A simulation study on the impact of RFID technologies applied to in-store inventory management processes subject to shrinkage delivery and transaction errors

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A simulation study on the impact of RFID technologies applied to in-store inventory management processes subject to shrinkage, delivery and transaction errors.

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Abstract

Radio-frequency identification (RFID) has generated lots of attention in the supply chain arena. RFID’s potential lies in the real-time tracking capabilities and increased visibility possibilities resulting in improvement and transformation in various processes of in-store inventory management. The upcoming research accesses the potential value of RFID when applied to an in-store inventory management process were inventory record inaccuracy (IRI) is a significant problem. As a result, this thesis presents a simulation study of an in-store inventory management process subject to shrinkage, delivery and transaction errors. These errors are mainly responsible for inventory inaccuracies, hereby decreasing retailer’s revenues. With help of this simulation study, the impact of inventory inaccuracy on an inventory system’s performance with and without the usage of RFID technology will be analyzed. Effects are compared of different RFID technology implementation levels. Ultimately, these impacts will be quantified by means of an achieved reduction in absolute deviations of products and linked to this, cost reductions.
Preface

This thesis marks the end of my study, herewith completing the Master of Science study in Innovation Management at the Eindhoven University of Eindhoven (TU/e). It is the final chapter of a journey of several years along numerous courses. In the end, the lack in knowledge I felt, concerning the ‘soft’ aspects within technical environments, after finishing my bachelor in Mechanical Engineering, is closed and this study has contributed to a higher level of understanding of both the human (soft) and technical (hard) aspects in the occurring business processes in organizations.

This thesis presents only the major and final part of my graduation project: the research; yet the entire graduation project consists out of a literature review on the added value of RFID within the scope of inventory control and a research proposal.

The project was carried out in cooperation with the company IKEA (store Heerlen) within the department logistics. The colleagues and supervisors from the company and the university provided me with valuable insights and support to complete this project. A graduation project requires significantly more effort compared to course work and projects during the study curriculum. It is therefore very important to have people around you to discuss the difficulties along the road. I am grateful for the support and motivation I received from supervisors and colleagues.

Firstly, I would like to thank my supervisors from the Eindhoven University of Technology, dr. ir. R.M. Dijkman and dr. Y. Zhang. Whenever I had a question, Mr. Dijkman was always more than willing to help me and he pointed out different research directions. I would also like to thank Ms. Zhang, who has provided me with valuable feedback. I think that insights from both Mr. Dijkman and Ms. Zhang were complementary to each other and enhanced this research to a higher level.

Secondly, I would like to thank all the people from IKEA, who have contributed to this thesis in one way or another. I would specifically like to thank Robert de Wild, Ingrid de Laat-Kok and Dominick van Dongen. Gaining insights with regard to the cycle count process were crucial to my understanding of the project. Despite busy schedules, they were always more than willing to make time to provide me with insights and feedback. Furthermore, I would like to thank my company supervisor Kevin van der Linden and the colleagues Marc Vleugels, Peter Keulen, Cyril Zijlstra, Jordy Voogt and Mariska Luyten for providing directions where to look for the relevant data within the information systems.

Thirdly, I would like to thank my family, my girlfriend Kimberley and my friends, who have all shown interest in my project and provided support, motivation and distraction when needed.

Lastly, I would like to thank my parents, for always being supportive during my studies.

Luc Alleleyn
Eindhoven, August 2016
Executive summary

RFID has generated lots of attention in the supply chain arena. RFID’s potential lies in the real-time tracking capabilities and increased visibility possibilities resulting in improvement and transformation in various processes of in-store inventory management. The upcoming research accesses the potential value of RFID when applied to an in-store inventory management process were IRI is a significant problem. As a result, this thesis presents a simulation study of an in-store inventory management process subject to shrinkage, delivery and transaction errors. These errors are mainly responsible for inventory inaccuracies, hereby decreasing retailer’s revenues.

The extent of IRI has been made visible in several academic articles. One of these articles performed such a research within a retail concern. It was concluded that on average 51% of the inventory records are equal to the actual inventory. Specifically, results from this study have been presented to retail executives on numerous occasions, and they have consistently acknowledged the findings. Similar findings were found within the case study company, implying that the case study company shares common characteristics based on its in-store inventory management processes, which makes it a strong case that results within this thesis are generalizable. Another study concluded that IRI accounted for a decrease of 10% of current profits, due to lost sales, additional labor and inventory carrying costs. Noteworthy, IRI is positively associated with the annual selling quantity of an item, negatively associated with the cost of an item, positively associated with inventory density as well as product variety.

In order to achieve the research goal, in a first phase, the initial literature review that examined the potential benefits of RFID was extended. This extension provided a good understanding of RFID’s true potential when applied to an in-store inventory management process suffering from inventory inaccuracies and how this potential is linked to an improvement of a company’s business performance.

In a next phase of this thesis, the mechanisms causing the inventory inaccuracy were thoroughly analyzed by defining the mechanisms itself and their deviation probability that are causing the discrepancies within an in-store inventory management process. This was done by creating a conceptual model of the (un)wanted routes of product flows accompanied with their probability occurrence. In a final stage, this conceptual model served as a basis to construct the simulation model that was constructed with help of the modeling software Vensim.
The simulation model simulated the extent of IRI within the case study company (figure on the previous page, scenario 0), which accounted for 70,303 absolute deviations in products for FY15. Another three scenarios were integrated in the model in order to evaluate the impact of various implementations levels of RFID technologies. In the first scenario, RFID technology was integrated at the pallet level with the least amount of RFID reading portals, scenario 2 and 3 integrated tags at the product level and both differed in number of portals. As imaginable, each scenario differed in costs and a decreased error rate(s) that contributes to an improvement in the IRI (figure on the previous page, scenario 1 till 3). Mainly RFID is able to reduce the error rates by automation of processes, hereby decreasing the probability of human error. Next to this, increasing the visibility of products will help to keep stock levels accurate and prevents products to be incorrectly defined as lost.

The figure below visualizes the cost per scenario versus the base scenario per year (scenario without RFID technology). This figure does not account for the fixed costs associated with purchasing technology components. If this cost component is taken into account, scenario 1 has a return on investment period of 5.18 years. Unfortunately, scenario 2 and 3 are too expensive based on the current tag price of €0.06. The integration of tags on product level is for now too expensive and will increase the overall in-store inventory management costs compared to the base scenario’s costs. Based on calculations, if the cost of a single tag drops below €0.03, scenario 2 and 3 will become profitable. The suggested cost price per tag is quite imaginable as costs have fallen steadily over the past few years and will decline further as adoption ramps up. Next to this, applying RFID tags on all products with higher sales prices (e.g. >€20) could lead to an interesting business case for scenario 2 and 3. In such situation the relative cost of lost product will increase. Finally, it can be theorized that the improvement in inventory record accuracy has a relation with a reduction in OOS. A reduction in OOS implies a greater availability of the product assortment, herewith serving the customer in a better way to buy a product. Potential revenue is for certainly lost due to the unavailability of the products. In the case this component accounts for a 1% increase in revenue, scenario 2 and 3 become profitable.

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1 https://www.rfidjournal.com/faq/show?84
These results apply to in-store inventory management processes with high volumes of products (>10,000,000 products). If the number of products to be processed is under 10,000,000 products per year, scenario 2 and 3 can become profitable.

In the situation that RFID is not applied within an in-store inventory management process, efforts should be channeled in reducing the inventory record inaccuracies at the check-out and cycle count processes. These processes have the greatest share in the inventory record inaccuracies. Spot checks should be introduced at the manned check-out desks in order to reduce theft and validate the quantities of theft. Cycle counting should be performed by ambassadors; a specific group of employees who have an affinity with this kind of work and would take responsibility for this process. In the case that a deviation is generated during cycle counting, another employee should recheck a substantial amount of these deviations. If the deviation is found to be incorrect, the responsible employee should be held accountable and offered supporting supervision processes that would monitor individual performance.

Future research could assess in what order IRI is responsible for causing OOS. A translation could be made in what order the reduction in OOS will increase revenue. Ultimately, this information could be combined with the ROI analysis of this thesis in order to conclude if tagging RFID chips on product level is profitable (assuming RFID tag prices are unchanged). In addition to this, future research could investigate in what order RFID is able to reduce OOS. A proof of concept study could be performed in order to validate the described improvements in process efficiency. Next to this, system integration of a company’s IS with the RFID software could be tested.
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List of acronyms

IS: Information System(s)
SKU: Stock Keeping Unit(s)
IMS: Inventory Management System
FY: Financial Year
KPI: Key performance indicator
RFID: Radio Frequency identification
DC: Distribution Center
DD: Direct Delivery
ROI: Return On Investment
TU/e: Technische Universiteit Eindhoven
IRI: Inventory Record Inaccuracy
OOS: Out Of Stock
1. Introduction

This thesis explores how Radio Frequency Identification (RFID) technology may improve business performance when this technology is applied to in-store inventory management. More specifically, it tries to quantify the relationship of RFID technologies and improved IRI by means of a simulation study. This chapter will start with a motivation (1.1), followed up by the problem identification/research goal (1.2) and context of the thesis (1.3). Finally, the outline of this thesis (1.4) will be described. The reader who is not familiar with RFID technology is referred to chapter 7. Chapter 7 will briefly explain the technology and its components.

1.1 Motivation

The need to find solutions and strategies in order to offer more valuable services to the customer and, parallel to this, decrease the costs of logistic processes is one of the main objectives of supply chain management (Christopher, 1992). This need is partially triggered by the strong competition among companies; improving the supply chain’s efficiency will gain a competitive advantage over competing companies. In the past few years, RFID technologies have drawn significant interest as one of these solutions (Sarac et al. 2009).

A great number of companies have automated their inventory management system (IMS) and put their trust into an IS when critical decisions have to be made. Unfortunately, considering all these investments in information technologies, a number of problems are not yet eliminated:

- **IRI**: Inventory inaccuracy is the situation in which the IS inventory does not match with the actual available inventory (Raman et al., 2001). Based on a study that analyzed 370,000 SKU’s, more than 65% of the inventory records did not match the available inventory. Even 20% showed a discrepancy of six or more items (Raman et al., 2001). These inaccuracies will significantly hamper the efficiency of a supply chain.

- **Out-of-stock (OOS)**: Based on a meta-analysis that examined the extent of out-of-stocks an average level of 8.3% of out-of-stocks within the retail industry was calculated (Gruen et al., 2002). The authors identified several main causes for out-of-stock: 47% of out-of-stock situations were caused by store location management and forecasting, 28% by upstream activities and 25% by incorrect shelf restocking from backroom (i.e. the product was in the store, but not on the sales location).

- **Inventory invisibility**: Being able to know where all the inventory is at any particular point in the supply chain offers better tactical and operational decision capabilities (Sahin, 2004). Without RFID a constant monitoring of products cannot be guaranteed. Which has consequences for tracking product movements accurately (Sahin, 2004). Within the in-store inventory management process of the case study company only 3 points in time offer the possibility to track product movements. In the case of RFID, this could be an infinite number of points.

According to a great extent of papers that were found, collected and analyzed in the literature review which was a preliminary part of this thesis, RFID technology is expected to address some of the root causes of the issues mentioned above. This is done by offering several innovative contributions to the inventory IS and therewith the whole supply chain, such as: unique identification of products, easiness of communication and real-time information (Saygin et al., 2007; Michael and McCathie, 2005). In addition, improvements can be expected...
in the traceability of products and its visibility throughout the supply chain, more reliable and faster operational processes such as tracking, shipping, check-out and cycle count processes, that ultimately lead to improved inventory flows and more accurate information (Chow et al., 2006; Tajima, 2007). Companies can integrate the more accurate data in their IS for better supply chain planning and management (Whitaker et al., 2007). Summing all the benefits, companies can achieve cost reductions, increased revenue, process improvements and improve their service quality (Banks et al. 2007), by reducing the IRI (main focus of this thesis), OOS and inventory invisibility issues.

Research on RFID studies continues to gain prominence to this day. Consultancy firm Gartner produces a hype cycle within a research area every year, which visualizes and sorts emerging technologies based on their maturity, adoption and expectations. In the hype cycle of 2015 (Appendix II) it can be seen that RFID for transport and logistics are at the slope of enlightenment: the benefits of applying RFID in enterprises are becoming more and more understood. It can be expected that within 2-5 years the plateau of productivity is reached: main adoption starts to take off, the technology’s broad market applicability and relevance clearly pay off. This means that if companies want to quickly benefit from this technology when it matures, now is the right time to start.

1.2 Research goal and problem identification

The upcoming research aims at accessing the potential value of RFID when applied to an in-store inventory management process. Most companies have automated their inventory management system and puts their trust into an IS when critical decisions have to be made. Unfortunately, the inventory IS is often inaccurate. Consequently, this thesis will focus on the inventory inaccuracy issue. RFID can offer a more complete overview and real time visibility of more accurate data throughout a company’s entire supply chain, from manufacturer to the warehouse to the retail store. As a result this thesis will present a quantitative analysis enabling to quantify the impact of inventory inaccuracy on an inventory system’s performance and what RFID can bring to tackle this issue. Ultimately, the potential improvements that can be reached with use of RFID will be linked to the overall business performance.

1.3 Case study context

This thesis will be executed within one of the stores of the Swedish concern IKEA. The company’s main focus is designing and selling ready-to-assemble furniture and home accessories. IKEA aims to offer high quality products at affordable prices. This can also be brought back when looking to IKEA’s vision: “Low prices are the cornerstone of the IKEA vision, business idea and concept.” “Our vision is to create a better everyday life for the many people”. IKEA values its affordable prices. Nevertheless, this can only be guaranteed by an efficient supply chain from the manufacturer to the end user. Mostly IKEA does not manufacture products by itself but uses subcontractors all over the world. IKEA currently purchases in five

2 http://www.ikea.com/ms/en_GB/about_ikea/the_ikea_way/our_business_idea/our_low_prices.html
main countries: China (20%), Poland (18%), Italy (8%), Germany (6%), and Sweden (5%). In total IKEA has about 1220 suppliers dispersed over 55 countries³.

IKEA’s distribution is done through 33 distribution centers and 15 customer distribution centers in 17 countries⁴. Distribution within the supply chain has strongly been improved by redesigning the products’ packages. IKEA is well known for its flat packages which do not take as much place and reduce transport damages if the products were already assembled. Furthermore this enables the customer to transport the products by their own, reducing the costs even more (Buisson, 2013).

IKEA stores offer a large range of functional home furniture (with an assortment of 9500 products present in all IKEA stores) at affordable prices. They are easily recognizable with their striking yellow logo lying on a blue background. Today, the company holds 328 stores in 28 countries generating a total revenue of €32.7 billion in financial year 2015 (FY15). Stores are often placed at the suburbs of big cities, near to the main transportation axis in order to be more accessible and facilitate the distribution operations. With an area between 15000 m² and 55000 m², all IKEA stores are divided into three parts: the exposition hall where inspiring home solutions are shown to the consumer, the home accessories self-service department and the self-service warehouse related to ready-to-assemble furniture (Buisson, 2013).

1.4 Outline

The remainder of this thesis is structured as following: chapter 2 will discuss the research design and the chosen methodology to this design. Chapter 3 will describe the theoretical background for this thesis by conducting a literature review on RFID applied to in-store inventory management processes. Chapter 4 provides a road map which visualizes the mechanisms (the routes of products that are leaving or entering the system unwanted) causing the inaccuracies within the system, accompanied by their probabilities. Chapter 5 then utilizes this visualization by depicting a model that simulates the behavior and mechanisms causing the discrepancies in the IS inventory; enabling the researcher to quantify the extent of the problem. In chapter 7, knowledge and understanding of the components that should be purchased is gained, enabling the design for the next phase (chapter 6). Next to this, data for the potential improvements is gathered. Finally, the extent of improvements made when RFID is used is quantified based on business performance parameters (chapter 8). Additionally, this chapter compares the monetary translation of the improved business performance parameters and the associated costs of the RFID technologies. Besides the use of literature, this thesis made use of interviews with experts in field. In appendix I the experts are linked to the information source used.

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³ http://www.ikea.com/ms/en_GB/about_ikea/facts_and_figures/
⁴ http://www.ikea.com/ms/en_US/this-is-ikea/company-information/
2. Research Design

This chapter will create structure and herewith guidance for the remainder of this thesis project. A methodology is chosen to address the problem statement in a stepwise and iterative manner (2.1). Ultimately, these steps will be described in more detail (2.2).

2.1 Methodology

The regulative cycle developed by van Strien was chosen, offering the structure needed by providing a research design approach and theoretical base to guide the research questions (Van Aken et al., 2007). This approach is suitable for this research as it is focused on giving clear answers to specific problems (Van Aken et al., 2007).

The regulative cycle consists of a sequence of five phases which offer the possibility of iteration, namely: problem definition phase, analysis & diagnosis phase, plan of action phase, intervention phase, and evaluation phase (figure 1).

2.2 Project steps

Having identified the research goal in the introduction of this research, assessing the potential value of RFID when applied to an in-store inventory management process, an elaboration of the remaining steps that will be executed in the thesis are described in this section.

2.2.1 Analysis & Diagnosis phase

This part of the thesis will analyze the problem statement, by analyzing/examining the potential mechanisms causing the problem and ultimately enabling the researcher to develop a diagnosis for the problem.

This part will start with gaining an understanding of RFID’s true potential when applied to an in-store inventory management process suffering from inventory inaccuracies (Step 1), and how this potential is linked to an improvement of a company’s business performance (step 2). Step 2 also considers the parameters that can be affected. These steps will be executed by means of the literature review, additional scientific literature and data of the case study company. The deliverable retrieved from these steps is a clear overview of the benefits that RFID can deliver when facing the IRI problem; related to a clear explanation of the mechanisms causing the IRI; related to the impact of the problem on business performance.

Objective steps 1&2: Define the problem of IRI and how it is potentially solved by means of RFID (Chapter 3).
The mechanisms (the unwanted routes of products that are leaving or entering the system) causing the inventory inaccuracy will be thoroughly analyzed by defining the mechanisms itself and the errors that are causing the discrepancies (=IS inventory minus the actual inventory) within a system (step 3). This step will be executed in three ways: by retrieving data from the IS of the case study company, using company specific literature and interviews with experts in the field. Next to this, a road map is made based upon data retrieved for the company’s whole product line within the FY2015. This map will visualize the routes of products leaving or entering the system unwanted hereby causing the inaccuracies (step 4).

**Objective steps 3&4:** Provide a road map (conceptual model) that visualizes the mechanisms (the routes of products that are leaving or entering the system (un)wanted) accompanied by the deviation probability causing the inventory record inaccuracies (Chapter 4).

Furthermore, a simulation model is devised that will reflect the status quo of the mechanisms causing the inaccuracies (step 5). Most preferably, the behavior of the simulation model will reflect the behavior analyzed of chapter 4. The researcher will execute this step by use of a literature review, interviews and extracting data from the IS.

**Objective step 5:** Create a model that simulates the behavior and mechanisms causing the discrepancies in the IS inventory; enabling the researcher to quantify the extent of the problem (Chapter 5).

2.2.2 Plan of Action phase

A design needs to eliminate the mechanisms that are causing the discrepancies in the IS. Step 6 will therefore elaborate on the researcher’s efforts of step 4 and 5. The conceptual model, the associated quantities, deviation probabilities (step 4) and simulation model (step 5) will serve as a basis to implement the new retrieved deviation probabilities from literature (step 6). With help of interviews and the literature review, the researcher will be able to execute this phase of the thesis. Step 6 will also give the researcher insights for the potential change of parameters, distributions and likelihoods which ultimately can be implemented in the next phase’s design.

**Objective step 6:** Design a general approach, enabling elimination of the most significant mechanisms that are causing the discrepancies in the system (Chapter 6).

This phase will be finalized by gaining knowledge and understanding of the necessary components of the RFID-technology. Related to this, the associated costs should also be well documented.

**Objective step 7:** Gain knowledge and understanding of the components that should be purchased, enabling the design for the next phase. Next to this the associated costs should be well documented (Chapter 7).
2.2.3 Intervention phase
The model of step 5 will be used to implement the interventions of step 6. Most likely this will influence parameters, distributions and likelihoods.

**Objective step 8:** Create a model that simulates the behavior when RFID is implemented to tackle the mechanisms causing the inaccuracies of the IS (Chapter 8).

2.2.4 Evaluation Phase
This phase will conclude the research by evaluating the potential improvements, herewith answering the research question. This will be done by comparing the model of step 8 with the model of step 5. From step 9 new insights can arise and these should, if possible, be implemented/adapted in the earlier steps of this research by means of iteration.

**Objective step 9:** Quantify the extent of the improvements made by RFID based on business performance parameters and RFID’s ability to influence the mechanisms causing the inaccuracies of the IS from step 3 and 4 (Chapter 8).

Additionally, a monetary translation of the acquired improvements will be made from step 9 (step 10). These will be held against the associated costs of the defined RFID system’s components (step 7). The monetary translation can be made by use of experts in field and scientific literature.

**Objective step 10:** Answering the question: will the gains outweigh the costs (Chapter 8)?
3. Literature review: from RFID towards improved inventory record inaccuracy

In the scenario that a company relies on an automatic replenishment system where the inventory record of each SKU is monitored, IRI can be a substantial problem. If discrepancies exist between the inventory record and the actual inventory, items may not be ordered in a timely fashion, resulting in out-of-stocks or overstocks. In case of out-of-stocks, customers might be misinformed by the retrieved stock information and consequently be confronted with empty sale shelves. Overstocks will cause unnecessary handling and consequently demand more man hours and occupy unnecessary space. This can result in a blockage of space for products that have a higher flow of sales.

Most literature pertaining to this field never differentiated between the inventory record and the actual/physical inventory. This assumption has proven to be wrong (Rekik, 2006), as the quality of product related information is one of the biggest problems currently faced in supply chain management (Kärkkäinen & Holmström, 2002). Inventory record accuracy is often referred as the ‘missing link’ in retail execution (Heese, 2007).

In order to obtain a complete overview of inventory control applying RFID, a literature review was performed. This review consisted out of a comprehensive overview of the articles that addressed or analyzed the added value, i.e. main benefits of RFID applied to inventory control. The benefits are mainly focused on improving the inventory accuracy, improving the visibility and communication for all the actors within a supply chain by providing real-time information and the development of new replenishment policies. As previously explained, this thesis shifts its focus to a more narrow scope, namely: reducing inventory record inaccuracies using RFID.

This chapter will extend the previously examined literature review by evidencing the main benefits of RFID applied to in-store inventory management (3.1). Based on the described benefits understanding is gained of how RFID will tackle the IRI problem. The remainder of this chapter will describe the root causes, their magnitudes responsible for IRI (3.2) and their relationship with the influence on business performance (3.3). Finally, this chapter will quantify the IRI for the case study company and conclude its similarities with the literature (3.4).

3.1 What are the possible contributions of RFID?

RFID technologies offer several contributions to the inventory IS and therewith the whole supply chain, such as: unique identification of products, easiness of communication and real-time information (Saygin et al., 2007; Michael and McCathie, 2005). In addition, improvements can be expected in the traceability of products and its visibility throughout the supply chain. This means that operational processes such as tracking, shipping, check-out and counting will be more reliable and faster and thus leads to an improved inventory flow with accurate information (Chow et al., 2006; Tajima, 2007). Companies can integrate these more accurate data in their IS for better supply chain planning and management (Whitaker et al., 2007). Summing all the benefits, companies can achieve cost reductions, increase revenue, improve their processes and service quality (Banks et al. 2007).

Basically, two types of (main) benefits can be defined, namely direct benefits, reducing certain operating costs, and indirect benefits, reducing certain uncertainties in the supply chain
processes. This section will, to some extent, leave the scope of the thesis, but will give a clear overview for IKEA on what can be achieved with RFID applied to in-store inventory management. These benefits have a direct combined effect in reducing the IRI of a warehouse. Noteworthy, there are far more benefits to imagine, but this would go beyond the scope of this thesis.

3.1 Direct benefits
Direct benefits include reduction of labor costs, acceleration of physical flows of goods and reduction of theft.

A Reduction of labor costs
Manual product identification, such as scanning processes generate additional labor costs. The automatic identification property of RFID makes it possible to synchronize the physical flow of goods and the associated information flow without the need of human intervention (Sahin, 2004). Tagging products on item level is also associated with a decrease in the number of check-out employees (Sahin, 2004).

B Acceleration of flows
An RFID reader can scan as many as 50 tags per second; enabling a faster material flow. For example, it is possible to scan an entire load of pallets coming to a warehouse. This in turn also reduces customer’s waiting time at check-out (improving service levels), as this has been proven to be a great dislike by end users (Sahin, 2004). A simulation study performed in an IKEA store concluded that RFID applied at the check-out can lead to a waiting time close to zero (Buisson et al., 2013).

C Reduction of theft
With RFID readers placed in a tactical locations, theft can be prevented. Systems can be set up to alert security when a product is moved in an unauthorized way. RFID tags create greater visibility of product movements and thus enables security to track stolen goods more easily (Sahin, 2004).

3.1.2 Indirect benefits
Indirect benefits relate to reduction of delivery disputes, labor costs due to the elimination of non-value adding control activities, a faster detection of out of stock situations, a reduction of uncertainties on demand and finally an increased visibility over the supply chain network.

A Delivery disputes
Discrepancies between invoices and the actual delivery arise due to the amount of products that have to be processed. There is simply not enough time to check-up every entity on quantity and type. If RFID is applied on product level, the auto ID property reduces the probability of an error to occur of this type (Sahin, 2004).

B Indirect labor costs
With manual identification processes, non-value adding activities such as inspection of the received goods (counting and verification processes) and cycle counting activities need to be carried out. With help of RFID these processes controlling whether the quantity and location of products are accurate, can be automated (Sahin, 2004).
C Out of stock
RFID can provide accurate data on shelf and backroom product availability without human intervention, hereby helping the customer to plan their visit with a greater probability of the product being available (Sahin, 2004).

D Uncertainty on demand
If scanners are integrated into shelves, a constant monitoring of products can be guaranteed. Product movements can be tracked more accurately when customers attempt to buy a product but give up for some reason. Customer buying patterns can be analyzed more accurately, which can be quite interesting for introducing new products. Main interest lies in how marketing can use this information for defining its product assortments, pricing and advertising policies. Also RFID can reveal the areas of the store that drive the highest sales; enabling store planners to strategically locate products to maximize sales (Sahin, 2004).

E Visibility
Knowing the precise location of products over the entire supply chain network and sharing information with trading partners as if they were part of the organization, would enable a product availability that will best serve customer needs. RFID can provide this information and also more accurately, offering the trading partners to anticipate in a timely manner (Sahin, 2004).

3.2 Root causes of inventory record inaccuracy
IRI is defined as the existence of varying unknown outputs and inputs in the physical flow of goods of an inventory system; the real flow of goods differs from the flow of goods of the IS. Based on the work of Sahin (2004), Rekik (2006) and Sarac et al. (2010) errors have been defined that to a great extent are responsible for IRI. Higher selling quantity, inventory density and product variety are associated with a higher level of IRI (DeHoratius & Raman, 2008). The remainder of this section will discuss these errors in more detail.

3.2.1 Transaction errors
Every inventory transaction has the potential to be erroneous, which logically is classified as a transaction error. Transaction errors have been defined as a group of errors referring to problems occurring during shipment, delivery and scanning process (Raman et al., 2001), as an incorrect identification of items (Lee et al. 2005) and as a problem that occurs when there is a routine in counting inventory (Rekik, 2006).

An example related to the check-out process can be given to illustrate this type of errors. If the cashier scans an item twice (in order to save time) that is identical in price but not in attributes (color, shape, etc.), a discrepancy in the inventory IS is generated.

3.2.2 Non-recorded item movements
In the case that an item of the inventory is misplaced, customer demand cannot be fulfilled until the product has been found. Several sources were defined generating errors of this type (Chapell, Durdan, Gilbert, & Ginsburg, 2003):

i) Customers moving products from the sales location and dropping it in another location because they decide not to buy the product;

ii) Personnel not storing products on the correct shelf at the right time;
iii) Personnel losing products.

A four-year longitudinal study of 333 large retailer stores concluded that increasing product variety and inventory level per product is associated with an increase in misplaced products (Ton & Raman, 2004). These authors also show that misplacement is related to sales loss.

3.2.3 Damage

An often occurring phenomenon is damage within a retail store. Customers can cause damage to products when tearing the carton package; for instance checking the color. Damage can also be caused by personnel, be it intentionally or not. If the product is not properly removed from the shelf and more importantly also from the system, inventory inaccuracies will occur: a damaged product will not be bought.

3.2.4 Shrinkage

Shrinkage is defined as a combination of employee theft, shoplifting, internal and external theft, vendor fraud and administrative errors (Rekik, 2006). ECR Europe\(^5\) conducted research that showed shrinkage is composed out of process errors, deceptions and internal and external thefts; in the year 2003 it accounted for 24 billion EUR within the fast moving consumer goods sector, which is 2.41% of the whole turnover value of this sector. Within the whole shrinkage value, process errors are accountable for 27%, deceptions for 7%, internal thefts for 28% and finally external thefts for 38%.

3.2.5 Supply errors: product quality, yield and supply process

Inventory inaccuracy will occur in the event of low yield of a production process, low product quality or unreliable supply process. The IS’s stock may consist out of both defective as well as non-defective products that are not available for sales.

3.3 Impact of root causes on business performance

Based on the errors defined in previous section, research has been conducted trying to quantify the extent of the IRI problem. In addition, the parameters that measure the impact of inventory record inaccuracies on product availability will be described with help of the literature and by use of the parameter used at the case study company.

3.3.1 Extent of the problem

The extent of the IRI problem has been described in several academic articles. One of these articles concerned its research with retail. It was concluded that the best performing store only managed to have 70%-75% of its inventory records to be equal to the actual inventory (Kang & Gershwin, 2004). The worst performing store was able to match 1/3 of its SKU’s with the actual inventory. Considering all the stores, an average of 51% was achieved (figure 2, left histogram).

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\(^5\) http://ecr-shrink-group.com/
Figure 2: Inventory accuracy as function of percentage of SKU’s in line with the IS’s inventory.

The right histogram of figure 2 measures against a less strict requirement: allowing the inventory record of a SKU to be accurate if it agrees with the actual stock within a lower and upper boundary of five units. Using this definition an average accuracy of 76% was obtained. Similar findings were found based on a study that conducted its research within a leading retailer concern. In figure 3, more than 65% of the inventory records were inaccurate (Raman et al., 2001). The study concluded that inventory record inaccuracies accounted to a decrease of 10% of current profits (roughly the profit of 100 stores concerned), due to lost sales and additional labor and inventory carrying costs (Raman et al., 2001).

3.3.2 Key performance indicators

One of the many key performance indicators (KPI’s) that the case study company tracks is the TT456 netto. The TT456 netto resembles the proportion of the cumulative financial impact related to the revenue. The goal for this KPI is set on -0.25% for all stores within the Netherlands. Meaning that if a store’s revenue for FY15 was €100 million, only -€250.000 of purchasing costs is allowed to ‘disappear’ due to IRI. Figure 4 visualizes this KPI for the store Heerlen compared to the country’s average for Q2 and Q3 of FY16.

Most commonly, when assessing the literature, inventory accuracy is measured in the way the case study company does: recording discrepancies during stock checks (equation 1).
The size of the discrepancy is measured as a percentage of quantity (equation 1):

\[
\% \text{ Discrepancy} = \frac{\text{Quantity on record} - \text{Quantity in stock}}{\text{Quantity on record}}
\]  

(1)

Or to express it by means of equation 2 in a value similar to the TT456 netto of the case study company:

\[
\text{Value discrepancy} = \text{Unit stock value} \times (\text{Quantity on record} - \text{Quantity in stock})
\]  

(2)

### 3.4 Inventory record inaccuracy at the case study company

The extent of IRI within the case study company can be visualized by analyzing the data of IKEA’s counting processes (figure 5). It is policy to count the complete range of products at least once per FY. This counting process is done on SKU level; so on all applicable sales and stock locations. Figure 5 visualizes the results of the counting processes of FY15 for all the products that had been counted once (N=6119 SKU’s, representing 53.3% of the total product range). The remaining product range had been counted more than once. The x-axis represents the absolute error observed, which is equal to the discrepancy of the IS’s inventory and the inventory observed. This can be a negative error (a product disappeared) or a positive error (a product has a higher quantity in stock than expected). Unfortunately, the negative errors out rule the positive errors, implying a major impact on costs. An absolute error of 0, meaning the counted inventory matched the IS’s inventory, was achieved for 53.8% of the SKU’s that were counted once. These results are comparable with the findings within the research of Kang & Gershwin (2004), implying that the case study company shares common characteristics based on its in-store inventory management processes, which makes it a strong case that results within this thesis are generalizable. Noteworthy, IRI is positively associated with the annual selling quantity of an item, negatively associated with the cost of an item and positively associated with inventory density as well as product variety (DeHoratius & Raman, 2008).
The y-axis visualizes the proportion of each absolute error (or range) and the proportion of the financial impact. The proportion of the financial impact is calculated on basis of the procurement value. The total absolute financial impact for the SKU’s that were counted once, considering the store IKEA Heerlen FY15, was €181,643. These costs are the sum of products lost and products retrieved.

Each year, the case study company conducts customer satisfaction surveys, hereby assessing the perception of stock availability. Looking at figure 6, 14% of the customers were not able to acquire all the products they wanted. Half of these customers could not acquire these products due to stock availability issues. Besides the direct loss in sales, it can be argued that a decreased product availability has an impact on customer satisfaction and/or willingness of a customer to purchase a product again (Gómez et al., 2004).

![Chart showing % of SKUs vs. impact](image)

**Figure 5: Inventory Record Inaccuracy IKEA Heerlen FY15.**

<table>
<thead>
<tr>
<th>Got everything I came for*</th>
<th>Did not get everything*</th>
</tr>
</thead>
<tbody>
<tr>
<td>92% (0% vs. LY)</td>
<td>8% (0% vs. LY)</td>
</tr>
<tr>
<td>86% (+3% vs. LY)</td>
<td>14% (-3% vs. LY)</td>
</tr>
<tr>
<td>87% (+1% vs. LY)</td>
<td>13% (-1% vs. LY)</td>
</tr>
<tr>
<td>86% (+3% vs. LY)</td>
<td>14% (-3% vs. LY)</td>
</tr>
</tbody>
</table>

**Figure 6: Customer survey results.**
4. Conceptual model

This chapter will describe the routes of the different flows of goods and its threats within an in-store inventory management process. First of all the overall in-store inventory management process will be described (4.1). Next to this, each of the system’s processes and their potential threats hampering the accuracy will be identified and described (4.2). Furthermore, the size of each of the different goods flows will be quantified (4.3). Finally, the threats described in section 4.2 will be quantified by means of a probability of deviation (4.4). Section 4.1, 4.2, 4.3 in combination with 4.4 will be summarized by means of a conceptual model of product flow, the threats to inventory inaccuracy, the size of the product flows following these routes and the potential deviation occurrence will be visualized. This conceptual model will serve as a basis for the simulation model of chapter 5: simulating the behavior of an inventory management process not subject to RFID technologies.

4.1 In-store inventory management process

Within an in-store inventory management process, several flow of goods can be defined. Namely an incoming flow of goods (inflow), an outgoing flow of goods (outflow) and an internal flow of goods (internal transactions). These routes of goods have been defined with help of the case study company’s specific literature and by conducting interviews with sales and supply support specialists in the whole country.

In figure 7 the routes of products have been visualized by means of a conceptual model, which have been derived by studying the process. The circular symbols visualize the end and start point of the process, the window shaped symbols reflect choices, whereas the rectangular symbols represent processes and the parallelograms visualize collection points of stock.

This roadmap starts at the inflow of goods. Firstly, a choice function should be passed as products can either be a customer return or a Distribution Center (DC)/Direct Delivery (DD). In the case that it is a customer’s return, another choice function should be passed where goods are checked on damage by an employee. If the product is damaged, the product will be processed by means of transaction type TT325 and handed over to the recovery department. In the situation that the product is undamaged it will be returned as sellable stock into a sales location (TT320). In the case of this conceptual model, the product will be placed into the stock collection parallelogram ‘In-store Inventory’.

Damaged products are not only caused by customers, damage can also be caused by employees during the replenishment process (TT390). Next to this, products might be damaged during loading processes of the freight, in this case the receiving company of the goods is not responsible; the damage was received (TT391). Products that have been booked under these transaction types will also be handed over to the recovery department to be further processed (inflow recovery department).

Recovery will further process the damaged article by judging if it is repairable (outflow recovery department). In the case it is unrepairable, the product will be thrown away as scrap ending at the outflow of goods endpoint or be handled as a quality issue and sent back to the
Figure 7: In-store inventory management process.
wholesaler (TT330). If the product is repairable and repaired, it will flow back into the in-store inventory by means of TT450.

The stock collection parallelogram ‘In-store inventory’ is used as a starting point for several deviation choices (see next section). First of all the outflow of goods is divided by means of a choice process in a TT440 flow, a TT310 flow and a check-out flow. The TT440 is a separate flow of goods which processes ‘outgoing articles’, leaving the store’s assortment. This flow of goods will be processed further in which the recovery department serves as a discount corner ‘sale shelf’. Eventually, TT440 goods will flow out the system by means of the check-out process. The TT310 flow of goods resembles the goods which were picked out of the in-store inventory stock to be used for display purposes.

Most of the products (check-out outflow from in-store inventory stock) will flow through the check-out process; this check-out process is composed out of exchange articles, home delivery orders and all the products that have been sold through the check-out process. Next to this, products from the TT440 will flow through this process. After the check-out process the products will flow to the outflow of goods endpoint: hereby ending the overall in-store inventory management process.

4.2 Threats to inventory accuracy

The author of this thesis attended a company specific training module in which working methods were shared for tackling the inventory inaccuracy issue. An understanding was gained regarding the diverse number of threats for each of the goods flows. The remainder of this section will focus on the three previously mentioned flows of goods, by looking at its specific components and their potential threats responsible for creating the IRI. Again, this section will be summarized by an updated conceptual model (figure 11). The added elements of figure 10 are marked orange.

4.1.1 Inflow of goods (α-type errors)

The inflow of goods and its related threats within an in-store inventory management process can be summarized by means of the cause and effect diagram in figure 8. The inflows that are colored red will be taken into account and described on its potential threats later on in this thesis. LSC returns (returns coming from e-store orders) and home delivery returns (returns coming from orders that have been delivered by the company) account for a very low amount of goods compared to the red colored inflows. As a consequence of time constraints, these flows are hard to track and analyze by use of the IS.

![Figure 8: Inflow of goods.](image-url)
A DC/DD deliveries ($\alpha_1$)

DC/DD deliveries are the main inflow of goods for the process. These are simply the freights, delivering goods in order to resupply the goods that have been sold. A depiction can be made of this inflow, namely a distribution center (DC) delivery or a direct delivery (DD). A DC delivery is a freight coming from a low or high flow distribution center, containing a diverse spectrum of different product lines. The high flow distribution centers deliver the products that have high outflows (= high numbers of sales). Delivery is done in full pallet amount, meaning that the pallet only holds one type of product. In contrast to this, a low flow distribution center delivers products that have low outflows (= low numbers of sales). Delivery is done in lower amounts by means of a mixed pallet, meaning that a pallet holds > 1 type of products. Next to the DC delivery, the DD delivery accounts for a big portion of this type of inflow. A DD delivery mainly consist of products of one specific product line that is directly coming from the manufacturer.

With help of the interviews conducted with the case study company’s sales and supply support specialists, low flow distribution centers are associated with increased probability of deviation occurrence leading to inventory record inaccuracies. In spite of a claimed 100% exit control at the low flow distribution center, errors are still reported when a 100% entrance control is conducted at the store. Meaning that the products that should be on the pallet are not in line with the expected quantity and/or type. As this type of inflow within the DC/DD delivery inflow accounts for 10% of the total number of freights, and with an average of two deviations per freight (which are not corrected), inventory record inaccuracies will arise$^6$.

Another risk for discrepancies can be theorized for the direct and high flow distribution center deliveries. With help of the IS, products that are not expected, based on their type or quantity, are automatically defined as an over and under delivery (assuming that identification of the barcode corresponds with the reality). In case the barcode corresponds with the expectation of the system, but physically deviates based on type and/or quantity, inventory inaccuracy issues can occur. In this situation the operator who is unloading the freight will receive a message to process the pallet directly towards the sales location or towards a stock location. If it needs to be directly replenished at one of its sales locations, the mistake will be recognized. The employees responsible for unpacking the product and replenishing the location will easily recognize that this type of product does not belong to the sales location. Hence, inventory inaccuracy issues can be prevented. Unfortunately, if the product needs to be processed towards the stock locations, the mistake will lead to inventory accuracy issues. A positive deviation of the actual product on the pallet is created (overstock) and a negative deviation of the product that is on the pallet based on the IS’s database is created (understock).

B Customer Returns

This inflow of goods will enable the choice decision in the model later to be described in this thesis (chapter 5). It is assumed that all the products that are returned are processed correctly in quantity and type. Inventory accuracy issues can arise when the product is further processed and in order to give this issue its due significance, these will be described in more detail in the

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$^6$ Based upon expert opinion retrieved from the training module.
next section. Therefore, this flow only serves as a starting point for other processes and their associated deviation probabilities.

### 4.2.2 Internal flow of goods (β-type errors)

Internal transactions, i.e. internal flow of goods, significantly contribute to the IRI. The internal transactions of goods that have been defined can be found in figure 9. Again, the red colored transactions have been taken into account within this thesis. The trans type 315 (TT), the internal use of products, will leave the scope of this thesis. Based on data retrieved, this type of transaction had practically no responsibility in causing inventory inaccuracies. Next to this, the amount of products processed through this transaction are significantly lower than other type of transactions. Still, this transaction has the potential to cause inaccuracies when a product is incorrectly booked out on this type of transaction.

![Figure 9: Internal transactions.](image)

**A  TT310 – Deco transfer (β1)**

This type of transaction is used when a product is removed from stock and used for display purposes. Products will be displayed in showroom settings. Inaccuracy issues will occur when an employee forgets to book a product they have used for decoration purposes (understock). Next to this, a possibility exist that products are unnecessary booked on this transaction type (overstock).

**B  TT330 – Quality claims (β2)**

The TT330 transaction type is used to adjust the stock levels when the retailer makes a quality claim to the wholesaler. Often, articles are booked on this transaction type but not physically removed from stock, hereby causing inaccuracy issues (overstock). Next to this, issues will occur if too few or too many products are booked on this transaction type than actually necessary (under- and overstock).

**C  TT440 – Undamaged & Q-article back to stock (β3)**

TT440 will be used in the situation that products are outgoing (the product will leave the assortment of the store). To quicken this process, the last pieces of such products will be placed in a discount corner. Additionally, it can be chosen to put quality issued products with some minor defects into the discount corner. Again, inaccuracies will occur if products are booked on this type of transaction and are not physically removed from stock (overstock). In addition, in the case of a counting mistake or an initial wrong number in stock, issues will occur if too
few or too many products are booked on this transaction type than actually in-house (under- and overstock).

D     TT450 – Recovery back to stock (β₄)

In the case that a damaged product is received at the recovery department and it was able to repair the product, the repaired product will be booked back to stock with help of this transaction type. To some extent inaccuracies will arise if the incorrect amount of products is booked on this transaction type compared to what is actually repaired. Also incorrect use of this transaction type is imaginable: if a product was not received defective at the customer returns (TT320) but again is booked back to stock with use of this transaction type, a virtual clone of this product has been created.

E     Cycle count error (β₅)

Cycle count error is by far the most responsible when it comes to internal transaction deviations. Every morning the replenishment crew receives a list of counting tasks on their handheld computer. These tasks are composed of manually imported tasks (in the case that a problem is suspected) or automatically generated tasks by the system, to assure a yearly counting coverage of the whole assortment of products. If an employee of the replenishment team makes a counting mistake and it is not rechecked and corrected by the sales and supply support specialist, an inventory deviation is generated.

F     Basics (β₆)

Often goods disappear and are incorrectly reported as ‘lost’ if products are replenished/located in wrong sales locations. Another mechanism that can be theorized which is responsible for this phenomenon is flexing. In case that the designated sales location is full, it is allowed to ‘flex’ a pallet of products. Flexing is a method where space is borrowed of a neighbor product’s sales location. In such a situation the flexed products might cover up the products that are in the neighbor location, making it hard to see if the product is still there. This might cause an employee to think the product is ‘lost’ and report this to the system.

G     Stock error (β₇)

This type of error will occur if the operator of a reach truck incorrectly books a product out of stock, causing the system to believe it is still in stock (sales quantity is higher than expectation). The opposite is also imaginable: a product is incorrectly booked into a buffer location, making the system believe it is still in its sales location (sales quantity is lower than expectation). Next to this, products can be mistakenly set on the wrong stock location, making it a challenge to find this product with 10,000 locations. Furthermore, in the situation that a pallet of one product type cannot be replenished entirely, a return task should be created. The employee should manually feed the system with the quantity information; a potential risk factor for inaccuracies. In case that a wrong number is given, an incorrect ratio of buffer quantity and sales quantity is derived, hereby causing inaccuracies in the sellable quantity of products.

H     Sales location error (β₈)

A sales location error will occur if the actual location is not in line with the system’s location. In this way, during cycle counting, inaccuracies are created because the employee cannot find the product. Also locations of products can be deleted or replaced without moving the actual
stock to its new location. Again, situations in which inaccuracies are created because the products are seemingly ‘lost’.

### Floating stock ($\beta_9$)

Floating stock is the situation in which logistics was not able to replenish all the products that have been sold the previous day within the given time. In such a situation the logistics department moves the products to be replenished back to an area that is not accessible by customers. Systematically, these products should be booked into the ‘parking’, making the stock invisible for customers by correcting the sales quantity of a specific product negatively. Unfortunately, this does not happen all the time and as a result of this, inventory record inaccuracies are created. This phenomenon applies to products that are not in its sales location nor in its buffer location nor booked as a product that is in the ‘parking’.

#### 4.2.3 Outflow of goods ($\gamma$-type errors)

The outflow of goods is the biggest player that contributes to the IRI. The outflow of goods that have been defined can be found in figure 10. The red colored transactions have been taken into account within this thesis. Return to LC or returns coming from e-store orders returned back to the e-store warehouse and DC/DD returns account for a very low amount of goods, compared to the red colored inflows. Also due to time constraints these flows are hard to track and analyze by use of the IS and will therefore leave the scope of this thesis.

![Figure 10: Outflow of goods.](image)

The different outflows of goods, namely: sales, theft and fraud will all be handled as one outflow of goods. These outflows are assumed to be all taking place at the check-out desk.

In the sales outflow, inventory inaccuracies will arise due to scanning errors at the check-out desk ($\gamma_1$). For instance, a product with the same appearance and price but a different color might be scanned two times in order to speed up the process. In such a case product of type X has been scanned two times instead of type X once and type Y once. Next to this, products can be scanned too often or are missed by the check-out employee. The same mechanisms count for self scan check-out desks, only the influence of theft on this ‘scanning error’ should also be added to the equation. Within this thesis it is acknowledged that the calculated scanning error of next section counts in the theft component.
Figure 11: In-store inventory management including the deviation choices.
4.3 Quantity of goods

With help of data retrieved from the IS, quantities were defined for each of the processes within the created map of figure 11. Eventually these quantities accompanied with the deviation probabilities will help the author to point out which process can be improved most and will lead to the greatest reduction in inventory record inaccuracies (figure 16). With help of table 1 the quantities for each of the processes are summarized of the case study company within the FY15. The remainder of this section will show motivation of the calculated/chosen numbers of table 1.

<table>
<thead>
<tr>
<th>Process/stock</th>
<th>Quantity [units/FY15]</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-store inventory (01-01-2015) - ([Q_{inv}])</td>
<td>2,375,598</td>
</tr>
<tr>
<td>DC/DD delivery - ([Q_{dc/dd}])</td>
<td>Such that outflow of goods (\approx 18,000,000)</td>
</tr>
<tr>
<td>Customer Returns - ([Q_{cr}])</td>
<td>TT320+TT325=168,684</td>
</tr>
<tr>
<td>Deco transfer [TT310] - ([Q_{310}])</td>
<td>44,346</td>
</tr>
<tr>
<td>Customer relations [TT320] - ([Q_{320}])</td>
<td>128,094</td>
</tr>
<tr>
<td>Customer relations [TT325] - ([Q_{325}])</td>
<td>40,590</td>
</tr>
<tr>
<td>Recovery [TT330] - ([Q_{330}])</td>
<td>12,238</td>
</tr>
<tr>
<td>Recovery [TT390/91] - ([Q_{390/91}])</td>
<td>31,482</td>
</tr>
<tr>
<td>Recovery [TT440] - ([Q_{440}])</td>
<td>66,959</td>
</tr>
<tr>
<td>Recovery [TT450] - ([Q_{450}])</td>
<td>19,713</td>
</tr>
<tr>
<td>Scrap - ([Q_{Scrap}])</td>
<td>Recovery inflow – Recovery outflow = 40,121</td>
</tr>
<tr>
<td>Check-out - ([Q_{check}])</td>
<td>Product of the deviations &amp; processes [(\approx 18,000,000)]</td>
</tr>
</tbody>
</table>

Table 1: Quantities of goods within the case study company its in-store inventory management process.

With use of the IS the overall in-store inventory was determined for 01-01-2015, namely 2,375,598 individual items. This is the sum of all the inventory physically in-house which is the sum of goods in stock and on sale shelves.

When constructing the model, the quantity for the inflow of goods start point will be the sum of the quantity of the DC/DD delivery and customer returns. The DC/DD delivery will serve as a set point: meaning that a quantity should be chosen in such a manner that the outflow of goods endpoint will contain \(\approx 18,000,000\) goods after a FY. This number is based on data that summed up all the goods sold at the check-out process for the months September 2015 till April 2016. Although these data only cover 8 months (FY16), it is a fairly good sample that could be representative for the FY2015. Within the FY16 almost the same range of products is sold and the same revenue is generated.

With help of the IS, data were obtained that summed up all the bookings of goods on the divers number of transaction types (TT310 till TT450). Unfortunately, these data were incomplete and only contained the bookings of a 15 week time frame. The average number of goods per day was calculated and multiplied with the number of opening days (361) resulting in the numbers of table 1. It is assumed that this time period isrepresentable for the behavior of the remaining fiscal year and for the FY15, as these numbers were verified by experts in field.
The scrap quantity in table 1 will serve as a ‘disposal’ quantity, as not every damaged good is repairable. The scrap quantity will be the result of the goods inflows (TT325+TT390/91) minus the goods outflows (TT330+TTT450). This is the quantity of goods that was not able to be repaired and therefore will be disposed.

4.4 Probability of a deviation

The absolute numbers of deviations, spread across the three types of goods flows can be found in figure 12. It was chosen to take the absolute number of deviations, such that a positive inaccuracy (there are more products than expected) and a negative inaccuracy (there are less products than expected) are summed. In this manner, the best possible insight is given on the problem. The model that will simulate the current behavior and its associated inventory record inaccuracies should reflect these numbers. This section of this thesis will reillustrate the numbers of figure 12, created by the deviation sources of figure 11. All this data have been retrieved with help of the IS and company specific documents that processed this data to relevant information.

### 4.4.1 Deviations within the inflow of goods

Within the case study company, specialist have put a great effort in retrieving causes of inventory record inaccuracies for almost two years. Deviations would be generated after finishing the counting tasks during the replenishment process. In the case that a deviation was observed, a random number of deviations was checked by a sales and supply support specialist and an attempt was made to identify the cause of this deviation.

With help of the data retrieved from a comparable in-store inventory management process the solving power of the sales and supply support specialist could be calculated. All the generated deviations were checked in the month April over a three year time period (figure 13). The blue bar in figure 13 represents the total value of goods (purchasing value) of the deviations generated after finishing the counting tasks. The orange bar represents the value
of goods of deviations when the sales and supply support specialist had finished their cause analysis. This resulted in a 65% resolving ‘power’ of the sales and supply support specialist department (grey bar in figure 13) for FY15. Meaning that 65% of the deviations observed can be linked to a cause. Based on expert opinion, the unexplained component can be fully related to theft.

Most of these causes could be related to a cycle count error (counting mistake). But also some deviations could be related to the DC/DD deliveries. Based on this data, the causal categories were divided into an inflow type cause, intern flow type cause and an ‘others’ flow type cause. A comparison was made in proportion for each of the flow types, resulting in a 2% component for all the deviations observed that were related to inflow type of causes (table 2).

In order to make the translation to quantities (for the case study company), the cycle count data were used. These data were used in a previous section to point out the problem of inventory record inaccuracies. As these data apply to exactly the same in-store inventory management processes, it is assumed that the same proportions of deviations sorted per flow type are present within the case study company’s in-store inventory management process. This cycle count data made a depiction in negative and positive errors observed and represented only 53% of the product line. This proportion counted for the products that were counted once. Products that were counted more than once would not result in an accurate deviation estimate; an average was taken if a product resulted in a deviation at time A and an accurate stock on time B or another deviation on time C. A translation was made for the whole product line accompanied with an absolute error, assuming that the observed errors within the sample of 53% of the product line are representable for the whole population. For the case study company’s in-store inventory management process this resulted in an absolute number of 70,304 observed deviations over the FY15.

Of these 70,304 deviations, 65% could be linked to a cause (figure 12), resulting in 45936 deviations. Multiplying this number of observed absolute deviations with the 2% deviation inflow type resulted in 1000 deviations. Meaning that 1000 deviations are generated at the DC/DD delivery flow of goods. Related to the quantities processed through this process (18,000,000 products/year), this is extremely low.

<table>
<thead>
<tr>
<th>Share [%]</th>
<th>Type of goods flow</th>
<th>Deviations (abs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Inflow (α)</td>
<td>1,000</td>
</tr>
<tr>
<td>57</td>
<td>Internal (β)</td>
<td>26,194</td>
</tr>
<tr>
<td>41</td>
<td>Others (γ)</td>
<td>18,742</td>
</tr>
</tbody>
</table>

Table 2: Share of deviations over the type of goods flows (total number of solved deviations: 70,304*0.65).

4.4.2 Deviations within the internal flow of goods

In a same manner as in the previous section, the deviation causes that were classified as internal flow type deviations were used to calculate the number of deviations within the internal flow of goods (26194 deviations, table 2). Next to this, the different internal flow types and their associated proportion contributing to the number of internal deviations is visualized in figure 14. These proportions are the product of excluding the inflow and ‘others’ type of deviation causes.
4.4.3 Deviations within the outflow of goods

The main outflow of goods is generated at the check-out process. This process can be split into two types of check-out processes, namely a manned check-out process (80% of the revenue) and a self scan check-out process (20% of the revenue). With help of data retrieved of the self scan check-out process a statement can be made on theft and scanning errors.

The self scan check-out simply enables the customer to register and pay their purchased products independently. An employee is responsible for four of the self scan check-outs in order to answer questions of customers and to perform spot checks. Per 25 transactions a spot check will be randomly performed at one of the self scan check-outs (0.75% of the generated revenues is spot checked). In this situation an employee will check the scanned items with what is actually on the shopping trolley. If a discrepancy is observed, it will be reported in the system.

These data have been used to construct the graph in figure 15. It visualizes the absolute observed number of deviations at the check-out process per month accompanied with a 95% confidence interval. These numbers reflect the scanning errors and (un)deliberately conducted theft. The graph has been constructed by multiplying the total sold products for that specific month with the quotient of the checked products and the total observed discrepancies (1:401). The quotient is the average of the months May 2015 till April 2016. These data are used as a representation for the behavior within the outflow of goods for the FY15. Ultimately, if the eight month average of deviations is translated to a 12 month period, a number of 53853 deviations at the outflow process is obtained.

Unfortunately, the store does not perform spot checks at the manned check-outs, which generate the most revenue. The translation of the spot check data of the self scan transactions towards the whole population of transaction is a limitation in this thesis, therefore these calculations will serve as a guideline. It is quite imaginable that other effects play a part at the manned check-out compared to the self scan check-out. Employees will scan items more correctly compared to customers, but at the other end an employee must scan more items per transaction, increasing the probability of a scan error (the self scan check-out process only allows a maximum of 15 items). On average the products scanned at the manned check-out are
more expensive, increasing the probability that theft is conducted in greater numbers. Next to this it can be theorized that the sense of self-control of a customer at the self scan check-out process will increase the numbers of theft.

To quantify the deviations within the outflow of goods, the ‘others deviation causes’ (table 2) are summed with the 35% unexplained deviations of figure 13 (=18,742+24,368=43,109 goods). The quantity of the cause ‘others’ reflects outflow type of causes like theft, scanning errors but also products that simply could not be found anymore. The deviations which could be related to theft and other out flow type causes is too low within this ‘others deviation causes’ based on calculations done of which the results are summarized in figure 14. Therefore it is assumed that the 35% component of ‘unexplained’ deviations are fully to be related to theft.

Based on the calculations done in figure 15 a number of 53,853 deviations was found within the processes responsible for the outflow of goods. When the 43,109 deviations of previous paragraph are subtracted from the deviation calculated within this paragraph, a gap is observed of ≈10,750 deviations. It is assumed that this gap is created by the unexplained effects (self scan check-outs vs. manned check-outs) by extrapolating the data of the spot check analysis towards the whole population of transactions. Next to this, the observed deviations during cycle counting would not be in line if the calculated deviations of figure 15 were chosen. Therefore, the calculated deviations of previous paragraph are a more accurate estimate for the number of deviations within the outflow processes.

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Figure 16: Conceptual model with quantities and deviations for FY15.
5. Simulation model

A simulation model that reflects the status quo of the mechanisms causing the inaccuracies was made (figure 17). The set parameters can be found in table 3 and 4. The in-store inventory process was simulated with use of the modeling software Vensim 6.3. Vensim models on the basis of the system dynamics methodology (continuous simulation). This is best suited to problems associated with continuous processes where feedback significantly affects the behavior of a system (Sweetser, 1999). A simulation approach has been chosen due to the probabilistic nature of some processes. Next to this, some components of the system have interconnectedness; they affect another. Despite the effectiveness of mathematical models in ensuring optimal solutions and good run times, these approaches can be considered insufficient to support the nature of supply chain processes and hence the warehouse operations (Karagiannaki et al., 2007). Appendix III will summarize the main components used. Assumptions made for this model can be found in this chapter.

Most preferably, the behavior of the model will reflect the extent of inventory record inaccuracies for the FY15 (chapter 4). In the remaining of this chapter the model (5.1) and its dynamics (5.2) will be described and validated (5.3).

5.1 Model description

This model makes its calculations on a daily basis, meaning that an inflow or outflow rate for a specific stock handles product flows per day. The retailer is open for 361 days a year from 10 AM to 9 PM, where products arrive at the store; either being a customer return or a DC/DD delivery. Products arrive at a constant rate of 50,169 products/day, such that an accurate inflow of goods at the customer return desk and logistic process is guaranteed. The rate of products returned by customers is the summation of the two normal distribution functions TT320 and TT325 (table 4). The rate of products received by means of the DC/DD delivery is the result of subtracting the rate of products returned with the arrival rate of products.

<table>
<thead>
<tr>
<th>Deviation source</th>
<th>Probability of deviation [units/FY15/deviations]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DD delivery</td>
<td>Deviation [inflow] inflow rate*((1,000/361)/ Deviation [inflow] inflow rate)</td>
</tr>
<tr>
<td>Deco transfer</td>
<td>Deviation [intern] inflow rate *((756/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Cycle Count Error</td>
<td>Deviation [intern] inflow rate *((15,519/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Basics</td>
<td>Deviation [intern] inflow rate *((2,896/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Stock Error</td>
<td>Deviation [intern] inflow rate *((2,554/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Sales Location Error</td>
<td>Deviation [intern] inflow rate *((2,153/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Floating Stock</td>
<td>Deviation [intern] inflow rate *((553/361)/ Deviation [intern] inflow rate)</td>
</tr>
<tr>
<td>Check-out</td>
<td>Deviation [outflow] inflow rate *((43,109/361)/ Deviation [outflow] inflow rate)</td>
</tr>
</tbody>
</table>

Table 3: Probability of deviation.
A product that is returned by a customer is checked for damage, this is either a damaged product (TT325) or an undamaged product (TT320). Both product rates follow a normal distribution function defined in table 4. The TT325 rate of goods will flow into the recovery department, the TT320 rate of goods will flow back to the in-store inventory and will be ready for sale. The TT320 rate of inflow equals the outflow in distribution, but a one day delay is built in the outflow rate, allowing some stock generation within this trans type’s stock. In practice this stock is accumulated in the recovery department and picked up by sales personnel in order to resupply. The TT325 flows directly from the customer return to the recovery department, implying that the inflow rate of the TT325 stock is equal to the outflow rate.

Focusing on the DC/DD delivery process, logistics will convert the deliveries towards goods that are in stock in the in-store inventory. It is assumed that all delivered stock is handled within one day, hereby implying that the logistic process inflow rate equals the outflow rate. During this process a 31,482 products/year are damaged (TT390/91 rate [in]). These will flow out of the logistic process stock. A five day delay is built in the outflow rate of the TT390/91 before it arrives at the recovery department.

The recovery department will check if the damaged products are repairable or not. If concluded that it is not repairable it is handled as scrap, which will be executed as such with a five day delay. If concluded that it is repairable, the product will be repaired and resupplied in the in-store inventory with a 15 day delay. If concluded that the product has a quality issue and therefore needs to be reclaimed at the manufacturer, stock will flow out of the system with a 15 day delay.

The in-store inventory has three outflows; namely a TT310 rate of outflow, a TT440 rate of outflow and an overall outflow rate of the in-store inventory. The TT310 rate of products will be subtracted from the in-store inventory, no delays are built in; the products are removed from stock and will be placed as display stock within one day. Products that are removed from stock and sold with a discount are removed from the in-store inventory stock (TT440 rate), followed by a customer that buys the product. The TT440 rate has a five day delay built in before the stock arrives at the check-out process. The overall outflow rate of the in-store inventory equals the inflow rate, meaning that the same quantity of replenished products are sold. If the products have been purchased, it will flow out of the system by means of the “outflow rate check-out”. This ultimately leaves the system by means of “rate of outflow”. This rate is the summation of the “outflow rate check-out”, “Scrap rate [out]” and “TT330 rate [out]”.

Deviations will be generated by means of the “Deviation [inflow] inflow rate”, the “deviation [intern] inflow rate” and the “deviation [outflow] inflow rate”. The rates will follow the formulas that are summarized in table 3. These rates of deviations/day are subtracted from the relevant stocks and will flow in the overall “Inventory record inaccuracy [ABS]” stock.

5.2 Dynamics

The distributions for the inflow rates of goods per day within the processes of the overall in-store inventory management process have been tested on normality. This distribution will serve as an input parameter to reflect the dynamics of the in-store inventory management process. This hereby decreasing the simplification of reality of the model. The shape of the distribution is analyzed with help of the company’s IS over a randomly selected 89 day sample.
Figure 17: Simulation model.
The minimum and maximum, mean as well as the standard deviation values of goods arrival per day per process have been retrieved and are summarized in table 4. Figure 18 serves as an example, visualizing the dynamics of the inflow rate TT390/91. The dynamics of other processes can be found in appendix IV.

A Kolmogorov-Smirnov test was performed to test for normality on the distribution of quantities of inflow of the processes, plotted probability functions can be found in appendix V. The researcher was unable to retrieve data for the rate of products received from the DC/DD delivery and check-out process on a daily basis.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deco transfer [TT310]</td>
<td>0</td>
<td>122.8</td>
<td>118.4</td>
<td>410</td>
<td>D=0.155, p&gt;0.05</td>
</tr>
<tr>
<td>Customer relations [TT320]</td>
<td>0</td>
<td>355.0</td>
<td>94.2</td>
<td>555</td>
<td>D=0.07, p&gt;0.05</td>
</tr>
<tr>
<td>Customer relations [TT325]</td>
<td>0</td>
<td>112.4</td>
<td>31.4</td>
<td>214</td>
<td>D=0.119, p&gt;0.05</td>
</tr>
<tr>
<td>Recovery [TT330]</td>
<td>0</td>
<td>33.9</td>
<td>217.4</td>
<td>937</td>
<td>D=0.374, p&lt;0.05</td>
</tr>
<tr>
<td>Recovery [TT390/91]</td>
<td>0</td>
<td>87.0</td>
<td>34.2</td>
<td>236</td>
<td>D=0.115, p&gt;0.05</td>
</tr>
<tr>
<td>Recovery [TT440]</td>
<td>0</td>
<td>185.5</td>
<td>354.5</td>
<td>2251</td>
<td>D=0.305, p&lt;0.05</td>
</tr>
<tr>
<td>Recovery [TT450]</td>
<td>0</td>
<td>54.6</td>
<td>37.9</td>
<td>214</td>
<td>D=0.133, p&gt;0.05</td>
</tr>
</tbody>
</table>

Table 4: Shape of distribution and test for normality

Clearly, all the processes with exception of the TT330 and TT440 processes are normally distributed. The TT330, the TT440, the DC/DD delivery processes and the check-out process will be modelled such that a constant inflow of goods per day is guaranteed.
5.3 Validation

With help of the modeling software Vensim 6.3 tables were generated for each of the different processes and stocks within the model. In table 5, these will be compared with the quantities analyzed in chapter 4. Next to this, table 5 will also compare the deviations defined in chapter 4 with the deviations generated by the model.

<table>
<thead>
<tr>
<th>Process/stock</th>
<th>Quantity analyzed</th>
<th>Quantity generated</th>
<th>Discrepancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DD delivery</td>
<td>≈18,000,000</td>
<td>17,994,500</td>
<td>5,500 (-0.03%)</td>
</tr>
<tr>
<td>Deco transfer [TT310]</td>
<td>44,346</td>
<td>56,494</td>
<td>12,148 (+27.39%)</td>
</tr>
<tr>
<td>Customer relations [TT320]</td>
<td>128,094</td>
<td>126,763</td>
<td>1,331 (-1.04%)</td>
</tr>
<tr>
<td>Customer relations [TT325]</td>
<td>40,590</td>
<td>39,945</td>
<td>645 (-1.59%)</td>
</tr>
<tr>
<td>Recovery [TT330]</td>
<td>12,238</td>
<td>11,744</td>
<td>494 (-4.04%)</td>
</tr>
<tr>
<td>Recovery [TT390/91]</td>
<td>31,482</td>
<td>31,386</td>
<td>96 (-0.30%)</td>
</tr>
<tr>
<td>Recovery [TT440]</td>
<td>66,959</td>
<td>66,966</td>
<td>7 (+0.01%)</td>
</tr>
<tr>
<td>Recovery [TT450]</td>
<td>19,713</td>
<td>22,671</td>
<td>2,959 (+15.00%)</td>
</tr>
<tr>
<td>Scrap</td>
<td>40,121</td>
<td>36,916</td>
<td>-3,205 (-7.99%)</td>
</tr>
<tr>
<td>Check-out process</td>
<td>≈18,000,000</td>
<td>18,033,400</td>
<td>33,400 (+0.19%)</td>
</tr>
<tr>
<td>Deviation [inflow]</td>
<td>1,000</td>
<td>1,000</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Deviation [intern]</td>
<td>26,194</td>
<td>26,194</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Deviation [outflow]</td>
<td>43,109</td>
<td>43,109</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Inventory Record inaccuracy [ABS]</td>
<td>70,303</td>
<td>70,303</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Table 5: Validation of the quantities.

Discrepancies are observed for the trans types, DC/DD deliveries, scrap and the check-out process. The discrepancies within the trans types quantities and the scrap quantity are caused by the normal distribution functions and delays. The dynamics of those functions do not guarantee a predefined average of products/day for each day; the average will fluctuate on a daily basis. These dynamics can be found in appendix IV visualizing the fluctuation of the daily goods arriving per day per process. The greater the fluctuation for a specific process, the greater the discrepancy listed in table 5. The scrap discrepancy is the result of the recovery outflow of goods minus the recovery inflow of goods and is therefore also influenced by the normal distribution functions. The DC/DD delivery and check-out discrepancy are the result of the set parameter of goods/day at the inflow start point of the model; an optimum was found by setting the constant rate of products on 50169 products/day.

No discrepancies are observed at the stocks of deviation. This is due to the buildup of the deviations, it is based on a function that includes the relevant rate of goods for the specific deviation flow (table 3). Hence, the rate of goods for the specific deviation flow has no influence on the buildup of deviations.
6. Redesign

A redesign of the in-store inventory management process that makes use of RFID technology needs to eliminate, or at least reduce, the mechanisms that are causing the discrepancies in the in-store inventory management process. This chapter will therefore elaborate on the researcher’s efforts of chapter 4 and 5. Three scenarios were defined in order to evaluate the impact of various implementation levels of RFID technologies (6.1). Furthermore, the three different scenarios will be linked to a change in parameters (6.2).

6.1 Scenarios

Partly based on the simulation approach of Sarac et al. (2009) three scenarios have been defined in order to evaluate the impact of various implementations levels of RFID technologies (table 7). The remainder of this section will describe these scenarios which all differ based upon penetration depth of the RFID technology. Connected to this, each scenario will differ in costs and a decreased error rate that contributes to an improvement in the IRI. Table 6 will summarize section 6.1.1 till 6.1.3 relatively to each other by means of the improvements achieved.

6.1.1 Scenario 1

In the first scenario, RFID technology is integrated at the pallet level (full and mixed pallet). Pallets are prepared at the supplier and tags displaying the correct quantity and type of product. Using the technology in such a manner will increase the visibility and traceability of products on pallet level. As this scenario has the lowest penetration depth of the RFID technology, the least amount of portals are placed on tactical places to track the pallets as good as possible. This is done by placing the portals at all the entrance and exit gates; from unloading area to store, this should decrease the floating stock error on pallet level. In this situation, pallets can only be in the sale shelves, their stock location or have the ‘parking’ status and are waiting to be replenished or put in stock the next day. Furthermore, placing RFID portals at the loading docks will increase the productivity of the unloading operators. This could lead to a decrease in personnel costs. No line of sight is necessary anymore, as it was with the barcode technology, simply driving through the portal is all that is necessary. The technology can be used in the same manner to increase the productivity of the operators putting the pallets into stock (reach trucks), by placing RFID readers on the truck itself. A floor map of the placement of the several RFID portals for this scenario can be found in appendix VI.

The RFID technology cannot identify products outside the pallet level. Thus, the visibility of products in the store does not change. Therefore in this scenario the RFID technology will have no effect on the scanning errors and theft at the check-out process. Next to this, the cycle count error will still hold, as employees still have to apply the same working methods for cycle counting as in the old situation. The only element that will change is the cycle count process of products in stock, as these will be in stock at pallet level with an associated RFID chip. The inability to track products on the item level will also have no effect on the stock error, basics error, sales location error and DC/DD delivery error.

6.1.2 Scenario 2

In the second scenario, RFID is integrated at the product level. Additional RFID portals are placed at the check-out desks and at the order picking collection room. Next to this a portal is placed at the recovery department to enable the several transactions of products. Finally, two more portals are added to divide the store into three sales zones, namely the warehouse,
markethall and showroom. Using the technology in such a manner will increase the visibility and traceability of products on product level. A floor map of the placement of the several RFID portals for this scenario can be found in appendix VII.

This scenario is associated with the same strengths of the technology of scenario 1. Additionally, the main source of IRI at the check-out process will be greatly reduced. Customers will walk through a portal with their shopping cart, enabling the system to scan the content (=reduction of scanning error). The inability to hide a product should also decrease the rate of theft. Next to this, the check-out employees will be more productive, a decrease in costs should also be counted in for this process. Furthermore, the employees who are responsible for shipping order pickings will be more productive. A checkup of the picked content on a pallet is now simply walking through a RFID portal. Hence, this process is associated with another decrease in costs.

Cycle counting can now be conducted faster and more accurate by simply walking and waving a handheld reader. This process is associated with a decrease in personnel costs but will not significantly reduce cycle count errors (6.2). Next to this, the DC/DD delivery error rate should decrease due to the RFID chips on product level. Error rates that were associated with deviations between the content of the full or mixed pallet and with the identification of this pallet are now in the past. Finally, the associated error rates of the trans type processes should decrease by placing a RFID portal in the recovery department. If a product is taken from stock, in case of the TT310 (stock to display), an employee should set the correct transaction in the portal and walk through the portal with his picked content. Simply forgetting to book a product, in wrong quantity and/or type is not one of the options anymore.

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce inflow error rate?</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reduce floating stock error rate?</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Reduce stock error?</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Reduce sales location error?</td>
<td>-</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Reduce basics error?</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Reduce cycle count error?</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Reduce transaction type errors?</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reduce outflow error rate?</td>
<td>-</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Decrease costs at inflow processes?</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Decrease costs at order picking process?</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Decrease costs at cycle counting process?</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Decrease costs at outflow processes?</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

*Table 6: Advantages per scenario.*

### 6.1.3 Scenario 3

In this last scenario, smart zones are added in the store by adding more RFID portals. These zones can frequently (e.g. every minute) check inventories. This scenario thus provides real-time information at product level in the store per zone. Products that are seemingly lost can
now be tracked more accurately. Associated with this, a reduction in sales location error rate, the basics error rate and stock error rate can be expected. Next to this, costs of cycle counting can be reduced even more. Furthermore, the rate of theft that is still present can be reduced more by matching the outflow rates of products with the sale rates per zone during opening hours. Warnings could be generated towards security employees if the discrepancy between the outflow rates and sales rates exceeds a threshold value. A floor map of the placement of the several RFID portals for this scenario can be found in appendix VIII.

### Table 7: Integration level of technology per scenario.

<table>
<thead>
<tr>
<th>Integration level</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID chip</td>
<td>Pallet</td>
<td>Product</td>
<td>Product</td>
</tr>
<tr>
<td>RFID portal</td>
<td>Unloading docks &amp; Entrance + exits of warehouse</td>
<td>Unloading docks &amp; Entrance + exits of warehouse</td>
<td>Unloading docks &amp; Entrance + exits of warehouse &amp; smart zones</td>
</tr>
</tbody>
</table>

### 6.2 Change in parameters

With help of the literature the described advantages of table 6 will be translated into a change of deviation probabilities (table 9). The remainder of this section will elaborate on the chosen parameters per scenario. A translation to the new number of deviations per scenario can be found in table 8. Advantages related to the decrease in costs will be elaborated during the components step (chapter 7).

### Table 8: Absolute number of deviations per scenario (highlighted = changed parameter compared to preceding scenario).

<table>
<thead>
<tr>
<th>Deviation source</th>
<th>Scenario 0</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DD delivery</td>
<td>1,000 (α₁)</td>
<td>1,000 (α₁₁)</td>
<td>29 (α₁₂)</td>
<td>29 (α₁₃)</td>
</tr>
<tr>
<td>Deco transfer [TT310]</td>
<td>774 (β₁)</td>
<td>774 (β₁₁)</td>
<td>22 (β₁₂)</td>
<td>22 (β₁₃)</td>
</tr>
<tr>
<td>Recovery [TT330]</td>
<td>786 (β₂)</td>
<td>786 (β₂₁)</td>
<td>23 (β₂₂)</td>
<td>23 (β₂₃)</td>
</tr>
<tr>
<td>Recovery [TT440]</td>
<td>792 (β₃)</td>
<td>792 (β₃₁)</td>
<td>23 (β₃₂)</td>
<td>23 (β₃₃)</td>
</tr>
<tr>
<td>Recovery [TT450]</td>
<td>167 (β₄)</td>
<td>167 (β₄₁)</td>
<td>5 (β₄₂)</td>
<td>5 (β₄₃)</td>
</tr>
<tr>
<td>Cycle Count Error</td>
<td>15,519 (β₅)</td>
<td>16,691 (β₅₁)</td>
<td>21,380 (β₅₂)</td>
<td>21,380 (β₅₃)</td>
</tr>
<tr>
<td>Basics</td>
<td>2,896 (β₆)</td>
<td>2,896 (β₆₁)</td>
<td>2,896 (β₆₂)</td>
<td>83 (β₆₃)</td>
</tr>
<tr>
<td>Stock Error</td>
<td>2,554 (β₇)</td>
<td>2,554 (β₇₁)</td>
<td>2,554 (β₇₂)</td>
<td>74 (β₇₃)</td>
</tr>
<tr>
<td>Sales Location Error</td>
<td>2,153 (β₈)</td>
<td>2,153 (β₈₁)</td>
<td>1,996 (β₈₂)</td>
<td>62 (β₈₃)</td>
</tr>
<tr>
<td>Floating Stock</td>
<td>553 (β₉)</td>
<td>446 (β₉₁)</td>
<td>16 (β₉₂)</td>
<td>16 (β₉₃)</td>
</tr>
<tr>
<td>Check-out</td>
<td>43,109 (γ₁)</td>
<td>43,109 (γ₁₁)</td>
<td>23,432 (γ₁₂)</td>
<td>23,432 (γ₁₃)</td>
</tr>
<tr>
<td>Total</td>
<td>70,303</td>
<td>71,368</td>
<td>52,376</td>
<td>45,149</td>
</tr>
<tr>
<td>Δ Scenario 0 (%)</td>
<td>n.a.</td>
<td>+1.52%</td>
<td>-25.50%</td>
<td>-35.78%</td>
</tr>
</tbody>
</table>

*Table 8: Absolute number of deviations per scenario (highlighted = changed parameter compared to preceding scenario).*
6.2.1 Parameters scenario 1

Considering the improvements in this scenario a decrease in the floating stock and cycle count error rate is expected. Focusing on the cycle count error rate the work of Buckel and Thiesse (2013) is used. It is hypothesized that a RFID cycle count is reliable and comparable to the accuracy of a conducted physical count. Within this work the potential benefit of a RFID cycle count was empirically verified. A study was performed within nine pilot stores where simply the total counted products with help of RFID was compared with the real quantity in store. Products were tagged on product level. Taking the average of these nine stores an accuracy of 99.1% was achieved. Meaning that the RFID technology was able to count 99.1% of the total physically present products. Figure 19 visualizes the distribution of reasons of the remaining 0.9% of products of which RFID was not able to count. The + and - signs of figure 19 indicate the impact on inventory. Meaning that the error incorrectly lowered or increased the inventory.

In scenario 1 the RFID tags are integrated on pallet level, meaning that cycle counting can be performed for the stock locations with help of RFID (as these locations contain full pallet amount of products). Translated to this study the new deviation amount for the cycle count process is the proportion of products in stock compared to the total number of products in-house (=2,375,598 products=\(Q_{inv}\)). Based on data retrieved an average of 20% of the total number of products are in stock. It is assumed that the deviations are evenly distributed over the products in stock and sale shelves. A new error rate is defined based on the new acquired error rate by using RFID technologies. The proportion of products in stock on a yearly basis will now be subjected to the new error rate of 0.9%. The new acquired absolute rate of deviations considering the cycle count error for scenario 1 is a summation of 80% of the old deviation rate and 20% of the new deviation rate. Therefore the new acquired absolute rate of deviations (\(\beta_{S1}\)) is \((0.8*\beta_5)+(0.2*Q_{inv}*0.009))=16691\) deviations/year.

The floating stock error rate (\(\beta_9\)) will be reduced by the use of RFID portals at all the entrance and exit gates from unloading area to store. In this manner products on pallet level will either be in stock, in the sale shelve or have the status ‘parking’. In this scenario the pallets will not get seemingly ‘lost’ due to the absence of the parking status. It is assumed that in the base
scenario all the pallets were not properly placed in the parking when needed, therewith responsible for the total number of deviations considering the floating stock error rate.

The only factors hampering the accuracy are the technological inabilities of RFID. With help of the study of Candolin (2011) the read rate of RFID technology was tested with a high rate of quantity in a short period of time. Around 2000 tags were scanned in a minimum of 15 seconds and a maximum of 80 seconds, which is comparable with the flow of products (products/time) within the case study company. With the help of the data within the study of Candolin (2011) a read accuracy of 98% was calculated. This accuracy purely takes the technological performance into account. Effects which were described in figure 19 are not taken into account. Therefore, this factor is also considered. As this scenario deals with pallet amounts of products again a proportion component is used for calculating the number of deviations. The new acquired absolute rate of deviations considering the floating stock error for scenario 1 is a summation of 80% of the old deviation rate (=553 deviations/year) and 20% of the new deviation rate. Therefore the new absolute rate of deviations ($\beta_{91}$) is $((0.8*\beta_9)+(0.2*\beta_9)*(1-(0.98*0.991)))=446$ deviations/year.

6.2.2 Parameters scenario 2

In scenario 2 RFID tags are integrated on product level. This offers the possibility to reduce the error rate at the inflow process of goods. Again the study of Candolin (2011) and Buckel and Thiesse (2013) are used as a basis. Meaning that the error rate of the technology and the effects of figure 19 are taken into account. The deviation rate which was observed in the base scenario will be reduced by the new acquired error rates ($\alpha_1*(1-(0.98*0.991))$) deviations/year. These deviations were the result of products that were physically present, but not in line with the systems expectancy. Due to the product level integration of RFID tags, products are now scanned on individual basis, making it possible to correct the stock if it not matches the system’s expectancy. A new rate of ($\alpha_1*(1-(0.98*0.991)))=29$ deviations/year should be expected ($\alpha_{12}$).

In this scenario, the floating stock error rate will be reduced to a greater extent. Due to the integration of RFID on product level the proportion component of products in stock versus the total products in-house can be excluded. A new deviation rate ($\beta_{92}$) is achieved, namely ($\beta_9*(1-(0.98*0.991)))=16$ deviations/year.

Focusing on the sales location error within this scenario, an increased visibility is created by placing RFID portals on tactical places. Products that deviate with the system’s sales location and the physical sales location can now be tracked more accurately. In the case that this deviation is observed during cycle counting, the system can give a warning that the product was registered in one of the three sales zones of scenario 2 (resp. the warehouse, markethall or the showroom). Employees will now effectively be triggered to look for the products within the correct zone. This should translate in a decrease in error rate. In scenario 3, 40 zones have been created. It is assumed that within this scenario the decrease in error rate will be a function of the number of zones in scenario 3. Hence, dividing the store into 40 zones will lead to recovering all the errors related to this type. The only factors that hamper the accuracy of this error type are again the technical inabilities of the RFID technology. Therefore the new acquired absolute rate of deviations is $((3/40)*\beta_8)*(1-(0.98*0.991))=1,996$ deviations/year ($\beta_{82}$).
Due to the product level integration of RFID technology, the opportunity is created to count the complete inventory. Therefore, the new acquired absolute rate of deviations is \( Q_{inv} \times 0.009 = 21,380 \) deviations/year \((\beta_{52})\). Unfortunately, this is almost a 38% increase in deviations considering this error type compared to the base scenario. Benefits are expected based on reduction in operational costs (chapter 8).

As described in section 6.1 the transaction error will be tackled by the use of one RFID portal placed at the recovery department. Due to the potential large amount of products that should be scanned in a relatively short period of time, the work of Candolin (2011) and Buckel and Thiesse (2013) is combined to a new error rate. All the trans types (internal transactions) will be reduced by \((0.991 \times 0.98) \times 100\% = 97.1\%\) \((\beta_{12}, \beta_{22}, \beta_{32}, \beta_{42})\).

Finally, in scenario 2 RFID portals are added at the check-out desks. In combination with the RFID tags on product level, the rate of theft shall significantly decrease. Based on an IBM’s estimate, a RFID enabled check-out scanning process has the potential to decrease the rate of theft by 47% (Alexander, et al., 2002). Next to this, the scanning errors will be reduced based on the work of Candolin (2011) and Buckel and Thiesse (2013). The only factors hampering the accuracy of the scanning process are the technological inabilities of RFID, therefore the new absolute rate of deviations within the outflow of products process will be \( \gamma_1 \times (1 - (0.991 \times 0.98 \times 0.47)) = 23,432 \) deviations/year \((\gamma_{12})\).

<table>
<thead>
<tr>
<th>Rate [deviations/year]</th>
<th>Accuracy [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow error rate</td>
<td>97.1% - (Candolin, 2011) &amp; (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Floating stock error rate</td>
<td>97.1% - (Candolin, 2011) &amp; (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Stock error rate</td>
<td>99.1% - (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Sales location error rate</td>
<td>(#zones/#totalzones)*(error rate)*99.1% - (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Basics error rate</td>
<td>99.1% - (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Cycle count error rate</td>
<td>99.1% - (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Transaction type error rate</td>
<td>97.1% - (Candolin, 2011) &amp; (Buckel &amp; Thiesse, 2013)</td>
</tr>
<tr>
<td>Outflow error rate</td>
<td>Reduction of 46% - (Alexander, et al., 2002) &amp; (Buckel &amp; Thiesse, 2013) &amp; (Candolin, 2011)</td>
</tr>
</tbody>
</table>

Table 9: Improvements in error rate.

6.2.3 Parameters scenario 3

In scenario 3 RFID portals are added appendix XII, hereby creating a total of 40 sales zones of which 29 in the warehouse, 10 in the markethall and one in the showroom. This feature increases the visibility of products on product level significantly. Therefore, a reduction in deviations within the basics and stock error can be expected. On zone level, an operator that puts the products in stock will receive a warning if he puts stock away in the wrong zone. If the operator puts the stock wrongly within the correct zone, it can be retrieved more easily. Next to this, it can be verified if the pallet is in the zone, which makes searching more efficiently. Furthermore, an operator who is performing the cycle count of a specific zone can now easily be warned if a discrepancy is observed in stock. This warning should contain the total number of products of the desired type that should be in the zone. The work of Candolin

Table:
(2011) and Buckel and Thiesse (2013) is used to determine the total number of deviations for the stock error and the basics error. It is assumed that with help of these 40 zones all the stock is retrieved and corrected. The stock error rate for scenario 3 is \((\beta_7^* (1-(0.991*0.98)))=74\) deviations/year \((\beta_{73})\). The basics error rate for scenario 3 is \((\beta_6^* (1-(0.991*0.98)))=83\) deviations/year \((\beta_{63})\). The sales location error rate in scenario 3 will be \(((40/40)^* \beta_8^* (1-(0.991*0.98)))=62\) deviations/year \((\beta_{83})\).

In this scenario it was hypothesized that by adding additional zones, theft could be reduced even more. In the situation that a discrepancy is observed (number of products leaving their sales location minus the products that are sold) a guard could perform spot checks or simply be visible to the shopping public. The literature suggests that adding security guards has no influence on the rate of theft (Farrington et al. 1993). Therefore the derived number of deviations of scenario 3 will be the same as scenario 2.
7. Components

In order to enable the redesign of chapter 6 the RFID technology should be purchased. This chapter will describe the technology (7.1) and provide an inventory of the technological components related to its costs per scenario (7.2).

7.1 Technology

RFID is an automatic identification and data capture technology that uses radio waves to provide real-time communication with objects at a distance, without any contact or direct line of sight (Sarac et al., 2008). A basic RFID system consists of three main components: the tag, the reader and the middleware (figure 20). The RFID tag is a microchip with an antenna and embedded into labels. The antenna enables the chip to transmit the label’s identification information to a reader. Based on the required read distance of a maximum of 7 meters, ultra High Frequency (UHF) Passive RFID gen2 Tags were chosen in this design⁸. The reader converts the radio waves reflected back from an RFID chip into digital information that can be passed on to computers that will collect, sort and convert the information into relevant data (Rekik, 2006).

![RFID system components](http://skyrfid.com/RFID_Tag_Read_Ranges.php)

The identification code of the RFID technology is the Electronic Product Code (EPC) (figure 21). The EPC code can carry more data than the traditional barcode and can be reprogrammed if necessary.

Information collected by RFID readers must be correctly analyzed before it is passed through an application system. In the case of multiple tags passing through a reader’s transmission range, its responses should be managed and processed in an orderly manner. This is the job of the middleware and control software. The middleware can be connected to an EPC network: a collection of network services that enable the sharing of RFID-related data throughout the

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⁸ http://skyrfid.com/RFID_Tag_Read_Ranges.php
supply chain (Verisign, 2004). The three main components, i.e. the microchip, the reader and the middleware, combined with the EPC network are defined as the Auto-ID technology (Rekik, 2006).

Figure 21: The Electronic Product Code (Rekik, 2006).

7.2 Technology costs

With help of the work of Banks et al. (2007) costs associated with implementing RFID technology can be divided into six groups: hardware costs, software costs, system integration costs, personnel costs and business process reengineering costs (figure 22). Hardware costs, installation service costs and software costs are straightforward to understand. System integration costs on the other hand are often overlooked. These costs are associated with creating the bridge of the data resultant from the RFID infrastructure into the other general business applications running at the company (Banks et al., 2007). Personnel costs are costs that are associated with the people involved in the deployment and operation of the RFID infrastructure (Banks et al., 2007). Purchasing costs of the readers for the trucks are kept out of the equation (14 pieces), as these prices were hard to obtain. These costs are significantly lower compared to the handheld readers due to the minimal required reading distance.

Figure 22: RFID implementation costs tree (Banks et al., 2007).
This thesis will apply the implementation costs tree of figure 22. Business process reengineering costs will be excluded. Hence, this thesis focuses on the technological associated costs. Nevertheless, more costs should be taken into account, but these have a minor share in the total costs.

<table>
<thead>
<tr>
<th>Component</th>
<th>Scenario 1 [€]</th>
<th>Scenario 2 [€]</th>
<th>Scenario 3 [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(UHF) Passive RFID Tags9</td>
<td>43,200</td>
<td>1,080,000</td>
<td>1,080,000</td>
</tr>
<tr>
<td>RFID readers handheld10</td>
<td>9,000</td>
<td>9,000</td>
<td>9,000</td>
</tr>
<tr>
<td>RFID readers portals8</td>
<td>70,000</td>
<td>273,000</td>
<td>630,000</td>
</tr>
<tr>
<td>Cabling and connectors8</td>
<td>5,000</td>
<td>19,500</td>
<td>45,000</td>
</tr>
<tr>
<td>Computers &amp; network8</td>
<td>10,000</td>
<td>39,000</td>
<td>90,000</td>
</tr>
<tr>
<td>System integration costs11</td>
<td>116,500</td>
<td>116,500</td>
<td>116,500</td>
</tr>
<tr>
<td>Installation service costs8</td>
<td>7,500</td>
<td>29,250</td>
<td>67,500</td>
</tr>
<tr>
<td>Software costs9</td>
<td>100,000</td>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Personnel costs9</td>
<td>250,000</td>
<td>250,000</td>
<td>250,000</td>
</tr>
<tr>
<td><strong>Total [€]</strong></td>
<td><strong>611,200</strong></td>
<td><strong>1,916,250</strong></td>
<td><strong>2,388,000</strong></td>
</tr>
</tbody>
</table>

Table 10: Costs of the implementation of the RFID technology per scenario.

Table 10 visualizes the component costs per scenario. The costs of RFID tags for scenario 1 till 3 is calculated on the basis of a tag price of €0.068. The cost difference of scenario 1 with 2 and 3 is created due to the RFID implementation level. In scenario 1 products are tagged on pallet level. On average products on pallet level have a quantity of 25 products per pallet (expert opinion). Having an inflow and outflow of approximately 18,000,000 products, on average, 18,000,000/25 (=720,000) pallets/year are handled within the case study company. Therefore the costs/year of tags of the RFID for scenario 1 is the product of 720,000*0.06 and for scenario 2 and 3: 1,800,000*0.06.

Three handheld readers should be purchased in order to perform cycle counts. The costs are the same for each of the scenarios. Having an individual price of €3,0009 the result of this cost post will be €9,000. Purchasing costs of the RFID portals is based on the number of portals installed per scenario (appendix VI till VIII). Scenario 1 is composed out of 10 portals, scenario 2 functions with the use of 39 portals whereas scenario 3 uses 90 portals. The cost for installing a fully functional portal is set on €9,2508 which is composed out of an installation and service cost component (€7508), a computers and network cost component (€1,0008) and a cabling and connectors cost component (€5008). System integration costs, personnel costs and software costs are chosen with use of the Forester Research (2004)10, that provided an estimation of the expected costs for a leading retailer. The estimates are conservative, as these estimates were based on data of 2004 and were based on a more complex and bigger company structure.

9 https://www.rfidjournal.com/faq/show?85
10 http://www.amitracks.com/2013/10/simple-cost-analysis-for-rfid-options/
11 http://www.rfidjournal.com/articles/view?1336/3
The redesign of chapter 6 and its associated scenarios will now be implemented in the model of chapter 5. Validation for each of the scenarios will be performed and a conclusion will be drawn on the improved IRI (8.1). Next to this, a return on investment (ROI) analysis was performed, enabling comparison in improvements between the different scenarios (8.2). In this chapter a fourth scenario will be taken into account, namely the base (status quo) scenario of chapter 5. In this scenario, a classical bar coding technology is used to identify the products.

8.1 Validation and conclusion redesign

With help of the modeling software Vensim 6.3 tables were generated for each of the different deviation sources. These will be compared in table 11 with the deviations theorized in the redesign (chapter 6). Red highlighted numbers are deviations that are expected to be changed within the scenario. The numbers in between brackets are the numbers theorized of the redesign that can be found in table 8.

<table>
<thead>
<tr>
<th>Deviation source</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DD delivery</td>
<td>1,000</td>
<td>29 (29)</td>
<td>29 (29)</td>
</tr>
<tr>
<td>Deco transfer [TT310]</td>
<td>774</td>
<td>22 (22)</td>
<td>22 (22)</td>
</tr>
<tr>
<td>Recovery [TT330]</td>
<td>786</td>
<td>23 (23)</td>
<td>23 (23)</td>
</tr>
<tr>
<td>Recovery [TT440]</td>
<td>792</td>
<td>23 (23)</td>
<td>23 (23)</td>
</tr>
<tr>
<td>Recovery [TT450]</td>
<td>167</td>
<td>5 (5)</td>
<td>5 (5)</td>
</tr>
<tr>
<td>Cycle Count Error</td>
<td>16,710 (16,691)</td>
<td>21,476 (21,380)</td>
<td>21,476 (21,380)</td>
</tr>
<tr>
<td>Basics</td>
<td>2,896</td>
<td>2,896</td>
<td>83 (83)</td>
</tr>
<tr>
<td>Stock Error</td>
<td>2,554</td>
<td>2,554</td>
<td>74 (74)</td>
</tr>
<tr>
<td>Sales Location Error</td>
<td>2,153</td>
<td>1,996 (1996)</td>
<td>62 (62)</td>
</tr>
<tr>
<td>Floating Stock</td>
<td>446 (446)</td>
<td>16 (16)</td>
<td>16 (16)</td>
</tr>
<tr>
<td>Check-out</td>
<td>43,109</td>
<td>23,432 (23,432)</td>
<td>23,432 (23,432)</td>
</tr>
<tr>
<td>Total</td>
<td>71,387 (71,368)</td>
<td>52,472 (52,376)</td>
<td>45,245 (45,149)</td>
</tr>
<tr>
<td>Δ Scenario calc.</td>
<td>+0.03%</td>
<td>+0.18%</td>
<td>+0.18%</td>
</tr>
</tbody>
</table>

Table 11: Validation of the quantities (redesign).

As almost all the deviations sources are generated on the basis of a function of its associated product flow, no deviations were observed between the model and what was theorized (functions can be found in table 3). On the other hand, the cycle count error in the redesign model is simply the product of the yearly inventory average and the new retrieved deviation error (0.009%, chapter 6). The in-store inventory slowly increases as the inflow does not equal the outflow, the (TT320+TT450)>(TT310+TT440). Calculating the theorized deviation quantity within the cycle count error source was on basis of the in-store inventory quantity of 1-1-2015. Therefore, this deviation is observed.
In order to translate the results of table 11 to a graph, the results of table 11 are now normalized with help of the formula:

\[ Z = \frac{x - \min(x)}{\max(x) - \min(x)} \]  

(3)

These graphs visualize the improvements gained per deviation source per scenario. Next to this a comparison can be made between the deviation sources itself based on the relative contribution on the IRI (figure 23 and 24). In these graphs 1 equals the maximum deviation count (=check-out process, scenario 0=43109 deviations) and 0 equals the minimum deviation count (=Recovery [TT450], scenario 3=5 deviations).

**Figure 23**: Relative deviation improvements \( y=[0,1] \).

**Figure 24**: Relative deviation improvements \( y=[0,0.025] \).
8.2 Return on investment analysis

In order to analyze the economic impact within the different scenarios a return on investment analysis (ROI) is performed. Hence, the gained accuracy of previous section in combination with process improvements described in the redesign (chapter 6) will be monetarily translated. The remainder of this section will discuss the formulas behind this analysis, an argumentation of the process related cost reductions and the results.

8.2.1 Methodology

Profit can be calculated through income minus costs of lost products, replenishment costs, cycle counting costs, inflow process costs, picking process costs, outflow process costs and technology costs (equation 4). This formula is based on the work of Sarac et al. (2008) which performed a ROI analysis within the same context. Within this work RFID was used to reduce several error types in a retailer context. Ultimately, products varying in price were compared on their profitability under several scenarios by means of a ROI analysis. Inflow process costs, picking process costs and outflow process costs were added to this equation.

Cost reductions that will be achieved will be partly motivated with help of the literature (table 12).

\[
\text{Profit} = \text{Income} - \text{Costs of lost products} - \text{Replenishment costs} - \text{Cycle count costs} - \text{Inflow process costs} - \text{Picking process costs} - \text{Outflow process costs} - \text{Technology costs}
\]  

Equation 5 shows the income which has been set based upon the revenue of the case study company for FY15.

\[
\text{Income} = €100.000.000,–
\]  

<table>
<thead>
<tr>
<th>Cost</th>
<th>Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs associated with the Picking process.</td>
<td>40-50% - (Lee &amp; Özer, 2007)</td>
</tr>
<tr>
<td>Costs associated with the inflow process.</td>
<td>17% - (Lee &amp; Özer, 2007)</td>
</tr>
<tr>
<td>Costs associated with the cycle counting process.</td>
<td>95% - Chappell et al. (2002)</td>
</tr>
<tr>
<td>Costs associated with the outflow process.</td>
<td>5-45% - Chappell et al. (2002)</td>
</tr>
</tbody>
</table>

Table 12: Advantage related to costs.
With help of equation 6, costs of the loss of items can be calculated, where $Q_{\text{Lost}}$ is the summation of negative deviations (=59108 products≈84%) and $Q_{\text{Gain}e}d$ is the summation of positive deviations (=11196 products≈16%) for scenario 0 and 1. The average buying price has been set on €3.6 excluding taxes. This has been calculated by dividing all the products sold divided by the revenue of FY15. This average selling price per product has been lowered by the average gross profit margin (≈44%)\(^1\). The gross profit margin is simply the proportion of (revenue-cost of sales)/revenue.

Stock loss at the check-out process, DC/DD delivery and trans types processes are definitely responsible for physical stock loss. It can be argued that cycle count related processes and its associated errors lead to a temporarily stock loss (due to the $Q_{\text{Gain}e}d$ component). Looking at this temporarily stock loss it can be theorized that some extent of customers will be misinformed when consulting the IS regarding stock availability. This might lead that some customers will not plan a store visit. Besides this, $Q_{\text{Gain}e}d$ is assumed to be fully generated within the cycle count process. This $Q_{\text{Gain}e}d$ is created in the situation that a seemingly negative deviation generated in a previous counting task is corrected due to a new counting task which counts the correct number of products. Summing these described effects it is safe to assume that the total calculated negative deviations can be used to calculate the costs of lost products for scenario 0 and 1. Within scenario 2 and 3 the cycle count deviations have been left out of scope and $Q_{\text{Gain}e}d$ equals 0. These numbers cannot be explained by the effects described within this paragraph.

\[
\text{Costs of lost products} = (\text{Buying price} \ast (Q_{\text{Lost}} - Q_{\text{Gain}e}d)) + (\text{Average profit margin} \ast (Q_{\text{Lost}} - Q_{\text{Gain}e}d)) \tag{6}
\]

Products that are seemingly lost are also associated with replenishment costs. Less freights could be unloaded and further processed. These costs are expressed by means of equation 7. $Q_{\text{Lost}}$ is now calculated at pallet level (#deviations/25) and the replenishment unit cost has been set on €25. Within scenario 2 and 3 the cycle count deviations have been left out of scope.

\[
\text{Replenishment costs} = (\text{Replenishment unit cost} \ast (Q_{\text{Lost}))) \tag{7}
\]

For each cycle count, costs are associated depending on counting unit cost and the number of units counted (equation 8). On average 50 SKU’s a day will be counted, in the base scenario two employees will need 2 hours to perform this task, with an hourly wage of €25. In scenario 1 the time and necessary manpower will be lowered with 20% (X=0.2). In this scenario 20% of the SKU’s can be counted with help of the new technology. In scenario 2 and 3 (equation 9) the time and manpower necessary will be lowered such that a cost reduction of 95% is achieved (Chappell et. al, 2002) (X=1).

\[
\text{Cycle count costs, scenario 1} = (X \ast \text{Number of employees} \ast \text{time} \ast \text{hour wage} \ast (1 - 0.95)) + (0.8 \ast \text{Number of employees} \ast \text{time} \ast \text{hour wage}) \tag{8}
\]

\[
\text{Cycle count costs, scenario 2,3} = (X \ast \text{Number of employees} \ast \text{time} \ast \text{hour wage} \ast (1 - 0.95)) \tag{9}
\]

The inflow process costs will be calculated based on the time necessary to process 500 SKU’s a day for 35 employees with a hourly wage of €25. With help of the RFID technology in scenario 1 till 3 a 5 second time gain per SKU is achieved (based on own expertise).

\[ \text{Inflow process costs} = \text{Number of employees} \times \text{time} \times \text{500} \times \text{hour wage} \]  

Picking costs will be calculated on the basis of the number of employees necessary to process and/or ship the picking. Again the hour wage has been set on €25. By adding the RFID portal in scenario 2 and 3 in the picking process, checking the contents of the ordered picking will be done 50% faster (Lee & Özer, 2007). Which would mean that half of the employees are necessary in scenario 2 and 3.

\[ \text{Picking costs} = \text{Number of employees} \times \text{hour wage} \]  

The outflow process costs will be calculated based on the time necessary to process 50,000 products a day for 8 employees with a hourly wage of €25. In the base scenario and scenario 1 the time necessary has been set on 10 hours. In scenario 2 and 3 the time necessary has been set on 6.9 hours (chappell et. al, 2002).

\[ \text{Outflow process costs} = \text{Number of employees} \times \text{time} \times \text{hour wage} \]  

Technology associated costs (equation 12) are composed of a variable and fixed cost component that are different for each scenario (table 13). Variable cost is the result of the number of pallets \((Q_{\text{pallet}})\) or products \((Q_{\text{product}})\) multiplied with the cost of a RFID tag \((C_t)\). The fixed cost component has been retrieved from table 10. Scenario 0 uses the barcode technology, cost price of a barcode label per pallet is €0.1\(^{13}\) (two labels are used per pallet). Printing barcodes on the product itself has a cost price of €0.01 (based on own expertise). In all the scenarios the barcodes are still used on product level, preventing that a huge number of RFID handheld readers should be bought (old barcode handheld readers still can be used).

\[ \text{Technology costs} = \text{Variable cost} + \text{Fixed cost} \]  

<table>
<thead>
<tr>
<th>Integration level</th>
<th>Variable cost FY15 [€]</th>
<th>Fixed cost [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 0</td>
<td>72,000 + 180,000</td>
<td>0</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>(Q_{\text{pallet}} \times C_t = 43,200 + 180,000)</td>
<td>568,000</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>(Q_{\text{product}} \times C_t = 1,080,000 + 180,000)</td>
<td>836,250</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>(Q_{\text{product}} \times C_t = 1,080,000 + 180,000)</td>
<td>1,308,000</td>
</tr>
</tbody>
</table>

\(^{13}\) http://www.crewnoble.com/BarCode.html

8.2.2 Results

This section will present the results by visualizing the achieved cost reductions, the achieved reduced absolute number of deviations and the return on investment analysis per scenario. Table 14 gives an overview of the achieved cost reductions per scenario.
Table 14: Achieved cost reductions per scenario.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Scenario 0 [€]</th>
<th>Scenario 1 [€]</th>
<th>Scenario 2 [€]</th>
<th>Scenario 3 [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of lost products</td>
<td>246,958</td>
<td>251,997</td>
<td>150,752</td>
<td>113,236</td>
</tr>
<tr>
<td>Replenishment cost</td>
<td>59,055</td>
<td>59,965</td>
<td>29,040</td>
<td>21,813</td>
</tr>
<tr>
<td>Cycle count cost</td>
<td>36,100</td>
<td>23,104</td>
<td>2,256</td>
<td>2,256</td>
</tr>
<tr>
<td>Inflow process cost</td>
<td>157,9375</td>
<td>1,504,167</td>
<td>1,504,167</td>
<td>1,504,167</td>
</tr>
<tr>
<td>Picking Cost</td>
<td>45,125</td>
<td>45,125</td>
<td>22,563</td>
<td>22,563</td>
</tr>
<tr>
<td>Outflow process cost</td>
<td>722,000</td>
<td>722,000</td>
<td>498,180</td>
<td>498,180</td>
</tr>
</tbody>
</table>

Scenario 1 shows an increase in costs when looking at the cost of lost products and replenishment costs. This is because scenario 1 shows a higher absolute number of deviations, but a reduction in total costs.

Figure 25 visualizes the cost per scenario versus the base scenario per year (scenario without RFID technology). A positive cost implies cost savings, a negative cost implies increased costs compared to the base scenario. This figure does not account for the fixed technology costs of table 13. Figure 26 does include this technology cost component by visualizing the return on investment period for scenario 1.

Figure 26 visualizes the decrease of relative income of scenario 1 and the base scenario (scenario 0) over a 10 year time period. As can be seen scenario 1 starts in year 1 with a lower relative cost, but has due to achieved reductions in costs a smaller slope (-0.0283x). If the equations of two lines are set equal to each other the intersection coordinates can be calculated, where x equals the time in which the investment has been returned. For this comparison, scenario 0 versus 1, x equals 5.18 years. Unfortunately, scenario 2 and 3 are too expensive based on the current tag price of €0.06. The integration of tags on product level is for now too expensive and will increase the overall in-store inventory management costs compared to the base scenario’s costs. Even if scenario 2 and 3 were able to reduce the negative deviations to zero, the eliminated cost of loss in products cannot account for the associated variable costs of scenario 2 and 3.
Based on calculations, if the cost of a single tag drops below €0.03, scenario 2 and 3 will become profitable. The suggested cost price per tag is quite imaginable as costs have fallen steadily over the past few years and will decline further as adoption ramps up\textsuperscript{14}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{scenario_0_vs_1.png}
\caption{Return on investment period scenario 0 vs 1.}
\end{figure}

Next to this, applying RFID tags on all products with higher sales prices (e.g. >€20) could lead to an interesting business case for scenario 2 and 3. In such a situation the relative cost of lost product will increase. Finally, it can be theorized that the improvement in inventory record accuracy has a relation with a reduction in OOS. A reduction in OOS implies a greater availability of the product assortment, herewith serving the customer in a better way to buy a product. Potential revenue is for certainly lost due to the unavailability of the products. In the case this component accounts for a 1\% increase in revenue, scenario 2 and 3 become profitable.

\textsuperscript{14}https://www.rfidjournal.com/faq/show?84
9. Conclusion

This chapter describes the conclusions based upon the results presented in previous chapter (9.1). Next to this, the limitations of this study that have limited the conclusions, merely the assumptions that have been made, will be described (9.2). Finally, recommendations for future research based upon the conclusions and limitations of this research will be listed (9.3).

9.1 Discussion of the research goal and problem identification

This research accessed the potential value of RFID when applied to an in-store inventory management process. Most companies have automated their inventory management system and put their trust into an IS when critical decisions have to be made. Unfortunately, stock level information deviates to some extent with the real stock. Consequently, this thesis had a focus on the inventory inaccuracy issue. As a result this thesis presented a quantitative analysis quantifying the impact of inventory inaccuracy on an inventory system’s performance with and without the usage of RFID technology. In a final stage, the potential improvements which were reached with help of RFID were linked to the overall business performance.

9.1.1 Impact of inventory record inaccuracy on business performance

The extent of IRI has been made visible in several academic articles. One of these articles performed such a research within a retail concern. It was concluded that the best performing store only managed to have 70%-75% of its inventory records to be equal to the actual inventory (Kang & Gershwin, 2004). The worst performing store was able to match 1/3 of its SKU’s with the actual inventory. Considering all the stores, an average of 51% was achieved. Specifically, results from this study have been presented to retail executives on numerous occasions, and they have consistently acknowledged the findings. Another study which conducted its research within a leading retailer concern found that 65% of the inventory records were inaccurate (Raman et al., 2001). They concluded that inventory record inaccuracies accounted to a decrease of 10% of current profits (roughly the profit of 100 stores within the concern), due to lost sales and additional labor and inventory carrying costs (Raman et al., 2001).

Overall similar findings were found within the case study company, implying that the case study company shares common characteristics based on its in-store inventory management processes, which makes it a strong case that results within this thesis are generalizable. Noteworthy, IRI is positively associated with the annual selling quantity of an item, negatively associated with the cost of an item and positively associated with inventory density as well as product variety (DeHoratius & Raman, 2008).

The extent of IRI within the case study company was made visible with use of the case study company’s cycle count data. An absolute error of 0, meaning the counted inventory matched the IS’s inventory, was achieved for 53.8% of the SKU’s that were counted once. The remaining 46.2% of SKU’s that deviated, represented a total purchasing value of €181,643. These costs are the sum of products lost and products retrieved.

Besides this loss of products, its potential sales and other associated costs it can be argued that a decreased product availability due to incorrect inventory records has an impact on customer satisfaction and/or willingness of a customer to purchase a product again (Gómez et al., 2004).
9.1.2 The role of RFID in reducing inventory record inaccuracy

Partly based on the simulation approach of Sarac et al. (2009) three scenarios were defined in order to evaluate the impact of various implementations levels of RFID technologies. These scenarios were implemented in the in-store inventory management process of the case study company. Like most companies, three main flows of goods can be defined namely an inflow, intern flow and outflow of goods. These flows are all associated with specific errors and magnitudes causing deviations. Next to this a great number of companies have automated their inventory management system and put their trust into an information system when critical decisions have to be made. Elements which all can be found within the case study company.

In the first scenario, RFID technology is integrated at the pallet level with the least amount of RFID reading portals, scenario 2 and 3 integrated tags at the product level and both differed in number of portals. As imaginable, each scenario differed in costs and a decreased error rate that contributed to an improvement in the IRI. Mainly RFID is able to reduce the error rates by automation of processes, hereby decreasing the probability of human error. Next to this, increasing the visibility of products will help to keep stock levels accurate and prevents products to be incorrectly defined as lost.

Introducing these new acquired error rates into the model (with help of literature) retrieved the new absolute number of deviations for FY15, namely 71,387 deviations for scenario 1, 52,472 deviations for scenario 2 and 45,245 deviations for scenario 3. Unfortunately, scenario 1 shows an increase in absolute number of deviations due to the increased cycle count error rate when applying RFID technology, but significant cost reductions have been achieved.

9.1.3 Will the gain outweigh the costs?

Figure 27: Cost per scenario versus base.

Figure 27 visualizes the cost per scenario versus the base scenario per year (scenario without RFID technology). This figure does not account for the technology costs. If this cost component is taken into account, scenario 1 has a return on investment period of 5.18 years. Unfortunately, scenario 2 and 3 are too expensive based on the current tag price of €0.06. The integration of tags on product level is for now too expensive and will increase the overall in-store inventory management costs compared to the base scenario’s costs. Based on calculations, if the cost of a single tag drops below €0.03, scenario 2 and 3 will become profitable. The suggested cost
price per tag is quite imaginable as costs have fallen steadily over the past few years and will decline further as adoption ramps up.\textsuperscript{15} Next to this, applying RFID tags on all products with higher sales prices (e.g. >\(\text{€}20\)) could lead to an interesting business case for scenario 2 and 3. In such situation the relative cost of lost product will increase. Finally, it can be theorized that the improvement in inventory record accuracy has a relation with a reduction in OOS. A reduction in OOS implies a greater availability of the product assortment, herewith serving the customer in a better way to buy a product. Potential revenue is for certainly lost due to the unavailability of the products. In the case this component accounts for a 1\% increase in revenue, scenario 2 and 3 become profitable.

These results apply to in-store inventory management processes with high volumes of products (>10,000,000 products). If the number of products to be processed is under 10,000,000 products, scenario 2 and 3 might become profitable.

\textbf{9.2 Limitations}

Although it is believed that this research is conducted systematically and reproducible, improvements can always be achieved. This section describes the limitations by means of the assumptions made within this thesis.

Data of the products flows for the check-out process in the period of September 2015 till April 2016 have been used to calculate the total number of goods sold of FY15. Although these data only cover 8 months (FY16), it is a fairly good sample that could be representative for the FY2015. Within the FY16 almost the same range of products are sold and the same revenue is generated as the same revenue targets for FY16 have been set as it was for FY15.

In order to calculate the quantities of the transaction types data of the product flows for each of the transaction types was used. Unfortunately, these data only contained data points of a 15 week time frame. It is assumed that this time period is representable for the behavior of the FY15, as these numbers were verified by experts in field.

Data of other in-store inventory management processes were used to quantify base scenario’s deviation rates. It is assumed that the same proportions of deviations sorted per flow type are present in the case study company’s in-store inventory management process. The in-store inventory management processes of which the data was extracted is exactly the same, but differs in customer population.

The observed errors within the 53\% sample of errors created by a cycle count that were conducted once was used to calculate the total number of absolute deviation in the base scenario. Products that were counted more than once would not result in an accurate deviation estimate; an average was taken if a product resulted in a deviation at time A and an accurate stock on time B or another deviation on time C. A translation was made for the whole product line accompanied with an absolute error, assuming that the observed errors within the sample of 53\% of the product line are representable for the whole population.

To quantify the deviations within the outflow of goods, the ‘others deviation causes’ of extern in-store inventory management process data was summed with the 35\% unexplained deviations

\begin{footnotesize}
\textsuperscript{15} https://www.rfidjournal.com/faq/show?84
\end{footnotesize}
component. Based on expert opinion, it is assumed that the 35% component of ‘unexplained’ deviations is fully related to theft. The ‘others deviations causes’ was mainly related to theft but also to scanning errors.

9.3 Future research

Future research could assess in what order IRI is responsible for causing OOS. A translation could be made in what order the reduction in OOS will increase revenue. Ultimately, this information could be combined with the ROI analysis of this thesis in order to conclude if tagging RFID chips on product level is profitable (assuming RFID tag prices are unchanged). In addition to this, future research could investigate in what order RFID is able to reduce OOS. Finally, future research could focus in what order temporarily stock loss (e.g. due to cycle count mistakes) leads to a decrease in sales, in the case that the IS reports a stock that is close to zero.

A proof of concept study could be performed in order to validate the described improvements in process efficiency. Next to this, system integration of a company’s IS with the RFID software could be tested.

Further research opportunities include linking IRI to other performance measures. Is the level of IRI in some way related to better or worse performance (e.g., store profit, customer satisfaction)?
Bibliography


### Appendix

| I | Interviews with experts in field | A |
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| III | Main components used in Vensim | C |
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| VII | Placement portals scenario 1 | H |
| VIII | Placement portals scenario 2 | I |
| IX | Placement portals scenario 3 | K |
# Interviews with experts in field

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<tr>
<th>What</th>
<th>Who</th>
<th>Function</th>
</tr>
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<tr>
<td>Number of deviations within freights that contain mixed pallets</td>
<td>Robert de Wild</td>
<td>Sales and supply support specialist</td>
</tr>
<tr>
<td>Verification of the quantities calculated of table 1.</td>
<td>Dominick van Dongen</td>
<td>Sales and supply support specialist</td>
</tr>
<tr>
<td>Verification of the quantities calculated of table 1.</td>
<td>Kevin van der Linden</td>
<td>Logistics Manager</td>
</tr>
<tr>
<td>The unexplained component (35%) of figure 13 can fully be related to theft</td>
<td>Mariska Luyten</td>
<td>Customer services team manager</td>
</tr>
<tr>
<td>On average pallets hold a quantity of 25 products.</td>
<td>Jordy Voogt</td>
<td>Customer services team manager</td>
</tr>
<tr>
<td></td>
<td>Mark Vleugels</td>
<td>Operations Manager</td>
</tr>
<tr>
<td></td>
<td>Peter Keulen</td>
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<td></td>
<td>Cyril Zijlstra</td>
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<td>Dominick van Dongen</td>
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<tr>
<td></td>
<td>Luc Alleleyn</td>
<td>Goodsflow coordinator</td>
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II Hype cycle

Figure 1: Hype Cycle for Emerging Technologies 2015 (Gartner, 2015).
### Main components used in Vensim

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<thead>
<tr>
<th>Building Block</th>
<th>Icon</th>
<th>Meaning</th>
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<td>Variable or Converter</td>
<td><img src="image" alt="Variable Icon" /></td>
<td>converts, stores equation or constant, does not accumulate</td>
</tr>
<tr>
<td>Box Variable or Stock</td>
<td><img src="image" alt="Box Variable Icon" /></td>
<td>noun, represents something that accumulates</td>
</tr>
<tr>
<td>Arrow or Connector</td>
<td><img src="image" alt="Arrow Icon" /></td>
<td>transmits inputs and information</td>
</tr>
<tr>
<td>Rate or Flow</td>
<td><img src="image" alt="Rate Icon" /></td>
<td>verb, changes magnitude of a box variable (stock)</td>
</tr>
</tbody>
</table>

*Figure 2: Main components used in Vensim.*
IV Dynamics of processes

Figure 3: Dynamics of TT310, TT320 and TT325

Figure 4: Dynamics of TT330, TT390/91, TT450 and TT440
V Kolmogorov-Smirnov tests

Figure 5: TT310

Figure 6: TT320
Figure 7: TT325

Figure 8: TT330
Figure 9: TT390/91

Figure 10: TT440

Figure 11: TT450
VI Placement portals scenario 1

Figure 12: Placement of portals scenario 1, red squares are portals for reducing floating stock, yellow squares are portals for the DC/DD deliveries.
VII Placement portals scenario 2

Figure 13: Placement of portals scenario 2 (warehouse), green square is the portal at the entrance gate to markethall, purple square are readers at the check-out desks and blue squares are the addition of portals in the recovery and picking department.
Figure 14: Placement of portals (green square) from unloading area to showroom.
VIII Placement portals scenario 3

Figure 15: Addition of smart zones in the warehouse (blue squares).
Figure 16: Placement of portals (green square) from unloading area to showroom.
Figure 17: Placement of portals scenario 3, markethall