Unit RTI Holding Cost***, ***Unit Transportation Cost***, and ***Full Truck Load of Empty RTIs*** were already given in section 7.2. ***Expected Annual Net RTI Demand*** was calculated by multiplying ***Expected Annual Full RTI Demand*** and ***Probability of Loss***.

Empty RTI consumption in one week may be large enough so that a replenishment size of one ***Purchasing Lot Size*** is not large enough to raise the inventory position above ***Reorder Point for Purchasing***. In such a situation, a solution can be using the minimum integer number of multiples of ***Purchasing Lot Size*** which is enough to raise the inventory position above ***Reorder Point for Purchasing***. On the other hand, it is possible to find a replenishment size which is large enough and gives smaller purchasing cost per RTI. The difference in unit purchasing cost between these two possible solutions was found to be very small for all the developed scenarios. As a result, it is found suitable to use the first solution, i.e. using the minimum integer number of multiples of ***Purchasing Lot Size*** which is enough to raise the inventory position above ***Reorder Point for Purchasing***. More detailed information regarding this conclusion and the calculation of ***Purchasing Lot Size*** can be found in Appendix I. Table 9.14 shows the values of ***Purchasing Lot Size*** for the scenarios of both the less and the more problematic cases.

Table 9.14: The values of ***Purchasing Lot Size*** for the scenarios of both the less and the more problematic cases

	Without RFID	**With RFID**			
		Pessimistic	**Neutral**	**Optimistic**	**Very Optimistic**
The Less Problematic Case	380	380	380	335	260
The More Problematic Case	380	380	380	380	380

10. EXPERIMENTAL ANALYSIS

In experimental analysis, the scenarios developed in Chapter 9 were analyzed. The simulation optimization model used to find optimal solutions for all scenarios of the cases in which emergency shipment is not an option and emergency shipments can be useful. In total, optimal solutions were found for 20 scenarios.

The optimal solutions are ***Initial Pool Size*** values giving the minimum ***Total RTI Pool Management Cost*** with the condition of satisfying target fill rate of 95% for the full RTI demand. The optimal values of ***Initial Pool Size*** were inputted into the simulation model in order to find out the values of other performance measures of the optimal solutions. In this analysis, we considered the following performance measures:

- Total RTI pool management cost
- Average Cycle Time
- Average pool size
- Average trippage
- Average lifetime
- Average time spent in the field
- Average rate of new RTI replenishment

We excluded the performance measures ***Fill Rate for Full RTIs*** and ***Fill Rate for Empty RTIs*** from this list, because we already ensured that they were at a desired level with the constraint of target fill rate for the full RTI demand on the optimal solution. It should be noted here that the ultimate reason of ensuring target fill rate of 99% for the empty RTI stock was to obtain the target fill rate for the full RTI stock. The values of these performance measures can be found in Appendix J.

The outputs presented in this chapter are the average values of 5 replications. Figure 10.1 shows optimal values of total RTI pool management cost for all scenarios. In the following figures, ‘No ES’ and ‘With ES’ refer to the case in which the emergency shipment is not allowed and to the case in which emergency shipment can be useful, respectively. In addition, ‘Case 1’ and ‘Case 2’ refers to the less problematic case and the more problematic cases, respectively.

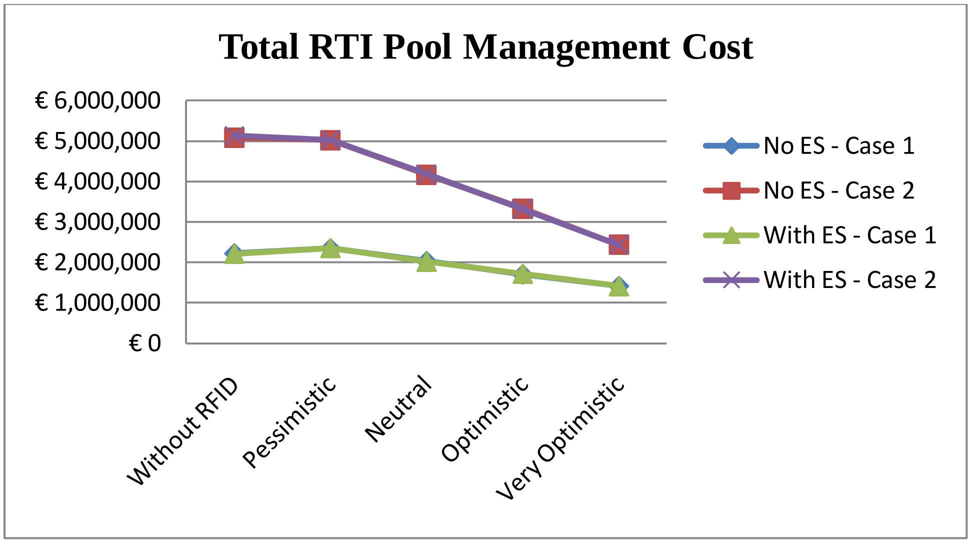

Figure 10.1: Optimal total RTI pool management cost values for all scenarios

Although it is hard to recognize at first sight, Figure 10.1 shows 4 lines. The lines for the case in which emergency shipment is not allowed and for the case in which emergency shipments can be useful, collide for the cases having the same degree of problems. The reason is that the optimal level of total RTI pool management cost is approximately same regardless of the option of emergency shipments, with all other things being the same. In fact, the same issue is valid for the other performance measures as it can be seen from figures 10.2-10.7. In the optimal solutions, the number of emergency shipments made in the time horizon of simulation runs is small due to high level of ***Emergency Shipment Threshold*** and ***Minimum Emergency Shipment Lot Size***. As a result, the option of emergency shipment does not affect the results significantly.

The lower and the upper line in Figure 10.1 show the change of optimal total RTI pool management cost with respect to the use of RFID technology and the extent of the improvement that it brings from pessimistic level to very optimistic level in the less and in the more problematic cases, respectively. In the less problematic case, total cost with the use of RFID technology is less than the same without it, if the extent of the improvement is neutral, optimistic or very optimistic. On the other hand, in the more problematic case total cost can be decreased with the use of RFID technology if the extent of improvement is not smaller than the pessimistic level.

Figure 10.2 shows the average pool size in optimal solutions of all scenarios. In this figure, the upper (lower) line belongs to the more (less) problematic case. In addition, Figure 10.3 shows the average rate of new RTI replenishment to maintain the RTI pool in optimal solutions. In this figure, the upper (lower) line also belongs to the more (less) problematic case due to higher (lower) RTI losses. The rate of decreases in pool size and in the rate of new RTI replenishment as the level of improvement increases are larger in the more problematic case than in the less problematic case.

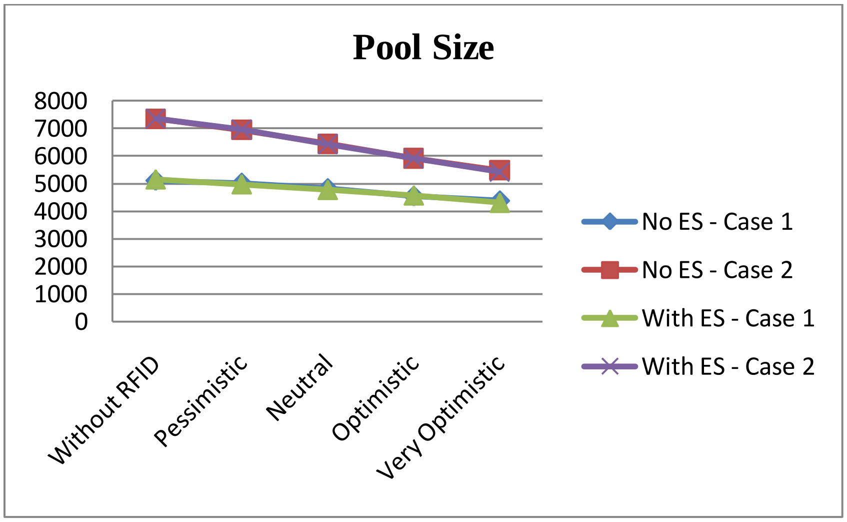

Figure 10.2: Average pool size in optimal solutions of all scenarios

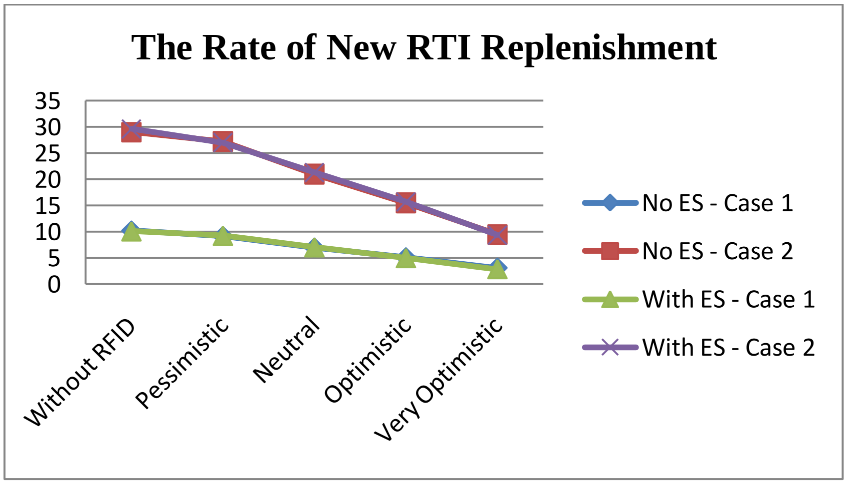

Figure 10.3: Average rate of new RTI replenishment in optimal solutions of all scenarios

Figure 10.4 shows the average cycle time in optimal solutions of all scenarios. In this figure, the upper (lower) line belongs to the more (less) problematic case. In addition, Figure 10.5 shows the average time spent in the field which is a part of the cycle time. As the extent of improvement increases, both cycle time and time spent in the field decrease less in the less problematic case compared to the more problematic case.

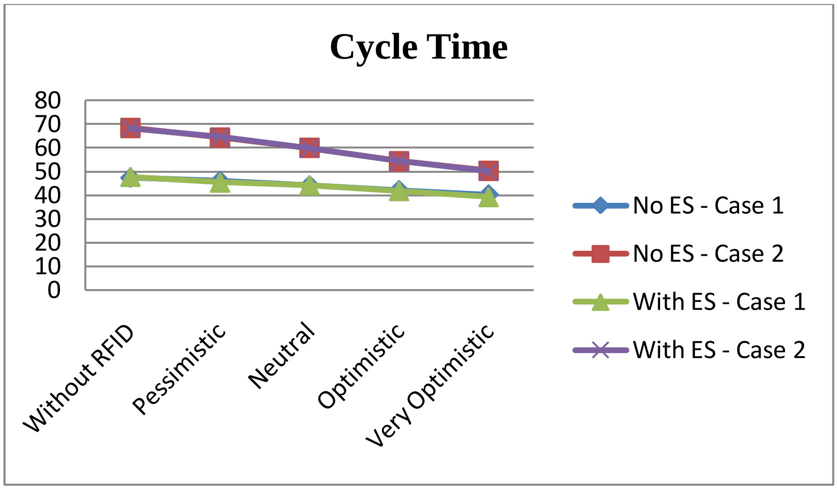

Figure 10.4: Average cycle time in optimal solutions of all scenarios

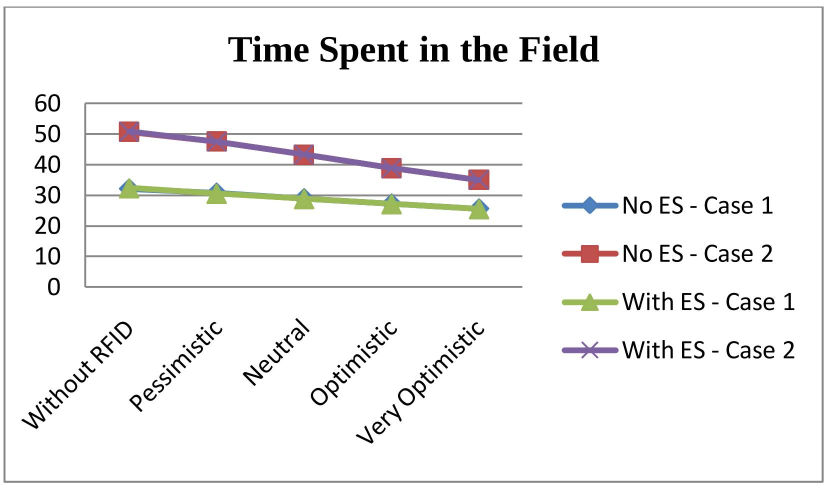

Figure 10.5: Average time spent in the field in optimal solutions of all scenarios

Figures 10.6 and 10.7 show the average trippage and the average useful lifetime of RTIs in optimal solutions of all scenarios. In these figures, the lower (upper) lines belong to the more (less) problematic case. The rates of increases in both of these performance measures rise as the level of improvement increases both in the more and in the less problematic cases.

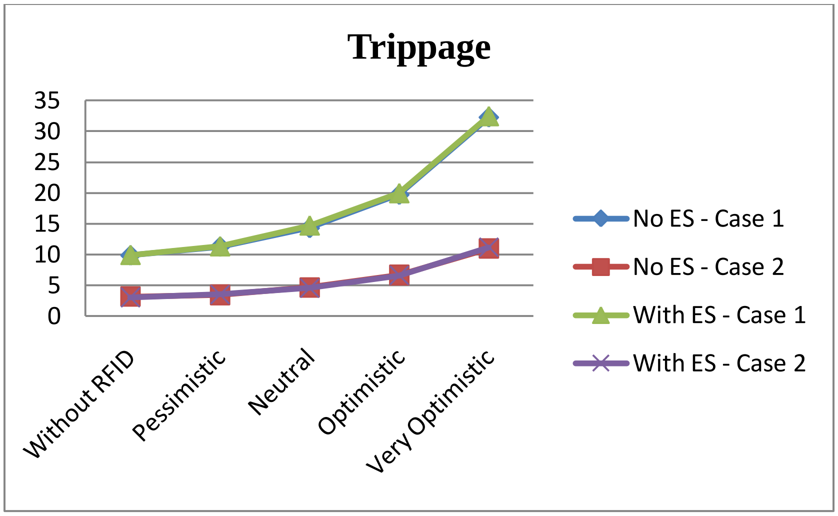

Figure 10.6: Average trippage in optimal solutions of all scenarios

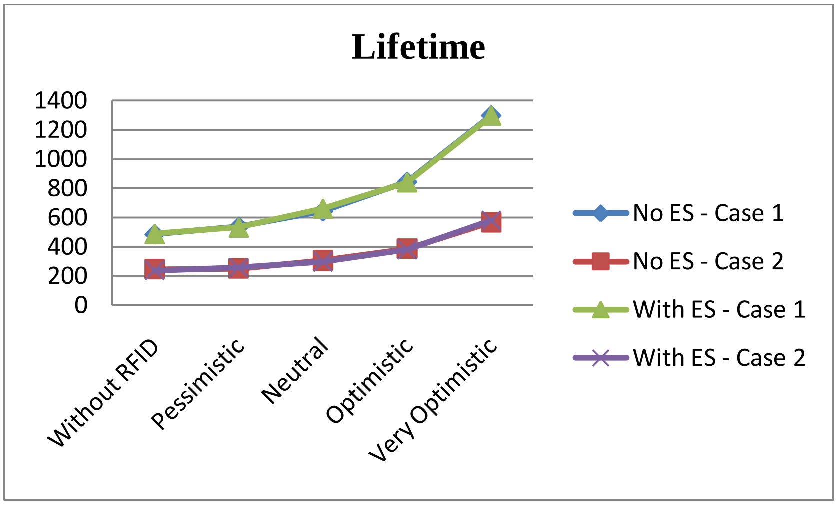

Figure 10.7: Average useful RTI lifetime in optimal solutions of all scenarios

11. SOFTWARE IMPLEMENTATION

The software packages used in this study together with the purpose of using them are as follows:

1. Arena simulation software was used to develop the simulation models.
2. Arena Input Analyzer was used to analyze both available and generated data in order to find out the distribution of parameters required for the simulation models.
3. OptQuest for Arena optimization routine was used for the application of simulation optimization method.
4. Arena simulation software together with Excel spreadsheets were used to generate data, for example to generate ***Emptying Duration*** data.

The implementation issues related with the above software packages were explained in sections 11.1-11.4.

11.1. Arena Simulation Software

The simulation models were developed in parallel to the development of the problem definition. As some specifications in the problem definition were modified and new ones were added to the problem definition, we updated the simulation models by adding the new decision rules or modifying the existing ones. The simulation models were updated conveniently with Arena since the models were composed of small units named as blocks. Each block has its own purpose. When a simulation model was needed to be modified, it was enough to change only the related blocks and elements. In the same way, the developed simulation models can be utilized after changing the related blocks and input parameters for similar problems and for different set of input parameters. In addition to the simulation optimization, they can be used by the manufacturer to measure the effect of some policy changes on performance measures of the RTI pool management.

The simulation models were verified by debugging the process of simulation runs with Arena's run controller. This run controller has various commands to trace the flow of entities from the selected block, the flow of selected entity through the blocks, the change of selected variable, the change of selected attribute value of active entities, etc. It is also possible to trace the flow of all entities through all blocks at the same time. Using this run controller was a convenient way to verify our simulation models due to available trace options and ease of use.

11.2. Arena Input Analyzer

Arena Input Analyzer was used for

- Fitting distributions to the available data, for example to the data of ***Demand Interarrival Time***;
- Generating data from a given distribution, for example the data for the waiting time at empty RTI stock of DCs with uniform distribution.

It is an easy to use input analyzer. It has an option named 'Fit All', which checks every possible defined distributions and returns with the best fitted one. In addition, it gives the formula of the fitted distribution in the format of Arena. So, its result can be directly copy-pasted to Arena without any change of format.

11.3. OptQuest for Arena

OptQuest is easy to use software only if the user has basic knowledge of optimization models. It tries to find the best value for the selected objective function by changing the value of the selected controls within their range in the simulation model. Its run time depends on several factors including

- The run time of a single replication of simulation model,
- The number of replications per simulation (can be fixed and varying), and
- The number of simulations which depends on the size of solution space determined by the controls (decision variables) and their ranges.

In our study, the run time of a single replication of simulation model turned out to be very large due to the high number of entities. Because of this reason, we used scaling in order to reduce the run time. If our study was just a simulation study, the run time would be acceptable. However, we needed to run the simulation models for each developed scenario for a high number of simulations each having 5 replications. With the help of scaling, we obtained reasonable run time for finding the best solution for one scenario. However, the process of giving the decision of scaling required additional efforts.

11.4. Data Generation with Arena and Excel

In addition to the development of the simulation models, Arena was also used to generate data. It is possible to read input and write output to Excel sheets with Arena. We could successfully generated required data with Arena and make it write the generated data to Excel sheets. From the Excel sheets we could make the necessary operations to the generated data and obtain what we needed. For instance, ***Emptying Duration*** data was generated with respect to ***Minimum Emptying Duration*** and ***Emptying Time Distribution*** in order to find out ***Emptying Duration Distribution*** for different scenarios. Using Arena was more convenient than using Arena Input Analyzer since the data was generated considering a minimum value and we needed the generated data in Excel sheets to do the operations necessary for obtaining ***Emptying Duration Distribution***'s for different scenarios.

12. CONCLUSION

In this study, we quantified the value of RFID technology for the management of RTI pools in a CLSC setting. We considered both the benefits and the costs of using RFID technology in this quantification. Our study started with literature search in order to discover all potential benefits of RFID technology in CLSC of RTIs. We provided a general quantification formula for all discovered potential benefits.

We conducted a case study in an RFID pilot project in a company who sells its product in a type of RTI. This case study helped us to make a problem definition in which all aspects of the CLSC and the management of RTIs were defined. Based on our problem definition, the simulation models of the CLSC were developed and embedded into a simulation optimization tool in order to find out the difference between the optimal way of RTI management with the use of RFID technology and the same without the use of RFID technology. The comparisons were made based on developed scenarios portraying the severity of problems (the less and the more problematic cases) related with the use of RTIs and the extent of improvement that RFID brings (pessimistic, neutral, optimistic and very optimistic) in the decrease of problems.

In the less problematic case, the use of RFID technology is only profitable if the extent of the improvement is neutral, optimistic or very optimistic. If the expected extent of improvement cannot exceed the pessimistic level, it is better not to use RFID technology. The threshold value for the extent of improvement is less in the more problematic case. Total cost of RTI pool management can be decreased with the use of RFID technology even if the extent of improvement stays at the pessimistic level.

To the best out knowledge, this study is the most comprehensive research on the value quantification of RFID for managing RTI pools. We considered every aspect of the CLSC that can be known by the owner of the pool and every decision under its responsibility. Although the results seem to be specific for the particular problem under study, they can be used for benchmarking to have an early impression before carrying out detailed study to give the decision of starting an RFID pilot project. The developed methodology for finding the optimal way of RTI pool management can be utilized alone even when using RFID technology is not a question. This study is also an example for the application of simulation optimization method to a real life problem. We believe that our study fills a gap in the literature and it is useful for practice.

The area of this study requires further research in different types of RTI pool management and CLSCs, especially to perceive the impact of using RFID technology in different cases. The true credibility of the positive value of RFID technology on RTI pool management can only be established with more studies on different types of cases. For further research, we suggest repeating a similar study on the cases having the following characteristics:

- Full RTI demand is non-stationary.

- RTI pool is shared and owned by more than one manufacturer.
- The product can be supplied with more than one substitutable RTI.
- Additional RFID scan points set at DCs and maybe at the sites of end users.

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APPENDIX A – RFID Technology

Fosso Wamba et al. (2008) classify RFID technology as a wireless automatic identification and data capture (AIDC) technology. RFID technology characteristics differ along intended uses, physical dimensions, radio frequencies, and data storage (Hassan & Chatterjee, 2006). A growing literature explains technical aspects of RFID (Hedgepeth, 2007; Myerson, 2007; Sheng, Li, & Zeadally, 2008).

The RFID is essentially composed of three components (See Figure A.1 taken from Langer et al., 2007). The tags and readers are the hardware components; the third component, the middleware, is the software that acts as a bridge between the data that the readers read from tags and a database. A more complete description of the RFID technology, its emerging standards, and its potential uses can be found in Bhuptani and Moradpour (2005). Langer et al. (2007) describes the basic components as follows:

1. Tags: An RFID tag is a small transponder attached to the object to be tracked. The tag holds data that are transmitted to a reader when interrogated.

2. Readers: Readers, which are the interrogators, track the tags. They collect and process information that is embedded in the tags.

3. Middleware: Although the tags and the readers have some software hardwired, middleware translates signals into usable data and facilitates the actual data operations. These software applications help in monitoring and managing the data that RFID tags and readers transmit and read. The data are then aggregated and standardized according to the specific application functionality. They can then be fed into the existing IT databases for reporting or other purposes.

RFID tag Radio waves RFID reader
Middleware Database

Figure A.1: The basic elements of RFID technology are tags, readers, and middleware

As stated by Ngai et al (2008b), RFID technology has been widely applied in many industries, including the airline industry, cattle industry, construction, logistics, healthcare, and manufacturing. According to Heim et al. (2009), many service sectors are also deploying RFID applications. Examples can be found among hospitals and health care providers, airlines and transportation services, postal services, libraries, veterinarian services, banking, and government services (Das &Harrop, 2008). They also state that large consumer-packaged goods manufacturers (e.g., The Gillette Co., Procter & Gamble, Johnson & Johnson) and logistics service providers (e.g., United Parcel Service, DHL) also have experimented with RFID.

According to Heim et al. (2009), RFID technologies enable both open-loop and closed-loop service applications. Open-loop RFID applications follow items from a starting point to a terminal destination. An open-loop application can use pallet-level, case-level, or item-level RFID tags for tracking products from a manufacturer to a store. These applications usually utilize less costly passive RFID tags because the tags may not be reused. In contrast, a closed-loop RFID application tracks an object throughout its life cycle, in other words both in forward channel and in reverse channel. For example, a museum may follow its visitors from their admission, to exhibitions, to their departure. These applications usually utilize battery-powered active RFID tags since the application may need to proactively send data. Because these RFID tags ultimately return back to their owner, the tags can be reused, which can decrease overall tag costs (Heim et al., 2009).

APPENDIX B – Barcode vs. RFID Tags

As stated by Ngai et al. (2008-b), the capability of RFID technology has been criticized as being too similar to that of the barcode. Burnell (1999) inferred that most of the functionality needed had already been achieved by barcode technology. On the other hand, Jones et al. (2004) argue that a main reason for RFID diffusion is the capability of tags to provide more information about products than traditional barcodes. Karkkainen (2003) pointed out the limitations of barcode data collection, including the occasional necessity to read barcodes manually and poor barcode readability in some environments.

Manufacturing site, production lot, expiry date and components type are among information that can be stored into the tag chip. Moreover, tags do not need line-of- sight scanning to be read, since they act as passive tracking devices, broadcasting a radio frequency when they pass within yards of a reader (Karkkainen, 2003). On the other hand, adding barcodes requires manual operations on packages, that is either the packages with barcodes or the reading devices should be manually handled to read the codes (Boxall, 2000; Bylinsky, 2000; Jones, 1999). This may result in time consumption and difficult data capture if large amounts of goods have to be handled, such as in distribution centres or retail stores. In some cases, readability of barcodes can also be problematic, due to dirt and bending, bringing about reduced accuracy and low reading rate (Ollivier, 1995; Moore, 1999).

In conclusion, RFID is an emerging technology intended to replace traditional barcodes in many ways (Asif and Mandviwalla, 2005; Chuang, 2005; DoIT, 2004a–c, Wang et al., 2005). According to Kok et al. (2008), more and more, RFID technology is expected to take the place of bar codes in the supply chain allowing manufacturers and retailers to know the exact location and quantity of their inventory without conducting time consuming audits at several points along the chain.

APPENDIX C – The Advantages and Disadvantages of RFID Technology

Overall Advantages and Disadvantages of RFID Technology

As illustrated by Ngai et al. (2007-a), RFID is an enabling technology that a company can adopt to enhance asset visibility and improve operations, like improving receiving and picking accuracies, and reducing human errors in handling repairable items by automation. Singer (2003) defined the four benefit factors of RFID technology as operational efficiency, accuracy, visibility, and security. As the various entities associated with business processes become increasingly mobile in the presence of RFID, the ability of the organization to monitor the location, history and changing states of these tagged entities increases the level of process freedom (Keen and Mackintosh, 2001). Though beginning as a tool to achieve operational efficiency, some practitioners believe that RFID could become the next major weapon for organizations to gain strategic competitive advantage (Tzeng et al., 2008).

According to Green at al. (2005), RFID has all the ingredients to deliver benefits for a range of reasons:

- RFID is maturing. RFID technology has been around for decades and successful RFID projects in logistics have been implemented since the early 90's.
- RFID greatly facilitates and automates labor-intensive work and is therefore a perfect tool for rationalization.
- RFID is non-intrusive. As a result, the flow of assets is not being disrupted and, therefore, the number of reads, i.e. the level of transparency, will not become a limiting factor.

On the other hand, RFID has limitations that can challenge its wide adoption. The broad adoption of RFID entails a large investment with significant risk and requires careful planning (Kulwiec 2005). Despite the achievable benefits, several authors agree that the main limit to a wide use of RFID technology has to be found in its cost (Prater et al., 2005; Karkkainen and Holmstrom, 2002; Burnell, 1999; Riso, 2001). Beside fixed costs related to the purchase and implementation of the necessary infrastructure, especially the substantial cost of RFID tags seems to prohibit widespread use at the item level (Heese, 2007).

Tzeng et al. (2008) indicates that the implementation of RFID is not just buying hardware and software; rather it requires the organization to undertake business process re-engineering (BPR) with an innovative spirit in order to attain the greatest synergy. Langer et al. (2007) points out that a key determinant of the success of a firm's RFID implementation is the degree to which that company can change its business processes to leverage the technology most effectively. To derive benefit from any technology, a firm needs to redesign its business processes or identify innovative uses for that technology (Bresnahan and Greenstein 1996). Clarke et al. (2006) have emphasized that RFID should be used less as a glorified barcode and more as a tool to leverage business intelligence for strategic planning. They recommend using RFID to fill information black holes in the supply chain.

Ngai et al. (2008-b) points out that a recent survey by the Computing Technology Industry Association revealed that 80 per cent of the responding companies said that there were not sufficient numbers of skilled RFID professionals. Two-thirds of them said training their employees in RFID technology and educating them about it was one of the biggest challenges they faced in order to succeed in the RFID market (Morrison, 2005).

In the early phase of RFID technology, its limitations related to its high cost and the unlikelihood of a pay-off of the investment (Burnell, 1999; Riso, 2001). However, according to Jones et al. (2005), the price of an RFID tag was about $1 in 2000, had fallen to $0.25–0.35 by early 2004, and is expected to drop to around $0.05 as RFID technology becomes more widely adopted. Langer et al. (2007) reports that retail giants, such as Wal-Mart and Gillette, have reported optimistic news detailing real and anticipated savings because of their pioneering RFID efforts (Faber 2005). Likewise, a test IBM traffic system in Sweden that uses RFID has reduced rush-hour congestion by 25 percent (Termen 2006). These reports suggest that RFID is being adopted extensively and that it is beginning to deliver what it promised—at least to some according to Langer et al. (2007). On the other hand, Tzeng et al. (2008) asserts that RFID applications are still in their infancy with their contributions to enterprises still unproven, although RFID is now considered to be a new technology application with the potential for explosive long-term growth. As stated by Langer et al. (2007), Industry Week reported that manufacturers have been finding it difficult to financially justify its implementation because they have been unable to make a good business case (Katz 2005). Instead, manufacturers and suppliers may be adopting RFID only to comply with demands from key customers (e.g., Wal- Mart or government/defense agencies such as the Department of Defense; Katz 2005). Many appear to be limiting their RFID projects to meet the minimum requirements needed to comply with these customer demands. Such ambiguity about RFID's value is not limited to small manufacturers; it also applies to larger manufacturers, logistics firms, and partners throughout the supply chain (Kharif 2005, Moad 2006). These facts have cast doubts on whether RFID will become a cost-reducing panacea for supply chains—or a cost-producing white elephant (Langer et al., 2007).

The Advantages and Disadvantages of RFID regarding Supply Chain Management

RFID is used to build up an ''internet of things''— a network that would allow companies to track goods through the global supply chain and run many applications simultaneously (Violino, 2005). RFID tools have assumed an important role in supporting logistics and SCM processes because of their ability to identify, categorize, and manage the flow of goods and information throughout the supply chain (Ngai and Riggins, 2008). RFID ‘‘smart tags” support the promise of an intelligent supply chain by allowing for container, pallet, or item level tracking of products (Ustundag and Tanyas, 2009). The applications also may lead to labor cost savings, inventory reductions, shrinkage improvement, out-of-stock reduction, and supply-chain information sharing (Lee and Ozer, 2007).

According to Ustundag and Tanyas (2009), one of the objectives of RFID integration is to diminish the gap between physical and system inventory on the whole supply chain occurring due to misplacement, damage, shipping, and theft errors. The rising level of accuracy, visibility, and security increases the product availability by narrowing the gap between physical and system inventory (Mannel, 2006). Consequently, the average inventory level is reduced, the costs of labor, inventory holding, and lost sales are decreased, but the order cost is raised. In addition to this, theft costs are diminished owing to the elevated security level.

The availability of real-time information is counted as the main benefit, even though additional benefits can be found in increased inventory visibility, stock-out decrease, real-time access and update of current store inventory levels, automated proof of delivery (Fernie, 1994), availability of accurate points of sale data, reduction of labor necessary for inventory counts of shelved goods, enhanced theft prevention and shrinkage, and better control of the whole supply chain (Bushnell, 2000). Lee and Ozer (2005) report that between 10% and 66% of the original shrinkage observed is reduced after implementing RFID technologies

According to Green et al. (2005), if supply chain data was accurate, current, and complete, then:
• Efficiency could be measured in real-time
• Analysis could be done ad hoc, and
• Optimized action could be taken at once.
Consequently, profits will increase significantly. The promise of RFID is to make this dream a reality (Green et al., 2005).

On the other hand, the disadvantages of RFID in supply chain management are basically the same as the ones explained under the previous title in this appendix.

APPENDIX D – The Simulation Model for Generated Demand Data

The simulation model was built in Arena. Its model and experimental frames were given below.

Model Frame

```
0$           CREATE,        1:,1:NEXT(16$);

16$          ASSIGN:        DC_ID=1;
2$           ASSIGN:        Demand_Arriving_Time_DC1=TNOW:
                            Demand_Size_DC_1=DISC(0.07,20,0.43,40,1.0,60):NEXT(1$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 1 (Demand Arriving Time DC1)
;
1$           WRITE,         Demand,RECORDSET(AT_All),Record_Number:
                            Demand_Arriving_Time_DC1:NEXT(21$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 8 (DC ID 1)
;
21$          WRITE,         Demand,RECORDSET(IDs),Record_Number:
                            DC_ID:NEXT(4$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 3 (Demand Size DC1)
;
4$           WRITE,         Demand,RECORDSET(DS_All),Record_Number:
                            Demand_Size_DC_1:NEXT(13$);

13$          ASSIGN:        Record_Number=Record_Number+1;
3$           DELAY:         MAX(0,-0.5 + 6 * BETA(8.3, 23.5)),,Other:NEXT(2$);


17$          CREATE,        1:,1:NEXT(18$);

18$          ASSIGN:        DC_ID=2;
6$           ASSIGN:        Demand_Arriving_Time_DC2=TNOW:
                            Demand_Size_DC_2=DISC(0.02,20,0.04,40,1.0,60):NEXT(5$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 4 (Demand Arriving Time DC2)
;
5$           WRITE,         Demand,RECORDSET(AT_All),Record_Number:
                            Demand_Arriving_Time_DC2:NEXT(22$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 9 (DC ID 2)
;
22$          WRITE,         Demand,RECORDSET(IDs),Record_Number:
                            DC_ID:NEXT(8$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 5 (Demand Size DC2)
;
8$           WRITE,         Demand,RECORDSET(DS_All),Record_Number:
                            Demand_Size_DC_2:NEXT(14$);

14$          ASSIGN:        Record_Number=Record_Number+1;
7$           DELAY:         MAX(0,-0.5 + LOGN(1.98, 1.07)),,Other:NEXT(6$);


19$          CREATE,        1:,1:NEXT(20$);

20$          ASSIGN:        DC_ID=3;
10$          ASSIGN:        Demand_Arriving_Time_DC3=TNOW:
                            Demand_Size_DC_3=DISC(0.01,20,0.23,40,1.0,60):NEXT(9$);
```

```
;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 6 (Demand Arriving Time DC3)
;
9$            WRITE,         Demand,RECORDSET(AT_All),Record_Number:
                             Demand_Arriving_Time_DC3:NEXT(23$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 10 (DC ID 3)
;
23$           WRITE,         Demand,RECORDSET(IDs),Record_Number:
                             DC_ID:NEXT(12$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 7 (Demand Size DC3)
;
12$           WRITE,         Demand,RECORDSET(DS_All),Record_Number:
                             Demand_Size_DC_3:NEXT(15$);

15$           ASSIGN:        Record_Number=Record_Number+1;
11$           DELAY:         MAX(0,-0.5 + ERLA(0.396, 7)),,Other:NEXT(10$);
```

Experiment Frame

```
PROJECT,      "Demand Data Generation","test",29/07/2010,No,No,No,No,No,No,No,No,No,No,No;

ATTRIBUTES:   DC_ID,DATATYPE(Real);

FILES:        Demand,"C:\Users\S099377\Desktop\Input Data Analysis\Demand Data
Generation\GeneratedDemandData.xls",MSExcel,,

Error,,Hold,RECORDSET(AT_All,"Arrival_Time_All",512),RECORDSET(DS_All,"Demand_Size_All",512),RECORDSET(IDs,"DC_
ID",512);

VARIABLES:    Demand_Size_DC_1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Demand_Size_DC_2,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Demand_Size_DC_3,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Demand_Arriving_Time_DC1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Demand_Arriving_Time_DC2,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Demand_Arriving_Time_DC3,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Record_Number,CLEAR(System),CATEGORY("None-None"),DATATYPE(Real),1;

REPLICATE,    1,0.0,380,Yes,Yes,0.0,,,24.0,Days,No,No,,,No,No;
```

APPENDIX E – Simulation Optimization Parameters

Table E.1: Simulation optimization paramaters for the scenarios in the less problematic case

Scenario	Lower Bound	Suggested Value	Upper Bound	Number of Simulations
Without RFID	113	234	354	120
Pessimistic	113	232	350	120
Neutral	113	228	342	110
Optimistic	113	223	332	110
Very Optimistic	113	217	320	100

Table E.2: Simulation optimization paramaters for the scenarios in the less problematic case

Scenario	Lower Bound	Suggested Value	Upper Bound	Number of Simulations
Without RFID	113	271	428	160
Pessimistic	113	266	418	150
Neutral	113	255	396	140
Optimistic	113	244	374	130
Very Optimistic	113	232	350	120

APPENDIX F – RFID Data Cleaning

It was realized that RFID data regarding ***Time Spent in the Field*** had inconsistent entries. There were data points stating unrealistically small and large values for ***Time Spent in the Field.*** Because of this reason, we removed unrealistic data points which are either

- Smaller than the minimum realistic value, or
- Larger than the maximum realistic value

of ***Time Spent in the Field***.

The minimum realistic value of ***Time Spent in the Field*** was calculated for all of DCs according to Table F.1.

Table F1. The calculation of the minimum realistic value of Time Spent in the Field for all DCs

Activity	**Minimum Assumed Duration (days)**
Transportation to DC	1
Waiting time at DC (full)	1
Transportation to end user	1
Waiting time at end user (full)	1
Emptying at end user	1
Waiting time at end user (empty)	1
Transportation from end user	1
Waiting time at DC (empty)	1
Transportation from DC	1
TOTAL	**9**

The maximum realistic value of ***Time Spent in the Field*** was calculated for DC-1 as shown in Table F.2. The maximum duration between the time that a full RTI leaves the manufacturer and the time it enters the empty RTI stock of the end user is at most 75 days, which is the shelf life of the product. When the shelf life ends, the end user is expected to move the RTI to its empty RTI stock even it is half-empty at that time. Considering the average full RTI demand of DC-1, it is expected to make empty RTI shipments to the manufacturer 1 in 8 days on average. As a result, this value was taken as the maximum assumed value for the waiting time at the empty RTI stock of DC-1.

Table F.2. The calculation of the maximum realistic value of ***Time Spent in the Field*** for DC-1

Activity	Maximum Assumed Duration (days)
Waiting at the manufacturer	75
Transportation to DC	
Waiting time at DC (full)	
Transportation to end user	
Waiting time at end user (full)	
Emptying at end user	
Waiting time at end user (empty)	1
Transportation from end user	1
Waiting time at DC (empty)	8
Transportation from DC	1
TOTAL	**86**

The same values for the other two DCs were calculated in a similar way. Table F.3 shows maximum realistic values of ***Time Spent in the Field*** for all DCs.

Table F.3. The maximum realistic values of ***Time Spent in the Field*** for all DCs

DC	Maximum Assumed Value (days)
1	86
2	87
3	93

APPENDIX G – The Estimation of Emptying Duration

DCs make shipments of returns once they have a ***FTL of Empty RTIs***. As a result, we can conclude that the stock level of RTI returns at DCs fluctuate between 0 and ***FTL of Empty RTIs***. Assuming that empty RTIs return to DCs at a constant rate, average WIP level of empty RTIs at DCs should be $(\boldsymbol{FTL\ of\ Empty\ RTIs} + 0)/2$. We also know the average demand rate of DCs and the average demand rate can be seen as the RTI throughput (TH) of DCs. ***Probability Of Field Loss*** is ignored because its effect is insignificant in such an estimation having days as time unit. With the information regarding WIP and throughput, Little's formula ($CT = WIP/TH$) give us average cycle time (CT) that RTIs spent in DCs. With the assumption that empty RTIs return to DCs at a constant rate, we can conclude that the waiting time at DCs uniformly distributed between 0 and 2CT. With the addition of the transportation time between DCs and the manufacturer, the time difference between ***Time Spent in the Field*** and ***Emptying Duration*** is estimated to be uniformly distributed between 0 and 2CT days. Since we need to fit normal distribution to this time difference, we generated data (5000 data points) with U(0, 2CT) and then fit a normal distribution to the generated data. The fitted normal distribution has the following parameters shown in Table G-1.

Table G-1: The parameters of the fitted normal distribution of the waiting time at the empty RTI stock of DCs

	Mean (days)	Standard deviation (days)
DC-1	3.81	2.21
DC-2	4.77	2.80
DC-3	7.75	4.51

The time difference between ***Time Spent in the Field*** and ***Emptying Duration*** is the total of waiting time at the empty RTI stock of DCs, the transportation times from the DC to the manufacturer and from the manufacturer to the DC. The total transportation time is constant and it is 2 days. If X is a random variable normally distributed with mean μ and standard deviation σ, then $X + a$ is also be normally distributed with mean $\mu + a$ and standard deviation σ. As a result, the time difference ***Time Spent in the Field*** and ***Emptying Duration*** is expected to be normally distributed with the parameters given in Table G.2

Table G-2: The parameters of the fitted normal distribution of the time difference between ***Time Spent in the Field*** and ***Emptying Duration***

	Mean (days)	Standard deviation (days)
DC-1	5.81	2.21
DC-2	6.77	2.80
DC-3	9.75	4.51

APPENDIX H – The Simulation Model for Generating Emptying Duration Data

The simulation model was built in ARENA. Its model and experimental frames are as follows:

Model Frame

```
$           CREATE,        1:,1:NEXT(2$);

2$           ASSIGN:        Emptying_Duration_DC1=Emptying_Duration_Distribution_DC1:NEXT(1$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 1 (Emptying Duration DC1)
;
1$           WRITE,         EmptyingDuration,RECORDSET(Recordset 1),Record_Number_DC1:
                            Emptying_Duration_DC1:NEXT(15$);

15$          BRANCH,        1:
                            If,Emptying_Duration_DC1>=Minimum_Emptying_Time,10$,Yes:
                            If,Emptying_Duration_DC1<Minimum_Emptying_Time,3$,Yes;
```

```
10$           ASSIGN:        Record_Number_DC1=Record_Number_DC1+1;
3$            DELAY:         1,,Other:NEXT(2$);


13$           CREATE,        1:,1:NEXT(5$);

5$            ASSIGN:        Emptying_Duration_DC2=Emptying_Duration_Distribution_DC2:NEXT(4$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 4 (Emptying Duration DC2)
;
4$            WRITE,         EmptyingDuration,RECORDSET(Recordset 2),Record_Number_DC2:
                             Emptying_Duration_DC2:NEXT(16$);

16$           BRANCH,        1:
                             If,Emptying_Duration_DC2>=Minimum_Emptying_Time,11$,Yes:
                             If,Emptying_Duration_DC2<Minimum_Emptying_Time,6$,Yes;
11$           ASSIGN:        Record_Number_DC2=Record_Number_DC2+1;
6$            DELAY:         1,,Other:NEXT(5$);


14$           CREATE,        1:,1:NEXT(8$);

8$            ASSIGN:        Emptying_Duration_DC3=Emptying_Duration_Distribution_DC3:NEXT(7$);


;
;
;     Model statements for module:  AdvancedProcess.ReadWrite 6 (Emptying Duration DC3)
;
7$            WRITE,         EmptyingDuration,RECORDSET(Recordset 3),Record_Number_DC3:
                             Emptying_Duration_DC3:NEXT(17$);

17$           BRANCH,        1:
                             If,Emptying_Duration_DC3>=Minimum_Emptying_Time,12$,Yes:
                             If,Emptying_Duration_DC3<Minimum_Emptying_Time,9$,Yes;
12$           ASSIGN:        Record_Number_DC3=Record_Number_DC3+1;
9$            DELAY:         1,,Other:NEXT(8$);
```

Experiment Frame

```
PROJECT,      "Emptying Duration Data Generation","test",29/07/2010,No,No,No,No,No,No,No,No,No,No,No;

FILES:        EmptyingDuration,
              "C:\Users\S099377\Desktop\Input Data Analysis\Emptying Duration Data 
Generation\EmptyingDurationGeneration.xls",
              MSExcel,,Error,,Hold,RECORDSET(Recordset 1,"DC_1",512),RECORDSET(Recordset 
2,"DC_2",512),RECORDSET(Recordset 3,"DC_3",512);

VARIABLES:    Record_Number_DC1,CLEAR(System),CATEGORY("None-None"),DATATYPE(Real),1:
              Record_Number_DC2,CLEAR(System),CATEGORY("None-None"),DATATYPE(Real),1:
              Record_Number_DC3,CLEAR(System),CATEGORY("None-None"),DATATYPE(Real),1:
              Emptying_Duration_DC1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Emptying_Duration_DC2,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Emptying_Duration_DC3,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
              Minimum_Emptying_Time,CLEAR(System),CATEGORY("None-None"),DATATYPE(Real),6;

REPLICATE,    
1,0.0,10000,Yes,Yes,0.0,(Record_Number_DC1>=5001)&&(Record_Number_DC2>=5001)&&(Record_Number_DC3>=5001),,24.0,D
ays,
              No,No,,,No,No;

EXPRESSIONS:  Emptying_Duration_Distribution_DC1,DATATYPE(Native),NORM(21.5,10.5):
              Emptying_Duration_Distribution_DC2,DATATYPE(Native),NORM(22.5,12.7):
              Emptying_Duration_Distribution_DC3,DATATYPE(Native),NORM(25.9,16.0);
```

APPENDIX I – The Calculation of Purchasing Lot Size

Purchasing Lot Size for the scenarios of the less and the more problematic cases were found separately according to modified EOQ method. Table I.1-I.5 show the calculation of ***Purchasing Lot Size*** for the scenarios in the less problematic case. On the other hand, Table I.6-I.10 show the calculation of ***Purchasing Lot Size*** for the scenarios in the more problematic case. The 1st columns in these tables show the number of shipments required to transport a replenishment size whose minimum and maximum values can be found in the next two columns. The columns named with "EOQ", "Best Value" and "Unit Purchasing Cost" show the values of $Q^{n\prime}$, Q^{n*} and $Y(Q)$ for each n, respectively. The difference between the values of unit purchasing costs provided by the best values for ***Purchasing Lot Size*** of n and $n+1$ was found to be at most 2% (and in most of the cases less than 1%). Because of this reason, for the times when a replenishment having a size of ***Purchasing Lot Size*** is not enough to raise the inventory position above ***Reorder Point for Purchasing***, it is found suitable to use the minimum integer number of multiples of ***Purchasing Lot Size*** which is enough to raise the inventory position above ***Reorder Point for Purchasing***.

Table I.1: The calculation of ***Purchasing Lot Size*** for the situation without the use of RFID technology in the less problematic case

The Less Problematic Case - Without RFID					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**469.4**	**380**	**122.18**
2	381	760	663.8	664	123.01
3	761	1140	813.0	813	123.69
4	1141	1520	938.8	1141	124.34
5	1521	1900	1049.6	1521	125.10
6	1901	2280	1149.8	1901	125.89
7	2281	2660	1241.9	2281	126.71
8	2661	3040	1327.7	2661	127.54
Minimum Cost Value					122.18

Table I.2: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: pessimistic) in the less problematic case

The Less Problematic Case - With RFID (Pessimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**445.9**	**380**	**122.27**
2	381	760	630.6	631	123.17
3	761	1140	772.3	772	123.88
4	1141	1520	891.8	1141	124.62
5	1521	1900	997.1	1521	125.47
6	1901	2280	1092.2	1901	126.36
7	2281	2660	1179.8	2281	127.27
8	2661	3040	1261.2	2661	128.19
Minimum Cost Value					122.27

Table I.3: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: neutral) in the less problematic case

The Less Problematic Case - With RFID (Neutral)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**394.3**	**380**	**122.54**
2	381	760	557.6	558	123.59
3	761	1140	682.9	761	124.42
4	1141	1520	788.5	1141	125.42
5	1521	1900	881.6	1521	126.54
6	1901	2280	965.7	1901	127.69
7	2281	2660	1043.1	2281	128.87
8	2661	3040	1115.1	2661	130.06
Minimum Cost Value					122.54

Table I.4: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: optimistic) in the less problematic case

The Less Problematic Case - With RFID (Optimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**334.1**	**335**	**122.99**
2	381	760	472.5	472	124.23
3	761	1140	578.6	761	125.38
4	1141	1520	668.2	1141	126.86
5	1521	1900	747.0	1521	128.46
6	1901	2280	818.3	1901	130.09
7	2281	2660	883.9	2281	131.75
8	2661	3040	944.9	2661	133.42
Minimum Cost Value					122.99

Table I.5: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: very optimistic) in the less problematic case

The Less Problematic Case - With RFID (Very Optimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**259.4**	**260**	**123.86**
2	381	760	366.8	381	125.46
3	761	1140	449.3	761	127.63
4	1141	1520	518.8	1141	130.23
5	1521	1900	580.0	1521	132.95
6	1901	2280	635.3	1901	135.71
7	2281	2660	686.3	2281	138.49
8	2661	3040	733.6	2661	141.28
Minimum Cost Value					123.86

Table I.6: The calculation of ***Purchasing Lot Size*** for the situation without the use of RFID technology in the more problematic case

The More Problematic Case - Without RFID					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**791.9**	**380**	**121.62**
2	381	760	1120.0	760	121.92
3	761	1140	1371.7	1140	122.22
4	1141	1520	1583.9	1520	122.53
5	1521	1900	1770.8	1771	122.82
6	1901	2280	1939.8	1940	123.09
7	2281	2660	2095.3	2281	123.35
8	2661	3040	2239.9	2661	123.62
Minimum Cost Value					121.62

Table I.7: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: pessimistic) in the more problematic case

The More Problematic Case - With RFID (Pessimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**754.3**	**380**	**121.65**
2	381	760	1066.8	760	121.98
3	761	1140	1306.5	1140	122.32
4	1141	1520	1508.6	1509	122.65
5	1521	1900	1686.7	1687	122.96
6	1901	2280	1847.7	1901	123.25
7	2281	2660	1995.7	2281	123.54
8	2661	3040	2133.5	2661	123.84
Minimum Cost Value					121.65

Table I.8: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: neutral) in the more problematic case

The More Problematic Case - With RFID (Neutral)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**670.6**	**380**	**121.74**
2	381	760	948.3	760	122.16
3	761	1140	1161.5	1140	122.58
4	1141	1520	1341.1	1341	122.98
5	1521	1900	1499.4	1521	123.33
6	1901	2280	1642.6	1901	123.69
7	2281	2660	1774.2	2281	124.07
8	2661	3040	1896.7	2661	124.46
Minimum Cost Value					121.74

Table I.9: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: optimistic) in the more problematic case

The Less Problematic Case - With RFID (Optimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**571.2**	**380**	**121.90**
2	381	760	807.8	760	122.48
3	761	1140	989.4	989	123.03
4	1141	1520	1142.4	1142	123.50
5	1521	1900	1277.3	1521	123.97
6	1901	2280	1399.2	1901	124.49
7	2281	2660	1511.3	2281	125.03
8	2661	3040	1615.6	2661	125.58
Minimum Cost Value					121.90

Table I.10: The calculation of ***Purchasing Lot Size*** for the situation with the use of RFID technology (the extent of improvement: very optimistic) in the more problematic case

The More Problematic Case - With RFID (Very Optimistic)					
n	**Min**	**Max**	**EOQ**	**Best Value**	**Unit Purchasing Cost**
1	**0**	**380**	**445.9**	**380**	**122.27**
2	381	760	630.6	631	123.17
3	761	1140	772.3	772	123.88
4	1141	1520	891.8	1141	124.62
5	1521	1900	997.1	1521	125.47
6	1901	2280	1092.2	1901	126.36
7	2281	2660	1179.8	2281	127.27
8	2661	3040	1261.2	2661	128.19
Minimum Cost Value					122.27

APPENDIX J – The Fill Rates of the Optimal Solutions

The following figures show the change of fill rates with respect to optimal solutions of scenarios. In all optimal solutions, the target service level of 95% fill rate for satisfying the full RTI demand is fulfilled.

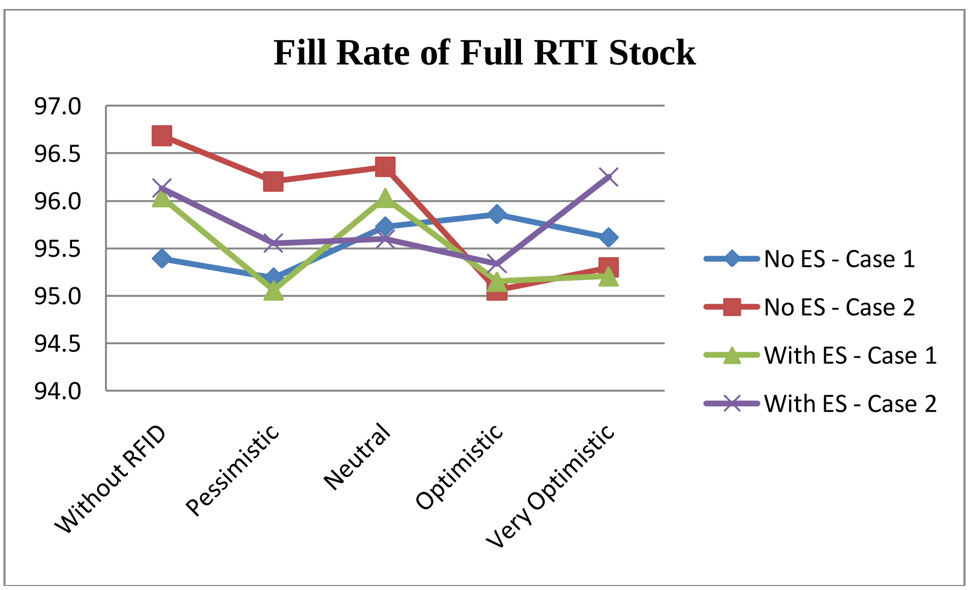

Figure J.1: The values of the fill rate of the full RTI stock at the manufacturer in optimal solutions of scenarios

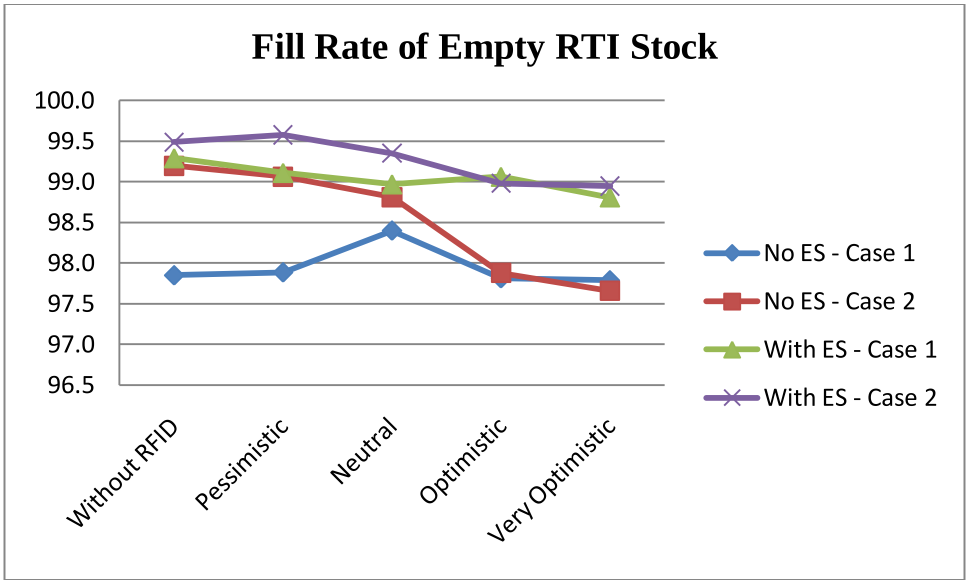

Figure J.2: The values of the fill rate for satisfying the demand of the filling operation in optimal solutions of scenarios