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A conceptual model for the use of RFID as a means to manage Reusable Articles in a closed-loop supply chain.

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Abstract

Reusable articles are physical objects which can be used to either transport other goods, to contain goods or to be used themselves several times in many different sectors in a closed-loop supply chain. At present, due to a lack of visibility, the owner of the reusable articles experiences uncertainty about when, how many and in which condition reusable articles will return. We research how these management issues can be solved by using RFID and focus on three types of reusable articles simultaneously. Our research was motivated by a research paper that identified the reusable articles' management issues in a closed-loop supply chain. Our reason for doing so is that we observed that previously other researchers focused on strictly one type of reusable article in the context of RFID and, in general, research regarding reusable articles is in an infancy stage. By examining three different types of reusable articles at once we obtain a sounder basis for generalization. We research three different case studies and conduct a cross-case analysis. In each case study we examine possible RFID options to understand how RFID can aid the pool manager in solving the management issues. Also we present cost descriptions to asses RFID profitability. We have observed that RFID technology can indeed help the pool manager deal with management issues, though this requires of the pool manager to analyze incoming and accumulated data.

Keywords: RFID, closed-loop supply chain, reusable articles, returnable transport items, reusable products, returnable packaging materials, RTI, RP, RPM, RA, conceptual model, case study, cross-case analysis, AUTO-ID, radio frequency identification, visibility, asset management.

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1 Introduction

In nearly every corner of the world there is a continuous demand for goods. Some goods are consumed in the sense that after the consumption almost nothing of value remains, like food. Other goods barely deteriorate by the use, e.g. the reading of a book usually leaves it in an as-good-as-new state. It is this particular group of goods we will concern ourselves with, which can be further classified into three different categories. The first category is goods that are used themselves (e.g. library books) repeatedly by users for generally a short duration; to make use of them one usually is obligated to pay the owner of these goods a small fee. These are referred to as “Reusable Products (RP)”[1]. Then there are goods that are used to contain other goods to transport them, for example: all liquids are transported in bottles, kegs, barrels etc. and when empty, they can be used again. These are referred to as “Returnable Packaging Materials (RPM)”[2]. Finally, in logistics we can also make use of items to facilitate transport which are not directly in contact with other goods, which can be re-used many times, for example: roll-containers. They are often called “Returnable Transport Items (RTI)”[3]. Carrasco-Gallego et al. (2012) coined the term “Reusable Articles (RA)” to address all three of them, because they claim that all these goods have similar characteristics. They also observed that there are many RA on the world (for example, Ray et al. (2006) mentions that there are over 4 billion pallets in use.) and that they constitute a large amount of capital.

These RA are utilized in a so-called closed-loop supply chain (i.e. almost similar to a regular supply chain, except it is expected that the (different) users, after a while, return RA either directly through the same channels or via a detour to their original point of issue). The intent of this return is that they become available for circulation again; this is possible because they retain a certain value after their, often short lasting use. Generally, there is an organisation responsible for the management of a certain volume (i.e. fleet or pool, these terms are interchangeable) of RA, the so-called pool manager. One would expect that recollection of RA from users is straightforward and trouble free for the pool manager. On the contrary, according to different authors, in many different sectors the pool manager experiences many problems with their respective RA.

[1] term coined by Carrasco-Gallego et al. (2012)
[2] term created by Van Dalen et al. (2005)
[3] term coined by Johansson & Hellström (2007)

In many cases, caused by a lack of visibility which occurs right after the issuing point (i.e. the moment the pool manager hands over RA to the user), the following problem is experienced:

The pool manager simply does not know when (i.e. time and date) their RA will be returned, and, at any given time, experiences difficulties determining the exact location of their RA in the supply chain.

According to Carrasco-Gallego et al. (2012) this lack of visibility also gives rise to several RA management issues for the pool manager, viz. how many items does he need/to purchase to satisfy his customer's needs?

It is important for these reusable articles to return because they are important for the business processes of the pool manager, and to acquire them a certain capital needs to be invested (e.g. Hanebeck and Lunani (2008) point out that "some auto manufacturers may well have over $1 billion invested in containers".) Moreover, as said earlier, the users normally only pay a small fee which never equals the real value of the items. It is therefore in the interest of the pool manager to receive their RA back, because when faced with a diminishing, or worse, a halt of RA returns this negatively impacts their business, for example: a loss of service, since very few have the financial resources to repeatedly replace RA.

Currently, a technology is available that according to many holds a lot of promises, called: Radio Frequency Identification (RFID). Although it has been around for some time now, and applications in various sectors have been realised, it is not yet ubiquitous. At the moment research regarding the application of RFID for reusable articles is quite scarce and progress is slow. With that in mind, it is unclear whether pool managers considering the adoption of RFID are aware of its potential impact on the management of RA.

With this research our objective is therefore to explore the use of RFID for reusable articles in a closed-loop supply chain. It is our intention to provide a better understanding of the ramifications of this technology. In particular, for logistics practitioners, we hope to shed light on how RFID can aid in dealing with the problems encountered with RA. And, we want to point out when it is actually profitable to apply this technology. For academics, our goal is to add to the body of knowledge so that they can build upon our work and point out future research opportunities.

1.1 Research question

With the prevailing RA management issues and RFID technology as an anticipated solution for these issues, we have formulated the following main research question:

How can RFID improve the management of reusable articles in a closed-loop supply chain for the pool manager?

Since our research question is quite general, we have to limit it in order to come up with answers in a short time period. With that said, at the very least, we want to acquire insights on the theoretical effects of applying RFID technology for reusable articles, such as benefits and limitations. These will shed light on the value of RFID for reusable articles. Also, quantifications of RFID costs can provide insights about when it is profitable to implement this technology.

To avoid any misunderstanding of “the management of reusable articles” (i.e. asset management), we will clarify what we exactly mean. In the introduction we previously stated, and reiterate, that uncertainty is a problem for the pool manager. Irregular returns of their reusable articles can be detrimental for their business (processes), thus need to be circumvented. In this context, asset management refers to: to be actively in charge of the physical assets. In other words, the pool manager can proactively regulate which user(s) should return them by specifying a date or take any appropriate measures in case irregularities are detected.

1.2 Sub-questions

The purpose of these sub-questions is similar to the main research question, to simply guide our research. In order to devise the appropriate questions, we turn to our main research question which contains the following terms: RFID, management, closed-loop supply chain and reusable articles. Essentially, what we do is break down the main research question into several smaller parts and formulate questions we want answered; this will help to ultimately answer our main research question.

In chapter 1 (paragraph 1.6) we aim to answer the following sub-questions:
1) Which issues have been identified regarding RA (i.e. RTI, RPM and RP) in a closed-loop supply chain?
2) What is currently known about the use of RFID to manage RA (i.e. RTI, RPM and RP) in a closed-loop supply chain?

The method we will employ to find answers to aforementioned questions is a literature review. A study of gathered literature will expose which issues have been identified by researchers. In addition, we can determine what the state is of current research.

In chapters 2, 3 and 4 we will respectively answer the following sub-questions:
3) What is RFID technology (i.e. how does it work) and how does it differ from barcodes?
4) What are RA (i.e. RTI, RPM and RP) exactly, what are the similarities and differences, and what are the general characteristics?

Again, the literature review will be the method of choice as we expect to find relevant data by reading through different sources of information (e.g. websites, white papers, research articles). Our intention with these questions is to both inform readers and to gain more knowledge about RFID, Reusable articles (RTI, RPM and RP) and closed-loop supply chain ourselves. Once we have obtained sufficient knowledge we have a firm basis to carry out the case studies.

After answering all the previous sub-questions, we will conduct a number of case studies wherein we examine the theoretical implementation of RFID to manage reusable articles. We will answer the following sub-question:
6) What information does RFID technology yield to manage RA (i.e. RTI, RPM and RP) and how does it help to solve the identified issues in a particular case?

1.3 Research plan

A step-by-step overview of our entire research is depicted in figure 1, which is our research plan. We will elaborate on it to clarify what is accomplished at each individual step.

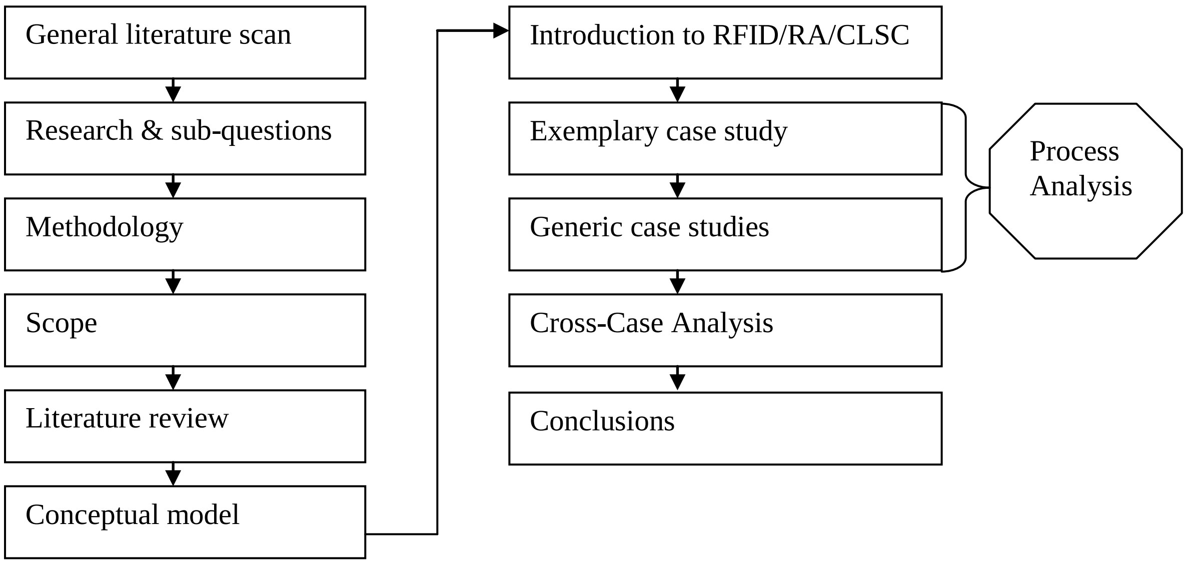

Figure 1: Overview of our research

Starting at the general literature scan, all the way up to and including introduction to RFID/RA/CLSC, form the basis of our research: by scanning through literature we formulate our main research question, from which sub-questions will be derived, all these questions are meant to guide our research. In the methodology section we explain and motivate which methods we will use to attain insights. To establish the boundaries of our research (i.e. what we will cover), we include a scope section. With the literature review we will learn about the current issues regarding reusable articles and gather information about RFID technology, reusable articles themselves and the closed-loop supply chain. With the conceptual model we illustrate (and go into details regarding) the problems with reusable articles and who (i.e. the actors) are involved; this model is tested in the case studies in order to validate it. The next three steps, starting at exemplary case study all the way through to cross-case analysis, is where we will investigate the theoretical implementation of RFID in different environments; central in these case studies are the issues identified, and a process analysis is also conducted. In the last step, conclusions, we basically are at the end of our research. Once all case studies are completed, we will compare the data from these case studies with one another in the cross-case analysis. Finally, we draw conclusions so that we can answer our main research question and recommend future research.

1.4 Methodology

In this section we elaborate on the selection of methods we will use during the course of our research to answer our research questions. Each method is discussed individually and we motivate why we opted for them. In addition, we state from which sources we plan to gather data and how we will analyze it.

We have organized this section as follows: we commence with the literature review. Next, we will talk about both exemplary and generic case studies. In paragraph 1.4.4, we will converse about the process analysis. We conclude with the cross-case analysis.

1.4.1 Literature review

The literature review is part of our thesis, for two reasons. First of all, with the review we can "convey to readers what knowledge and ideas have been established on a topic, and what their strengths and weaknesses are" (Taylor, 200-). Secondly, in the process of searching for information and writing the review, we will also learn more about our own research topic (Taylor, 200-).

In order to compose our literature review, we have to gather relevant literature. Our main source of information will be the internet (i.e. a public source). We believe that with the search engine Google and Google Scholar[4] we can find sufficient data, hence we ignore other websites (i.e. Bing and Yahoo!) completely. We will use a variety of different search terms which we will derive from, or have a very close relation with, our main research question; also we will do a quick literature scan to determine which terms are used by the authors. Our strategy for the search queries will be to use search terms individually as well as combining them. In the event of insufficient search results, we will obtain new search terms from literature found and again look at our main research question for inspiration. Though we expect that a majority of the search results will be academic papers, we will not strictly focus on them. Also white papers and websites dedicated to RFID, reusable articles and closed-loop supply chains will be investigated, because our aim is to gather as much relevant data as possible. And, if relevant, we will use the references in a paper.

[4] Quote from website: "Google Scholar provides a simple way to broadly search for scholarly literature." Source: http://scholar.google.com/intl/en/scholar/about.html

All the search results will be judged for relevancy in the following way: by reading abstract, the conclusion and scanning the entire content for specific terms. Analysis of the literature will be done as follows: first and foremost, we are interested in the findings of the authors because this is what we will read through first to decide if it is indeed relevant for our own research. Additionally, we will review the research methods chosen by the authors for their own research and study how they analyzed their gathered data; details, such as calculations, interviews etc. will also be investigated. From the literature we will select the most relevant or remarkable content and quote, paraphrase or summarize it in our own research.

1.4.2 Generic conceptual model

Once the literature review is finished, we will proceed with the construction of a generic conceptual model; it will be based upon work from different authors found with our literature review. The objective of this model is to show at a glance (by means of a figure) the current problems experienced by the pool manager, display how reusable articles circulate in a closed-loop supply chain and the actors involved. To ensure that readers can fully comprehend it, we provide the necessary details about the entire model. In order to demonstrate that the model is indeed a correct representation of reality, we will perform several case studies to validate our model.

1.4.3 Case studies

Our main research results will come from three different case studies, details about these case studies are provided later on. Our choice for case studies is motivated by our main research question. The author Yin (1994, p.1) states that “case studies are preferred strategy when “how” or “why” questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context”. It is true that our main research question begins with a how. Our research is explorative since our subject matter is relatively new and not yet fully explored. We examine the theoretical use of RFID in practice and are mere observers/analysts of a process; thus, we have no control.

In total we will examine three different case studies: one exemplary case study and two generic case studies. The reason for investigating several is that “the evidence from multiple cases is often considered more compelling, and the overall study is therefore regarded as being more robust” (Herriott & Firestone 1983 cited in Yin 1994 p. 45). The purpose of each case study is to provide us unique insights on how RFID can solve the management issues in that specific environment. In addition, we will observe the probable costs of a RFID investment in each case study, so that we can determine at which point it becomes profitable.

We start with the exemplary case study which is about the supermarket shopping cart (RA type: RTI). It is meant to provide us with first insights and give an indication of what to expect in the generic case studies. The data for this case will be gathered from various sources: internet (i.e. Dutch/English websites) also known as desk research, from employees/managers (i.e. interviews) and the business environment (i.e. observations) also known as field research. On the internet we will use a combination of search terms that we presume are predominantly used in articles that explored issues with shopping carts. To collect data from the managers/employees we will carry out interviews which will only contain open-ended questions. By observing the supermarket we will learn about how shopping cart are used in practice.

Similar to the literature review, the search results gathered via Google will be scanned for relevant terms and quantitative data, to decide if a particular search result has any value. The content that we choose to use will be quoted, paraphrased or summarized. From the interviews we will select either relevant excerpt, summarize or paraphrase the answers. The data from the observations will be used to compare supermarkets with one another to come up with a general, but representative, supermarket design which will be used to discuss possible RFID approaches.

After the exemplary case study, we will conduct several so-called generic case studies. The generic case study is an investigation of a completed study (e.g. research article), therefore set up as a regular case study. However, the difference is that only a minimum amount of data needs to be collected, since most of the work has already been done by the respective author(s). The generic case studies we have chosen are: Erasmus MC surgical instruments (i.e. RP) and MedGas Gas Cylinders (i.e. RPM), these two cases are from the article by Carrasco-Gallego et al. (2012); there is no particular reason for selecting these cases, we simply selected different types of reusable articles.

We will analyse the generic case studies as follows: first, we read them thoroughly to understand the situation. Then, we carefully select data for our own case study description; criterion: data is only eligible if it says something substantial about the particular reusable articles. We then commence with the case study itself by providing a case description in our own words, and once completed, checking with the original case study to determine if the content is similar. If the case study does not provide sufficient data, our approach is to reason logically to come up with the missing data (e.g. description of a process). And, if necessary, we will search the internet for additional data for clarification purposes.

1.4.4 Process analysis

We use the term process analysis to indicate how reusable articles circulate in a specific environment before returning to the original issuing point (i.e. from point A to point B and back to A again). We include this analysis since reusable articles are continuously brought into circulation, thus are part of a recurring process. This will provide us with insight into how the respective reusable article is used in that environment. We consider which information is available with and without RFID to manage the logistic process (i.e. make sure the right amount is available at the right time at the right place). Finally, we will identify exceptions (e.g. shrinkage, etc.) and assess their impact and likelihood.

1.4.5 Cross-case analysis

It is theoretically possible to use findings from a single case study to draw conclusions, however, with the cross-case analysis we will avoid early conclusions because we will look at the data in different ways (Soy, 1997). The cross-case analysis is just another means of analyzing data. The goal is that we can draw conclusions from another perspective (Yin, 1994). We will compare the data of one case with the other cases, in order to find patterns (Soy, 1997); we will do this for all of the case studies. It is possible that the cross-case analysis might produce the same results as our within-case analysis, but we could also stumble upon other findings (Yin, 1994). When we come across similarities or differences between cases we will carefully examine them to explain our findings.

1.5 Scope

In this section we define the boundaries of our research, so that one is fully aware of what to expect from us. Since we cover a variety of topics, namely: RFID, reusable articles and the closed-loop supply chain, we discuss the research limitations for each one separately. We commence with RFID technology. Then, we focus our attention on reusable articles. We conclude with the closed-loop supply chain.

1.5.1 RFID technology

We do not investigate RFID technology itself (i.e. how it could be improved or anything of that nature), neither is our goal to present a detailed technical description of an implementation or how to plan it, nor to suggest the best technical solution. Instead, we describe what the value of RFID technology (as a means to an end) is in each case study. When discussing the implementation of RFID we will minimize details about: frequency, brand of reader, type of software, proper placement of tag etc.

Since we explore the theoretical use of RFID, thus no implementation in practice, difficulties are expected with regards to cost calculations. Our approach is to provide a comprehensive cost description solely for the exemplary case study, because one complete overview would suffice for our research. In the generic case studies we still include a cost overview, though limiting it to the core components (i.e. readers, tags, software and middleware). It goes without saying that we try to have a realistic as possible cost description, which we intend to achieve by checking different sources online (e.g. websites, (white) papers and RFID vendors) for actual figures by using search terms (i.e. primarily combined), such as: RFID components, readers, tags, printers, software, middleware, prices, implementations etc. basically we will use any term that is related to RFID implementations.

1.5.2 Reusable articles (RA)

We examine three types of reusable articles (RTI, RPM and RP) utilized in either a commercial or non-commercial setting, since (to our knowledge) researchers have limited their research primarily to RTI in the context of RFID. Whilst on the consumer level a plethora of reusable articles are available, for instance: sporting equipment (e.g. tennis racket), shopping bags, bicycles, DVDs, DIY-tools, plastic boxes, bikes, vacuum cleaner etc, they are not the focus of our research. We focus on the management issues identified by Carrasco-Gallego et al. (2012) for aforesaid (non-)commercial reusable articles.
In the case studies the pool manager already owns a fleet of reusable articles and these are used by users in an existing closed-loop supply chain. In our research we therefore do not

cover questions regarding the acquisition of new reusable articles (e.g. from which suppliers to purchase them?) nor which third party logistics provider to select. Furthermore, we will not talk about the repairs that need to be carried out to keep reusable articles in working order. At some point in time the pool manager will experience shrinkage (e.g. damage or theft), though we do not discuss how to charge culprits or how to recover the most value in case of recycling or disposal of parts. At the moment many people are of the opinion that companies must put the utmost effort into minimizing their impact on the environment. We assume that the priority of the pool manager simply lies with the return of their assets and their constant circulation, not to minimize waste. Hence, we do not examine which materials are best suited to reduce damage to the environment or how to properly dispose of them at the end of their useful life. We assume that the pool manager is capable enough to decide for himself what needs to be done when confronted with such questions, and basically any other questions that are not related to the management of reusable articles.

1.5.3 Closed-loop supply chain

We focus our research on existing closed-loop supply chains, but their design or how to optimize them remains out of the research scope. We look no further than the pool manager and the users, because it is the circulation of reusable articles and interaction between these two actors that we focus on; we assume that the pool manager intends to circulate reusable articles until they reach the end of their useful life and the users (i.e. individuals are not examined) use them.

We neglect the supplier of reusable articles, companies that repair/recover value or perform waste management, and therefore do not discuss which company/supplier to select, because (we reiterate) it is up to the pool manager to make that decision.

Thierry et al. (1995) and Krikke et al. (2004) cited in Visich et al. (2007) identified a number of value recovery options in closed-loop supply chains, of which we only focus on “direct reuse”. We assume that the pool manager is strictly concerned with the constant reuse of their RA and therefore the other value recovery options are neglected.

A variety of closed-loop supply chains have been described by Flapper et al. (2005, p. 4), we focus on what they describe as “distribution related” (it includes (among others) items used for the distribution of other items) and “use related” (it includes (among others) products returned after they are no longer necessary).

Moreover, we will consider two reusable articles networks identified by Carrasco-Gallego et al (2012) which are: “star systems” and “multi depot systems”, basically these two networks depict to which location reusable articles can be returned. Any other networks are beyond the scope of our research.

1.6 Literature review

Here we review the gathered literature. The structure of this section is as follows: we commence with our literature search strategy to show how we went about looking for literature. We follow up with the actual literature review which is split up into two parts: first, we discuss one paper that has identified reusable articles’ management issues. The second part covers literature regarding the application of RFID technology for reusable articles. In both parts we provide a strength weakness analysis of the respective papers, to simply assess them. Next, we will analyse and discuss the methods used by the authors to understand why they were selected for data gathering. Finally, we will present our conclusion.

Search strategy

In our search for literature we only used Google and Google Scholar[5]. The reasons for doing so are that this search engine is the most popular one on the internet[6] as well as our past experiences using it. We disregarded other search engines (i.e. Bing and Yahoo!) because we assumed that they would not provide relevant results. Our focus was on finding research that investigated potential or actual use of RFID technology in a closed-loop supply chain to manage any category of reusable articles. In order to find appropriate literature we inspected a variety of sources: websites, white papers and academic papers.

At the very start of our search, after a quick literature scan, the following search terms emerged: RFID, returnables, asset management, RPM, RP, RTI, returnable transport item, returnable transportation items, visibility, assets, shrinkage, reusable articles, leakages, closed-loop supply chain, supply chain, control, reusable assets, pallets, roll containers,

[5] http://scholar.google.com/intl/en/scholar/about.html Quote from Google website: “Google Scholar provides a simple way to broadly search for scholarly literature.”
[6]http://www.comscore.com/Press_Events/Press_Releases/2010/1/Global_Search_Market_Grows_46_Percent_in_2009 (date: December 2009)

reverse logistics and tracking and tracing. Our strategy was to first use these terms individually for queries. The result, surprisingly, was that a majority of these terms did not provide the results we hoped for. A possible explanation is that abbreviations, such as: RPM, RP and RTI, might not yet be common amongst practitioners/researchers. Also, it is a matter of terminology, for example, the term “reusable articles” coined by Carrasco-Gallego et al. (2012) is relatively new and, presumably for that reason, not yet frequently used in papers. Other search terms, such as: visibility, assets, shrinkage and asset management lead to many irrelevant search results. In hindsight, we believe that these terms are not specific enough when used individually and appear to be used in many different contexts, therefore a wide variety of results are returned. Only one term, remarkably, Returnable Transport Item lead to 8 interesting search results, ranging from the years 2004 to 2009. The next step was to continue our search by combining the previous terms with the following additional terms (which we came up with ourselves and also spotted while looking for literature): reusable packaging, reusable items, reusables, products, reusable assets, management, transparency, radio frequency identification, technology, primary packaging, secondary packaging, tertiary packaging, visible, theft, transparency, returnable transport items, asset visibility and handling. Our belief was that by combining search terms we hoped to increase the odds of finding relevant literature. Table 1 provides an excerpt of the combinations (i.e. 17 in total see appendix 1) we used; we included the term RFID in each combination as it is the application of this technology we are investigating.

RFID	Visibility	Management						
RFID	Theft	Reusable articles						
RFID	Shrinkage	Reusable articles						
RFID	Supply chain management	Returnable transport items						
RFID	Management	Reusable packaging						
RFID	Closed loop supply chain	Theft	RTI					
RFID	Assets	Returnables	Reusable assets	Products	Leakages	Control	Visible	Transparency

Table 1: Excerpt of combined search terms used for literature review

Reusable articles: management issues

In this section we only discuss the seminal article by Carrasco-Gallego et al. (2012). In their research they deal with three categories of reusable articles (RA) in a closed-loop supply chain. They found that research regarding reusable articles is limited, and that previous literature dealt with certain types of reusable articles and covered certain problems. They could, however, not find any paper that reflected on different types of reusable articles at the same time "and identifying with a holistic approach the management issues arising in the context of reuse". To refer to returnable transport items (RTI), returnable packaging materials (RPM) and reusable products (RP), they coined the term reusable articles, as they observed that "the three categories share the same logistical characteristics" and claim that findings for one particular type of reusable article are applicable to the other ones. Also, they explain how reusable articles networks differ from other types of closed-loop supply chains. Elaborate on the similarities and contrast between the three types of RA and identify two reusable articles networks, namely: "star-systems" and "multi-depot systems"; which refers to a return location for reusable articles. From their empirical research they observed that practitioners experience difficulties managing their reusable articles. On the basis of ten case studies (i.e. six performed by the authors themselves and four obtained from scientific literature) they unveiled five issues[7] managers are faced with in closed-loop supply chains.

In our opinion, the strength of their research is the amount of case studies conducted as well as their empirical data set with which they support their findings. A big portion of their case studies concern RTI, while the other types (i.e. RPM and RP) could have gotten equal attention; we consider this imbalance a weakness. An explanation could be that large quantities of RTI circulate and it is thus easier to find relevant cases for research. On the other hand, RPM quantities might be smaller compared to RTI, and RP are usually used in a specific setting (i.e. one company) which makes it more difficult to find cases for both types or companies do not want to cooperate with the scientific community.

RFID and reusable articles

We have to mention that our search yielded only a small amount of papers: five in total. At first we thought that our search terms were the cause. However, after reading through some of the gathered literature, we found that researchers also acknowledged that papers are indeed limited. For example, Hellström (2009) states that "empirical research covering

[7] In our thesis we will focus on three of them.

implementations of RFID technology to track returnable transport items is surprisingly scarce”.

The papers we were able to find have dealt with different aspects with regard to RFID use for reusable articles. There are two papers that provide an introduction to RFID technology in both a closed-loop and a regular supply chain. Furthermore, two other papers discuss what the consequences of asset visibility are for RTI. The last research article describes the costs involved and how RFID technology could be implemented for managing RTI.

We start with the papers that provide an introduction to RFID technology. According to Visich et al. (2007), at the time of writing, no one had yet examined RFID technology in closed-loop supply chains. They elaborate on various “value recovery options” (Thierry et al., 1995; Krikke et al., 2004 cited in Visich et al 2007) in closed-loop supply chains, and discuss the role of RFID technology (i.e. how it could aid in making decisions regarding product returns and to improve value recovery). In their conclusion they remark that “due to the infancy of both RFID and closed-loop supply chains, research is still needed to identify best practices and applications that integrate RFID and closed-loop supply chains”. The motivation for the research of Angeles (2005) was that RFID was regarded as an up-and-coming research topic. She demonstrates the use and potential of RFID in logistics by summarizing various cases from literature. For managers she provides a list of points, also extracted from literature, which are important to consider for a RFID implementation.

We proceed with the authors who focused their research on the consequences of asset visibility when RFID is implemented. Ilic et al. (2009) found that previously no one had researched “the impact of RFID technology on a high-volume and low-value RTI management model”. In their research they examined the circulation of pallets (i.e. RTI) between three actors: pool operator, fast moving consumer goods manufacturer and retailer. For the pallets, they describe five distinct parts of “a typical RTI flow process”. The particular issues the pool operator experiences in each of these parts are identified and they explain which improvements are possible with RFID. Their findings, resulting from one real life case study (i.e. 12 million RTIs) and a simulation model, point out that with RFID the RTIs can circulate more frequently, consequently, the pool operator’s RTI fleet can be reduced and savings can be realized. Also, in the case of shrinkage, RFID can help identify the culprits.

They also show that the RTI pool operator can fulfil a significant part in improving the management of RTIs.

Johansson and Hellström (2007) investigated what kind of effect shrinkage (i.e. theft or misplacement) has on the management of RTIs, since it was largely unexplored by other authors. They introduce a framework that includes six RTI costs[8] and list the possible advantages of asset visibility for these costs. To examine the consequences of asset visibility for their case study, they build a simulation model to simulate RTI handling for three scenarios: no tracking system, use of tracking system (i.e. RFID & Barcodes) and a tracking system along with management actions. The insights from their research were as follows: "the appropriate fleet size can be calculated for different scenarios", risks can be exposed so that the company can prioritize monitoring actions, a decrease in RTI investment cost as well as a reduction of the total cost (i.e. operating & non-operating cost) is possible "if asset visibility is coupled with proper managerial actions"; unfortunately, the authors omit details about what these management actions entail.

Hellström (2009) researched how RFID could be implemented, and presented a quantification of the cost of this technology. He has composed a RFID implementation model, which is "based on Cooper and Zmud's (1990) model of the IT implementation process" and on data collected from two cases in practice: a RFID trial and a RFID implementation. The case studies detail why both companies decided to implement RFID and what their overall experiences were with this technology; also for each case study a cost as well as a cost-benefit analysis is presented. The six stages of his RFID implementation model are discussed (supported by the empirical results acquired from both case studies) to inform managers about the implication of each stage and to guide them in the implementation process.

A closer inspection of these papers reveals the following strengths and weaknesses: Visich et al. (2007) and Angeles (2005) very early on discussed the role of RFID technology and this provides readers with first insights about its value. However, their research lacks empirical data which we consider a weakness. Nonetheless, many references to prior literature shows that they performed a thorough investigation. Ilic et al. (2009), Johansson and Hellström (2007) and Hellström (2009) obtained results by doing one or multiple case studies (only

[8] The costs are: "investment in RTI fleet, rental charges, replacement cost, repair and maintenance cost, transport cost and warehousing and handling cost"

Hellström (2009)) in combination with a simulation model. In addition, plenty of references to previous literature are included, which is a sign of comprehensive research. We are of the opinion that these three papers have a solid foundation as they present empirical data and their simulation models have been verified by the people involved in the RFID projects. Yet, at the same time, we consider the amount of case studies a weakness. There is nothing wrong with research that is based on one or two case studies, since it still provides useful insights. But this makes it difficult to generalize research results, which the authors themselves acknowledge. Something that we also found remarkable is that nearly all authors have only concentrated on returnable transport items, only Visich et al. (2007) very briefly mention RPM, but RP is simply neglected. There is a chance that if they researched other types of reusable articles (i.e. RPM and RP) they could find conflicting or corroborating insights; we are of the opinion that more case studies would further strengthen their findings.

Our final discussion is focused on examining the methods utilized in the different papers. The preferred method of all the aforementioned authors to obtain results was a literature review (Visich et al. (2007) only performed a literature review) in combination with summarizing case studies from practice (Angeles (2005)) or a literature review in combination with a case study and a simulation model (Ilic et al. (2009); Hellström (2009); Johansson and Hellström (2007)). The literature review enabled the authors to study the previous work of other researchers and observe which discoveries have been made about reusable articles and RFID; besides, research articles often include a future research section which can be used as a starting point for new research (see Ilic et al. (2009)). As the use of RFID is not yet widespread (Hellström (2009) chose the case study, among other reasons, “due to the novelty of using RFID in logistics and supply chain management”), we understand the choice for solely the case study (or in combination with a simulation model) by academics. Since RFID is a relatively new topic this means that plenty of research needs to be done and case studies provide this opportunity. However, an RFID implementation inherently involves an investment of a certain amount of money and time. Because of this many companies could be hesitant to cooperate or are reluctant to share their experiences with the academic world; there are exceptions (see Hellström (2009)). We assume that they simply do not want their competitors to reap the benefits or acquire important knowledge from their efforts; which is to some degree logical, understandable and acceptable. However, we are also aware of the limitations of the case study; the insights obtained might be correct in theory and only applicable to certain areas, but still have to be tested in practice to confirm them. We also understand why simulation models are used in their research. With a simulation model one can make quantitative statements on the value of RFID information in specific cases. With ease a model can be run a given number of times in a controlled environment to determine the outcome of one or more scenarios. However, also for a simulation model limitations apply. It might take some time for practitioners to verify these theoretical results, and they could notice minor or significant deviations in practice. Nonetheless, academics are obviously aware of the limitations of both research methods, but still decide to apply them to acquire insights.

Conclusion

The literature we scrutinized predominantly focuses on one type of reusable article, namely RTI; only one paper mentions RPM in brief, but RP is simply disregarded. Since results are gathered from studying RTI, this implies that generalizing insights is difficult. Not one of the authors has yet considered three types of reusable articles simultaneously to explicitly tackle reusable articles management issues with RFID technology; though, Carrasco-Gallego et al. (2012) did investigate all reusable articles together in their paper, except it is not in the context of RFID.

Even though we reviewed a small number of papers, the insights acquired by the authors are still of value to our research, for example: the placement of RFID components and the consequences of a RFID implementation. At the same time, several questions arise that in our opinion need further investigation. First of all, there are the management issues identified by Carrasco-Gallego et al. (2012): how can RFID technology tackle these issues? Also, since management actions are mentioned by Johansson and Hellström (2007) but not discussed in detail, what do they actually entail? Moreover, although costs of a RFID investment are presented in detail by Hellström (2009), it is merely for RTI. Something that is left out of their discussion, and other authors, is: at which point is it profitable to implement RFID technology for reusable articles?

On the basis of our literature review we conclude that research regarding the use of RFID technology for managing reusable articles (i.e. RPM, RTI and RP) is in an infancy stage. With our research we will explore the uncharted research territory we observed, clarify the unanswered questions and, above all, achieve generalizable research results.

1.7 Generic conceptual model

In this section we introduce our own generic conceptual model which is based on the work of Johansson & Hellström (2007), Hanebeck & Lunani (2008), Ilic et al. (2009), Carrasco-Gallego et al. (2012) and Hellström (2009). Although these authors in their research do describe which problems are experienced with a certain type of reusable article (almost all of them concentrate on returnable transport items, with the exception of Carrasco-Gallego et al (2012)), none have included a conceptual model that covers all reusable articles. To our knowledge, the lack of a conceptual model in literature similar to the one we present here is one reason we developed it, but there are additional motives. First of all, we believe this model to be a practical way to educate readers who are uninformed about the situation regarding reusable articles (RA), as we bring them up to speed about the current state of affairs. It is designed in such a way that, at first glance, one can quickly grasp the current situation. Though, in order to eradicate any misinterpretations and be absolutely clear in what we try to convey, we will discuss it in its entirety. Secondly, it can be used by researchers for their own research which saves them valuable time. Lastly, it is valuable for our own research as it becomes the blueprint (i.e. to explicate which actors and issues we will focus on). And, while the model is based on previous work, it will be tested in different case studies with the intention of validating it.

The remainder of this section is organized as follows: in paragraph 1.7.1 we present the model itself so that one has the opportunity to study and process it. Next, we discuss the various components of the model. In paragraph 1.7.2 we strictly converse about the actors in order to establish their role as well as their relationship, while at the same time defining our scope. Then, we provide a general description of the reusable articles process from beginning to end for all types of reusable articles in the closed loop supply chain. In addition, we further define our research scope by explicitly stating the issues that we will focus on.

1.7.1 The generic conceptual model

The generic conceptual model below (figure 2) is a high level overview of the circulation of reusable articles. It illustrates the beginning (i.e. the transfer from supplier to the user) as well as the end (i.e. the return from user to supplier). Moreover, the potential issues are also included.

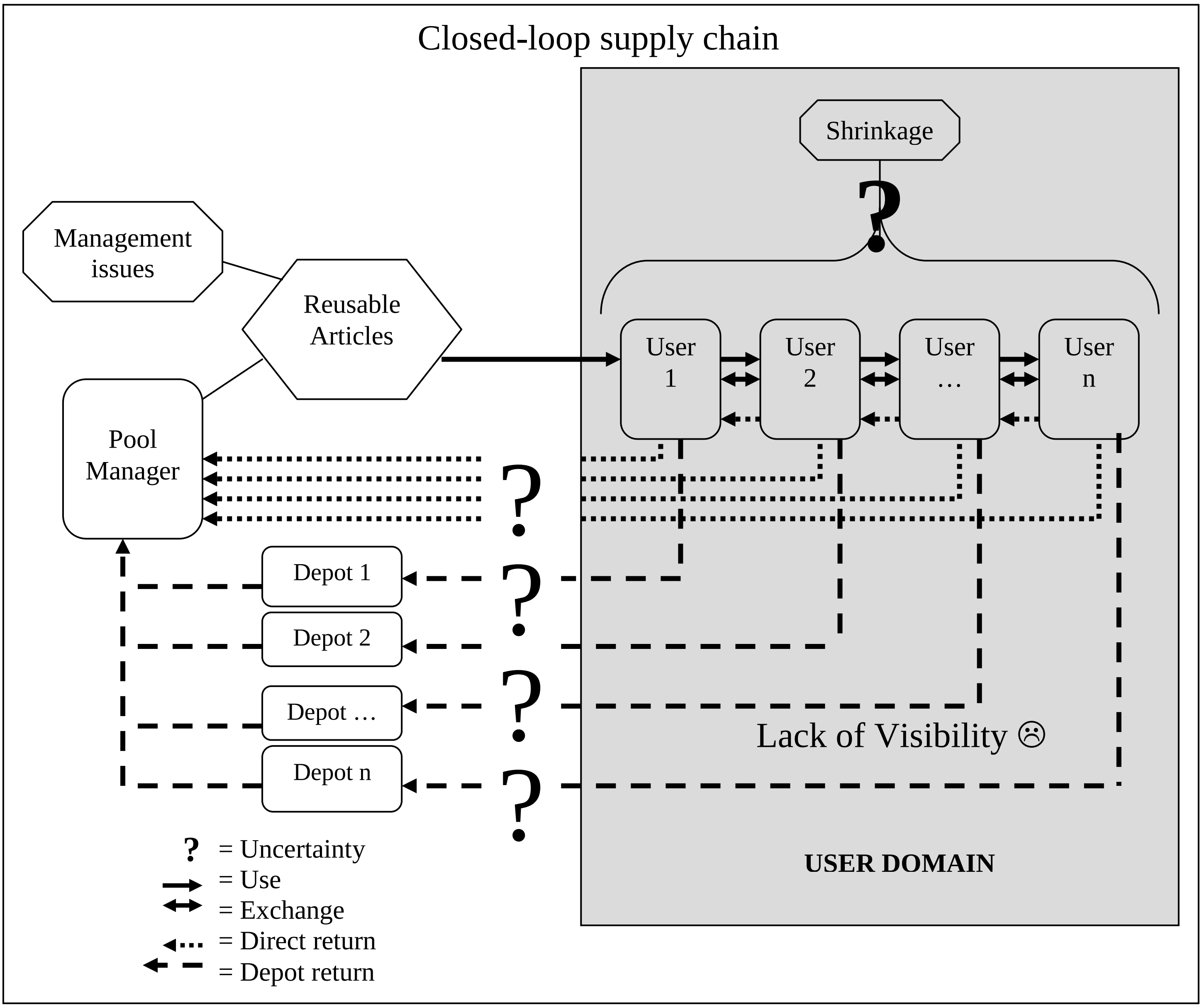

Figure 2: Generic conceptual model for reusable articles in a reuse closed-loop supply chain (source: own development)

1.7.2 Actors

We have narrowed down the conceptual model to the following actors: the pool manager (with and without depots) and the users, a general term which refers to essentially anyone who can use the pool manager's reusable articles, for example: retailers, consumers, 3PL etc. Other actors (e.g. reusable articles manufacturers, companies that recover value from scrap or carry out repairs etc.) are excluded because they are beyond the research scope, because they are never directly affected when the pool manager experiences problems with his reusable articles.

The pool manager

At the inception of his company in a (non-)commercial setting (e.g. library vs. supermarket) he purchases an initial fleet of reusable articles because they are needed for the business (e.g. selling gas to consumers requires gas cylinders) and/or processes (e.g. transporting products safely requires, for example, pallets). With this initial fleet, which can alter over time for a number of reasons, the pool manager needs to meet a certain (daily) demand generated by his unique group of users. Consequently, it is important that reusable articles return on time, preferably in the condition they were issued (i.e. not requiring any repairs and immediate reuse is thus possible), so that a sufficient quantity during the day, or his original fleet at the end of the day, is always on hand and users are thus never disappointed. The types as well as the volume of reusable articles present at the pool manager can be diverse: while one can have a single type (e.g. RTI) and a few hundred available, others can have a mixture (e.g. RTI, RPM and RP) and a few thousand at their disposal, since the sector they operate in demands the use of a certain type(s) and a certain quantity. In general, this means that the pool manager invests a certain sum of money, so his aim is to keep them in constant circulation for a very long period of time, if possible, until they have reached the end of their useful life so that unnecessary expenditures as well as negative consequences (e.g. loss of turnover or lower service level) are averted.

In the previous explanation it is clear that the pool manager is the sole investor in reusable articles, hence, this automatically makes him the supplier and the only one that can claim rightful ownership. In the event that problems arise with his reusable articles he is the only one directly affected and all responsibility lies with him to take the appropriate measures.

The users

User, as stated earlier, is a general term. One pool manager can operate in a totally different sector than another and the types of reusable articles can also differ, hence the users can either be one kind or a combination of the following: retailers, consumers, supply chain partners (e.g. third party logistics provider (3PL)) and/or employees (they may seem out of place in this list, but they too can use them during their work). Irrespective of whom they can be, their role is straightforward: receive/pick up reusable articles, utilize them and when no longer necessary, return them to the pool manager. They can never claim ownership when the reusable articles are in their possession (i.e. temporarily using and holding on to the objects), even if they are required to pay a fee/deposit that never equals or exceeds the value of the reusable article in question, or even when they are allowed to use them free of charge.

1.7.3 Reusable articles process

In the previous section we established who the actors are and what their part is in the model. Here we discuss for all types of reusable articles how they currently circulate in the closed loop supply chain as well as what can happen to them during use. The entire process can be divided into three recurring steps: supply, use and return, and in this order we will explain in detail what currently occurs during each one.

<u>Supply</u>

The process starts (and ultimately ends) at the pool manager (i.e. the supplier) as he is the rightful owner. At his location (or at his depots) reusable articles are in stock and ready for deployment, and will most likely be issued on a daily basis. There are three different ways of distributing them:

1) The pool manager himself transports his reusable articles to any destination
2) The distribution is carried out by third party logistics provider (3PL)
3) The users themselves pick them up from the pool manager

It is possible that one pool manager offers several of these options (e.g. library pick up and delivery of books) and others limit themselves to only one (e.g. shopping cart pick up), it is basically inherent to the type of reusable article present.

Before the reusable articles actually come into the hands of the users, depending on the policy of the pool manager, they either need to register their personal data or are allowed to remain anonymous. Besides identity, he could also require from the user to declare (i.e. by means of a contract) for how long the reusable articles will be in use, while some allow use for an undetermined period of time. Either way, the users can be required to either pay a small fee/deposit before or after use, or in some cases, are allowed to use them free of charge.

<u>Use</u>

In this phase, the reusable articles reside in the user domain, denoted by the grey coloured area in figure 2. Once they are in the hands of the user(s), the pool manager experiences a lack of visibility: this means that the reusable articles are out of sight of the pool manager i.e. he simply cannot see them anymore. One would assume that this lack of visibility is caused by the distance, this is partially true. Indeed, the pool manager cannot see what happens at a location (extremely) remote from him, but this can also occur at his own premises, simply because they are out of direct line of sight. The number of users, denoted by multiple rounded squares (containing user 1, 2, …, n), can vary for each pool manager. It is possible that one has a large group of simultaneous users, while another only has a few at the same time, this (more or less) depends on the type of reusable articles present and of course the size of the pool manager. To add to the complexity, it is possible that these users are spread around in the same region/country, operate abroad or can even be a mixture of both. Regardless of distance, this lack of visibility has consequences: he cannot determine, in real time or at any given moment, where the reusable articles exactly are, the quantity present at a particular location or at a particular user or how many, in total, are in circulation, basically (on a grander scale) it becomes extremely difficult to see what is happening across the whole closed-loop supply chain.

When in the user domain, as illustrated in figure 2, several things can happen: shrinkage, use and exchange. Shrinkage is a broad term (which we define as follows: shrinkage encompasses any form of temporary or permanent loss which results in a cease of service for the user and/or financial expenditure for the pool manager) which encompasses theft, damage, deterioration and misplacement. Theft constitutes a deliberate act by a human to take away an object without full imbursement (i.e. the actual historical purchase price) to the rightful owner and with no intentions of ever returning it. Damage refers to either deliberate or an accidental action aimed at an object which renders it useless for day-to-day business. Deterioration refers to an object eventually becoming unusable after a period of time (i.e. at the end of its useful life) rough or normal use has some influence on the deterioration. And, misplacement refers to negligent behaviour of a human which usually leads to a temporary disappearance of an object, and contrary to theft, is more likely to return if enough effort is put into retrieving it. There are several reasons why shrinkage can occur. First of all, since the users are not the owners, they sometimes tend not to handle them with proper care. Second, the user's awareness of the limited visibility means that they sometimes do not act responsibly. Third, the individual item value could sometimes lead to a lack of control by the pool manager. Fourth, the material which the reusable article is made of is valuable to certain people (i.e. miscreants). Finally, humans in general simply make (deliberate) mistakes. To complicate things even more, while in the user domain there is uncertainty with regard to use and exchange of reusable articles. The pool manager expects that the user who initially received it, uses it at the same location it was delivered, for the purpose it is intended for, and returns it afterwards. However, there is a chance that without the consent of, or properly informing the pool manager, the user transfers it to another user, who in turn uses it within the same country or even could take it abroad. Exchange of a small or vast quantity of reusable articles between users can also occur and is unpredictable, but instead of active use they are simply stored at an unknown location; both use and exchange can be repeated indefinitely.

<u>Return</u>

The process concludes with the return of reusable articles to the pool manager so that they can be issued again. While some own depots where users can drop them off (i.e. a multi depot network), others have only one return location namely where they were originally distributed from (i.e. star network). In this phase, similar to the supply phase, there are three ways reusable articles can return:

1) The pool manager picks them up or receives them from his depots
2) A 3PL carries out the return either directly to the pool manager or to a depot
3) The users themselves return them either directly to the pool manager or to a depot

Since the use phase is characterized by uncertainty due to the lack of visibility, this has repercussions for the return, as illustrated in the model by the four question marks. As mentioned in the supply phase, the pool manager either knows who the users are and for how long they will be in use or knows nothing at all. This uncertainty makes the pool manager uncertain about the following: when will reusable articles return?, what quantities will return?, in what condition will they return? and, in the case of depots, where will they be returned?; even with contracts, it is still no assurance that they will return (in time).

In the event of shrinkage, it is cumbersome for the pool manager to establish where (i.e. which location exactly) it has happened, when (i.e. date and time) it happened and also to identify vulnerable areas in the closed loop supply chain. Furthermore, since one reusable article can unknowingly have many different users and exchange can also take place, it is thus extremely difficult to identify who (i.e. the culprit(s)) can be held accountable. Aforesaid is extremely complicated in the case of anonymous users. However, even if the pool manager knows who his users are, it is still difficult to ascertain this with confidence.

It is apparent from the process description that uncertainty makes managing reusable articles a difficult undertaking for the pool manager. Even though the aforesaid authors describe which problems he must deal with, we however focus on the management issues identified by Carrasco-Gallego et al. (2012) for our research. The main reason for doing so is that they, for the first time, investigated different types of reusable articles simultaneously, as we also do in our research. Of the five issues they identified, we selected three and include another one ourselves derived from one issue as the focus of our research.

The management issues we will focus on are as follows:
1) Define the fleet size dimension: the pool manager needs to accurately calculate the quantity of reusable articles necessary to prevent disruptions of the logistics process as well as to minimize unnecessary expenditures.
2) Control and prevent fleet shrinkage: the pool manager will at some point in time notice that his fleet will reduce in size due to shrinkage. While it is easy to detect damage because this is visible, on the other hand, misplacement and theft is complex to pinpoint and therefore it is difficult to get an accurate overview about quantities returning.
3) Define purchase policies for new articles: the pool manager needs to establish when it is sensible to purchase additional or replace reusable articles as shrinkage will occur from time to time and, unexpectedly, the market circumstances can change.
4) Accurate cost allocation (own issue, derived from issue 2): in the event reusable articles go missing or become unusable due to shrinkage or return from the user at a different date than contractually agreed, the pool manager is the only one who has to face the financial consequences (i.e. the acquisition of new reusable articles or any other related costs), instead, the right culprit(s) should be held accountable for the costs.

As of now, RFID technology is not yet widely implemented in practice by companies that use reusable articles for their business (e.g. in a Dutch news article is stated that TNT Innight is considering the use of RFID[9]) and as a result practical experiences are very scarce. Hence our research on how RFID technology could help the pool manager both manage their RA in a closed-loop supply chain and solve all aforementioned issues. The generic conceptual model described above is used as the basis for our research.

[9] http://www.nieuwsbladtransport.nl/nieuws/id29584-TNT_Innight_overweegt_inzet_RFID.html (26 march 2010)

2 Radio Frequency Identification (RFID)

This chapter is an introduction to RFID technology. Our objective is to inform readers who are unfamiliar with this subject matter, so that one is able to follow our research. A minimal amount of technical details are included as it is beyond the scope of our research and certainly not required to understand RFID.

We have structured this section as follows: we start with a brief history of RFID. In paragraph 2.2, RFID technology is explained. We will first explain how it works in the context of reusable articles since that is our focus. Thereafter in the subparagraphs, the components are separately discussed. Next, in paragraph 2.4, we look into different applications of RFID. Finally, we have a comparison between RFID and barcode to identify the differences between the two.

2.1 History

As mainstream media in the last few years has increasingly begun to cover radio frequency identification (RFID) technology, it may seem as if this technology was invented recently. This is definitely not the case, on the contrary: one would be surprised to learn that it has been around for more than 60 years. According to Landt (2001) RFID was actually invented in 1948, it is assumed that one of the first to explore RFID was Harry Stockman in 1948, who wrote the paper entitled: Communication by Means of Reflected Power. Furthermore, Landt (2001) states that the first actual use of RFID related technology is considered to be during World War II, when the British used radar to distinguish allied planes from enemy planes, so-called: identification, friend or foe (IFF). He further mentions that electronic article surveillance (EAS) is the “first and most widespread commercial use of RFID” which was developed by several companies in the 1960s to stop theft. Only a few decades ago, to be precise in 1983, Charles Walton received a patent that contained, for the very first time, the acronym RFID[10]. Obviously, the technology as it is available today could only be possible due to the contributions of many different scientist, companies and governments, for more detailed information about the history of RFID we refer to Landt (2001).
Even though RFID has been around for a while now, only recently it is getting more and more attention for use in supply chains. The reasons for many companies not to implement or consider RFID technology earlier, as stated in an article at foodproductiondaily.com (2005),

[10] http://www.wellpacktaper.com/rfid-about.htm [accessed June 2012]

were “the high costs of RFID hardware, software and services, the immaturity of the technology and the lack of common standards”; as RFID components costs continue to decrease and the technology matures, it is assumed that more companies will become interested. Moreover, the mandates from two major players in the United States: Wal-Mart (the largest retailer in the world (Fishman, 2003)) and the Department of Defense (DOD) also have contributed to an increased interest in RFID. Both are considered by many to be the biggest pushers of RFID technology. The main reasons being that Wal-Mart asked their top 100 suppliers to tag their cases and pallets starting from January 2005 (RFID Journal, 2003) and all their suppliers by the end of 2006, and the DOD wanted all their suppliers to put RFID tags on all their shipments by January 2005 (RFID Journal@, 2003).

2.2 What is RFID?

RFID is a technology that belongs to the Automatic Identification (AUTO-ID) technologies which as stated by Agarwal (2001) also includes (amongst others): Bar Code, Optical Character Recognition and Magnetic Stripe. With AUTO-ID technologies it is not necessary for humans to both read data and enter it manually into a computer system, because this all happens automatically and thus data entry is done efficiently and errors are minimized (RFID Journal, 200-)[11]. In a RFID system an object or person can be assigned a unique serial number (i.e. the identity) and this number is send out wirelessly by means of radio waves (RFID Journal[12], 200-).

2.3 How does RFID work?

A RFID system is comprised of several components, they are: tag, reader, antenna, middleware and enterprise applications. In order to understand how RFID technology works we provide a brief but simple example in the context of reusable articles (i.e. returnable transport item); although components are introduced which may be new to the reader they are explained in the subparagraphs.

Example: imagine that a pallet has a RFID tag (a small plastic device which contains a unique identification) attached to it. This pallet is transported from location A (the pool manager) to B (the retailer). The pool manager can identify this particular pallet as follows (see figure 4): a reader will send out radio frequency signals via its antenna and then wait for a response from

[11] http://www.rfidjournal.com/article/view/1339 [accessed March 2011]
[12] http://www.rfidjournal.com/article/view/1339 [accessed March 2011]

the tag. When the tag is in the neighbourhood of this reader it is activated (i.e. this only applies to passive tags (i.e. a type of tag)) and then sends back its data (via its own antenna) which is collected by the same antenna/reader that send out those signals. This data is then transported to software called middleware which filters data, and then (usually) sends it to an enterprise application (e.g. warehouse management system (WMS)) or a database. This basically describes how RFID technology works. As is clear from figure 4, the RFID system is made up of different components and each serves a specific purpose in the system, hence they are only useful when used collectively.

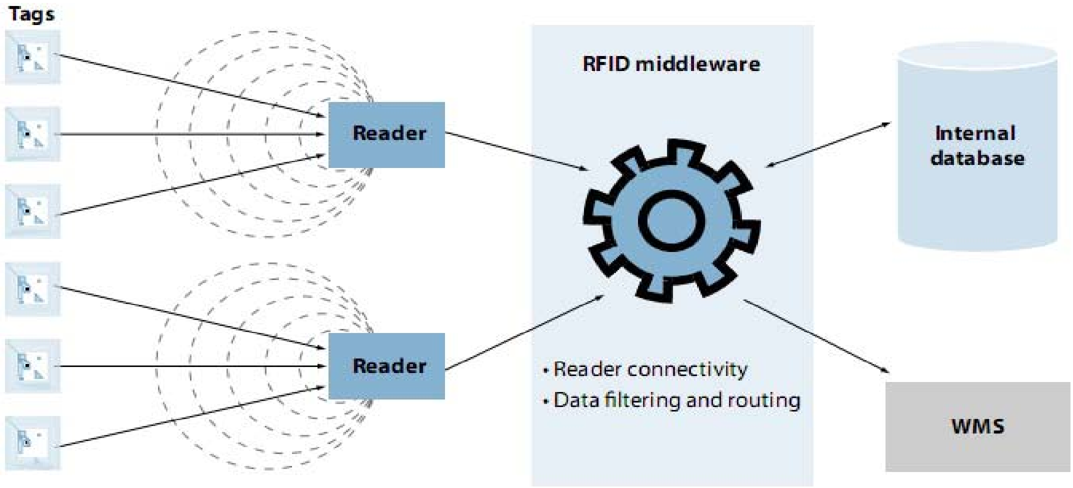

Figure 3: General RFID system overview (Source: Leaver et al. 2004, p. 10)

2.3.1 Tag

The tag (or transponder) could either be attached to a physical object (e.g. a pallet) (i.e. with screws or an adhesive) or carried by a person (i.e. embedded in a card) or animal (i.e. implanted in body) and it contains data that uniquely identifies or provides information about the carrier. This identification is possible due to the Electronic Product Code (EPC) that is stored on a microchip which can be found on every tag, the integrated antenna is used to send out the tag's data (see figure 5).

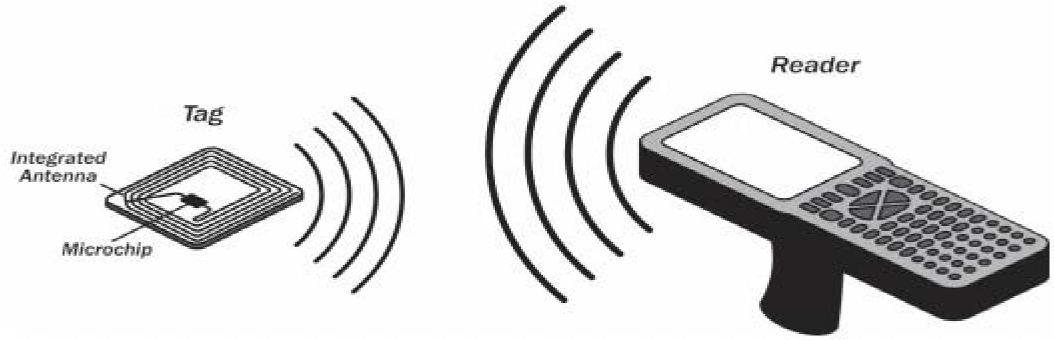

Figure 4: Wireless communication between tag and reader (source: Karygiannis et al. 2007, p. 21)

The EPC is made up of four parts (see figure 6), they are: Header, EPC Manager, Object Class and Serial Number; each part is used for identification (Karygiannis et al. 2007). Specifically for returnable assets a Global Returnable Asset Identifier (GRAI) was developed that enables unique identification of an asset all over the world and it can be embedded into EPC (GS1, 2008).

Figure 5: 96-bit EPC (Source: Karygiannis et al. 2007, p. 71)

There are three different types of RFID tags: passive, semi-passive and active tags. The difference between them is the source from which they get their power and how communication takes place. The passive tag is unable to send data on its own and needs radio waves from the reader's antenna as energy in order to communicate. This dependency means that it has a short read range (i.e. the distance from which a tag and reader can communicate with each other (RFID Journal glossary of terms*, 200-). On the other hand, the active tag has a battery which is used for communication and is able to send data independently from a further distance. The semi-passive tag has a battery, but still needs radio waves from the reader's antenna to operate (RFID Journal the basics of RFID technology**, 200-).

There are various frequencies on which a RFID system can operate, namely: low frequency (LF), high frequency (HF), ultrahigh frequency (UHF) and microwave. The frequency determines the read range (i.e. the maximum distance between tag and reader) and the data transfer rate (i.e. the number of characters that are transmitted from tag to reader in a certain time (RFID Journal glossary of terms***, 200-)). This means that one frequency is better suited for certain applications (RFID Journal the basics of RFID technology****, 200-) as is shown in table 2.

Band	Estimated read range+	Common applications++
Low Frequency (LF)	less than 0,5 metre	animal ID, beer kegs, auto key & lock, library books
High Frequency (HF)	up to 1,5 metres	item level tracking, airline baggage, building access
Ultra High Frequency (UHF)	up to 100 metres or 0,5 to 5 metres (depending on frequency band)	case, pallet and container tracking, truck and trailer tracking
Microwave	up to 10 metres	access control (vehicles)

Table 2: Overview of different frequencies (sources: +=Ward & Van Kranenburg 2006, p. 10; ++= UPS 2005, p. 2)

2.3.2 Reader and antenna

Both the reader (a.k.a. interrogator) and antenna will be used to communicate with tags and to capture data. The function of the antenna, which can be placed at diverse locations (e.g. on the ceiling, near the door, in the ground), is to send out radio frequency signals and to receive data from the tag. However, actual communication with a tag is done by the reader.

There are a variety of readers available, namely: agile, multi-frequency, dumb and intelligent. The main difference between them is what they are capable of: the agile, multi-frequency and intelligent readers are able to perform more operations than a dumb reader (RFID Journal RFID system components and costs$+, 200-) A reader can be placed either into the mobile or fixed category. The mobile reader can be brought along by an individual (i.e. handheld reader) or attached to a vehicle to read tags in an environment where fixed readers are not present. In contrast, the fixed reader is attached to fixed structures (e.g. wall) so to read tags passing it (RFID Journal glossary of terms**++, 200-).

2.3.3 Middleware

Before the captured data can be made available to the end user, it needs to undergo a quality check. The component that will perform this check is called middleware. It is software that operates between readers and enterprise applications (see 3.3.4). The function of middleware is to filter raw data received from readers, because this data is generally polluted (e.g. multiple reads). Once the filtering is complete, the clean data will be transported to enterprise applications. Besides filtering, some middleware can perform extra tasks, for example, automatically send and receive shipping information between business partners (RFID Journal RFID system and components cost#$, 200-).

2.3.4 Enterprise applications

Filtered RFID data on its own has no value at all, because it is merely an amount of gathered data that has not yet been subject to analysis by the end user. Though, to actually unleash the value of this data, enterprise applications (e.g. warehouse management system (WMS) software) are required which can help the end user to analyze RFID data by providing the necessary analytical tools. This data, after thorough analysis, will then evolve into valuable information which will form the basis for decisions and relevant actions (RFID Journal RFID system components and costs&&, 200-).

2.4 Applications of RFID

Currently there is much interest in RFID technology from many practitioners. While some rather wait-and-see how this technology further develops, others in different sectors have already opted for implementation. As is apparent from the overview below (figure 7), use of RFID is not limited to a particular business, but it already is, or soon will be, applied in various sectors for different applications. Only a few applications (i.e. luggage handling, hospital equipment, public transport ticket and passport) will be highlighted to give an idea of this diversity by giving examples from practice.

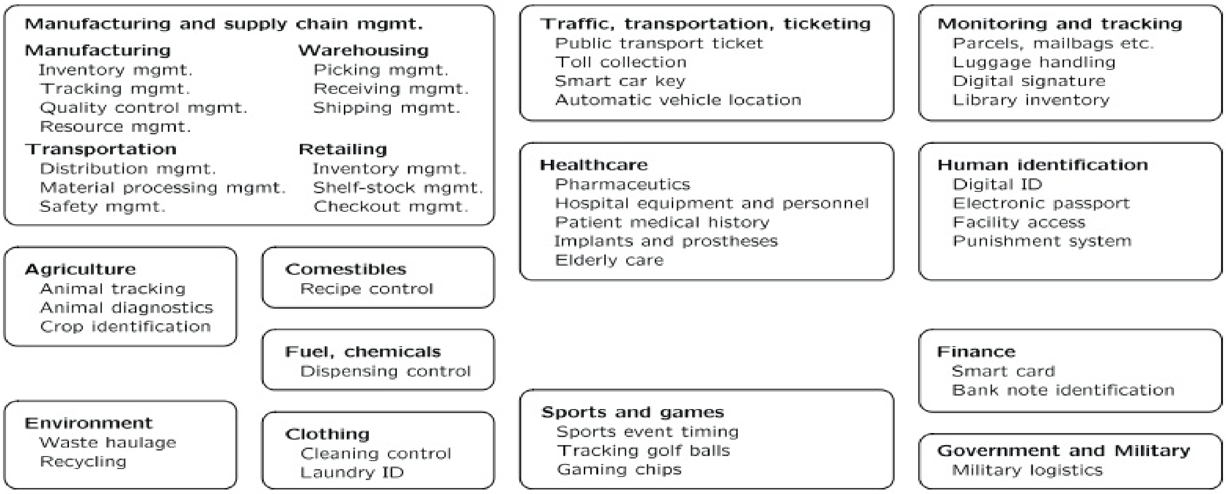

Figure 6: Examples of current and expected RFID application areas (source: Ilie-Zudor et al. 2006, p. 7)

Luggage handling (Swedberg, 2009): at Hong Kong International Airport (HKIA) RFID tags are used for all 40.000 pieces of luggage that are handled daily at the airport. HKIA has automated the transportation of luggage by having readers at strategic locations read the tags and route luggage from start (check-in) to finish (designated plane).

Medical equipment (Swedberg, 2010): Health First located in Florida USA is using RFID to track all its infusion pumps and other medical equipment. Besides tracking, it also uses RFID to check the temperatures of coolers at their facilities to see if the infusion pumps are active or not and to determine if the pumps are properly cleaned and repaired.

Public Transport: to pay (without coins or bank notes) for all public transport (i.e. metro, bus, tram and train) in the Netherlands, people can either purchase an anonymous, personal or disposable OV-chipkaart. As of 16 March 2011 the Ov-chipkaart is accepted everywhere (ANP, 2011) in Holland. The personal OV-chipkaart contains the following data: balance, automatic upgrade of balance (optional), last 10 transactions and birthdate of cardholder (ov-chipkaart.nl, 2012). The anonymous card lacks the birthdate as well as the automatic upgrade of balance (ov-chipkaart.nl*, 2012). The disposable card strictly contains a preset travel time.
Government: Dutch citizens, as of August 2006 (paspoortinformatie.nl, 2009), receive a passport that has a RFID chip which contains: personal data (e.g. name, date of birth, gender etc.) a full color photo and, as of 21 September 2009, it also includes two fingerprints (De Jonge, 2010)

2.5 RFID versus barcode

RFID technology is regularly compared with barcode (i.e. Universal Product Code (UPC) or European Article Number (EAN)) by practitioners when discussing the (dis)advantages of RFID. This is quite logical since the barcode is most commonly used in retail (the first UPC barcode was scanned on June 26, 1974 (Harris, 2009)) and logistics as it is inexpensive to use (i.e. a barcode costs “half a cent each” (Shih, 2009)) and can be easily integrated into packaging; to this day barcodes are still in use in many different areas. Moreover, both technologies function as data carriers and are attached to an object which eventually will be read. Currently, there is a debate among practitioners about whether RFID will be the successor of the barcode or not, or that it will simply co-exist. For clarity purposes in table 3 a comparison is made, so that one is able to exactly tell the difference between the two.

2.6 Conclusion

In this chapter we have answered our third sub question: What is RFID technology (i.e. how does it work) and how does it differ from barcodes?

RFID systems consist of several components (i.e. readers, antennas, tags, middleware and enterprise application software) that each serve a role in the total system and are only useful when used together. RFID technology works by sending and receiving radio waves to wirelessly transfer data from RFID tags to RFID readers. The tags on the products carry a unique identity that is read by the readers/antennas, and the software that processes the incoming data from which the user can extract information with enterprise applications. At the moment RFID is already used for passports, animal tracking, airports, public transportation, medical equipment and for many other sectors there are numerous potential applications. RFID is regularly compared to barcodes, while there are similarities between the two (i.e. both are data carriers and placed onto products) the main difference is currently the price and their capabilities (e.g. RFID tags inside a closed box can be read from a distance, barcodes need to be visible to a scanner).

	RFID	Barcode
Read rate	A large amount of tags can be read at the same time from a (certain) distance, within a second: humans are not required to read tags as it is done automatically.	Barcodes have to be read individually by hand from a very small distance; reading a single barcode takes a few seconds, mistakes are easily made, and is labour intensive.
Line of sight	Not compulsory for a reader to see the tag to read it; tags do have to be in read range in order to communicate.	A barcode must be visible for it to be read by a scanner.
Read/write	A tag can have read/write capabilities.	A barcode is strictly limited to reading.
Placement	A tag can be placed inside an object. This means it is less likely to get damaged and thus it can be reused numerous times. It can be used in environments that are not suited for barcodes.	Due to line of sight requirements, barcodes must be visible. They can get filthy or damaged due to (rough) handling resulting in unreadable barcodes.
Security	A tag is not easy to copy since it contains unique data which is stored in a secure manner.	Barcodes lack this protection and thus are simple to copy or forge.
Costs	At the moment RFID, compared to barcodes, is more expensive to implement.	Barcodes are inexpensive to use and ubiquitous.

Table 3: RFID and barcode a comparison, (sources: atlasrfidsolutions 2010 and technovelgy 200-)

3 Reusable articles

This section is an introduction to reusable articles (RA). Our objective is to inform readers by providing the necessary details so that one can understand our research. However, we refrain from the following: technical details (e.g. exact measurements, materials composition), vendors that sell RA, which RA should be purchased, what material they should be made of, or any other information related to RA that is too detailed, because it is beyond the scope of our research and irrelevant to the basic understanding of RA.

We have structured this section as follows: in paragraph 3.1 we give a general description of reusable articles and explain why the pool manager uses them. Next, we will discuss the different reusable articles types separately. We conclude with paragraph 3.3 where we present an overview of the general characteristics of reusable articles.

Our source for this chapter is largely Carrasco-Gallego et al. (2012): for section 3.1 pages 4 and 6, for section 3.2 pages 5 and 8 and for section 3.3 page 6 of their research article were used. Any other sources used are clearly mentioned.

3.1 What are reusable articles?

The term reusable articles (RA) is coined by and first used in the research article of Carrasco-Gallego et al. (2012). It refers to physical objects available in various dimensions (e.g. varying from a small box to a large maritime container) and made of different materials (e.g. plastic, aluminum, wood etc.), which can and are to be used repeatedly (but not indefinitely) by probably many different users during its useful life. RA is simply an umbrella term which covers three types: returnable transportation items (RTI), returnable packaging materials (RPM) and reusable products (RP) more details about them are provided in paragraph 4.2.

There are a number of reasons why it is possible to reuse RA and why different users are to be expected. First of all, they are designed to be long-lasting. The materials RA are made of, as well as their design, give them a certain useful life (e.g. 10 years for plastic pallets, as stated at aalhysterforklifts.com (2011)). They are never consumed by the users, and assuming normal use (i.e. users handle them responsibly), they slowly wear-and-tear which means that they have quite a long lifespan; albeit, depreciation of useful life is certainly influenced by the way they are handled by users and the environment in which they circulate.

Second, RA return to the pool manager after use and are put into circulation again in the forward supply chain (i.e. flowing from the pool manager to the users). The users merely desire the contents carried with the RA or simply use RA themselves to carry out an activity for a short period of time. After having served its purpose, users normally do not discard nor are interested in owning them and therefore are returned to the pool manager. The time they are generally in use by a user is brief (e.g. one week for a plastic pallet) which significantly differs from their useful life (see earlier example of plastic pallets) and thus makes repeated use possible for a long period of time; hence, there is a high probability they will end up in the hands of different users during their lifetime.

Third, any necessary operations (e.g. inspection, testing, cleaning, repairs, etc.) are carried out in order to continue reuse. The pool manager upon receipt of RA, in many organizations (if not all) checks the current condition of the RA. If necessary, operations are carried out to restore RA to a condition which makes it safe to reuse them again. The repairs vary per RA as the purpose they are intended for demands either simple or complex operations. Once they are in the right condition, they are ready for recirculation and are given out to whoever has a need for them; the pool manager does not discriminate, this is another reason why RA will most likely end up in the hands of different users.

There is a financial as well as an environmental motive for the pool manager to opt for reusable articles instead of disposable articles. The financial motive is to decrease the purchase and disposal costs (if required for respective RA). Instead of continually purchasing disposable articles which could become costly (e.g. logistics operations where thousands of units are needed), a one time investment is intended to last a time (e.g. plastic pallets); assuming circumstances remain the same, during that whole time minimal expenses are expected with regard to the RA fleet. Also, operations on reusable articles are cheaper instead of purchasing new disposable articles time and again. Depending on the kind of RA, disposal costs are only expected at the end of the useful life they are disposed of. The environmental aspect refers to the decrease of the amount of waste generated by the pool manager as "demanded by governmental regulations" (Livingstone and Sparks, 1994; Kroon and Vrijens, 1995 cited in Johansson & Hellström 2007). If users use RA properly, they are in use for a long period. It is expected that only at the end of their useful life they end up at a landfill or are recycled; this means the amount of waste generated is far less in comparison with a scenario where disposable articles are strictly used.

3.2 Types of reusable articles

Before we proceed, a brief yet informative description of packaging types is presented to help understand reusable articles. According to Hook & Heimlich (199-) there are three types of packaging available: primary, secondary and tertiary, and each has a special purpose. Primary packaging is intended to directly hold the product that will eventually be consumed by a consumer (e.g. a can of corn). Secondary packaging is intended to hold a certain amount of primary packaging together in storage or during transport and to protect the products at all times (e.g. a box that holds 20 cans of corn), additionally, to display them at retail locations. Tertiary packaging is intended for the transportation and storage of primary and secondary packaging together to their destination (e.g. a pallet wrapped in plastic that holds 100 boxes that individually contain 20 cans of corn).

Returnable transportation items (RTI)

The definition of RTI according to (ISO 2005 cited in Johansson & Hellström 2009) is "all means to assemble goods for transportation, storage, handling and product protection in the supply chain which are returned for further usage." Based on this definition and the previous description of packaging types, RTI fall into the secondary and tertiary category. They are normally used in logistics to safely transport a collection of other products to a destination, but they can also be used as storage and to display other products (e.g. promotions in a supermarket). RTI are predominantly used in business-to-business (B2B) settings for the transportation of products between businesses. Companies can choose from a wide selection of RTI which come in a range of sizes, for example: plastic/wooden pallets, maritime containers, roll cages, plastic boxes, plastic trays, wooden/plastic crates, barrels, boxes, pallet collars, lids and many more. However, it is not uncommon to see companies offer them in a business-to-consumer (B2C) settings as well. For example, many have at least once used a shopping cart or basket in a supermarket to carry around their groceries. Furthermore, it is not uncommon that these are used internationally (e.g. maritime containers that are shipped from China to Europe and vice versa) as well as locally (e.g. the pool manager who transports his products to a local retailer). RTI are generally standardized (i.e. if one would visit several European countries one would find wooden pallets of exactly the same measurements again and again). According to (Witt, 1999; Maloney, 2001; Twede and Clarke, 2004 cited in Johansson & Hellström 2009) this standardization has the following benefits on an operation level: improved protection and security of products (i.e. products are grouped safely and packaged tightly together so that they cannot fall off and cannot be taken away easily), enhancement of working environments (i.e. employees can move around in an organized environment, since products are neatly stored) and enabling more efficient handling and cube utilization (i.e. maximum use of space means more goods can be transported per trip and employees can move group of products instead of individual units, which is both labour intensive and inefficient).

Figure 7: An example of a widely used RTI: the EURO pallet[13] (source: tillwood.nl)

Returnable packaging materials (RPM)

The purpose of this reusable article is to contain and shield the product which is destined to be consumed by consumers. Hence, it falls into the primary packaging category. Similar to RTI they can either be found in a B2B or a B2C environment. In business-to-business settings, for instance, companies can purchase industrial gas for their production process which will be delivered in returnable gas cylinders. On the other hand consumers can purchase refillable plastic bottles for beverages at the supermarket; when empty their return is expected. In practice RPM are commonly used within the same country the pool manager operates in.

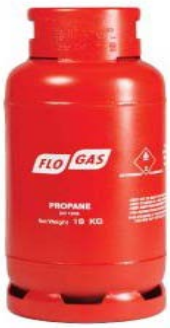

Figure 8: A refillable propane gas cylinder[14] (source: flo-gas.co.uk, 2012)

[13] http://www.tillwood.nl/pallets-1/euro-pallets [accessed June 2012]

[14] http://www.flogas.co.uk/prod/136/19kg-propane-gas [accessed June 2012]

RPM, contrary to RTI, are more difficult to standardize as the packaging is in direct contact with the product. Since the packaging is visible to the customers, it is an opportunity for the pool manager to market their products in a way that distinguishes them from the competition, which usually means the use of unique packaging. Also, there are products that due to their size or technical requirements cannot be stored into a standard package, which also requires the use of packaging of unique dimensions.

Reusable products (RP)

These reusable articles do not fall into any packaging category, because they are not packaging. They are to be used themselves over and over again in a (non)-commercial setting for a short period of time. Similar to RTI and RPM, they also can be used in B2B or B2C. In B2B, for instance, in order to perform a particular task a company can rent a truck, heavy duty equipment or special tools from another company. In a B2C situation, consumers can rent cars, sports equipment, books from a library, DVDs from a video store or bikes from a bike shop to carry out an activity. There is a likelihood that they will be used internationally (e.g. library books read on holiday) as well as locally (e.g. consumers that rent golf clubs for the day) or strictly remain within an organization (e.g. surgical instruments in a hospital).

Figure 9: Surgical instruments[15] (source: zaskmedical.com, 200-)

In the descriptions we did not look into the quantitative presence of reusable articles; whilst difficult, we were able to find data. In the USA alone it is estimated that the wooden pallet pool is about 2.5 billion in total (Douglas, 2008). In India there are over 150 million gas cylinders in circulation (Vijay, 2010). In the Netherlands Centraal Bureau voor de Statistiek (CBS, 2011) noted that there were 166 libraries with in total 31.323.000 million books. From the gathered data we can cautiously deduce that RTI (e.g. pallets) and RPM (e.g. gas

[15] http://www.zaskmedical.com/SURGICAL%20INSTRUMENTS/surgicalmain.htm [accessed June 2012]

cylinders) generally have a larger presence than RP (e.g. books). There are billions of consumers who consume goods on a daily basis; this could explain the enormous amount of RTI since these are essential for the safe transportation of secondary and primary packaging and RP to their destination.

3.3 Characteristics of reusable articles

In this paragraph we enumerate the characteristics which differentiate reusable articles from single use equivalents (e.g. single use pallets, single use beer bottles, single use plastic bags, single use plastic cutlery, single use wooden trays/boxes etc.). The reason we considered single use items is that the pool manager can choose to only employ them rather than RA.

Characteristics	**Explanation**
Users make no distinction between new and reused products*	Whether users use a new or reused product, this is irrelevant to them (quality wise there is minimal difference). In a fleet one can find used as well as new RA as they are intended for the same market. Both provide the same functionality and the same cost for the user. Only new single use items are expected and previously used ones are commonly refused by users (i.e. the product has been consumed or a lower quality after use).
Simple operations bring used RA into an as-good-as-new state. Swift recirculation in the forward supply chain*	A series of operations are sometimes required to ensure that reusable articles are safe to be reused. These operations are not that time consuming so they are quickly available for recirculation. The costs associated with these operations are usually lower than buying a new product. Strictly new single use items enter the forward supply chain.
Large quantities of RA are returned; these are used to meet most demand*	Large quantities of circulating RA are returned to the pool manager to meet future demand, even with shrinkage (i.e. theft, damage, misplacement) which affects returns. Single use items never return.

They play an essential role for the business (processes)**	RA are purchased to fulfill a task during their respective useful life. In case of insufficient quantities, due to shrinkage or poor management, the pool manager will experience difficulty to fulfill demand and production or distribution of products could come to a halt. In the worst case, if all RA were to be absent the pool manager could lose its reason for existence (e.g. a library without any books cannot function as a library). Single use items never return; they can be purchased again.
Vulnerable to shrinkage**	RA are vulnerable to shrinkage for a number of reasons: first of all, their durability, functionality and/or the deposit can be of interest to miscreants. Second, materials they are made of have scrap value (e.g. steel or aluminum). Third, they can be misplaced at a remote location which makes it difficult to retrieve them. Single use items are used only once, which means they have a very short lifetime.
Primary operational challenge is to balance demand and returns*	Even though a large quantity of RA return, it is still difficult to balance demand and returns. Due to shrinkage the fleet size will diminish, which means timely replacement is necessary to prevent disappointed users. Even if plenty RA circulate in the supply chain they still need to be returned to the pool manager on time to meet demand. In the case depots exist and exchange of RA takes place between them, sufficient RA needs to be present at the right locations to meet demand. Single use items are disposed of.

Table 4: Characteristics of reusable articles (source: *Carrasco-Gallego et al, 2012 & **McKerrow,1996; Twede, 1999; Witt, 2000 cited in Johansson & Hellström, 2007 & own analysis)

3.4 Conclusion

In this chapter we have answered our fourth sub question: What are RA (i.e. RTI, RPM and RP) exactly, what are the similarities and differences, and what are the general characteristics?

Reusable articles is an umbrella term that refers to three different kinds of reusable articles (i.e. RTI, RPM and RP). These reusable articles are objects which are available in different sizes and made of different materials (e.g. plastic, wood). They are intended to be used repeatedly (i.e. the end of their useful life) by most likely many different users during its lifespan; this is possible because they are long lasting, never consumed by the users and return to the owner who circulates them again. RTI are predominantly used in logistics (e.g. pallet) to carry other products to a destination or for temporary storage purposes. RPM hold and protect (e.g. plastic bottle) a particular product that in time will be consumed by consumers. RP are used themselves to carry out a particular activity for a short period of time (e.g. surgical instruments). Despite the different application of these reusable articles they all share the same characteristics, which differentiate them from single use articles (e.g. users are indifferent to new or used reusable articles, while single use articles must be new).

4 Exemplary case study: Shopping carts at a supermarket

This exemplary case study[16] is our first venture into investigating the theoretical application of RFID technology for reusable articles. With this case study we therefore will attain first insights on how RFID could help the pool manager to deal with RA management issues and observe if RFID is profitable or not.

This chapter is organized as follows: first, we introduce the subject of our case study. Next, we present some important data regarding this case. In paragraph 5.3, a process analysis is conducted and we identify our generic conceptual model. Thereafter, the types of shrinkage are identified, assessed and quantify the impact of shrinkage. Next, the general characteristics of reusable articles are discussed for shopping carts. In paragraph 5.6 RFID technology is discussed. We propose RFID options and examine which data will become available. Then, we look into how RFID can tackle management issues. In the subsequent paragraph we discuss the RFID investment and assess the profitability. Finally, we draw conclusions.

4.1 Introduction to shopping carts in supermarkets

As a service, supermarkets in the Netherlands have shopping carts and shopping baskets available to help the customers carry and protect products during shopping; nowadays, use of either one is mandatory to prevent theft of products. In this case study we concentrate on the shopping cart (later on we explain why we disregard the shopping basket). While many think of a supermarket, shopping cart use is actually widespread and they are found at (albeit in a slightly different form/size): DIY (do it yourself)-stores, garden centers, furniture stores and wholesalers, with exactly the same purpose as at a supermarket.

There are several reasons why we chose a supermarket as our exemplary case study. First of all, it is a familiar environment. Second, data gathering is relatively easy (e.g. observations). Third, to our knowledge, RFID is not yet implemented at Dutch supermarkets for managing shopping carts, so this is a research opportunity. However, the most important reason is that a supermarket experiences shrinkage, as seen in a news article[17]. The article states that: “the theft of shopping carts costs the supermarkets 5 million euros annually. The Centraal Bureau

[16] Yin (1994) has described five general characteristics in his book (see appendix 2 for an overview) of an exemplary case study. We are of the opinion that most of the characteristics mentioned by the author can be found in this case study.

[17] http://www.distrifood.nl/web/Nieuws/Branchecijfers/Branchecijfers-artikel.htm?contentid=127642 (date: 26/11/2007) [accessed September 2009]

Levensmiddelenhandel (CBL)[18] estimates that 20.000 shopping carts are stolen every year. The theft of a shopping cart is a tedious cost for supermarkets, as they cannot insure themselves against shopping cart theft." This news article was published in 2007, but the problem still exists today (see appendix 3). Even though shopping baskets also vanish at a supermarket (according to distrifood[19]) we ignore them, because these figures are not disclosed on the internet. Also there is a huge difference in purchase price between shopping cart and basket (see appendix 3).

4.2 Case study data

We conducted this case study in 2009 at three Dutch supermarkets (i.e. the retail sector): Albert Heijn, C1000 and Plus Supermarket.. All three are (roughly) of similar size and situated in the same village (population: 25.338). Although the fleet size varies per supermarket, on average 183* shopping carts are available. The shopping cart has a purchase price of €152,50*. This means that on average per supermarket €27.907* is invested in shopping carts. The total amount of shopping carts at supermarkets in the Netherlands is estimated to be 786.900*. Earlier we stated that around 20.000 carts are stolen every year, this translates in an estimated shrinkage of 2.54%* per supermarket. The cycle frequency (i.e. the total number of times one shopping cart is used per day) is estimated to be 10.59*. At a supermarket the customers can pick up a cart from four assembly points[20] (AP) which means that a supermarket has a multi depot network[21]; the customers are allowed to return shopping carts to whichever assembly point (*sources and calculations can be found in appendix 3).

4.3 Process analysis and the generic conceptual model

In paragraph 1.7 we introduced a generic conceptual model which depicts how reusable articles circulate and which problems are experienced. In this section our objective is to identify how the conceptual model is modelled here. There are two reasons for doing this: one to validate our model and, two, to uncover which problems are experienced with the shopping cart. We will first describe the shopping cart process which is the result of our own analysis

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[18] Centraal Bureau Levensmiddelenhandel (CBL) looks after the interest of the supermarkets in the Netherlands. All supermarkets in Holland are affiliated with the CBL.

[19] http://www.distrifood.nl/web/Nieuws/Formules/Formules-artikel-pagina/124193/AH-zet-alarm-in-tegen-diefstal-winkelmand.htm [accessed September 2009]

[20] Assembly point (own term) refers to a designated location where shopping carts can be picked up and returned.

[21] According to Carrasco-Gallego et al. (2012) "in multi-depot systems, is not compulsory for RA to return to the issuing depot"

and observations. Thereafter we will focus on identifying the different concepts of the generic conceptual model.

The shopping cart process is as follows: during opening hours the customer picks up a shopping cart from one of the assembly points which are spread around, near and/or inside a supermarket. All the available carts have locks and these are connected together with chains as an anti-theft measure. In order to uncouple a cart at an AP a temporary deposit (i.e. a coin or a valueless token) is required. Once uncoupled, the customer enters the supermarket where he/she gathers items and when finished, heads towards the checkout counters to pay for all the items. The process ends with the customer returning the empty cart to an AP to recollect the deposit.

We can deduce from the description that a supermarket is the pool manager, because it provides a service and solely invests in shopping carts. The shopping cart is the reusable article, because it will be reused repeatedly at the premises of a supermarket by different users to carry items while shopping (type: returnable transportation items). The customer is the user because he/she picks up the shopping cart for shopping and also is responsible for the return; employees (not at all supermarkets) also use a shopping cart for their work (usually near closing time); though, the shopping cart is not the focus of the customer, as (s)he is only interested in the products sold at the supermarket.

Further analysis of the process as well as observations allows us to identify the types of shrinkage and how it can occur, and to link probable culprits. The following types of shrinkage can be distinguished: theft, damage (e.g. vandalism), misplacement and deterioration. Theft will occur when the customer (before or after shopping) deliberately takes the cart home for indefinite personal use; which sometimes happens at the observed supermarkets. Also miscreants could pilfer large amounts of carts to sell them as scrap. Misplacement will happen when the customer abandons a shopping cart out of sight of a supermarket or temporarily borrows a cart to take items home, while immediate return is intended; which also happens in practice. Also employees could leave a cart at a wrong location when they have completed their work; misplacement could become theft if a cart is not retrieved within a certain time frame, for example, 24 hours. Damage will occur when humans unintentionally or deliberately damage a shopping cart in such a way that it renders it unusable for day-to-day business. Deterioration will inevitably happen because shopping carts are subject to both wear and tear on a daily basis and outside weather conditions; the lifespan of a shopping cart is 10 years indoors, however, outdoor placement and abuse will decrease it to 5 years[22]. While deterioration is partially a result of use, it is difficult to attribute to one particular customer.

We can ascertain that assembly points, the surrounding area[23] of a supermarket, carts themselves and anonymity of the customers can be the cause for shrinkage. We observed that the supermarkets each have four assembly points: located around, in front of and inside (only Albert Heijn). There is no system in place, or employees present inside a supermarket as well as at all the AP to confirm that each uncoupled cart is indeed used and returns. Instead, a supermarket trusts the customers to return the cart immediately after it is emptied, in the same condition it was picked up earlier. Also there is a chance that the customer hands over the cart to another customer instead of returning it to an AP. None of the supermarkets actively checks carts for damages, it relies upon the customers to report faulty carts. This basically means that a supermarket always experiences uncertainty with regard to the (timely) return and quality of the shopping cart. The surrounding area of a supermarket is quite large and currently nothing prevents the customer from leaving with a cart. The shopping carts themselves are not constantly supervised, easy to uncouple (i.e. deposit or brute force) at an AP and their size makes them easy to move around. Anonymity means that the identity of the customer remains unknown to a supermarket, and that theft, misplacement or damage has no repercussions: a supermarket will always carry the financial burden.

During opening hours there is also uncertainty regarding the availability of carts at an AP. The customer is allowed to return the cart to any AP, therefore it is unknown beforehand which AP will have insufficient or an abundance of carts during the day, in other words, an imbalance is to be expected. However, there are planned checks performed at different times throughout the day or initiated by customer complaints. The intent of these checks is to verify if one particular AP has sufficient carts present and to ensure that the AP at the parking lot does not obstruct traffic.

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[22] Quote from ideafinder.com: “Carts kept inside can last up to 10 years. Carts kept outside or carts that are subjected to abuse will only last about five years.” Source: http://www.ideafinder.com/history/inventions/shopcart.htm

[23] This refers to the area (i.e. parking lot) around a supermarket where customers are allowed to walk around with the cart to transfer the items into their means of transportation (e.g. car). Leaving this area is forbidden.

A majority of the AP are dispersed around a supermarket because this is convenient for the customer. While the AP in front of and inside a supermarket are visible from within the store, employees never continuously monitor them. The other AP are beyond the direct visibility of employees and impossible to visually monitor and thus a lack of visibility is experienced; admittedly, only one AP would not pose a problem.

4.4 Shrinkage assessment

The interviewees declared that shopping cart shrinkage barely takes place in their environment (i.e. there is social control in a village) and that is why it is never registered. Since data is missing, no one could provide insight about the occurrence of shrinkage, we take it upon ourselves to assess likelihood. We assume that not all shrinkage occurs equally frequent, the idea is that we become aware of which type of shrinkage is more likely to occur and this will help set priorities. We envisioned one or more probable scenarios for each type of shrinkage and assessed these by logical reasoning and by making use of our observations; the supermarkets take their carts inside when closing down: an effective way to prevent many kinds of shrinkage. For that reason, all scenarios take place during opening hours.

Our assessment shows that, in theory, scenarios 1, 4 and 6 are implausible. Taking away all carts at once requires a lot of manpower which will unquestionably stand out. Employees without question follow orders. A supermarket replaces old shopping carts to prevent customer complaints. The remaining scenarios are more prone to happen because they essentially take place unnoticeably, involve fewer carts and the customers' identity is unknown.

Scenario	Shrinkage	Event	Likelihood
1	Theft	All shopping carts disappear at once	Unlikely, a supermarket will be warned in time by customers. Besides, some AP are visible from within the store.
2	Theft	One or more shopping cart(s) disappear	Very likely, disappearance of a single or a few cart(s) will not be noticed.
3	Damage	One or more cart(s) are destroyed	Likely, carts located outside at a remote AP are not visible from within the store.
4	Misplacement	Shopping carts are misplaced by employees	Unlikely, employees are instructed to return them after use.
5	Misplacement	One or more cart(s) are borrowed by customers	Very likely, temporary absence of a single or a few cart(s) will not be noticed right away.
6	Deterioration	Carts become unusable during shopping	Unlikely, a supermarket replaces old shopping carts as soon as possible.

Table 5: Assessment of six scenarios (own analysis)

We go one step further and attempt to quantify the impact of these six scenarios, to provide a financial perspective of these scenarios; the calculations are not based on actual shrinkage figures, they are fictive to show possible impact.

Examination of table 6 reveals that if a single scenario would take place, a series of financial consequences are to be expected. For example, if scenario 1 would occur, this means that a loss of investment (i.e. carts are gone), a lower turnover (i.e. the customers resort to shopping baskets) and replacement cost (i.e. new carts need to be purchased) are expected simultaneously. What the financial consequences exactly will amount to, depends on the following: the loss of investment and replacement cost are both determined by the unit price and the quantity that disappeared. We assume that the number of customers who visit a supermarket gradually increases as the week progresses and reaches a peak on Friday and Saturday. Also we assume that the number of customers is unevenly distributed during the day: a majority prefers to visit a supermarket in the afternoon, people are less inclined to visit a supermarket in the morning and the evening. This explains why a higher impact on the turnover is expected on a Saturday afternoon than on a Monday morning. The cost for repair or search and retrieval of carts depends on the quantity that require repair and the time a supermarket is willing to invest in finding lost carts.

Scenario	Consequences	Description	Impact
1, 2, 3 and 5	Loss of investment	Irreparably damaged or missing carts will result in a loss of investment.	Loss of investment = (missing carts * purchase price) Example: 40 * €152,50 = €6.100 loss
1, 2, 3, 4, 5 and 6	Lower turnover	The customer uses a shopping basket when carts are unavailable. Due to size difference, fewer items can be carried, hence a lower turnover.	GFK data (date: 22/12/2009)[24] indicates that preliminary receipt value for 2009 for all supermarkets is €21.74. We assume that receipt value for a basket and a cart differs (based on the size), respectively (an average of) €15 and €35 Cart trips per day = unavailable cart(s) * average cycle frequency per cart Turnover shopping cart = cart trips per day * shopping cart receipt value Turnover shopping basket = cart trips per day * shopping basket receipt value Example cart: (50 * 10,59) 530 trips * €35 = €18.550 Example basket: 530 trips * €15 = €7.950 Lower turnover: €10.600 = €18.550 -/- €7.950
1, 2, 3, 5 and 6	Replacement cost	Replacement is necessary in case carts vanish, are irreparably damaged or break down.	Replacement costs = cart quantities * purchase price Example: 40 new carts * €152,50 = €6.100 (discounts and employee costs associated with purchasing carts are excluded)
3	Repair costs	Repairs could make a cart fully functional again.	Total repair costs per cart = third party employee hour rate * repair time + (eventual) material costs of replacement parts[25] Example: (€64,55/ 8 working hours =) €8,07[26] * 2,5 hours + €25 = €45,17 (total repair costs per cart)
4 and 5	Search and transport costs	Missing carts found have to be transported back.	Two options: third party recovers carts or supermarket recovers carts itself. In either case, search and transport costs = employee hourly wage * recollection time + (if carts are at another location) truck rental Example: €8,07 * 4 hours + €105,98[27] = €138,26

Table 6: Shrinkage quantified for different scenarios (fictive shrinkage figures) (own analysis)

[24] GFK publishes key figures about supermarkets. GFK does not differentiate between shopping cart/shopping basket. http://publications.gfk.nl/?view=SupermarktkengetallenActueel.xml&order=descending
[25] Overview of replaceable parts: http://www.alrecar.nl/winkelwagen_service_onderdelen
[26] Minimum wage in the Netherlands (as of 01/07/2009) €64,55 per day for employees at the age of 23 year or above for full employment. http://www.rijksoverheid.nl/onderwerpen/minimumloon/nieuws/2009/06/10/minimumloon-per-1-juli-2009-omhoog.html
[27] Daily rate is €105,98 from: http://www.sixt.nl (2009)

4.5 Discussion and relation to general reusable articles characteristics

In paragraph 3.3 six characteristics of reusable articles are discussed. In this section we will examine if these characteristics are also applicable here.

Reusable articles characteristics	**Supermarket shopping cart**
Users make no distinction between new and reused products	We have observed that the customers picks up any cart, as long as it functions properly.
Simple operations bring used RA into an as-good-as-new state (swift recirculation in the forward supply chain)	Simple repairs are carried out by supermarket employees themselves, complex repairs are carried out by a third party; the fixed carts are then added to the fleet again.
Large quantities of RA are returned; these are used to meet most demand	Shrinkage rarely happens at the observed supermarkets. In addition, the customers immediately return almost all of the shopping carts after use. The same carts are thus present to serve the next wave of customers.
They play an essential role for the business (processes)	If carts are unavailable, customers can use shopping baskets. However, the shopping basket makes it difficult to carry around many items. If no alternative is available, shopping becomes an unpleasant experience. Then carts are indeed essential for the business: no customer wants loads of products in their hands.
Vulnerable to shrinkage	Due to their size, the material (e.g. steel) and lack of constant supervision at an AP, shopping carts are indeed of interest to miscreants.
Primary operational challenge is to balance demand and returns	The cycle time, demand and shrinkage of shopping carts can vary from day-to-day. It is difficult for a supermarket to decide when to buy additional carts. The customer can return the cart to any AP, so throughout the day a supermarket has to be wary of an imbalance and needs to correct this swiftly to satisfy the customers.

Table 7: Shopping carts characteristics assessment (own analysis)

4.6 RFID technology

In the previous sections, we described which types of shrinkage can occur and identified the probable causes as well as potential culprits. We explored the likelihood of different shrinkage scenarios and attempted to quantify these scenarios to understand the financial consequences. In this section we discuss the theoretical application of RFID to address the management issues identified by Carrasco-Gallego et al. (2012).

This section is organized as follows: we first propose potential RFID options and elaborate on them. Next, we will compare RFID and manual data gathering. In paragraph 5.6.3 we look at how RFID can address the management issues. Thereafter, in paragraph 5.6.4 and 5.6.4.1 we will look into the costs of the proposed RFID options. Finally, in paragraph 5.6.4.2 we determine if the investment is profitable.

4.6.1 RFID options

The application of RFID technology implies that objects with RFID tags will be tracked and readers and antennas will be set up at one or several locations to read them. In this case all of the shopping carts will be suited with tags, because they will provide a supermarket with relevant data (see paragraph 5.6.2). In order to find eligible reader and antenna locations, we observed cart use and overall mobility of the shopping carts at a supermarket (see figure 10).

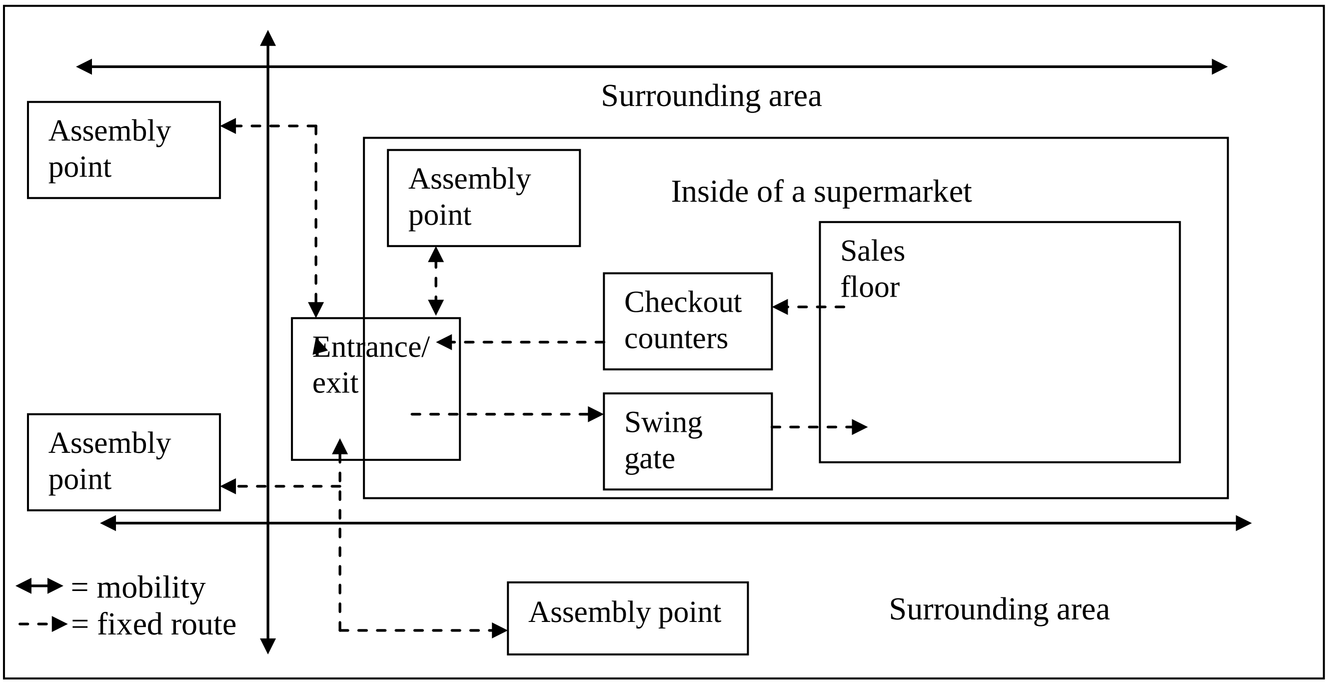

Figure 10: fixed shopping cart route and mobility (own development)

In figure 10 the fixed route and the mobility of the shopping cart are illustrated. The fixed route indicates how the customer travels with the shopping cart. The mobility indicates the potential cart movement at the surrounding area. Also the potential locations are visible where carts can be spotted, which are: assembly points, the entrance/exit, swing gate, sales floor, checkout counters and the surrounding area.

In order to propose the right RFID options we refer back to paragraph 5.3 where we explained what could stimulate shrinkage: no supervision at AP, the surrounding area, the carts themselves and anonymity of the customer. It would be in the benefit of a supermarket if assembly points could be monitored from a distance, carts do not leave unnoticed, individual carts could be tracked and to identify culprits. Nowadays people can obtain customer cards this means that coupling identity with a cart is viable, though it is unclear whether people will accept this (i.e. privacy concerns). Based on our earlier findings as well as figure 10 we put forward two options: complete coverage and customer card coupling (see figure 11).

Option 1: complete coverage

In case the customer prefers to remain anonymous, accountability is out of the question. At the assembly points, entrance/exit and the surrounding areas fixed readers will be installed. The shopping cart process begins and ends at the assembly points, thus readers should be present here. At the surrounding area a huge quantity of readers is necessary because readers have a read range and thus can only cover a certain area. All the readers together create an invisible border to monitor unauthorized use. At the entrance/exit the reader acts as a checkpoint: a confirmation that a cart is indeed used inside a supermarket as well as to signify that a cart will soon appear at an assembly point.

Option 2: couple customer card with shopping cart

In case customers accept this coupling, a minimum amount of readers are required, because accountability is now possible. For this option the setup of readers is similar to option 1, though, readers are absent at the surrounding area.

In both options swing gate, sales floor and checkout counters are neglected. The swing gate prevents customers from leaving with full carts once inside. The inside of a supermarket is an enclosed environment and employees are always present. This means that misplacement or vandalism is immediately noticed and theft cannot occur. Also, checkout counters are always manned. Therefore readers serve no real purpose at these three locations for monitoring carts; unless a supermarket is interested in analyzing, for example, customer behavior.

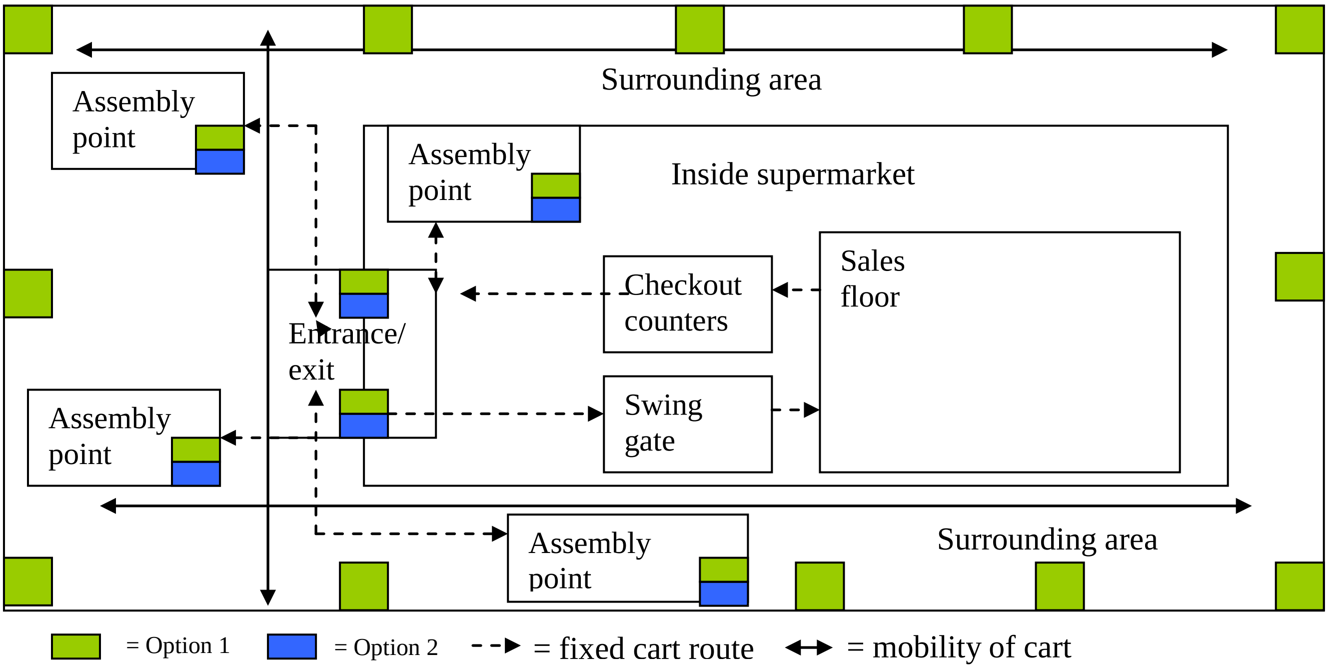

Figure 11: Two RFID options for a supermarket (own development)

4.6.2 Data gathering: RFID versus manual

In the previous section we put forward two RFID options. In practice a supermarket has the choice to either implement RFID or to have employees monitor carts and manually register data. Because both options are feasible, a comparison allows us to objectively assess in which way RFID technology differs.

In table 8 we present an overview of the data that could become available at the four locations. This overview reveals that almost exactly the same data can be collected, except for the surrounding area. At this area employees can visually distinguish shrinkage, which RFID is unable to do. Furthermore, we can also affirm that for both methods of data registry, visibility is possible. Though, the manual approach has several drawbacks. It is somewhat tedious work, so it might be difficult to find enthusiastic employees in the first place. If employees agree, it asks of them to remain focused. Since people in general have an aversion to doing repetitive work, it is error prone. It could also be potentially dangerous, because of weather conditions (i.e. thunderstorms, excessive rain or heat waves) or dealing with aggressive customers. Also during certain periods (e.g. Christmas) employees might struggle to keep a good overview and to register data without making errors. Though, the biggest concern is a lag in updates. If data is noted on paper it will take some time (e.g. an hour, or worse, perhaps a few days might pass) to have data available for review.

Location	Employees (manual/visual registry)	RFID option 1	RFID option 2
Assembly point (AP)	Manually assign a number to each individual assembly point and shopping cart. This enables unique identification of AP and cart. - available quantity unique carts - date/time of check out/check in of unique cart at unique AP - customer data	- available quantity unique carts - date/time check out of unique cart at unique AP - date/time check in of unique cart at unique AP	- available quantity unique carts - date/time check out of unique cart at unique AP - date/time check in of unique cart at unique AP - customer data
Entrance (in case of multiple entrances)	- date/time passage of unique cart at (unique) entrance - customer data	- date/time passage of unique cart at (unique) entrance	- date/time passage of unique cart at (unique) entrance - customer data
Exit (in case of multiple exits)	- date/time passage of unique cart at (unique) exit - customer data	- date/time passage of unique cart at (unique) exit	- date/time passage of unique cart at (unique) exit - customer data
Surrounding area	- type of shrinkage - where (which area of surrounding area) - when (date/time) - quantity of carts affected - customer data	- date/time unique cart leaving at unique location	No data available

Table 8: Overview of data registry employees versus RFID (own analysis)

Earlier we mentioned briefly that there is a difference in the time it takes to have registered data available. In order to provide insight into this difference we estimate the durations (table 9) for the activities associated with monitoring shopping carts. **Note:** a majority of the activities are never performed in practice by employees. Though, transfer of carts and AP sufficiency check do take place in practice and employees provided us with durations. For the other activities we assume that employees perform these diligently during a calm weekday; a busy week is likely to affect the durations. For RFID we found that Gen 2 readers are able to read less than 600 tags per second[28] and we used this information to estimate durations.

Activity	Employees	RFID
Counting carts	≈ 1.5 minutes (per AP)	≈ 1 second (per AP)
Check out cart	≈ 30 seconds (per cart)	≈ 1 second (per cart)
Check in cart	≈ 30 seconds (per cart)	≈ 1 second (per cart)
Customer data registry	≈ 2 minutes	≈ 2 minutes to manually register customer data and print out card. Thereafter ≈ 1 second to read card.
Cart entrance check	≈ 10 seconds (per cart)	≈ 1 second (per cart)
Cart exit check	≈ 10 seconds (per cart)	≈ 1 second (per cart)
Detecting carts leaving surrounding area + data registry	≈ 5 seconds (visual detection) ≈ 40 seconds data registry (per cart)	≈ 1 second (per cart)
Transfer of carts	≈ 10 minutes (requires 2 employees)	Impossible
Quality check cart	≈ 25 seconds per cart	Impossible
Assembly point sufficiency check	≈ 5 minutes	≈ 1 second (per AP)
Data availability	≈ 1 hour	≈ 3 minutes

Table 9: Estimated durations for different activities employees versus RFID (own analysis)

A comparison between employees and RFID divulges that there is a significant difference with regard to data availability, respectively around 1 hour versus about 3 minutes. This is not surprising: employees need to take their time to minimize mistakes. With RFID all data capturing is automated and takes several minutes because of wireless transfer and middleware data filtering and modification. Based on the speed at which RFID generates visibility of the shopping carts, this suggests that it is the preferred choice; even though employees are still required to print out RFID cards and distinguish shrinkage. However, such a conclusion is premature, because we still have not looked into addressing the management issues and the implementation costs.

[28] In slow mode Gen 2 readers can read less than 600 tags per second. Since there are in general 183 carts available at a supermarket, it takes about 1 second to detect carts. Source: http://www.skyrfid.com/RFID_Gen_2_What_is_it.php

4.6.3 RFID: addressing management issues

In this section we discuss how RFID can solve the management issues identified by Carrasco-Gallego et al. (2012). In paragraph 5.6.2 we already showed which data can be captured at four locations. Here we use fictive RFID data (see table 10) of one completed shopping cart trip for RFID option 1: the anonymous customer (i.e. AP pick up, entrance, exit, AP return and surrounding area) and RFID option 2: the identity of customer is known (i.e. AP pick up, entrance, exit and AP return).

First we look into which information can be derived from table 10. Thereafter we examine how RFID can solve the management issues.

AP pick up	**Entrance**	**Exit**	**AP return**	**Surrounding area**
Assembly point: 1 (front of store)	Entrance: 1 (right side)	Exit: 2 (left side)	Assembly point: 3 (parking lot)	Reader zone: 1
Available quantities: 25			Available quantities: 80	
Cart: 101	Cart: 101	Cart: 101	Cart: 101	Cart: 101
Date: 05-07-2009	Date: 05-07-2009	Date: 05-07-2009	Date: 05-07-2009	Date: 05-07-2009
Check out time stamp: 10:05 am	Entrance time stamp: 10:08 am	Exit time stamp: 10:28 am	Check in time stamp: 10:34 am	Zone 1 time stamp: 10:10 am
Name: Mr. John Doe	Name: Mr. John Doe	Name: Mr. John Doe	Name: Mr. John Doe	

Table 10: Fictive data registry of one shopping cart trip captured with RFID (own analysis)

At first glance it seems as if the data has little value and is meaningless, perhaps because the data captured at different locations looks very similar; such an observation is therefore understandable. However, one has to look further since there is more than meets the eye. Whilst some of the gathered data can immediately be used, in some cases (to make sense of the data) certain operations need to be performed (e.g. combine with other data) so that new data can emerge. The following information can be derived from table 10 (see table 11).

Information	Explanation	RFID data required
Assembly point imbalance (option 1 and 2)	The distribution of shopping carts over all the assembly points for a certain time period (e.g. one business hour).	Available quantities at assembly points.
Available carts (option 1 and 2)	The total number of shopping carts available at the assembly points for a time period (e.g. one business hour).	The sum of available quantities at assembly points.
Shopping cart cycle time (option 1 and 2)	The actual time of an individual shopping cart to return to a specific AP after pick up, at a specific date.	Check in time and check out time need to be subtracted. Example: 10:34 am -/- 10:05 am = 29 minutes
Demand (option 1 and 2)	The number of shopping carts that are in use (only check out) within a particular time period (i.e. one hour, quarter of an hour, half hour).	Check out time, Entrance time (to discern actual use from theft)
Accountability (only RFID option 2)	The identification of the right culprit responsible for theft, damage or misplacement.	Identity of the customer
Shopping cart useful life (option 1 and 2)	The gradual adaptation of the shopping cart lifespan based on captured data resulting in an actual remaining useful life.	Cycle time, Assembly point (i.e. duration of outside/inside placement), frequency of shopping cart use (check out time stamp indicates frequency)
Shrinkage (option 1 and 2)	A collection of all types of shrinkage including at which date and time and how frequent it occurred.	Identity of customer (RFID option 2), Check out time, Entrance time, Exit time , Check in time and Surrounding area.

Table 11: Information extracted from RFID data for RFID option 1 and 2 (own analysis)

On the basis of the information in table 11 we examine how RFID can solve the following management issues: define fleet size dimension, control and prevent shrinkage, define purchase policies and cost allocation.

1) Define the fleet size dimension

At start-up a supermarket acquires a fleet of shopping carts, with no prior knowledge of demand and cycle times. With very little data around to analyze at present, it is difficult to determine when to accurately refine the current fleet size. However, the observed supermarkets have sufficient carts around for the whole year, so they can cope with an increase in demand. Though, imbalance needs to be corrected regularly.

In order to verify if the initial fleet size is adequate, a supermarket can use a key performance indicator[29] (KPI). A KPI helps assess if a certain goal is achieved. For example, a goal in this case could be: to provide the customers a pleasant shopping experience all year round (which means sufficient carts should always be present at AP). A feasible KPI could be “spare shopping carts” which we define as: the number of carts available at the assembly points at a certain point in time minus the carts used inside a supermarket during that corresponding point in time. A supermarket must then set a target, for example: at any given time, minimal 20 spare carts in total must be available at the AP (to cope with a sudden change in cycle time and/or demand). To measure if the goal is achieved: shopping cart check out times and entrance times are to be used (as long as carts do not check in, they are unavailable for other customers).

According to Carrasco-Gallego et al. (2012) the fleet size is dependent on both cycle time and demand. A change in either one or both simultaneously, for whatever reason, necessitates an adjustment (i.e. reduction/expansion) of the fleet size. Since both can be derived from accumulated data, a supermarket can analyse them individually. Also both are dynamic, thus the data needs to be monitored constantly to see how both gradually evolve over time. This is possible because data becomes available during opening hours on all days of the week and in the weekend. By plotting the cycle times and demand in a graph (i.e. visualisation) as soon as data is available it is easier to see how both develop. If a supermarket notices that spare carts are below or constantly above the example value of 20 carts, it is an indication that the fleet size needs to be refined in such a way that 20 spare carts are available again. Thereafter, a supermarket needs to continue analyzing the same RFID data to verify that expansion of the fleet was indeed accurate.

At all times a supermarket needs to understand these changes. A management action could be to always initiate an investigation when changes are discovered to clarify the increase/decrease. In addition it needs to be established if this change is structural (e.g. population growth/decline, competitors closing down, new competitors etc.) or temporary

[29] The key performance indicator was developed by D. Ronald Daniel in 1961.

(e.g. holidays, sales etc.); this could require a supermarket to look beyond RFID data and consult external data sources to further explain findings. Since all amassed data is stored, historical analysis can also be performed: this helps a supermarket discover seasonality and to come across patterns which were not noticeable earlier; using RFID data to predict future cycle time and demand is an option but is not recommended because it is too whimsical. However, to pinpoint seasonality a vast amount of data (i.e. year) is required because it is not immediately clear from a limited amount of data spanning, for example, only one month. If it is ascertained what kind of change has occurred, a supermarket can then act accordingly, decrease or increase the fleet size with the number of carts required to cope with observed cycle times and demand. As RFID data keeps pouring in a supermarket can verify if the changes to the fleet were indeed correct or that it needs correction. This needs to be done every time a fleet has been refined.

Another management action could be to search for cost effective solutions if a fleet size frequently needs to be expanded due to, for example, an increase in cycle time. Instead of purchasing new carts, a supermarket can experiment on how to reduce cycle times by relocating AP or even minimize AP. The success of a solution can be measured in a short period of time, because data rapidly becomes available. Since available carts at assembly points are also known, assembly point imbalance can be solved as soon as it is detected instead of discovering it too late; the distance to be cleared by the customer to pick up a cart could increase cycle time.

2) Control and prevent fleet shrinkage

At the moment, a supermarket has little to no data available regarding shrinkage, therefore it is unknown which measures are necessary to control and prevent it. There is not much shrinkage noticeable at the observed supermarkets, sometimes theft occurs and after some time carts that were taken away do return.

Also for this issue a KPI can be established. The goal is still the same: to provide the customers a pleasant shopping experience all year round (which means sufficient carts should always be present at AP). A feasible KPI is “return rate” which we define as: the number of carts that return to an assembly point after checking out, excluding carts that have deteriorated. The way to measure this KPI is to use: check out time (i.e. no carts that check in, means that the fleet will shrink), deteriorated carts (check out time + deteriorate date), date of check out. Target: cart returns should be 100% (at the end of the day the same fleet size is available).

First of all, simply the knowledge that shopping carts are tracked with RFID could scare off many miscreants, but some will never be discouraged. In the case of theft, misplacement and damage, as long as readers read RFID tags at assembly points as well as at the entrance/exit at a supermarket, this confirms that not theft, neither misplacement nor damage (i.e. no one wants to use a damaged cart) has happened. For RFID option 1, the readers at the surrounding area will constantly screen for unauthorized use and could timely inform employees where exactly the cart(s) leave the premises (i.e. indication of theft). Only RFID option 2 will reveal who is actually responsible, for example: Mr John Doe. RFID itself does not protect a shopping cart from vandalism however RFID data can reveal which shopping carts never check out. Employees now are aware at which assembly point they have to look for potentially unusable carts. In case of misplacement RFID data can help shorten the time a shopping cart is temporary lost. It can disclose at which assembly point the lost cart last checked out and readers in the surrounding area can help locate it. RFID cannot prevent deterioration as it is unavoidable: shopping carts have a certain lifespan. The purchase date of all shopping carts can be registered and the useful life can automatically be adjusted by using detailed RFID data: where (e.g. inside/outside AP) and how long carts reside there, cycle times, frequency of use. It is then known how much time is actually left before individual carts reach the end of their useful life, timely replacement is possible. In addition, from the same data is revealed when exactly carts should undergo a quality check. Employees play an essential role in recognizing and registering shrinkage because RFID cannot do this. It is imperative that employees register which type of shrinkage happened (i.e. misplacement, damage, theft and deterioration), which cart is affected and when it happened. Only then a complete insight into shrinkage is possible.

If from the KPI return rate is found that a certain quantity of carts has disappeared, a management action could be to start an investigation; this applies to RFID option 1 and 2 (in option 2 the culprit is known: Mr. John Doe). Since of every type of shrinkage data is available, this investigation will expose where (e.g. AP or other location), when (i.e. date and time), and how frequent certain types of shrinkage has taken place, thus weaknesses are identified. It will help to think of measures and prioritize them that can limit and control shrinkage, for example: assembly point relocation, placement of cameras, sealing off surrounding area, removing assembly points, purchase other types of carts that are more durable and less of interest to miscreants etc. After the measures have been implemented, new RFID data needs to be closely monitored to observe if the desired effect is achieved. This needs to be repeated every time new measures are implemented.

3) Define purchase policies for new articles
Eventually changes in shrinkage, cycle time or demand of shopping carts will occur that necessitate a correction of the fleet size. With no data to analyse, it is difficult to formulate purchase policies to decide which quantities and when exactly to purchase new shopping carts. At the observed supermarkets there is not really a purchase policy for shopping carts: if new ones have to be bought it is because either carts have been damaged or the current fleet size is not sufficient anymore, which rarely happens.

With RFID a supermarket has insight into individual cycle times, demand and shrinkage of the shopping carts. Because RFID data gradually becomes available, it allows a supermarket to see how all evolve over time (i.e. hour, day, week or months) and with enough data a whole year can be reviewed. It is sensible to analyze all of the aforementioned data together, because analyzing, for example, shrinkage independently is not enough to conclude that the current fleet size is adequate for the time being. Also cycle times and demand need to be analyzed to see how these have evolved pertaining to shrinkage.

Since actual data is available, appropriate purchase policies can be formulated. For example, a purchase policy for new shopping carts: if cycle time or demand change for a consecutive number of days, and shrinkage remains stable the whole time, and it is confirmed that this change is structural and no measures can be implemented on the short term to decrease cycle times or demand so that the current fleet is still sufficient, only then new carts are to be purchased. This hypothetical policy enforces a supermarket to first consider and verify a number of things before proceeding to actually purchasing new shopping carts. Such a policy is intended to impede unnecessary expenditures.

All in all, RFID data helps with establishing purchase policies for all potential scenarios relating to changes in cycle time, demand and shrinkage of shopping carts. The data also allows a supermarket to buy the right amount of carts at the right time, and to review and rephrase earlier formulated purchase policies.

4) Accurate cost allocation (own issue, derived from issue 2):
At the moment customers are allowed to remain anonymous when using shopping carts, so in case theft, damage or misplacement happens it is impossible to hold the right culprit accountable; deterioration is difficult to attribute to one specific customer. The interviewees at the supermarkets never mentioned anything about cost allocations in the event of shrinkage.

With RFID option 2 this issue is easy to solve, because it is compulsory for the customer to register their personal details and couple their identity with cart pick up. The customer's identity remains coupled with an individual shopping cart until it checks in at an AP. If shrinkage occurs, RFID data serves as proof to request reimbursement. However, if the customers prefer to remain anonymous, it is difficult to solve with RFID option 1. The customer still cannot be held liable. However, the amount of readers could limit theft, damage and misplacement in such a way that cost allocations might not even be necessary.

4.6.4 RFID investment

In this section we will examine the investment costs for RFID options 1 and 2. We found it a difficult task to provide an accurate total costs description, for two reasons. First, to our knowledge, RFID has not yet been implemented at a supermarket for tracking shopping carts so there are no examples. Second, the initial RFID investment is made up of both constant (e.g. tags, readers) and variable (e.g. research, pilots) costs. The latter cost element complicates matters the most as these are difficult to estimate, unlike the constant costs.

We will use the article entitled "Scoping out the real costs of RFID" by Shutzberg (2004) to present a complete and accurate overview of the initial investment in RFID (see table 12). Shutzberg (2004) explains the different costs for implementing RFID and therefore the article serves as the basis for our cost calculation. The parts we will use are adjusted to our case and since the financial figures stated in the article are dated we merely use them as indicators. Our solution is to search on the internet to find more recent prices.

We have a number of assumptions that influence the cost calculation, which are briefly explained. In practice, a supermarket already has some IT infrastructure (e.g. computers for scanning barcodes and customer loyalty cards and communications with head office). However, for the sake of simplicity, we assume that RFID is set up from scratch. Furthermore, we assume that a supermarket is the sole user of RFID data and that it is irrelevant to third parties. And, we assume that no research and development will be performed during the useful life of the RFID system.

4.6.4.1 Components

In this section we will elaborate on the different components that need to be acquired for the RFID implementation.

Tags

The tags on shopping carts should be able to withstand harsh weather conditions (i.e. outside placement) as well as frequent use and rough handling. The tag of choice is a passive UHF RFID tags (i.e. UHF tags work well around metal and have a customizable read range[30]). We found tags which are more or less suited for shopping carts and are available in a bundle of 1000. Only option 2 necessitates RFID badges. However, it is unknown how many customers a supermarket serves, so it is difficult to buy a fixed number of badges. A solution is to purchase ID card printers to print out these badges, two are necessary in case there are too many customers requesting a badge. Note: first manual data entry of customers' details is required before badges can be printed, this will take some time and effort.

Readers

UHF readers are required to communicate on the same frequency with UHF tags. Due to outside placement, readers should be able to also withstand harsh weather conditions. In and around a supermarket fixed readers will be placed at the following locations: assembly points, entrance/exit and the surrounding area (a UHF reader has a read range of 15 meters[31]). Also, handheld readers (four in total, to have more employees search at the same time) are necessary in the event carts need to be identified in an area where fixed readers are not present.

[30] Introduction to UHF tags: http://www.vizinexrfid.com/uhf-tags/934/
[31] http://www.1888pressrelease.com/long-range-uhf-rfid-reader-dl910-offers-read-range-from-8m-t-pr-89301.html

Middleware

Middleware is necessary to filter captured data and to forward the right data to enterprise applications (RFID Journal, 200-[32]). The exact costs cannot be determined as it depends on the scope of the project and vendor. We found several estimates. According to Shutzberg (2004) costs are "as little as $25,000 for a small operation". In 2006[33] Nurminen mentioned the price tag of middleware to be "as little as $5.000 to $20.000"; with the passage of two years, a decline in cost is noticeable. Assuming that the price has dropped even further these past few years, we assume the costs to be about $4000. Middleware is software and thus needs hardware in the form of edge servers (i.e. basic computer servers).

Enterprise applications

Also software is essential to utilize the captured data (received from middleware) and which a supermarket will use for decision making. As the focus is on asset management, there is a need for asset management software (license for 5 users) because there are two users appointed at a supermarket. We assume that at a supermarket two users are appointed for carrying out the management tasks, thus two desktop computers are necessary on which the software is installed.

Consultancy

Beforehand there will be talks with consultants about technical specifications, etc; basically, the whole project will be discussed in detail before the implementation of RFID, and after (e.g. discussing results of pilot etc.). According to a consultancy firm, it takes about 2 weeks to setup a pilot and 12 weeks (if project is complex, it could take longer) for a full RFID implementation. We assume that experienced (senior level) consultants will be on site. The hourly wage for an IT-consultant with 10 to 19 years of experience is $80,36. Duration for the implementation is 12 weeks. We assume for this scale two consultants suffice. Calculation: 40 hours per week * $80,36 (hourly wage) = $3214,40 * 12 weeks = $38572,80

Training and change management

Employees have to get acquainted with RFID technology. We assume that they need a basic training to have general knowledge of RFID technology. More intensive training is meant for the employees responsible for the maintenance of the RFID system.

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[32] http://www.rfidjournal.com/article/glossary/3
[33] http://www.rfidjournal.com/article/articleview/2035/1/128/

4.6.4.2 Initial investment

The initial investment costs are displayed in table 12. The basis for the cost descriptions is figure 11 (overview of the RFID readers for both RFID options) as well as the previous paragraph.

Hardware	Price	Quantity	RFID option 1	RFID option 2
UHF Tags	$590	(only sold per 1000)	$590	$590
ID card printer	$3.516	2 (option 2)		$7.032
UHF Fixed readers	$2.478,35	18 (option 1)	$42.131,95	
(integrated antenna)		6 (option 2)		$12.391,75
Handheld readers	$2.499	4	$9.996	$9.996
Server	$1.295	1	$1.295	$1.295
Desktop computer	$679,97	2	$1.359,94	$1.359,94
Software				
Asset tracking software	$9.150	1	$9.150	$9.150
Middleware	$4.000	1	$4.000	$4.000
Additional cost				
Consulting & implementation	$38.572,80	1	$38.572,80	$38.572,80
Training	$3.990	1	$3.990	$3.990
		Initial investment	**$111.085,69**	**$88.377,49**
		Euro[34] conversion	**€74.974,81**	**€59.648,42**

Table 12: Total initial investment for RFID option 1 and 2 (see appendix 4 for sources) (own analysis and Shutzberg (2004))

4.6.4.3 Payback period

To assess the profitability of the investments (see table 12) we will use a financial metric called the payback period. By calculating the payback period we will know how long (in years) it will take to earn the investment back. Generally speaking, it is assumed that the longer the payback period, the less attractive an investment becomes as there are more risks involved.

In a research by Bolte et al. (2008) it is mentioned that RFID readers have a useful life of 3 years. We therefore assume that when readers are replaced, at the same time the other

[34] http://www.x-rates.com/d/USD/EUR/hist20009.html (1.48164 USD for 1 Eur)

components (i.e. computer, tags, mobile readers, asset tracking software, ID card printer, middleware and server) are replaced. This means that within 3 years the initial investment needs to be earned back. After this period RFID has no more economic life and a supermarket again has to make an investment to replace all the depreciated components.

In order to calculate the estimated benefits for RFID option 1 and 2, our approach is to review table 5 and pick scenario 2, 3 and 5; these are prone to happen, not the other scenarios. Then we looked at table 6 to determine what the consequences of these scenarios are to quantify the estimated benefits. While we calculated that 2.54% theft occurs, it is unknown what the amount of damage and misplacement is. The interviewees stated that shrinkage data is not registered, but they all did provide an estimate. The highest value was 15, which we opted to use. We then assumed that RFID option 1 will prevent shrinkage for 80% and RFID option 2 for 100%; identity coupling will deter shrinkage for good, while anonymity does not. The value of 15 is distributed equally over the shrinkage types associated with scenario 2, 3 and 5 and we applied the earlier mentioned rates (see table 13). According to Shutzberg (2004) the recurring cost for RFID components maintenance is about 15 - 20% of the acquisition costs. However, we assumed 15% for all the components (see table 14).

Shrinkage	**RFID option 1**	**RFID option 2**
Theft	€2.702,60	€3.378,25
Damage	€2.175,28	€3.378,25
Misplacement	€1.596,65	€1.967,30
Total benefits	**€6.474,53**	**€8.723,80**

Table 13: Yearly benefits for RFID option 1 and 2 (calculations in appendix 5)

Components	Acquisition costs	RFID option 1 Recurring cost	RFID option 2 Recurring cost
Tags	$590	$88,50	$88,50
ID card printer	$7.032	$0	$1.054,80
Fixed readers	$42.131,95 (option 1) $12.391,75 (option 2)	$6.319,79	$1.858,76
Handheld readers	$9.996	$1.499,40	$1.499,40
Server	$1.295	$194,25	$194,25
Desktop computer	$1.359,94	$203,99	$203,99
Asset tracking software	$9.150	$1.372,50	$1.372,50
Middleware	$ 4.000	$600	$600
	Total yearly recurring cost	$10.278,43	$6.872,20
	Euro conversion	€6.937,19	€4.638,23

Table 14: Yearly recurring cost (15%[35] of acquisition cost, we assumed the lowest percentage) for RFID option 1 and 2 (own analysis and Shutzberg (2004))

	RFID Option 1	RFID Option 2
Yearly benefits	€6.474,53	€8.723,80
Yearly recurring costs	€6.937,19	€4.638,23
Annual cash inflow **(Yearly benefits -/- Yearly recurring cost)**	-€462,66	€4.085,57
Initial investment	€74.974,81	€59.648,42
Annual cash inflow	-€462,66	€4.085,57
Payback period in years **(Investment/Annual cash inflow)**	-162,05	14,5

Table 15: Payback period calculation for RFID option 1 and 2 (own analysis)

The payback period for option 1 is negative (see table 15), this is because the yearly recurring costs are higher than the yearly benefits, in other words, each year more money is spend than is saved. If we have to base our investment decision on the calculation in table 15, it is not sensible because the investment is simply never earned back. On the other hand, RFID option 2 has a positive payback period of 14.5 years, because the yearly benefits are higher than the yearly recurring costs. However, the useful life of the entire investment is 3 years, but the payback period of option 2 is much higher. Also in this case it is not sensible to initiate option 2 because it takes too long to earn the investment back. Besides, as said earlier, a long payback period is not preferred as there are more risks involved.

[35] http://www.informationweek.com/news/51201525?pgno=2

We are of the opinion that there is a medium uncertainty with respect to the outcome of all the calculations. The reason why we proclaim this is that we, first of all, used an article that discusses RFID implementation costs and components. Second, instead of using the data from that article (dated 2004) we searched for recent prices on the internet; we used these prices in our calculations. Third, to determine if the RFID investment is profitable we used data gathered ourselves to estimate probable shrinkage figures. Even though we used recent prices and have estimated shrinkage figures available, there are still a lot of factors that makes it difficult to present an accurate cost calculation and profitability assessment. However, we consider the aforementioned calculations to be a good indicator of a potential application in practice. All of the aforementioned also applies to both generic case studies.

4.7 Conclusion

RFID technology is indeed viable for the shopping carts and valuable for a supermarket. This technology provides a supermarket with data that makes shopping cart use visible and provides more control over them. However, RFID only becomes valuable if collected data is analyzed and transformed into information for making informed decisions. It can also help with the assessment of decisions, since the effects are visible within a short period of time. Though, when RFID is compared to employees with respect to data collecting, there is minimal difference: both provide a supermarket with almost the same data and visibility is also achieved. The real difference lies in the speed at which data becomes available (it is time consuming for employees) and the likelihood of errors when data is collected manually. The data RFID cannot generate by itself is which type of shrinkage occurred, so there is still a role for the employees.

Furthermore, we found that management of shopping carts is not a simple task. The management issues identified by Carrasco-Gallego et al. (2012) are also experienced here. In particular theft (i.e. prevent fleet shrinkage) and imbalance (i.e. defining the fleet size dimension) are an issue whereas purchase policies and cost allocations are less of an issue. However, theft is not common at the observed supermarkets, but imbalance is experienced on a daily basis. With RFID the imbalance at the assembly points will be immediately visible, though it still requires some effort to solve it; thus, the multi depot network becomes easier to handle. RFID cannot prevent all types of shrinkage at a supermarket, only severely limit it: deterioration is expected and some miscreants can never be discouraged. A way to make

RFID technology more effective with regard to theft, misplacement and damage is to require the users to identify themselves, with for example a customer loyalty card. The customers at a supermarket can refuse identification therefore it is a legitimate issue, which may not be a problem in other cases.

We also found that the characteristics of reusable articles discussed in paragraph 3.3 are also applicable here. This confirms what Carrasco-Gallego et al, (2012) & McKerrow,(1996); Twede, (1999); Witt, (2000) cited in Johansson & Hellström, 2007, assert about reusable articles. This means that the insights from this case study are also applicable to other reusable articles. In addition, we established that our generic conceptual model is also valid. In other words, what is illustrated in our model concerning the use of reusable articles in theory is confirmed in practice.

At the moment the proposed RFID options are not profitable, because the recurring costs are simply higher than the expected benefits and it takes too long to earn the investment back. Since a large area needs to be covered at a supermarket, there are options regarding the placement of readers (i.e. beforehand a supermarket has to ponder where to place readers and how many to use, this influences the total investment). In the costs calculations the readers contribute more to the total costs than the tags. As for software, training and implementation costs this really depends on the application and the scale.

Generally speaking we can state on the basis of our calculations that the application of RFID will become profitable if:
- There are more reusable articles circulating with an equal number of readers.
- The purchase price of individual reusable articles is higher
- The administration of an individual reusable article after a full circulation requires a lot of time
- There are high costs involved with stocktaking (i.e. determining where reusable articles are and counting if all carts are available)
- The reusable articles in question experience high shrinkage percentages

5 Generic case study: Gas cylinders in a multinational chemical company (MedGas)

This generic case study was conducted by Carrasco-Gallego et al. (2012) for their research. We chose this case study because it concerns returnable packaging materials (RPM) and our goal is to research different types of reusable articles.

5.1 Introduction

The subject of their case study is the Spanish subsidiary (MedGas) of a multinational company which produces and distributes medical and industrial gases (i.e. chemical industry sector). These gases can be transported to the customers via pipelines, cryogenic tank trucks or cylinders. The focus at this subsidiary is on the compact cylinders which contain medical oxygen intended for healthcare.

MedGas delivers these compact cylinders either directly to customers (e.g. hospitals) or to an intermediate distributor who in turn distributes these cylinders to the customers. At the moment MedGas can manage the removal of cylinders from the fleet which are in a poor state. However, there is a lack of control over cylinder losses at the customers as well as the distributor as it is not known where and when it happens. To guarantee that shrinkage is kept to a minimum, MedGas employs two policies: a full-for-empty swapping rule and to register in an information system the number of cylinders delivered and received from each customer. The data in this information system is then used to calculate a daily fee which depends on the amount of cylinders present every day at the respective customer’s location. However, from this data MedGas still cannot see how many are lost at the customers or distributors. Sometimes these policies are neglected, because customers who use large amounts of medical oxygen rather not pay rentals. For such customers, more losses and an increase in cycle time of cylinders has been experienced. Even with the policies in place, MedGas simply experiences uncertainty about when compact cylinders will return, which quantities will return and in what condition they will return. This means that with an uncertain return of empty cylinders it is complicated to meet demand of medical oxygen. Their solution is to have large quantities of spare cylinders on hand.

5.2 Case study data

The compact cylinders have an individual price of roughly €100. It is estimated that around 20.000 pieces are owned by MedGas for strictly serving their customers in Spain. In total the company has invested approximately €2 million in these cylinders alone. Shrinkage (i.e. theft, damage, deterioration or misplacement) values are not mentioned. Also cycle times are absent in the case study. The supply chain partners are the customers (consumers of oxygen and temporarily store them) and the intermediate distributors (distribute cylinders for MedGas and temporarily store them). The compact cylinders circulate in a star network[36]: empty gas cylinders are picked up when full ones are delivered (i.e. full-for-empty swapping policy) and can only return to the same filling plant.

5.3 Process analysis and the generic conceptual model

In this section we will first describe the compact cylinder process and then identify our generic conceptual model.

The cylinder process is as follows: the customer places an order at MedGas. The cylinders are then gathered: usually the amount to be shipped depends on the number of empty cylinders that will be given in return by the customer. Next, the cylinders are delivered to the customer, either directly or via an intermediate distributor. This all depends on the importance of the customer and distance from the filling plant. Upon delivery of full cylinders at the same time empty ones are picked up from the customer. The return is carried out by the same actor (i.e. MedGas or intermediate distributor) who delivered the full cylinders. The process ends with the receipt of empty compact cylinders at the filling plant.

It is clear from the description that MedGas is the pool manager. The company is the supplier of medical oxygen and to sell it invests in cylinders. The compact gas cylinder is the reusable article as it will be reused repeatedly at the premises of (many) different customers. The customer is the user as (s)he consumes (and the only interest is in) the gas and the empty cylinders are temporarily in storage at their premises; (s)he is never responsible for the actual return, nor interested in keeping the cylinder at all.

[36] According to Carrasco-Gallego et al. (2012) in star systems, RA return to the same location from where they were issued

The types of shrinkage associated with cylinders are difficult to draw from the process description. In the introduction it is stated that cylinders in poor condition (i.e. deterioration) are removed from the fleet. The term “losses” is used by the authors instead of differentiating shrinkage; as earlier said MedGas has little control over cylinders lost at the customers and distributors. We can only conclude from their observations that either misplacement (e.g. empty cylinders stored wrong) or theft (e.g. steel or aluminium alloy has scrap value) could occur at the site of the end customer as well as at the distributor. The supply chain partners can be identified as the culprits, because the gas cylinders remain temporarily at their premises. It is also suggested that damage can occur, because it is unknown in which state the cylinder will return.

The probable causes for shrinkage are: the cylinder itself (i.e. empty cylinders have scrap value or can get lost easily), distance of use (i.e. cylinders are stored at distributors and used and stored at customers situated remotely from MedGas) and lack of (high) deposits (i.e. a high deposit can encourage return).

The uncertainty at MedGas is with respect to cylinder return: at which time will they return, will enough quantities return and what is their state. With a full-for-empty swapping policy there is a slim chance of unauthorized cylinder exchange occurring between customers or distributors.

The lack of visibility is caused by the distance at which the cylinders temporarily dwell at the customer as well as the distributor. These supply chain partners operate at a certain distance from the filling plant which obstructs MedGas from visually monitoring use.

5.4 Shrinkage assessment

In this section we assess the likelihood of different scenarios to provide insight into which shrinkage is most likely to occur. Also we briefly state which consequences are to be expected. The scenarios do not take place inside the filling plant: we assume security measures and restricted access prevent shrinkage at MedGas and that employees follow instructions.

Scenario	Shrinkage	Event	Likelihood
1	Theft	One or more cylinder(s) disappear	Very likely, MedGas does not monitor cylinders at the customer/distributor.
2	Damage	One or more cylinder(s) return damaged	Likely, MedGas does not monitor use at the customer/distributor. Though, cylinders must be handled with care due to content.
3	Misplacement	One or more cylinders are misplaced	Very likely, MedGas does not monitor cylinders at the customer/distributor.
4	Deterioration	Cylinders become unusable during use	Unlikely, MedGas is obliged by law to test cylinders. Unusable cylinders are removed from the fleet.

Table 16: Assessment of four scenarios (own analysis)

The consequences of scenario 1, 2, 3 and 4 are that MedGas has to replace cylinders, carry out repairs, experience a lower turnover, purchase new cylinders and lose the investments in assets.

5.5 Relation to general reusable articles characteristics

In this section we examine if the characteristics for reusable articles discussed in paragraph 3.3 are applicable here.

Reusable articles characteristics	MedGas gas cylinder
Users make no distinction between new and reused products	The customer solely wants the oxygen and is indifferent to new or reused cylinders.
Simple operations bring used RA into an as-good-as-new state (swift recirculation in the forward supply chain)	MedGas is obliged by law to test gas cylinders. If they pass the test, they are added to the fleet again.
Large quantities of RA are returned; these are used to meet most demand	The cylinder returns are more than 90% After a visual inspection are added to the fleet again for future use.
They play an essential role for the business (processes)	If cylinders are unavailable, MedGas cannot sell oxygen to the customers.
Vulnerable to shrinkage	The size, material (i.e. steel/aluminium alloy), no deposits and remote use (i.e. limited control) are the potential causes for cylinder disappearance.
Primary operational challenge is to balance demand and returns	More than 90% of the issued cylinders return, but it is unknown in advance when and if enough empties will return and if instant reuse is possible. This makes it difficult for MedGas to meet customer demand.

Table 17: Compact cylinders characteristics (own analysis)

5.6 RFID technology

In this section we will focus on the theoretical application of RFID technology at MedGas.

This section is structured as follows: in the first subparagraph we propose the RFID options and elaborate on them. Next, we will provide a comparison between manual and RFID data gathering. In subparagraph 6.6.3 we look into how RFID can address the management issues. Finally, we elaborate on (in subparagraph 6.6.4) the components and the costs of the proposed RFID options and in subparagraph 6.6.4.2 we determine if the investment is profitable.

5.6.1 RFID options

MedGas circulates compact cylinders because these contain the product that will be consumed by the customers. Therefore these cylinders need to be fitted with RFID tags. This enables the company to track and gather data about them. In order to establish where readers should be set up, the distribution of cylinders needs to be examined. There are two routes: route 1 is direct delivery to the customer: this only happens if the customer is of a certain size and within a certain radius of the filling plant. If the customer does not meet these criteria, then the intermediate distributor receives the cylinders (route 2) who distributes them to the end customer.

With current practices MedGas knows of each customer the amount of cylinders issued and returned. This data enables the company to view the amount of cylinders assumed to be present at the respective customer. The limitation of this data is that it does not reveal how many cylinders are lost at the supply chain partners: MedGas barely has control over the compact cylinders that disappear at the customers and the distributors. However, MedGas (for some reason) does not register the quantity of cylinders delivered to and received from a particular distributor. As of now the customer and the distributor is invisible to MedGas. If we refer back to paragraph 6.3 we mentioned that among others the distance could cause shrinkage. The problem is that MedGas has little control over losses since there is no real time visibility thus the company cannot remotely monitor cylinders. It would be in the benefit of MedGas if it can establish where cylinders are lost, how many are present, who is responsible and what the cycle time and demand is. We thus propose two options: complete coverage and semi-complete coverage (see figure 12).

In both options the readers placed at the distributors and the customers need to be connected via internet to the information system at MedGas to receive RFID reads from their locations.

Option 1: complete coverage
At the customers and at the distributors is where cylinder leakages can occur. Therefore readers need to be placed at MedGas, all the customers and all the distributors to read incoming and outgoing cylinders. In this option the cylinders can be tracked throughout the entire closed-loop supply chain as well as inside the filling plant; since the cylinders have RFID tags. Consequently, this provides MedGas with better control and visibility which is now virtually nonexistent. From its own location the company can confirm that cylinders are delivered and picked up and that none leave the premises of the supply chain partners unnoticed. The readers at the filling plant are essentially there to automate certain data registry tasks (i.e. registering that visual inspection was completed and that a retest has been conducted for a certain cylinder) and to help minimize mistakes with counting cylinders.

Option 2: semi-complete coverage
In this option we assume that the customers refuse the placement of readers, for whatever reason. The distributors still accept the readers, because we assume that their income partially depends on MedGas making use of their services. At the filling plant the reader placement is the same as in option 1. The drawback of this option is that there is still a lack of control at the customers because readers are missing. However, control is now limited to the distributor.

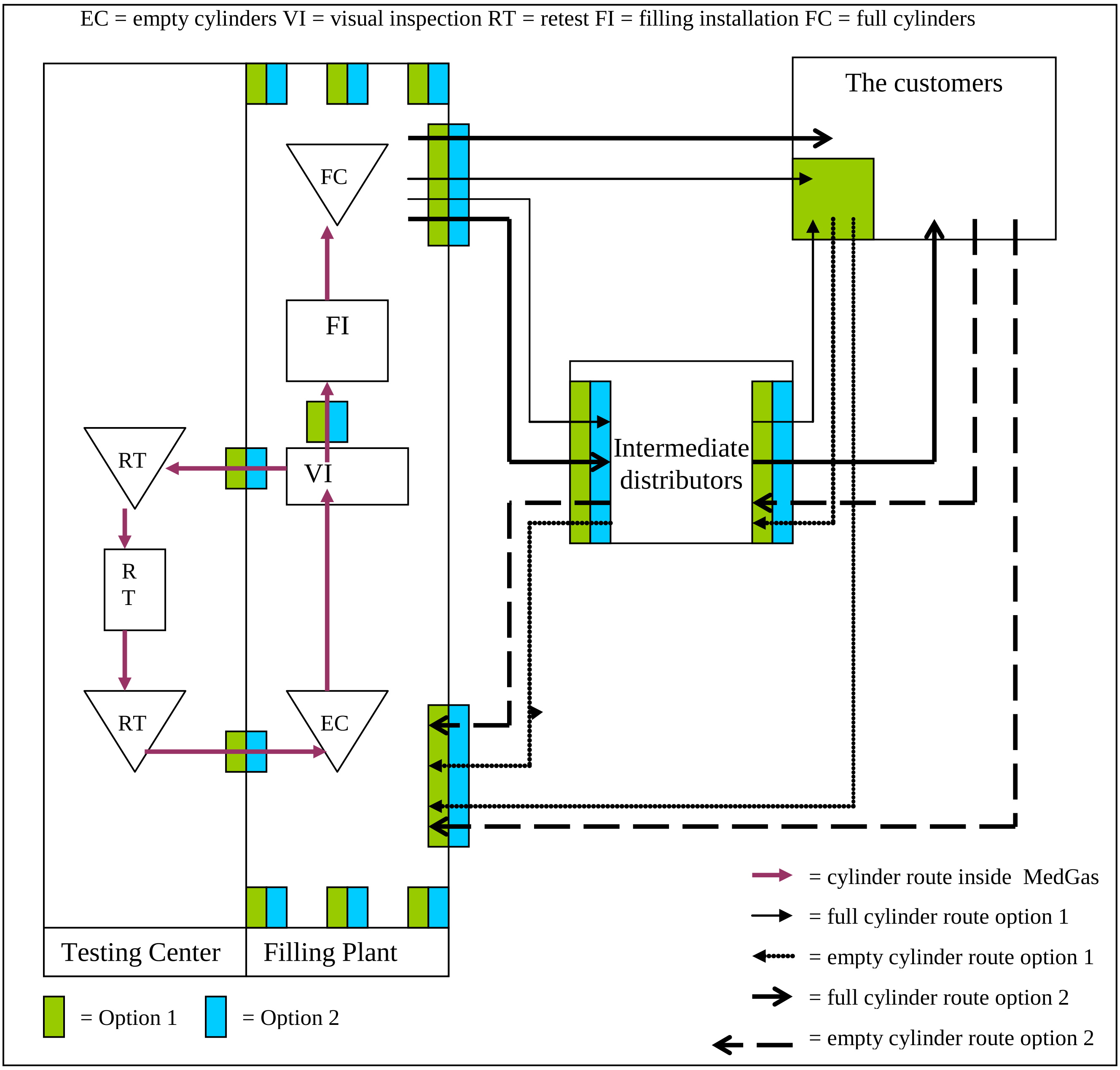

Figure 12: RFID option 1 and 2 for MedGas source: adaptation of figure 4 (p. 31) of Carrasco-Gallego et al. (2012) and own analysis

5.6.2 Data gathering: RFID versus manual

In this section we compare manual data gathering by the employees of MedGas with RFID to objectively determine the value of RFID.

Location	**Employees**	**RFID option 1**	**RFID option 2**
MedGas filling plant empty cylinder section	- Receipt empty cylinders - Available quantities empty cylinders	- Receipt empty unique cylinders - Available quantities empty unique cylinders	- Receipt empty unique cylinders - Available quantities empty unique cylinders
MedGas filling plant visual inspection	- Visual inspection passed or not - Retest required for cylinders	- Visual inspection unique cylinders passed or not (RFID cannot visually check cylinder condition)	- Visual inspection unique cylinders passed or not (RFID cannot visually check cylinder condition)
MedGas testing center retest route (before and after)	Cylinder retest start/finish	Unique cylinder retest start/finish	Unique cylinder retest start/finish
MedGas filling plant full cylinder section	- Available quantities full cylinders - Issuing cylinders	- Available quantities full unique cylinders - Issuing unique cylinders	- Available quantities full unique cylinders - Issuing unique cylinders
The intermediate distributor	-Delivery confirmation full cylinders - Receipt confirmation empty cylinders	- Delivery confirmation full unique cylinders - Receipt confirmation empty unique cylinders - Issuing full unique cylinders to customers - Receipt empty unique cylinders from customers - Illegal activity unique cylinders	- Delivery confirmation full unique cylinders - Receipt confirmation empty unique cylinders - Issuing full unique cylinders to customers - Receipt empty unique cylinders from customers - Illegal activity unique cylinders
The customer	- Delivery confirmation full cylinders - Receipt confirmation empty cylinders	- Delivery confirmation full unique cylinders - Receipt confirmation empty unique cylinders -Receipt full unique cylinders from distributor -Return empty unique cylinders to distributor - Illegal activity unique cylinders	No data available, since readers are absent.

Table 18: Overview of data registry by employees and with RFID technology (own analysis)

In table 18 we observe that data registered by employees and with RFID technology is near identical. The main difference is that with manual data registry there is still minimal control and no real time visibility can be achieved. However, RFID provides this visibility as well as more control for MedGas as the readers will signal that a cylinder is delivered and picked up, and unauthorized movement can be detected as well. Also, an advantage of RFID over manual data registry is that for unique cylinders actual usage history is available; it is not clear if compact cylinders already have a unique number at MedGas.

There is also a difference in the speed at which registered data will become available. For RFID technology only a few seconds are necessary to register data at MedGas, the distributors and the customers (based on Gen 2 read speeds[37]). However, readers at the distributors and the customers have to send data over the internet to information systems located at MedGas. This will take several minutes, depending on the internet speed and amount of data. Manual data registry is assumed to be time consuming and potentially error prone. Though, the main issue is a delay in data availability at MedGas (i.e. employees have to manually enter gathered data, assuming barcodes are not used).

5.6.3 RFID: addressing management issues

In this section we look into which information will become available for MedGas with RFID technology and explain how it can be used to solve the reusable articles' management issues.

The RFID readers at MedGas, the distributors (option 1 and 2) and the customers (only option 1) will repetitively read tags on the cylinders. In table 19 we show fictive data of the distribution of cylinders. Next, we look into which information (see table 20) can be derived from table 19. Thereafter we examine how RFID can solve the management issues.

Some of the data in table 19 can immediately be utilized as information when RFID readers read the tags, for example, available quantities at the distributor. However, in order to obtain other information about, for example, cylinder cycle times, MedGas needs to review various data sets to generate this information. This merging or any other operation on data sets has to be done frequently as much valuable information is hidden within RFID data.

[37] In slow mode Gen 2 readers can read less than 600 tags per second. Source: http://www.skyrfid.com/RFID_Gen_2_What_is_it.php

MedGas	**The distributor**	**Medgas**	**The distributor**	**The customer (only option 1)**
Available quantity: 2000	Available quantity full: 75 Available quantity empties: 50	Available quantity: 2330	Available quantity: 73	Available quantity full: 12
Date: 02/08/2012	Date: 02/08/2012	Date: 02/08/2012	Date:05/08/2012	Date:05/08/2012
Time: 11:00	Time: 11:25	Time: 12:00	Time: 10:00	Time: 10:45
Full cylinder: 5/9/10	Full cylinder: 5/9/10	Empty cylinder: 11/14/59	Full cylinder: 5/9/10	Full cylinder: 5/9/10
Quantity: 3	Full cylinder quantity: 3	Empty cylinder quantity: 3	Full cylinder quantity: 3	Full cylinder quantity: 3
Distributor ID: 405	Empty cylinder: 11/14/59	Distributor ID: 405	Customer ID: 105	Distributor ID: 405
Customer ID: 105	Empty cylinder quantity: 3	Customer ID: 105	Date: 05/08/2012	Empty cylinder: 75/87/95
	Distributor ID: 405		Time: 11:45	Empty cylinder quantity: 3
			Empty cylinder: 75/87/95	Customer ID: 105
			Empty cylinder quantity: 3	Distributor ID: 405
			Customer ID: 105	Illegal activity cylinder: 9 Date: 05/08/2012 Time: 10:50 Quantity: 1 Customer ID: 105
			Illegal activity cylinder: 75 Date: 05/08/2012 Time: 12:15 Quantity: 1 Distributor ID: 405	

Table 19: Fictive data of cylinder distribution (Medgas delivery to and return from the customer) and (the distributor delivery to and return from the customer) (own analysis)

Information	Explanation	RFID data required
Available full cylinders at MedGas (option 1 and 2)	The amount of full cylinders ready for distribution.	Available full cylinder quantities at MedGas
Available empty cylinders at MedGas (option 1 and 2)	The number of empty cylinders for refilling.	Available empty cylinder quantities at MedGas
Total cylinder cycle time (option 1 and 2)	The total time it takes a cylinder to return to MedGas	Outgoing time stamp (full cylinder section) at MedGas and incoming time stamp (empty cylinder section) at MedGas
Specific cylinder cycle time distributor (option 1 and 2)	The time a cylinder resides at a distributor	Receipt from MedGas time stamp Outgoing to customer time stamp Receipt from customer time stamp Outgoing to MedGas time stamp
Specific cylinder cycle time customer (option 1)	The time a cylinder resides at a customer	Receipt from distributor time stamp Outgoing time stamp to distributor
Customer demand (option 1 and 2)	The number of full cylinders in use for a particular time period	Outgoing full cylinders time stamp at MedGas
Cylinder useful life (option 1 and 2)	The actual remaining cylinder useful life based on RFID data	Outgoing time stamp MedGas (full cylinder section) and incoming time stamp MedGas (empty cylinder section)
Available quantities distributor (option 1 and 2)	The number of full and empty cylinder at a distributor	Receipt time stamp MedGas/Customers Outgoing time stamp MedGas/Customers
Available quantities customer (option 1 only)	The number of full cylinders at a customer	Receipt time stamp MedGas/ Customers Outgoing time stamp MedGas/ Customers
Shrinkage distributor (option 1 and 2)	The number of cylinder lost at a distributor	Unexpected read event of cylinder at distributor
Shrinkage customer (option 1 only)	The number of cylinders lost at a customer	Unexpected read event of cylinder at distributor
Confirmation cylinder receipt and return (option 1 only)	Proof of receipt and return of cylinder at MedGas, distributor and customers	Receipt time stamp MedGas/distributor/customer
Cylinder receipt and return confirmation (option 2)	Proof of receipt and return of cylinder at MedGas, distributor.	Receipt time stamp MedGas/distributor
Accountability (option 1 only)	The identification of culprits either customer or distributor, (date, time, frequency and quantity)	Identity of customer/distributor Illegal activity read at customer/distributor
Removed gas cylinders	The number of cylinders removed from the fleet due to damage.	Visual inspection time stamp Retest gas cylinders failed time stamp.

Table 20: Information extracted from RFID data for RFID option 1 and 2 (own analysis)

On the basis of the information in table 20 we examine how RFID can solve the following four management issues: define fleet size dimension, control and prevent shrinkage, define purchase policies and cost allocation.

1) Define fleet size dimension
Due to constant uncertainty about the return of cylinders MedGas has decided to have large quantities of spare cylinders on hand; this represents a large investment.

In order to evaluate if the current fleet size is sufficient a KPI can be formulated. The goal of MedGas can be to supply medical oxygen to customers without any interruption. An example KPI could be “available cylinders for distribution” which we define as: the number of full and empty cylinders available at MedGas for the distribution of medical oxygen. A target must be set that defines if the fleet is adequate or not (e.g. 2000 cylinders must be available at all times). The goal can be measured with the following data: customer demand (i.e. full cylinder outgoing reads at MedGas), cylinder cycle times (i.e. outgoing full cylinder time stamp and incoming empty cylinder time stamp at MedGas) and available empty cylinders (empty cylinder (incoming) reads at MedGas). This KPI will reveal in due time if the fleet is undersized or oversized: as RFID data becomes available, the amount of cylinders available for recirculation can be seen in real time.

RFID readers automatically read the quantity of cylinders being delivered and going out at distributors (option 1 and 2) and customers (only option 1). This helps MedGas to see where cylinders actually reside and what these quantities exactly are. In addition, MedGas can specify for each distributor as well as each customer for how long unique cylinders are stored at their premises. The complete cylinder cycle time is also known: the total time it takes for cylinders to return to MedGas. In option 2 readers are absent at the customer, thus cycle time cannot be specified for the customer, though the distributor as well as complete cycle times can still be calculated. Also demand is now known (option 1 and 2): outgoing full cylinders are registered and indicate the total demand and the demand per customer for a certain time period.

RFID data enables MedGas to see how cycle times and demand develop over time for each distributor and each customer and to recognize seasonality. In the case study MedGas already knows when seasonality occurs and what the estimated associated demand is. With RFID data the company will exactly know when seasonality starts and ends and what the demand actually is; this does require to review a whole year as only over a long period fluctuations are visible. If any changes are noticed in cycle times, demand or seasonality these need to be examined to understand why these occurred. If it is established that there are valid reasons for these changes (i.e. external data sources: reports about the rise of certain health issues), the fleet size needs to be redefined to cope with this change. Obviously, previously mentioned data need to be continuously monitored to ascertain that the fleet size has been adjusted correctly. If the financial situation does not allow for expansion of the fleet size, perhaps other measures can be implemented to increase return rates and shorten cycle times. For example, a high deposit instead of rental charges or a certain discount, this might motivate the customer to return all cylinders sooner and to handle cylinders with even more care. RFID data gathered after certain measures have been implemented will reveal if any of these had the desired effect.

Aforementioned cycle time, demand and seasonality data can also help MedGas built in alerts in their information system to identify customers and distributors (in a certain radius to minimize transport cost) who have cylinders in storage for a certain period of time, which are almost certain empty (this can be determined by comparing past cycle times of respective customer/distributor with current cycle times). By acting on these alerts, instead of awaiting customer orders, the empties return is increased and cycle times will decrease, consequently a smaller amount of spare cylinders is necessary. The alerts should be adjusted when the number of customers increases and when the period of seasonality has commenced.

2) Control and prevent fleet shrinkage

Currently MedGas has limited control over cylinders lost at customers and distributors, so uncertainty is experienced with regard to cylinder returns.

RFID (only option 1) will provide MedGas with more control and visibility over the whole supply chain than currently is possible. As long as readers do not detect unauthorized movement (i.e. cylinders are read at a day that delivery is not planned), no action of MedGas is required. However, if a read is unexpectedly received MedGas instantly knows where and how many cylinders are taken away and can contact the respective culprit to explain this activity. This enables them to somewhat control the behaviour of users. Perhaps the announcement that RFID technology will be implemented to track cylinders will induce a change in behaviour of the distributors and the customers. If a certain cylinder never again is read at a particular distributor or customer, MedGas can initiate an investigation as the RFID data read with an older time stamp serves as proof that the cylinder is still present at their location. Also it will become clear from shrinkage data at which date and time it is experienced more frequently and who is actually responsible (i.e. leakage detection). If it is determined that a particular distributor/customer is responsible for large amounts of losses, measures can be taken to prevent this from happening again, for example, exclude them from gas delivery or only allow use after payment of high deposits. However, in option 2 there is still a lack of control over the customer and visibility and control is limited to the distributors. Therefore this option is marginally better from what is currently experienced.

RFID cannot see that a cylinder has deteriorated but it can help MedGas determine the remaining useful life of cylinders, because data regarding use frequency of a cylinder is available. Instead of relying on guesses, MedGas will know for certain how much time is left before it needs to replace cylinders. Also it can help with assessing the quality of the current cylinders as will become clear how many of them are rejected upon return and who manufactured them. This insight can lead to MedGas selecting another supplier/manufacturer of cylinders or to purchase cylinders of material that is more durable to prevent large shrinkages of the fleet in the future. Unfortunately, RFID data cannot tell MedGas that a cylinder is unusable or that it is damaged, this still needs to be checked by the employees.

3) Define purchase policies for new articles

At the moment MedGas knows what the demand is (outgoing cylinders are registered), partially is aware of shrinkage figures (deteriorated cylinders are removed from the fleet) but cycle times are not registered. We conclude that a purchase policy is established at MedGas since there already is a large quantity of cylinders available to help the company counter uncertainty, though it is not clear how the company formulated this policy.

RFID data will provide insight into cycle times, demand and shrinkage of cylinders. MedGas can use the gathered data to see how each develops over time (only option 1). In option 2, however, shrinkage and cycle times are only known for the distributor. If extreme changes are noticeable in shrinkage, at the same time MedGas must always review demand and cycle time values, because these determine how long the company has to wait on empty cylinders to meet a stable or increasing demand. Using RFID data MedGas can create several scenarios and link it to a certain purchase policy. If MedGas, after regularly analyzing accumulated data has recognized a certain scenario, it knows which purchase policy has to be executed to ensure that the operations of the company do not come to a halt.

As more and more data becomes available and eventually changes occur (e.g. new customers at remote locations), RFID data helps MedGas to define new scenarios or to modify current scenarios that in turn help define better, additional or rephrase current purchase policies. This will aid MedGas in ensuring that medical oxygen is continually available for the customers.

4) Cost allocation

There is no indication in the case study that MedGas requests compensation from the distributors or the customers for lost cylinders. We assume that this has to do with the limited visibility and thus it cannot be established who is responsible for the loss, so not to offend or accuse anyone wrongly.

With option 1 this issue can be solved without much hassle. The readers at the customers and distributors inform MedGas directly if these cylinders exhibit illegal behaviour (i.e. cylinders leave the premises without explicit permission of MedGas). Even if a cylinder has not checked out for a long time, and after intensive search cannot be found at the respective culprit, RFID data can serve as evidence to request reimbursement. In option 2 the cost allocation is limited to the distributor, the customer is simply left out and MedGas still is unable to determine which customer can be held responsible for shrinkage.

5.6.4 RFID investment

In this section we examine the costs for RFID options 1 and 2. We first limit the costs description on tags, readers, middleware and software since these contribute the most to the investments costs. Only if the investment is deemed profitable after review, we will add implementation cost and recurring cost to actually calculate the payback period.

5.6.4.1 Components

In this section we will elaborate on the following components: tags, readers and software.

Tags

The tags on gas cylinders do not have to withstand rough handling or certain weather conditions, because we assume they are stored in a secure manner (i.e. dry environment and upright position) and they need to be carefully handled because of the content. The requirement for tags is that they need to work on metal. We found UHF tags that are specially designed for metal objects. MedGas has about 20.000 cylinders. These UHF tags are sold in packs of 5, so 4000 packs are required.

Readers

UHF readers are required to communicate on the same frequency with UHF tags. These readers will not be placed outside because we assume that cylinders are used inside, and will never be stored outside in the open air to prevent corrosion. In addition, the readers need Ethernet ports to connect them to the internet, because tag reads need to be send to MedGas. As internet is ubiquitous, we assume that each customer and distributor has internet available. In option 1 all the customers, distributors and MedGas will have fixed readers. In option 2 only MedGas and the distributors will have fixed readers. At MedGas (see figure 12) 13 readers are required (3 for counting full cylinders, 3 for counting empty cylinders, 2 for issuing full cylinders, 2 for receipt empty cylinders, 1 for visual inspection and 2 for cylinder the retest).

It is difficult to determine the total amount of readers because the number of customers and distributors is not disclosed. We assume a minimal amount of readers per customer and distributor: readers only need to be placed at the locations where cylinders will certainly pass when delivery and return takes place. This is sufficient for MedGas to detect shrinkage and will minimize costly readers.

In order to estimate the number of customers and distributors we start with what we know: 20.000 cylinders and large amounts of spare cylinders available. We assume MedGas serves around 1.500 customers and each one on average uses 10 gas cylinders. This means around 15.000 cylinders will be in use and 5.000 cylinders remain as spares. We further assume that

MedGas directly serves 250 customers and 1250 customers are served by the distributors. If each distributor serves around 80 customers, this amounts to around 16 distributors in total. At each customer 1 reader is sufficient 1.500 (1.500*1) and at each distributor 2 readers are sufficient 28 (16 * 2). So for option 1 in total 1541 (1500 + 28 + 13) readers are required. Option 2 requires 41 readers (28 + 13).

Middleware

The tag reads received need to be filtered and send to the existing enterprise application (i.e. ERP) of MedGas. In our exemplary case study we estimated the cost to be about $4.000, derived from statements of Shutzberg (2004) and Nurminen (RFID Journal, 2006).

Enterprise applications

Enterprise resource planning (ERP) software is already available at MedGas. This software, however, needs to be connected with Middleware to receive reads from readers placed at customers and distributors.

5.6.4.2 Cost calculation

The costs for both RFID options are displayed in table 21. The basis for the cost descriptions is the previous subparagraph and the sources for the prices can be found in appendix 6.

Hardware	**Price**	**Quantity**	**RFID option 1**	**RFID option 2**
UHF tags	$39.95 (5-pack)	4000	$159.800	$159.800
UHF fixed readers (integrated antenna)	$1.145	1541 (option 1) 41 (option 2)	$1.764.445	$46.945
Software				
Middleware	$4.000	1	$4.000	$4.000
		Total costs	$1.928.245	$210.745
		Euro conversion[38]	€1.677.756,03	€183.368,13

Table 21: Cost calculations for RFID option 1 and 2 (own analysis and Shutzberg (2004))

In order to asses the profitability of both options we will only focus on loss prevention, since this is something MedGas has little control over. In the case study it is said that the return rate is more than 90%. We assume this to be a constant 95%. We assume that a cylinder is in use

[38] GWK koerslijst http://www.gwktravelex.nl/personal/CR_default.asp?content=erh&lang=NLD (date: 07/08/2012) €1 = $1,1493

for 2 months, so for two months (1500 customers * 7 gas cylinders) 10.500 gas cylinders are in use. The loss will be (10.500 * 95% return rate = 9975 cylinders) = 10.500 -/- 9975 = 525 loss of cylinders. Every 2 months 525 * €100 = €52.500 worth of gas cylinders is lost. Yearly loss will amount to: 6 * €52.500 = €315.000 this applies only to option 1. In option 2 readers are not placed at customers, so the savings are assumed to be a fraction of option 1. Since the customers consume the oxygen, a majority of the gas cylinders reside at their premises, we assume that only 10% of 525 are lost at the distributors. This will amount to a yearly loss of: (53 * 100) * 6 = €31.800

In the exemplary case study we found that RFID readers have a useful life of 3 years. We assume that when readers are replaced, all other components are replaced as well. This means that within 3 years the investments mentioned in table 21 need to be earned back.

In option 1 MedGas invests €1.677.756,03 to acquire yearly savings of €315.000. After 3 years it will amount to €945.000. This is far lower than the original investment and thus can never be earned back within 3 years. In option 2 MedGas invests €183.368,13 to acquire yearly savings of €31.800. After 3 years this will amount to €95.400. This is also far lower than the original investment and thus can never be earned back within 3 years. However, these savings are solely for the distributors and still there is limited control over cylinders lost at the customers. Also MedGas has to be aware of the ever expanding RFID investment in option 1 and option 2. It is possible that over time the number of customers as well as distributors required for serving remote customers will increase. In order to maintain visibility and control over the whole supply chain, readers are also required at their location. Based on the aforementioned discussion we can conclude that both of the options are not profitable.

5.7 Conclusion

RFID is possible and valuable for MedGas to manage their gas cylinders. The company will attain visibility as well as more control over its cylinders than now is possible. If a transition will be made from manually registering data to RFID, almost the same data will be available. The main difference will be that data will become available faster with RFID and that for individual cylinders data will be captured. Also incoming RFID data needs to be analyzed in order to actually get this visibility and control so that the management issues can be dealt with. If this is not done, there will be no difference experienced from the current situation.

One drawback of RFID is shrinkage detection, for example, damage to cylinders cannot be derived from RFID data this requires a visual check from employees.

At the moment the control is limited over gas cylinders at the supply chain partners and this leads to uncertainty with respect to empty cylinder return, consequently problems meeting demand. Even though two RFID options are proposed, the success of the RFID implementation greatly depends on the customer. If the customer refuses collaboration then solving a majority of the management issues becomes a difficult task.

We also found that the characteristics of reusable articles discussed in paragraph 3.3 are also applicable here. This means that the insights from this case study are also applicable to other reusable articles. We confirmed our generic conceptual model, except exchange of gas cylinders is not expected between the distributor and the customer. In other words what we illustrated is almost completely confirmed by this case.

At the moment the proposed RFID options are not profitable, because too many readers are necessary which will amount to a high investment in order to prevent a small amount of shrinkage at the customers and distributors. In the cost calculation the readers form the biggest portion of the investment, the total tag costs are still considerable but are significantly less than the readers and the software is the smallest cost component.

Generally speaking we can state on the basis of our calculations that the application of RFID will become profitable if:

- There are more reusable articles circulating with an equal number of readers.
- The purchase price of individual reusable articles is higher
- There are high costs involved with stocktaking (i.e. determining where reusable articles are and counting if all carts are available)
- The reusable articles experience high shrinkage percentages
- The prices of RFID readers significantly drop

6 Generic case study: Surgical instruments at Erasmus MC

This generic case study was conducted by Glorie, K. 2008 cited in Carrasco-Gallego et al. (2012). We chose to use this case study because it concerns reusable products (RP) and our goal is to research different types of reusable articles

6.1 Introduction

Erasmus MC is an academic hospital situated in Rotterdam. As mentioned on their website[39]: "the Erasmus MC is the biggest and most versatile of the eight academic medical centres in Holland". At this hospital they frequently perform operations and therefore a supply of reusable surgical instruments is available. Before and after any operation, these surgical instruments need to be sterilized and have to undergo the necessary repairs. This is essential as to ensure that surgeons repeatedly have clean and as-good-as-new instruments to work with during operations.

6.2 Case study data

The surgical instruments are usually available in nets. These nets contain a bunch of surgical instruments intended for one kind of operation. These instruments have an individual price tag of about €100. A complete net contains 100 items and represents a value of €10.000. While the total amount of nets available is not specified in the case study, Erasmus MC stated that the investment is in the millions of euros. The yearly losses of surgical instruments are believed to be below 5%. Cycle times are unknown. The surgical instruments circulate in a star network: after the operation, the used surgical instruments always return to one central sterilization department (CSD) for repairs, replacement and sterilization.

6.3 Process analysis and the generic conceptual model

In this section we will first describe the surgical instruments process and then identify our generic conceptual model.

The surgical instruments process is as follows: it begins with sterile nets awaiting pick up in a sterile room near the operating room. The instruments necessary for a particular operation are taken from this room and delivered to the operating room. Once the operation is finished the used instruments are moved to a non-sterile room. These instruments are picked up from the

[39] http://www.jaarverslagerasmusmc.nl/over-erasmus-mc/cDU650_Over-Erasmus-MC.aspx

non-sterile room and delivered to the CSD. At this department the received instruments are registered in the information system and thereafter cleaned using special equipment. Next, nets are inspected to verify if all instruments are present, if so, they are ready for sterilization. If an instrument is missing or damaged, the CSD makes sure that this is solved. The complete and sterile nets are registered in the information system and then moved again to the sterile rooms and so the process ends.

The CSD is the pool manager which is clear from the process description. The CSD purchases new instruments or repairs and cleans previously used instruments to ensure that operations can still be performed at Erasmus MC. The surgical instrument is the reusable article, as these were purchased to be repeatedly used for operations strictly within the hospital. The surgeons are the users who must use these instruments for operations in one of the operating rooms at Erasmus MC; the users are not responsible for the return to the CSD.

The types of shrinkage associated with these instruments are difficult to derive from the process description. The surgical instruments, as stated in the case study, can be subject to damage and getting lost. Deterioration is not mentioned, but this is something that will happen eventually. However, theft could also take place but is not explicitly mentioned in the case study. The surgeons as well as their assistants can be the cause for instruments getting lost or being damaged during an operation.

The probable causes for shrinkage are: the instruments themselves (i.e. small in size and could get lost easily) and distance of use (i.e. the CSD does not monitor the (non-)sterile and operating rooms in real time). We assume that the (non-)sterile rooms and operating rooms are accessible to authorized personnel only and strictly forbidden for visitors or any other people. So the floors on which these rooms are located are not the cause of shrinkage.

There is not much uncertainty at Erasmus MC with respect to surgical instruments return. The CSD expects that the instruments are returned in a different condition than they were delivered earlier and maybe later than expected (i.e. if an operation takes up more time than planned). No exchange of instruments is possible after any operation, because they are immediately stored at a designated location (i.e. non-sterile room).

The lack of visibility is caused by the distance of the (non-)sterile and operating rooms from the CSD. The CSD simply does not monitor where the instruments are used (i.e. aforementioned rooms can be found on different floors (27 in total[40]) at Erasmus MC).

6.4 Shrinkage assessment

In this section we assess the likelihood of several scenarios to provide insight into which shrinkage could occur. Also, we briefly state which consequences are to be expected. All scenarios take place inside Erasmus MC: we assume security measures and restricted access prevent shrinkage caused by visitors and that employees follow instructions.

Scenario	**Shrinkage**	**Event**	**Likelihood**
1	Theft	One or more sterile surgical instruments disappear	Likely, the CSD does not monitor instruments in the different rooms.
2	Theft	One or more non-sterile surgical instruments disappear	Unlikely, dirty surgical instruments are collected at the end of the operation.
3	Damage	One or more surgical instruments returned damaged	Likely, a surgeon accidentally can drop a surgical instrument.
4	Misplacement	One or more surgical instruments are misplaced	Very likely, due to their size they can get lost.
5	Deterioration	Surgical instruments become unusable during use	Unlikely, the CSD always checks surgical instruments and removes unusable ones.

Table 22: Assessment of five scenarios (own analysis)

The consequences of scenarios 1, 2, 3, 4, and 5 are that the CSD has to replace surgical instruments, carry out repairs, purchase new instruments and lose the investments in assets. In the worst case operations can no longer be performed

[40] http://www.kuijpers.nl/gezondheidszorg_30.html/

6.5 Relation to general reusable articles characteristics

In this section we examine if the characteristics for reusable articles discussed in paragraph 3.3 are applicable here.

Reusable articles characteristics	**Erasmus MC surgical instruments**
Users make no distinction between new and reused products	The surgeons will use new or reused instruments, as long as these are sterile and still meet the strict requirements demanded of surgical instruments.
Simple operations bring used RA into an as-good-as-new state (swift recirculation in the forward supply chain)	The CSD will clean and sterilize surgical instruments. If damages to these instruments are detected, repairs are carried out. Then they are again available for future operations.
Large quantities of RA are returned; these are used to meet most demand	Less than 5% of the surgical instruments are lost. In other words, almost all return to be reused again for future operations.
They play an essential role for the business (processes)	If surgical instruments are unavailable, surgeons cannot perform (specific) operations.
Vulnerable to shrinkage	The size of the instruments and no monitoring of rooms could be the cause for shrinkage.
Primary operational challenge is to balance demand and returns	At the CSD some instrument quantities are below the desirable number, and of some instruments there is an excessive amount. As a result, this often leads to expensive orders for swift sterilization of surgical instruments.

Table 23: Surgical instruments characteristics assessment (own analysis)

6.6 RFID technology

In this section we will focus on the theoretical application of RFID technology at Erasmus MC.

This section is structured as follows: we first put forward the RFID option and talk about it. Next, we will look into which data can be gathered by the employees (i.e. manual) and with RFID technology. In subparagraph 7.6.3 we look into how RFID can help the CSD address the management issues. Finally, we elaborate on the components (subparagraph 7.6.4.1) and the costs of the proposed RFID options as well as determine if the investment (subparagraph 7.6.4.2) is viable.

6.6.1 RFID option

In this section we will propose and discuss only one RFID option.

The CSD manages and circulates surgical instruments and makes sure that they are always available for operations. A check that is always performed is to verify if the net is complete. Therefore each surgical instrument as well as the nets needs to be fitted with RFID tags. This enables the CSD to track and gather data about them. In order to establish where readers should be placed, the circulation of these instruments needs to be inspected. According to the case study, the instruments never leave the hospital. Also, there is only one specific route at Erasmus MC: it starts and ends at the sterile rooms.

With current practices the CSD knows from the data in the information system which surgical instruments are issued, returned and removed. This data also enables the CSD to determine how much of each instrument is available at the moment. Though, the limitation of this data is that it does not give the CSD insight into the exact loss percentages. The CSD has little control over the instruments as they do get lost, and it is unknown where exactly this happens. It would be beneficial for the CSD if it can establish where these instruments are lost, who is responsible and what the cycle time and demand is. We propose a single option: complete coverage (see figure 13).

RFID option: complete coverage

The identity of the user is assumed not to be a problem. We assume that an operating room has to be reserved ahead of time and the names of all the people present during an operation will be registered, before an operation can actually take place. Also, in case of emergency operations, the names of all people present will also be registered. At the (non-)sterile rooms and the operating rooms located on almost all of the floors of Erasmus MC is where leakages can occur. Therefore readers need to be placed at each one of the aforementioned locations because surgical instruments will always reside/pass here. The surgical instruments/nets become visible at different stages because they are automatically read. Consequently this provides the CSD with more control and visibility of the instruments. The CSD can see that the nets have been delivered to the (non-)sterile rooms and entered the operating rooms. Also that none of the nets leave the (non-)sterile room unnoticed. The reader at the entrance/exit of the operating room (i.e. red rectangle) is to alert surgeons and assistants that instruments were forgotten to be collected. Since the nets and instruments have RFID tags, they can also be tracked inside the CSD department itself. Readers are not necessary at different locations inside the hospital because it is registered who was working at the CSD while these nets were picked up; so the employee can be traced back.

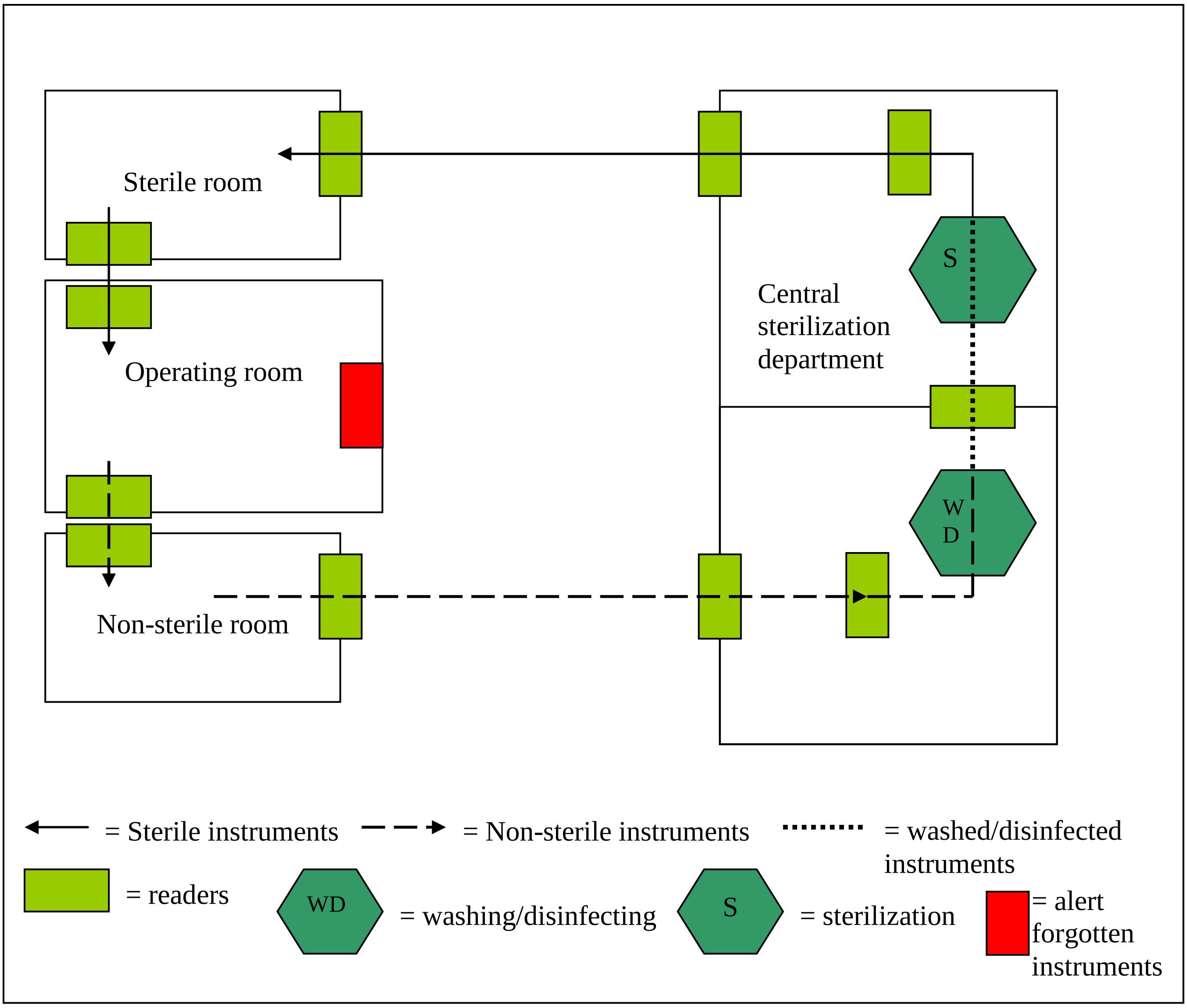

Figure 13: RFID option at Erasmus MC (source: own development based on process description (p. 36) of Carrasco-Gallego et al. (2012)

6.6.2 Data gathering: RFID versus manual

In this section we compare manual data gathering by the employees (the CSD and operating personnel) with RFID technology to objectively determine the value of RFID.

Location	Employees	RFID option complete coverage
Sterile rooms	- Delivery of nets (date/time/room) - Counting nets (contents are not counted as we assume these nets must stay closed) - Pick up of nets (date/time/sterile room and intended for operating room)	- Delivery of unique nets (date/time/room/quantity) - Counting unique nets (date/time/room/quantity) - Counting contents nets (date/time/room/quantity unique instruments) - Pick up of unique nets (date/time/room/quantity unique instruments) - Unauthorized removal (date/time/room/quantity unique instruments)
Operating rooms	- Entrance operating room (date/time/quantity/room) - Counting instruments/nets before/after operation (date/time/quantity instruments/room) - Exit operating room (date/time/quantity/room)	- Entrance operating room (date/time/unique nets/instruments/room) - Counting content nets before operation (date/time/quantity unique instruments/room) - Exit operating room (date/time/quantity unique nets/instruments/room) - Alert forgotten instrument (date/time/unique instruments/quantity/room)
Non-sterile rooms	- Delivery of nets (date/time/room/quantity) - Counting nets (date/time/room/quantity) - Pick up of nets (date/time/room/quantity)	- Delivery of unique nets/instruments (date/time/room/ quantity unique nets/instruments) - Counting nets (date/time/room/quantity) - Counting contents (date/time/room/unique instruments/quantity) - Pick up of nets (date/time/room/unique nets/quantity) - Unauthorized removal (date/time/room/net/instruments)
The CSD	- Receipt non-sterile instruments/nets (date/time/instruments/quantity/non-sterile room) - Washed/disinfected instruments (date/time/instruments/quantity) - Complete nets (date/time/quantity instruments) - Repair/removal of instruments (date/time/instrument) - Sterilization of nets (date/time/quantity) - Issuing of nets (date/time/quantity)	- Entrance confirmation CSD (date/time/unique nets/instruments/room) - Receipt non-sterile unique instruments (date/time/quantity/unique instruments) - Washed/disinfected unique instruments (date/time/unique/instruments/quantity) - Complete unique nets (date/time/unique instruments/nets quantity) - Repair/removal instruments (date/time/quantity/instruments - Sterilization of nets (date/time/quantity/instruments) - Issuing of nets (date/time/quantity/instruments) - Exit confirmation CSD (date/time/unique nets/instruments)

Table 24: Overview of data registry by employees and with RFID technology (own analysis)

A closer examination of table 24 reveals that data registered by employees and with RFID technology is almost alike. The main difference is that with manual data registry real time visibility cannot be achieved and control over the instruments is still limited. RFID will endow the CSD with visibility as well as more control because the readers will read the nets/instruments at the (non-)sterile rooms and the operating rooms. Also, at all the locations unauthorized movement can be detected and especially one reader at the entrance/exit of the operating room will alert personnel if a non-sterile instrument is not collected. The advantage of RFID over manual data registry is that for all unique instruments it is known how long exactly they have been in use; it is not clear if instruments are assigned a unique number.

In addition, the speed at which registered data will become available is also different. With RFID only a few seconds are required to register data at the different rooms (based on Gen 2 read speeds[41]). However, these readers have to send data over a distance (Erasmus MC has 27 floors) so it can take a couple of minutes (depending on the amounts of data) before it is available in the information systems of the CSD. Manual data registry is time consuming and mistakes are easily made (e.g. personnel tired after an operation). Though, the most problematic issue is a delay in data availability at the CSD (i.e. manually entering gathered data can take a while).

6.6.3 RFID: addressing management issues

In this section we look into which information will become available for the CSD with RFID technology and discuss how it can be used to solve the reusable articles' management issues.

The RFID readers placed inside all the rooms (see figure 13) will continually read tags attached to the surgical instruments and nets. In table 25 we present fictive data of a single trip of surgical instruments from the sterile room to the CSD. In table 26 we depict which information can be derived from table 25. Some data in table 25 can immediately be utilized as information when RFID readers read the tags, for example, confirmation of the delivery of sterile instruments to the sterile rooms. However, if the CSD is curious about the cycle times of an individual instrument, then different data sets (e.g. time stamps of instruments use) need to be analyzed together to extract that information.

[41] In slow mode Gen 2 readers can read less than 600 tags per second. Source: http://www.skyrfid.com/RFID_Gen_2_What_is_it.php

Sterile room	Operating room	Non-sterile room	CSD
Delivery: 01/07/2012 13:01 net: 004 room: 1	Entrance: 01/07/2012 15:05 net: 004 room: 2	Receipt nets: 01/07/2012 18:11 net: 004 instruments: 1, 3 and 9 room: 3	Entrance: 01/07/2012 18:35 net: 004 instruments: 1, 3 and 9 quantity: 3 location: CSD
Quantity nets present: net: 004 quantity: 1	Quantity before operation: 01/07/2012 15:05 net: 004 quantity: 3 room: 2	Quantity nets present: 01/07/2012 18:12 net: 004 quantity:1 room: 3	Receipt non sterile instruments: 01/07/2012 18:40 net:004 instruments: 1, 3 and 9 quantity: 3
Contents nets: net: 004 instruments:1, 3 and 9 quantity: 3	Exit: 01/07/2012 18:10 net: 004 quantity: 3 room: 2	Counting contents: 01/07/2012 18:15 net: 004 instruments: 1, 3 and 9 quantity: 3 room: 3	Washed/disinfected instruments: 01/07/2012 19:30 instruments: 1, 3 and 9 quantity: 3
Pick up nets: 01/07/2012 15:00 net 004 room: 1	Alert instrument forgotten: 01/07/2012 18:12 instrument 3 quantity 1 room 2	Pick up nets: 01/07/2012 18:20 net: 004 quantity: 1 room: 3	Complete unique nets: 01/07/2012 19:45 instruments: 1, 3 and 9 net: 005
Unauthorized movement: 01/07/2012 14:40 net: 004 instruments: 1, 3 and 9 room: 1	Unauthorized movement: 01/07/2012 15:07 net: 004 instruments: 1, 3 and 9 room: 2	Unauthorized movement: 01/07/2012 18:17 net: 004 quantity: 1 instruments: 1, 3 and 9 room: 3	Sterilization of nets: 01/07/2012 20:30 instruments: 1, 3 and 9 quantity: 3
			Issuing of nets: 01/07/2012 22:00 instruments: 1, 3 and 9 quantity: 3 net: 005
			Exit confirmation CSD: 01/07/2012 22:03 instruments: 1, 3 and 9 net: 005
			Unauthorized movement: 01/07/2012 20:40 net: 005 quantity: 1 instruments: 1, 3 and 9 room: CSD

Table 25: Fictive data of surgical instruments distribution and return (own analysis)

Information	Explanation	RFID data required
Available sterile quantities at sterile rooms	The number of sterile instruments that are ready for use in a particular sterile room.	Available quantity data at sterile rooms
Available non-sterile quantities at non-sterile rooms	The number of non-sterile instruments that can be picked up by the CSD for sterilization.	Available quantity data at non-sterile rooms
Available non-sterile quantities at the CSD	The number of non-sterile instruments at the CSD that are ready for sterilization.	Available quantity data at the CSD
Shrinkage instruments	The number of instruments lost at the (non-)sterile and operating rooms and removed from the fleet at the CSD.	Unauthorized movement read event at (non-)sterile, operating rooms and the CSD. Removal instruments read at CSD.
Accidental forgotten instruments	The number of times (and quantities) that an instrument was forgotten to be collected in an operating room.	Read event at the entrance/exit of operating rooms
Useful life per instrument	The actual remaining useful life of an instrument based on RFID data.	Entrance time operating room Exit time operating room Repair time stamp instrument
Total cycle times per instrument	The total time it takes for an instrument to return to the CSD for sterilization.	Sterile room delivery time stamp Entrance time stamp the CSD
Specific cycle time instruments	The time instruments are in use at the operating room or reside in the (non-)sterile rooms	Operating room entrance/exit time stamp of instruments (Non-)sterile room delivery time stamp/exit time stamp of instruments
Total demand of nets	The number of nets present at all sterile rooms	Sterile rooms nets quantity read
Confirmation delivery and return sterile instruments	Proof of receipt of sterile nets at the sterile rooms and operating rooms.	Delivery time stamp of sterile and operating rooms
Confirmation delivery and return of non-sterile instruments	Proof of delivery and return of non-sterile nets at the non-sterile rooms and the CSD.	Delivery time stamp non-sterile room Return time stamp the CSD
Accountability	The identification of culprits.	Unauthorized read event (note: also data needs to be retrieved from personnel attendance list)
Available quantity total instruments	The total number of sterile and non-sterile instruments available at the CSD.	Available quantity reads at (non-)sterile, operating rooms and the CSD
Available quantity per instrument	The total number of an individual instrument (a sum of sterile and non-sterile) available at Erasmus MC	Available quantity individual instruments read at (non-)sterile and operating rooms and the CSD.
Quantities unavailable instruments per type	The number of instruments in use at the operating rooms	Operating room quantity of individual items in net read

Table 26: Information extracted from RFID data (own analysis)

On the basis of the information in table 26 we discuss how RFID technology can solve the following four management issues: define fleet size dimension, control and prevent shrinkage, define purchase policies and cost allocation.

1) Define fleet size dimension

At the moment the CSD has of some instruments too many and of others too few available. Consequently, a majority of the sterilization orders need to be completed quickly, which (from a cost perspective) are undesirable since normal orders are five times lower in cost.

In order to evaluate if the current fleet size is sufficient a KPI can be formulated. The goal of the CSD can be to continuously have a supply of surgical instruments available to ensure all types of operations can be performed at any time of the day. An example KPI could be “available instruments for distribution” which we define as the number of instruments (per type) available in the instrument inventory ready for any type of operation. A target must then be set that defines if the fleet is adequate or not (e.g. 4 of instrument type X, 25 of instrument type Y, 50 of instrument type Z and so forth must be minimally available at all times). The goal can be measured with the following data: demand of nets (i.e. nets going to one sterile room are not available anymore for other sterile rooms), cycle times and available quantity total instruments (i.e. instruments inventory). This KPI will reveal, when data becomes available, if the current fleet size is adequate or not because the defined target is either met or not. If certain instrument quantities continuously are above a certain level (defined as undesirable by the CSD) then for those particular instruments purchases should be suspended for a while.

RFID readers placed at the CSD, the sterile rooms and the operating rooms on different floors automatically read the quantity of nets as well as instruments being delivered and in use for operations. The readers at the non-sterile rooms also on different floors read how many instruments are awaiting return to the CSD. This helps the CSD to see where instruments actually reside and exactly what quantities are present there. Also, the CSD can determine how long these instruments have been stored at all individual rooms. The complete cycle time is also known: the time it takes for surgical instruments to return to the CSD. Also demand is now known: outgoing nets are registered and indicate the total demand as well as the total demand per operating room for a certain time period.

RFID data enables the CSD to find out how specific cycle times (i.e. per operating room) and total cycle times (i.e. return to the CSD) and demand develop over time and to recognize periods of unusual demand. RFID data will reveal when this extreme demand exactly occurred and ended and what the actual demand was. However, to discern this unusual demand requires data of an extended period of time, for example, one whole year. It is sensible for the CSD to research any changes noticed in cycle times, demand (i.e. certain operations are carried out more frequently) or the frequency of unusual demand to understand why these occurred. If it is established what caused this change the fleet size can be adjusted by acquiring the right (quantity of) instruments for the inventory to deal with this change. Fortunately, a constant stream of data keeps flowing in thus it can be determined if the fleet was adjusted correctly. However, this data cannot be used to predict future demand, because it cannot be foreseen if certain operations need to be carried out at the exact same time as was previously recognized with RFID data. Therefore, it is essential that RFID data is regularly analyzed.

An option for the CSD is to create alerts in their information system by using cycle times and demand to signal that the current fleet size is inadequate to perform planned operations. By acting on these alerts the non-sterile instruments can be picked up earlier than before so that these are available again in the sterile rooms. Consequently there will be no need for fleet expansion, since the cycle times will decrease by these alerts. Perhaps the data will indicate that cycle times constantly increase and that the fleet needs to be enlarged. The alerts should be modified when the number of planned operations increases and when the period of unusual demand is again identified.

2) Control and prevent fleet shrinkage

At the moment the CSD notices that certain instruments get lost or are unusable for new operations. The yearly losses are lower than 5% of the total stock of surgical instruments.

RFID will provide the CSD with more control and visibility over the closed loop flow of surgical instruments than now is possible. The readers can detect unauthorized movement, and this will instantly be known to the CSD. The CSD will know where (i.e. which room on which floor) and how many instruments were taken away and can contact the person responsible on that floor to explain this activity. This enables the CSD to control the behaviour of users. Perhaps the message that RFID technology will be used to track instruments will induce a change in behaviour of people. If a certain instrument never again is read where it once was delivered (i.e. sterile or non-sterile room), the CSD can initiate an investigation as the data is readily available. Also it will become clear from shrinkage data at which date/time it is experienced, how frequent it happens, and who is actually responsible (i.e. check of attendance list). This will help the CSD to devise appropriate measures to prevent it from happening again.

RFID cannot see that an instrument has been severely damaged this needs to be visually checked by the employees. Though, from RFID data the CSD can determine the actual useful life for all individual instruments. The data regarding their frequency of use is available and, instead of relying on hunches, the CSD will know for certain when to replace particular instruments. As a result impulsive purchases of instruments can be lowered significantly. Also it can help with assessing the quality of the current instruments as it will become clear how many of them are rejected upon return. This information can be used by the CSD to find another manufacturer or to choose cylinders of more durable material to prevent premature shrinkage of fleet in the future. RFID data can then be checked to see if the new instruments are indeed doing better than the previous ones.

3) Define purchase policies for new articles

The CSD does not know what the demand is, can only provide estimates for their losses and cycle times are not registered.

RFID data will provide insight into cycle times, demand and shrinkage of surgical instruments. The CSD can analyze this data to follow how each develops as time progresses. If any changes that are noticeable in shrinkage, then it is especially important for the CSD to review demand and cycle time progression, because this could mean that the CSD has to wait longer on non-sterile instruments to return. With too few instruments present at the sterile rooms, operations can thus no longer be performed with disastrous consequences. Using RFID data the CSD can define several scenarios and link it to a particular purchase policy. If the CSD, by analyzing accumulated data has recognized a certain scenario, it knows which purchase policy has to be put into action to ensure that the operations can be performed. RFID data helps the CSD to establish new scenarios or to adapt current scenarios which in turn help define improved, other or rearticulate current purchase policies. This will aid the CSD to guarantee that surgical instruments are always available with almost zero interruption.

4) Cost allocation

In the case study is not disclosed if lost or damaged surgical instruments need to be compensated. We assume that the CSD wants personnel to concentrate on the operations than rather worry about paying for any losses or damaged instruments.

If the CSD does prefer compensation, RFID data provides details about where and when exactly unwanted activity (i.e. surgical instruments are removed without any logical explanation) has taken place and can be used as evidence. Then the attendance list should be consulted to see who was present at the time the losses occurred.

6.6.4 RFID investment

In this section we discuss the costs involved for the proposed RFID option. The costs description will first be limited to tags, readers, middleware and software, because these are the biggest cost components. If we find that the investment is profitable with these components alone, then we will add implementation costs and recurring cost to calculate the payback period.

6.6.4.1 Components

In this section we will elaborate on the following components: tags, readers and software.

Tags

The tags on surgical instruments and nets have to withstand (rough) handling and repeated washing/disinfecting and sterilization. Also, they should be small enough to never obstruct surgeons during operations. And the tags need to work on metal and not interfere with hospital equipment. We found UHF tags that are specially designed for metal objects and surgical instruments as well as extremely small in size. In the case study is mentioned that the investment in instruments is in the millions of euros. If we assume that it is around €5 million, we can calculate how many instruments in total are available. A complete net contains 100 items and is worth €10.000, so 5 million/€10.000 = 500 nets * 100 items = 5000 instruments. These UHF tags are sold in packs of 10, so 500 packs are required for the instruments and 50 packs for the nets.

Readers

UHF readers are required to communicate on the same frequency with the UHF tags. These readers will be placed inside because the surgical instruments only circulate within the hospital. Also it is important to ensure that readers do not interfere with hospital equipment; we assume the readers we found are hospital friendly. The readers need Wi-Fi or Ethernet ports to connect them to the internet, because tag reads need to be send to the CSD enterprise application. In the case study it is not cited how many operating and (non-)sterile rooms are available. We searched the website of Erasmus MC and could not find any specific information. We did find on the internet that Erasmus MC has 27 floors. If we assume that the first two floors are not intended for patients, then 25 floors remain. At each floor we assume that there are two operating rooms: one for planned and one for emergency operations. In the case study is mentioned that near the operating rooms, the sterile rooms are located. However, it is not clear if there is one non-sterile room near the operating rooms or that there is only one central non-sterile room; we assume the former. This amounts to (see table 27) 255 fixed readers in total (see figure 13 for readers per room).

Location	**Rooms**	**Readers per room**	**Readers**
Operating rooms	(25 floors * 2 operating rooms) 50	3 readers	150
Sterile rooms	(25 floors * 1 sterile room) 25	2 readers	50
Non-sterile rooms	(25 floors * 1 non-sterile room) 25	2 readers	50
CSD	1	5 readers	5
		Total fixed readers	255

Table 27: Fixed readers for Erasmus MC (own analysis)

Middleware

The tag reads received from readers need to be filtered and send to the enterprise application at the CSD by middleware. In our exemplary case study we estimated the cost to be about $4.000, derived from statements of Shutzberg (2004) and Nurminen (RFID Journal, 2006).

Enterprise applications

Also software is needed to process the captured data (received from middleware) and which the CSD will use for decision making. Since the focus is on asset management, there is a need for asset management software. It is not stated in the case study how many employees are working at the CSD so we assume a license for 5 users is sufficient.

6.6.4.2 Cost calculation

In order to asses the profitability of this single RFID option we will strictly focus on loss prevention, because the CSD experiences losses: these are approximately less than 5% a year of the total stock. We assume this to be constantly 4%. There are 500 nets available (see earlier calculation) * 4% = 20 nets or (20 nets * 100 instruments) = 2000 instruments get lost every year. This will amount to a total yearly loss of €200.000 (2000 * €100 (price of 1 instrument))

Hardware	**Price**	**Quantity**	**RFID**
UHF tags	$49.95 (10 per pack)	550	$27.472,50
UHF fixed readers	$1.145	255	$291.975
Software			
Middleware	$4.000	1	$4.000
Asset tracking software	$9.150	1	$9.150
		Costs	$332.597,50
		Euro conversion[42]	€289.391,36

Table 28: cost calculation RFID option complete coverage (see appendix 7 for sources) (own analysis and Shutzberg (2004))

In the exemplary case study we mentioned that RFID readers have a useful life of 3 years. We assume that when one component (i.e. the readers) is replaced, all other components are replaced as well. This means that within 3 years the investments mentioned in table 28 need to be earned back.

The CSD invests €289.391,36 to acquire yearly savings of €200.000. After 3 years this will amount to €600.000. This is far above the original investment and thus can be earned back in less than 2 years. Based on these savings alone, we conclude that the investment of RFID is profitable. However, we ignored the recurring cost. The yearly recurring cost are estimated to

[42] GWK koerslijst http://www.gwktravelex.nl/personal/CR_default.asp?content=erh&lang=NLD (date: 07/08/2012) €1 = $1,1493

be 15% of the acquisition cost (as found in our exemplary case study), so this amounts to €43.408,70 ($332.597,50 * 15% = $49.889,62). We assume the implementation cost to be €50.000, slightly above of what we calculated in the exemplary case study. In total the investment becomes €289.391,36 + €50.000 = €339.391,36 With these new values we can calculate the payback period to see if it is still profitable. The payback period (see table 29) is 2.16 years. The payback period is less than the useful life of the entire investment which is 3 years and thus we can conclude that the proposed RFID option is profitable.

	RFID complete coverage
Yearly benefits	€200.000
Yearly recurring costs	€43.408,70
Annual cash inflow (Yearly benefits -/- Yearly recurring cost)	€156.591,30
Cost calculation	€339.391,36
Annual cash inflow	€156.591,30
Payback period in years (Investment/Annual cash inflow)	2,16

Table 29: Payback period calculation (own analysis)

6.7 Conclusion

At the moment for some instruments there are too many and of others too few are available, consequently the CSD has to perform certain sterilization orders quicker which leads to higher costs. RFID is in this case possible and valuable for the CSD to manage the surgical instruments. The CSD will attain visibility as well as more control over the instruments than currently is experienced. If a switch is made from registering data by hand to automating it with RFID, almost the same data will still be available. The only difference will be swift data availability and that for individual instruments data will be captured. However, gathered RFID data cannot be ignored by the CSD, it needs to be analyzed so that visibility is actually realized and more control becomes possible in order to deal with management issues. If analysis is not performed, essentially the current situation will still be experienced. Also, RFID cannot determine by itself if an instrument is damaged or dirty, this still needs to be visually checked by employees.

A single RFID option is proposed and members of the organization will cooperate with the CSD to achieve control and visibility throughout the closed loop supply chain. The proposed

RFID option is profitable since the yearly savings make it possible for the CSD to earn the investment back within a short time period. The readers are the biggest cost factor in the investment, the tag costs are not substantial and the software is the smallest cost component.

We also found that the characteristics of reusable articles mentioned in paragraph 3.3 are also applicable here. This means that the insights from this case study are also applicable to other reusable articles. We also confirmed our generic conceptual model, except exchange of surgical instruments is not expected between users, because used instruments are considered hazardous.

Even though the RFID option is profitable in this case, we can generally state on the basis of our calculations that the application of RFID will become profitable if:
- There are more reusable articles circulating with an equal number of readers
- The purchase price of individual reusable articles is higher
- There are high costs involved with stocktaking (i.e. determining where reusable articles are and counting if all carts are available)
- The reusable articles experience high shrinkage percentages
- The prices of RFID readers significantly drop

7 Cross-case analysis

In this section we will analyze the data of all previous case studies (i.e. Supermarket shopping cart, MedGas gas cylinders and Erasmus MC surgical instruments) to find similarities and differences between them concerning the theoretical application of RFID. We will examine: data availability, visibility, control, management issues (i.e. define fleet size dimension, control and prevent fleet, define purchase policies for new articles, cost allocation) RFID options and RFID profitability. By performing the cross-case analysis we aim to find more insights on answering our main research question: How can RFID improve the management of reusable articles in a closed-loop supply chain for the pool manager?

	Supermarket	**MedGas**	**Erasmus MC**
Data availability	Relevant data to manage shopping carts will become available, the user cannot obstruct.	Relevant data to manage gas cylinders will become available, though one of the users can obstruct.	Relevant data to manage surgical instruments will become available, the user cannot obstruct.
Visibility	Shopping carts will become visible, the user cannot obstruct.	Gas cylinders will become visible, though one of the users can obstruct.	Surgical instruments will become visible, the user cannot obstruct.
Control	More control over shopping carts, the user cannot obstruct.	More control over gas cylinders, though one of the users can obstruct.	More control over surgical instruments, the user cannot obstruct.
Define fleet size dimension	Defining fleet size dimension possible, the user cannot obstruct.	Defining fleet size dimension possible, though one of the users can obstruct.	Defining fleet size dimension possible, the user cannot obstruct.
Control and prevent fleet shrinkage	RFID can severely limit shrinkage, the user cannot obstruct.	RFID can severely limit shrinkage, though one of the users can obstruct.	RFID can severely limit shrinkage, the user cannot obstruct.
Define purchase policies for new articles	Purchase policies possible, the user cannot obstruct.	Purchase policies possible, though one of the users can obstruct.	Purchase policies possible, the user cannot obstruct.
Cost allocation	Reimbursement possible, though this depends on RFID option.	Reimbursement possible, though this depends on RFID option.	Reimbursement is possible.
RFID options	Two options	Two options	One option only
RFID profitability	No	No	Yes

Table 30: Cross-case analysis for three case studies

A review of table 30 reveals that the Supermarket and Erasmus MC have the most similarities, with the exception of cost allocation, RFID options and RFID profitability. MedGas only shares similarities with the supermarket regarding cost allocation, RFID options and RFID profitability, there are no similarities at all with Erasmus MC. In other words, MedGas in this cross-case analysis is quite different from Erasmus MC and the supermarket.

The similarities can be explained as follows: the supermarket and Erasmus MC do not require the cooperation of the user at all for RFID to provide data, visibility over their assets, control, to define their fleet size, to control their fleet and define purchase policies, because their reusable articles are respectively used nearby/within the company and strictly within the organisation thus little influence can be exerted by the users. The supermarket and MedGas do need the cooperation of the user for cost allocation to ensure that the right culprit can be held liable for what happens to their respective reusable articles; if not, then the customer will remain anonymous at the supermarket and at MedGas the right culprit (i.e. the customer) cannot be identified because of the enormous distance. The reason for the proposal of two RFID options for the supermarket and MedGas is related to cost allocation: the user (i.e. the customer) respectively can refuse to couple their identity or the placement of readers at their premises, therefore an alternative option is required, which in the MedGas case is a slight improvement over the current situation. The reason that RFID is not profitable for the supermarket is that the investments in both options can never be earned back since shrinkage values are too low. At MedGas for both RFID options the investments are too high and shrinkage values too low so that the investment can never be earned back.

The differences can be explained as follows: MedGas, in contrast to the supermarket and Erasmus MC, heavily depends on one of the users (i.e. the customer) to fully cooperate since the gas cylinders are used remotely from MedGas. If cooperation by the customer is refused, this means that: data availability, visibility and control is limited to the distributor and management issues (i.e. fleet size dimension, control and prevent fleet shrinkage, define purchase policies for new articles) are more difficult to solve since RFID is only limited to the distributor, while the customer is the most important user of medical oxygen. However, full cooperation of the customers concerning RFID readers at their location also means a staggering investment, because of the amount of readers involved (even if it is kept to a minimum per customer). The user is not dependent on MedGas and could easily find more lenient suppliers of medical oxygen if RFID cannot be refused. Without the collaboration of the customers, the RFID application is essentially useless and almost comparable to the current situation at MedGas. At Erasmus MC there are a fixed number of known users who cannot refuse the placement of readers since it happens within the own organisation and they depend on the surgical instruments to perform operations. This also explains why there is only one RFID option at Erasmus MC: as members of the organization, the users will simply benefit from it and therefore refusal of RFID is not expected. At Erasmus MC there is always an attendance list for the operation rooms available and the surgeons (we assume) always appear on such a list. The RFID option is profitable because the shrinkage values we assumed (i.e. below the estimated values mentioned in the case study) in combination with the unit price of surgical instruments enables Erasmus MC to earn back their investment.

7.1 Conclusion

Despite the environment in which the different types of reusable articles circulate, RFID can help the pool manager to acquire visibility and more control over their respective reusable articles by providing relevant data. Also with this data, almost all the management issues can be solved, except cost allocation in two cases (i.e. MedGas and the supermarket). In order to realise cost allocation in these cases the customer has to grant permission for identification or cooperate with reader placement or else reimbursement is difficult to accomplish. Also the customer can play a decisive role in the success of an RFID implementation, in one particular case: MedGas. This concerns reusable articles that are used remotely from the pool manager (i.e. outside of the company/organisation thus visual detection is no longer possible) and requires RFID technology to be installed at their location for local visibility of assets and remote control in order to solve the management issues. If there is less dependency on a reusable article to carry out an activity (i.e. shopping) or there are more suppliers of a particular product (i.e. medical oxygen) the user can decide to refuse to cooperate with the pool manager when RFID is being implemented; the user can simply choose another competitor or more lenient suppliers. In other words, the dependency on the respective reusable article of the pool manager more or less determines the success of a RFID implementation. The role of the customer should therefore be taken seriously if RFID is to be successfully implemented in such cases.

8 Conclusions & future research

In this last chapter we will answer our main research question and provide conclusions of our research. Also, we will suggest which future research is interesting on the basis of what we have observed during our research.

8.1 Research question

The main research question we formulated for our research is:

How can RFID improve the management of reusable articles in a closed-loop supply chain for the pool manager?

In order to answer this research question we conducted three case studies (focusing on three types of reusable articles) and one cross-case analysis. We consistently observed that RFID technology in theory will provide the pool manager (i.e. the owner) of the reusable articles with visibility, more control and all relevant data in order to manage the reusable articles. However, for one reusable article type, namely: returnable packaging materials (RPM: gas cylinders), we found that the customer can have a big impact on the success of a RFID implementation. The success of RFID for this type of reusable article depends on the willingness of the customer to participate in the implementation because (usually) these reusable articles are used remotely from the pool manager. If not, then in theory RPM is expected to be difficult to manage with RFID and the same problems will still be experienced by the pool manager.

Implementing RFID is just the first step and does not suffice in itself. It is required of the pool manager to actively analyze and perform certain operations (i.e. merging) on collected RFID data to extract information or else no changes in management of reusable articles will ever be noticeable. We can theoretically generalize these observations to all reusable articles, because we found that the general reusable articles characteristics are applicable in all three cases.

The three management issues identified by Carrasco-Gallego et al. (2012), and one added by ourselves, can also be solved:

1) Define fleet size dimension: adjusting fleet size requires cycle time and demand data, which will be available with RFID.

2) Control and prevent fleet shrinkage (i.e. misplacement, deterioration, theft and damage): preventing shrinkage requires control over reusable articles, which is possible with RFID. The limitation of RFID technology is that shrinkage of reusable articles cannot be completely prevented, since it will always be a part of doing business. Also the role of employees in distinguishing shrinkage is important, since RFID can only provide data, not visually check a reusable article itself or make a distinction (i.e. theft, misplacement, damage of reusable articles) itself between shrinkage.
3) Define purchase policies: to establish policies, shrinkage, demand and cycle times are necessary, which will be available with RFID.
4) Cost allocation (our own issue, derived from issue 2): requires the identification of the user and RFID is able to provide this information, though this is only possible if the customer is willing to cooperate.

RFID technology for reusable articles is an interesting solution, though in two out of the three cases it was not profitable. This was mainly due to the costs involved with a RFID implementation and the small amount of savings realized. The calculations performed in the different case studies give us the following insights about when RFID will become profitable:
- More reusable articles will be in circulation with an equal number of readers.
- The purchase price of individual reusable articles is higher
- High costs involved with stocktaking (i.e. determining where reusable articles are and counting if all carts are available)
- High shrinkage percentages are experienced
- The prices of RFID readers significantly drops

8.2 Future research

We suggest for future research to conduct our research again, but now investigating even more case studies (i.e. different types of reusable articles) and to build a simulation model to simulate the application of RFID. Several scenarios, varying from moderate to extreme, can be developed for reusable articles and tested in the simulation model. The focus of some of these scenarios could be on the role of the customers for reusable articles in general and in particular for RPM, for example, which incentives (and the consequences of these incentives) can be initiated by the pool manager to motivate the customer to participate in an RFID implementation. This will deepen the understanding of the use of RFID technology for all reusable articles.

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10 Appendices

Appendix 1: Search terms for literature review

RFID	Asset Management							
RFID	Visibility	Management						
RFID	Theft	Reusable articles						
RFID	Primary packaging	Management						
RFID	Secondary packaging	Management						
RFID	Tertiary packaging	Management						
RFID	Closed loop supply chain	Reusable items						
RFID	Closed loop supply chain	RTI						
RFID	Asset visibility	Management						
RFID	Management	Reusable articles						
RFID	Shrinkage	Reusable articles						
RFID	Supply chain management	Returnable transport items						
RFID	Management	Reusable packaging						
RFID	Tracking	Tracing	Reusables					
RFID	Closed loop supply chain	Theft	RTI					
RFID	Reverse logistics	Reusable articles	Management					
RFID	Assets	Returnables	Reusable assets	Products	Leakages	Control	Visible	Transparency

Appendix 2: The 5 characteristics of an exemplary case study explained

According to Yin (1994) (p. 147 – 152) an exemplary case study has the following five general characteristics:

“1 The case study must be significant: the individual case or cases are unusual and of general public interest, the underlying issues are nationally important, either in theoretical terms or in policy or practical terms or they are both of the preceding.

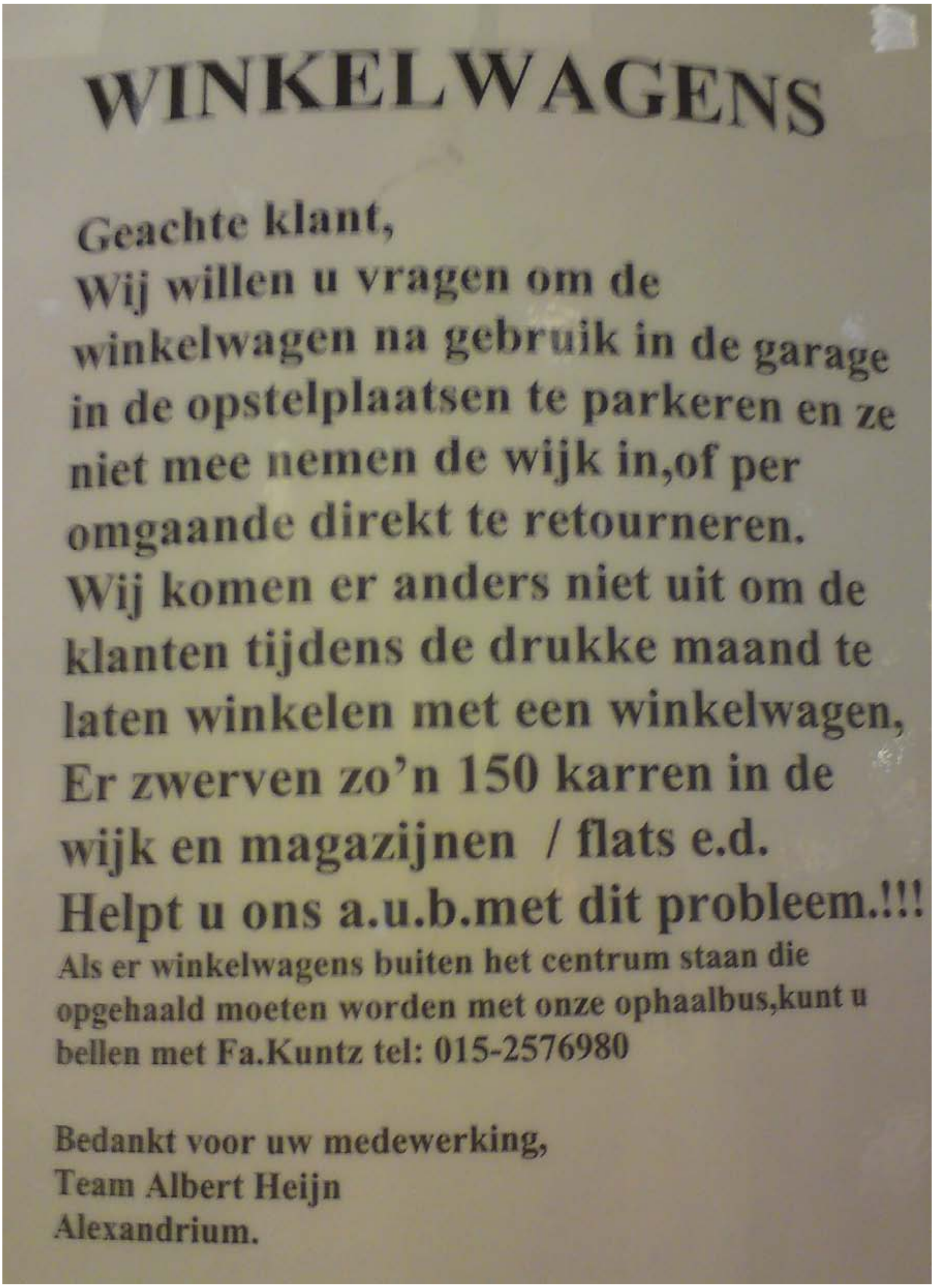
2 The case study must be “complete”: completeness can be characterized in at least three ways. First, the boundaries of the case (the distinction between the phenomenon being studied and its context) are given explicit attention. Second, the collection of evidence. And thirdly, the absence of certain artifactual conditions.

3 The case study must consider alternative perspectives: the examination of the evidence from different perspectives will increase the chances that a case study will be exemplary.

4 The case study must display sufficient evidence: the exemplary case study is one that judiciously and effectively present the most compelling evidence, so that a reader can reach an independent judgment regarding the merits of the analysis.

5 The case study must be composed in an engaging manner.”

Appendix 3: Supermarket data and calculations



Albert Heijn requests the return of 150 shopping carts in Rotterdam (Source: own photo, 2009)

Appendix 3: Supermarket data and calculations (continued)

Name	Assumptions/calculations
Unit price	We assume the classic shopping cart (110 liters) is used by supermarkets in the Netherlands. Shopping cart 110 liters (classic/metal) purchase price €152,50 Source: http://www.shophouse.nl/shophouse/categorie/Winkelwagens/25/hoofd (date: 03/06/2009) Standard shopping basket (plastic) price €4,95 Standard shopping basket (metal) price €17,50 Source: http://www.shophouse.nl/shophouse/categorie/Winkelmandjes/16/hoofd (date: 03/06/2009)
Total quantity at location/country	Location: 183 shopping carts (estimate) is available at supermarkets in the Netherlands Country: a total of 4.300[43] supermarkets in the Netherlands 4.300 * 183 = 786.900 carts in total (estimate)
Total investment	Initial investment in shopping carts (excluding any other costs associated with an initial investment) per supermarket Calculation: 183 * €152.50 = €27.907 (estimate)
Shrinkage	Calculation: 20.000 (stolen carts)/786.900 (estimate of total shopping carts) = 2.54% yearly loss percentage of shopping carts (estimate)
Turnover	This is an estimate of (see of average turnover)

[43] According to Hoofdbedrijfschap Detailhandel (HBD) http://www.hbd.nl/view.cfm?page_id=4914 (Source: HBD, from source Locatus (07/08/2009)

Appendix 3: Supermarket data and calculations (continued)

Quantity of shopping carts at three different supermarkets (source: own data).

Country: Netherlands	Location: village	Population: 25.338
Supermarket	Quantity of shopping carts	Assembly Points
Albert Heijn	190	1 inside 3 outside
C1000	200	0 inside 4 outside
PLUS	160	0 inside 3 outside
Estimate of carts at supermarkets in the Netherlands	(190+200+160)/3 =183	

Cycle frequency: own analysis, based on real visitor figures from managers
While the actual visitors are known by the supermarkets, the managers did not disclose figures for the days of the week because of company policy. However, the manager of C1000 did provide a figure of 14.000 customers per week and added that there is a peak of visitors on both Friday and Saturday. The manager at Albert Heijn stated that on Saturday 3500 customers visit the supermarket. And the manager at Plus supermarket did not disclose any figures.

We know from the C1000 manager that Saturday and Friday are two of the busiest days of the week. Our starting point is Saturday. We pick the data of Albert Heijn as the basis for our cycle frequency calculation. Our assumption is that every workingday 1000 shopping baskets are utilized. So at Albert Heijn on Saturday (3500 -/- 1000) = 2500 customers will use a shopping cart. For the supermarkets Plus and C1000, we estimate that visitors on Saturday slightly differs from Albert Heijn, respectively 3000 and 3200. We then assumed that this customer total is divided as follows: 15% (morning), 75% (afternoon) and 10% (evening). This division applies to all supermarkets since they are of almost the same size and operate in the same village.

Appendix 3: Supermarket data and calculations (continued)

We estimate the number of visitors for normal weekdays (Monday to Friday) as follows: in the morning (most) people are occupied with chores at home. Consequently, a small number of people are expected. In the afternoon more people will go shopping and cart use will be at its highest, because now there is time. In the evening, few people have a desire to shop and a small number of visitors are expected. As the week progresses, the visitors in the morning, afternoon and evening will slightly increase because products are consumed daily and the need for replenishment increases. In general, Saturday is the busiest day for a supermarket.

We estimated the daily use of shopping carts for all three supermarkets, because of:
1) Time constraints: counting in practice means investing 230 hours (the total sum of opening hours of all three supermarkets).
2) None of the three supermarkets we observed record the cycle frequency of shopping carts.
3) Even if we would count in practice, there are just too many factors that could influence cycle frequency, for example: weather conditions, special deals, location, holidays, fleet size, size of the supermarket.

Supermarket: Albert Heijn					
Total Hours open: 74	**Morning** 08:00 - 11:59	**Afternoon** 12:00 - 17:59	**Evening** 18:00 – 20:00 (21:00 on Thursday/Friday)	**Daily total cart use**	**Cycle frequency calculation: daily total/ carts present**
Monday	267	1335	178	1780	1780/190 = 9.37
Tuesday	273	1365	182	1820	1820/190 = 9.58
Wednesday	285	1425	190	1900	1900/190 = 10
Thursday	322	1613	215	2150	2150/190 = 11.31
Friday	345	1725	230	2300	2300/190 = 12.10
Saturday	375	1875	250	2500	2500/190 = 13.15
Sunday	0	0	0	0	0
				Average cycle frequency	65.51 (sum of cycle frequencies)/6 days = 10.92

Supermarket: Plus					
Total Hours open: 72	**Morning** 08:00-11:59	**Afternoon** 12:00-17:59	**Evening** 18:00-20:00	**Daily total cart use**	**Cycle frequency calculation: daily total/ carts present**
Monday	238	1193	159	1590	1590/160 = 9.93
Tuesday	252	1260	168	1680	1680/160 = 10.5
Wednesday	262	1313	175	1750	1750/160 = 10.93
Thursday	270	1350	180	1800	1800/160 = 11.25
Friday	285	1425	190	1900	1900/160 = 11.87
Saturday	300	1500	200	2000	2000/160 = 12.5
Sunday	0	0	0	0	0
				Average cycle frequency	66.98 (sum of cycle frequencies)/6 days = 11.16

Supermarket: C1000					
Total Hours open: 84	**Morning** 07:00-11:59	**Afternoon** 12:00-17:59	**Evening** 18:00-21:00	**Daily total cart use**	**Cycle frequency calculation: daily total/carts present**
Monday	268	1343	179	1790	1790/200 = 8.95
Tuesday	270	1350	180	1800	1800/200 = 9
Wednesday	277	1387	186	1850	1850/200 = 9.25
Thursday	285	1425	190	1900	1900/200 = 9.5
Friday	300	1500	200	2000	2000/200 = 10
Saturday	345	1725	230	2300	2300/200 = 11.5
Sunday	0	0	0	0	0
				Average cycle frequency	58.2 (sum of cycle frequencies) /6 days = 9.7

Average cycle frequency for supermarkets in the Netherlands (estimate)	10.92 (Albert Heijn) + 11.16 (Plus) + 9.7 (C1000)/3 = 10,59

Appendix 3: Interviews at supermarkets (continued)

Interview 1
Date: September 2009
Supermarket: Albert Heijn
Interviewee: Employee & Manager

1) Are there any shopping carts subject to shrinkage (e.g. theft, misplacement, vandalism)?
Yes, but it is mainly customers that take away a cart; it's about 15 on an annual basis, though this is an estimate; we do not actually register losses (i.e. theft); while some eventually return, others are gone for good. Misplacement does not really happen, as we employees return them afterwards. As for vandalism, it really does not happen in this community, people will notice immediately.

2) How often do you check if a sufficient amount of carts are available for customers?
The main priority for us is the assembly point (AP) located inside. On weekdays we check this AP once every hour, because it's not really necessary to do it more frequent. On Saturday we increase this to twice every hour, as this is the busiest day for us. During the holidays (e.g. Easter, Christmas) we check at the same frequency as on Saturday. When we see that this AP is (near) empty we gather a sufficient amount of carts from the assembly points located outside and move them here.

3) How long does it take to gather shopping carts and how many employees are necessary?
It takes approximately 10 minutes to move shopping carts from the outside assembly points to the inside AP, for this activity we need two employees. At the end of the day when the supermarket closes down, we collect all the carts outside and take them inside which also requires two employees.

4) At which moment do you decide to expand the fleet of shopping carts?
We do not have any particular moments to purchase the carts, because the current quantity of carts is sufficient for the whole year. We have spare shopping carts in the back of the store to solve any problems with shortages. Even with busy times, such as holidays, we can manage it

all with our current fleet size. The current quantity of carts is sufficient to provide a service to our customers; constantly the carts are available.

5) Do you check for damages to shopping carts?
We do not inspect the shopping carts at the end of the day, but rather during the day, when we receive complaints from customers. If a cart is damaged we remove it from the fleet. When we have damaged shopping carts that need to be fixed, they are sent to a third party who will repair them. If restoration is not possible, new ones are bought to replace them. However, it is not up to the manager to decide, it's the headquarters which makes that decision.

Interview 2
Year: September 2009
Supermarket: C1000
Interviewee: Employee & Manager

1) Are there any shopping carts subject to shrinkage (e.g. theft, misplacement, vandalism)?
There are indeed shopping carts lost, however we do not know the exact numbers as we do not register these losses; maybe about 13 yearly. Our employees also use the shopping cart for collecting cardboard/plastic while working, but afterwards they are always returned to an assembly point. We have not experienced vandalism, perhaps it is because we operate in a small village. And sometimes the carts have indeed broken wheels, locks, but this happens rarely. We hardly ever count the carts (perhaps once a month), because we have plenty available.

2) How often do you check if a sufficient amount of carts are available for customers?
We do not have a fixed schedule for checking an assembly point. In total we have four assembly points, two located outside at the parking lot are quickly full and to make sure cars can leave we have to empty those two regularly. We do this either when receiving complaints from customers about this assembly point or check it ourselves irregularly. Sometimes in the morning we use a single cart while stocking shelves to hold the cardboard and plastic packaging of the products. In the evening, between 18:00 and 20:00 o'clock more carts will be used by the employees, because it is not so crowded in the supermarket.

3) How long does it take to gather shopping carts and how many employees are necessary?

When we move the carts from the parking lot assembly point to the two assembly points at the front of the store, it takes approximately 9 minutes. We do this with two employees and always use a machine, as is it heavy work to move a huge quantity of carts.

4) At which moment do you decide to expand the fleet of shopping carts?

We do not have a particular moment at which we buy additional shopping carts. With our current fleet of shopping carts customers can do their shopping, even during demanding times of the year, like the month of December.

5) Do you check for damages to shopping carts?

This only happens once every few months, and not every day when we close down. If we get complaints from customers, we take away the cart and check if we can repair it ourselves (spare parts are available). If it is too complex, we send them to a company that repairs them for us. We replace carts only when they cannot be repaired (i.e. if the body is completely damaged) and these are send to the head office.

Interview 3

Year: September 2009

Supermarket: Plus supermarket

Interviewee: Employee & manager

Are there any shopping carts subject to shrinkage (e.g. theft, misplacement, vandalism)?

We do not register theft, but we do notice it on the long run. Besides, it is not such a huge number. We estimate that about 12 carts yearly go missing, mostly because customers take the cart home; theft seldom happens, therefore we do not register it. And we do not count the carts at the end of the day. Other types of shrinkage are not very common in this environment, but are to be expected in cities.

2) How often do you check if a sufficient amount of carts are available for customers?

We have appointed the head cashier to check once every hour whether enough shopping carts are present at the assembly point at the front of the store, because this is the spot where customers usually pick up the shopping cart when they commence shopping.

3) How long does it take to gather shopping carts and how many employees are necessary?

If the assembly point at the front of the store is (near) empty, we ask two employees to gather the shopping carts from the other two assembly points, all-in-all this takes about 7 minutes. Also, at the end of the day we take all of our carts inside the store because we do not want our assets outside, this requires two employees and takes about 12 minutes.

4) At which moment do you decide to expand the fleet of shopping carts?

We base our stock of shopping carts on our turnover and number of customers, a busy month, for example December, does not influence our decision to expand the fleet. If for some reason shopping carts are indeed needed they are purchased via the headquarters.

5) Do you check for damages to shopping carts?

We periodically check our cart for damages, but we mostly get reactions from customers as they are the daily users, which is good enough for us to detect the damage. If we have a broken cart we remove it from the fleet. We then send it to a third party who will try to fix it, and if repairs are not possible, we’ll replace them.

Appendix 4: RFID investment calculation sources for option 1 and 2 (supermarket case)

Hardware	Sources [all accessed 2009]
Tags	http://buyrfid.com/catalog/product_info.php/ cPath/21_55/products_id/249?osCsid=2ffdf41c9b84d545a72bba18bd17992b (29 October 2009)
ID card printer	http://www.beresfordco.com/product/Z81-000C0000US00.html
Readers Fixed Handheld	 http://www.rfidsupplychain.com/-strse-172/Motorola-%28Symbol%29-RD5000-Mobile/Detail.bok http://www.rfidinfotek.com/detail/rfid-uhf-handheld-reader/436.html
Server	http://h10010.www1.hp.com/wwpc/us/en/sm/WF05a/15351-15351-3328412-241644-241475-3929672.html?dnr=1
Desktop computer: monitor, desktop, mouse and keyboard	Monitor http://www.shopping.hp.com/en_US/home-office/-/products/Accessories/Monitors/XP597AA?HP-2011x-20-inch-Diagonal-LED-Monitor Desktop http://www.shopping.hp.com/en_US/home-office/-/products/Desktops/HP-Pavilion-Slimline/B3F71AV?HP-Pavilion-Slimline-s5-1310t-Desktop-PC Mouse and keyboard http://www.shopping.hp.com/en_US/home-office/-/products/Accessories/Mice-and-Keyboards/CR3992?Logitech-Wireless-Desktop-MK710-Keyboard-and-Mouse
Software	Sources
Asset tracking software	http://www.redbeam.com/products/rfid/
Middleware	Own assumption, based on two estimates by Shutzberg (2004) and Nurminen (2006)
Additional cost	Sources
Consultancy and implementation	http://nje-rfid.com/Rfid_Pilot.htm http://www.payscale.com/research/US/ Job=Information_Technology_%28IT%29_Consultant/Hourly_Rate
Training	http://www.rfid4u.com/certification/RFID+training.asp

Appendix 5: Calculations of benefits

Quantity 5*80% = 4 (option 1) Quantity 5*100% = 5 (option 2)					RFID Option 1	RFID Option 2
Shrinkage: theft						
Loss of investment	Q	PPSC				
Option 1	4	€152,50			€610	
Option 2	5	€152,50				€762,50
Lower turnover	Q	CFSSC	TCFSC	RVSC		
Option 1	4	10,59	42,36	€35	€1.482,60	
Option 2	5	10,59	52,95	€35		€1.853,25
Replacement cost	Q	PPSC				
Option 1	4	€152,50			€610	
Option 2	5	€152,50				€762,50
Shrinkage: damage						
Loss of investment	Q	PPSC				
Option 1 (2 counted as loss)	2	€152,50			€305	
Option 2	5	€152,50				€762,50
Lower turnover	Q	CFSSC	TCFSC	RVSC		
Option 1 (4 in □otal unavailable)	4	10,59	21,18	€35	€1.483	
Option 2	5	10,59	52,95	€35		€1.853,25
Replacement cost	Q	PPSC				
Option 1 (2 to be replaced)	2	€152,50			€305	
Option 2	5	€152,50				€762,50
Repair cost	Q	RCSC	SP	TRCSC		
Option 1 (2 to be repaired)	2	€16,14	€25	€41,14	€82,28	
Option 2	0					0
Shrinkage: misplacement						
Lower turnover	Q	CFSSC	TCFSC	RVSC		
Option 1	4	10,59	42,36	€35	€1.482,60	
Option 2	5	10,59	52,95	€35		€1.853,25
Search and transport costs	Q	SC	TR			
Option 1	4	€8,07	€105,98		€114,05	
Option 2	5	€8,07	€105,98			€114,05
				Total benefits	**€6.474,53**	**€8.723,80**

Q = Quantity
RCSC = Repair cost shopping cart (hourly wage €8,07 * repair time 2 hours)
PPSC = Purchase price shopping cart €152,50
CFSSC = Cycle frequency single shopping cart 10,59
TCFSC = Total cycle frequency shopping cart (10,59 * quantity)
SP = Spare parts €25,-
SC = Search cost (hourly wage €8,07 * search time 1 hour)
TR = Truck rental (daily rate €105,98)
RVSC = Receipt value shopping cart €35,-
TRCSC = Total repair cost single cart (RCSC + SP)

Appendix 6: Case study MedGas gas cylinders cost calculation sources

Components	Sources
Tag	http://www.atlasrfidstore.com/Confidex_Ironside_RFID_Tag_pack_of_5_p/confidex_ironside.htm [accessed August 2012]
RFID readers	http://www.atlasrfidstore.com/ThingMagic_Astra_Integrated_RFID_Reader_WIFI_p/a5-na-wifi.htm [accessed August 2012]
Middleware	Own assumption, based on two estimates by Shutzberg (2004) and Nurminen (2006)

Appendix 7: Case study Erasmus MC surgical instruments cost calculation sources

Components	**Sources**
Tag	http://www.atlasrfidstore.com/Xerafy_Dash_XS_RFID_Tag_p/xerafy_dash_xs.htm [accessed August 2012]
RFID readers	http://www.atlasrfidstore.com/ThingMagic_Astra_Integrated_RFID_Reader_WIFI_p/a5-na-wifi.htm [accessed August 2012]
Middleware	Own assumption, based on two estimates by Shutzberg (2004) and Nurminen (2006)
Enterprise application software	http://www.redbeam.com/products/rfid/index.php [accessed August 2012]