ULg Library

http://lib.ulg.ac.be

matheO

http://matheo.ulg.ac.be

Inventory routing problems for the management of returnable transportation items (RTI)

Auteur : Pirotte, Myriem

Promoteur(s) : Limbourg, Sabine

Faculté : HEC-Ecole de gestion de l'ULg

Diplôme : Master en ingénieur de gestion, à finalité spécialisée en Supply Chain Management and Business Analytics

Année académique : 2016-2017

URI/URL : http://hdl.handle.net/2268.2/2708

Avertissement à l'attention des usagers :

Tous les documents placés en accès ouvert sur le site le site MatheO sont protégés par le droit d'auteur. Conformément aux principes énoncés par la "Budapest Open Access Initiative"(BOAI, 2002), l'utilisateur du site peut lire, télécharger, copier, transmettre, imprimer, chercher ou faire un lien vers le texte intégral de ces documents, les disséquer pour les indexer, s'en servir de données pour un logiciel, ou s'en servir à toute autre fin légale (ou prévue par la réglementation relative au droit d'auteur). Toute utilisation du document à des fins commerciales est strictement interdite.

Par ailleurs, l'utilisateur s'engage à respecter les droits moraux de l'auteur, principalement le droit à l'intégrité de l'oeuvre et le droit de paternité et ce dans toute utilisation que l'utilisateur entreprend. Ainsi, à titre d'exemple, lorsqu'il reproduira un document par extrait ou dans son intégralité, l'utilisateur citera de manière complète les sources telles que mentionnées ci-dessus. Toute utilisation non explicitement autorisée ci-avant (telle que par exemple, la modification du document ou son résumé) nécessite l'autorisation préalable et expresse des auteurs ou de leurs ayants droit.

INVENTORY ROUTING PROBLEMS FOR THE MANAGEMENT OF RETURNABLE TRANSPORTATION ITEMS (RTI)

Jury :
Promoter :
Sabine LIMBOURG
Readers:
Yasemin ARDA
Célia PAQUAY

Dissertation by
Myriem PIROTTE
For a Master in Business Engineering
with a specialization in Supply Chain
Management and Business Analytics
Academic year 2016/2017

Acknowledgements

First and foremost, I would like to thank my thesis promoter Ms. Limbourg for her help and availability during this Master thesis. She supported me throughout the thesis with her precious advice. I would also like to thank Ms. Paquay for her suggestions and guidance during the meetings we had and Ms. Arda for reading my Master thesis.

Then I would like to thank Mr. Coline from the CHU Logistic Center for having welcomed me in the warehouse of Chênée and answered my questions.

I would also like to express thankfulness to Mr. Sullon and Mr. Plumer from Trafic for having respectively welcomed me in the back shop of Trafic Grivegnée and answered my questions at the level of the global warehouses.

Then, to my family and friends, on whom I have always counted during all my academic years at HEC-Liège, thank you for the special support during the Master thesis, last step of this long 5-years journey.

1. Introduction

1.1 Context

Nowadays, the environment matter is no longer a not-in-my-back-yard (NIMBY) issue. Indeed, the linear and traditional growth model is no longer viable and its consequences have substantial impacts on governments, industries and societies. The necessity of a change in attitude towards the environment is not anymore to be proved (Kroon & Vrijens, 1995). Companies too have to deal with these environmental concerns and with the scarce and volatile supply of natural resources that drive up uncertainty and prices (Accenture, 2014). In addition, they are confronted with regulations related to ecology, such as European directives aiming at preventing packaging waste production (European Parliament and Council, 1994).

The circular economy, which has its roots in sustainable development, suggests an alternative model that aims to manage the natural resources in an efficient way (European Environment Agency [EEA], 2016) and that decouples development and growth from the consumption of scarce resources. It provides a key to these environmental challenges and makes the economic development and growth possible within natural resources limits. It makes enterprises innovate to enable customers to do *"more with less"* (Accenture, 2014). Enterprises want to make their supply chains greener but the environmental aspect only makes sense if additional economical value is considered. They have carried out studies to find out about their environmental impacts and about the economic benefits of using more environmentally-friendly alternatives. Industries have come up with solutions based on the collection, reuse and recycling of products and materials (Kroon & Vrijens, 1995). The manufacturing sector has particularly been active in putting in place sustainable initiatives in the frame of supply chains (Sarkis, 2001, cited by Hariga, Glock & Kim, 2015).

The development of reverse logistics took place in this frame. This concept refers to the "*logistic management skills and activities involved in reducing, managing and disposing of hazardous or non-hazardous waste from packaging and products*" (Kroon & Vrijens, 1995, p.56). According to Guide, Harrison and Van Wassenhove (2003), reverse logistics integrates a reverse supply chain that necessitates cautious design, planning and control. The traditional supply chain must indeed be redesigned to support the reverse activities and to use resources effectively (Dowlatshahi, 2000). Reverse logistics also includes reverse distribution, which refers to the flow of information and goods in the opposite direction from traditional logistic activities (Kroon & Vrijens, 1995). The concept has increased its importance as a sustainable and profitable business strategy (Dowlatshahi, 2000).

The driving force for change is not only a growing concern for the environment and the related regulations from the government; there are also valuable commercial and economic reasons behind this evolution (Kroon & Vrijens, 1995). Indeed, if used effectively, reverse logistics can help an organization to be more competitive in its industry by improving the global performance of its supply chain, in both quality and cost aspects. This is particularly true in highly competitive industries with complex products and with low profit margins. Moreover, increasing consumers' consciousness about environmental matters constitutes a driver for companies to tend towards reverse logistics (Dowlatshahi, 2000).

All these elements have set the stage for the concept of closed-loop supply chain (CLSP). Indeed, this concept has been developed when considerations about the environmental consequences of industrial activities and the pursuit of economic advantages have mushroomed (Iassinovskaia, Limbourg & Riane, 2017). According to Akçalı and Çetinkaya (2011), CLSP consists of both the forward supply chain and the counterpart reverse supply chain. The traditional forward supply chain aims at providing end-consumers with value in terms of goods, from the extraction of raw materials to the final distribution; whereas the goal of reverse supply chain is "*is to recover economic and environmental value from used products in a cost effective manner*" (Akçalı & Çetinkaya, 2011, p.237). The return flow includes the product acquisition from the end-user, the reverse logistics bringing these back, the testing, sorting and disposition defining the most interesting reuse options in terms of costs, remanufacturing and finally the remarketing to build and exploit new markets (Guide et al., 2003). Thus the CLSP *"is characterised by recovered material, component, and product flows between the forward supply chain and the reverse supply chain" (Akçalı & Çetinkaya, 2011, p.2374)* and its aim is to supply the end-consumers with the recovered value, in a cost effective way (Akçalı & Çetinkaya, 2011).

The CLSC field gives rise to several areas of research and various opportunities. Some of them are related to packaging activities (Iassinovskaia et al., 2016). Sustainable packaging has to be "*effectively recovered and utilized in biological and/or industrial closed loop cycles*" (Sustainable Packaging Coalition, 2011, p.1). Effective recovery entails the substantial recovery and collection of material at the highest value possible. In this perspective, supply chain coordination and collaboration is needed to create a closed-loop material chain. This includes the use of recyclable materials, the design of packaging made for recovery, the establishment of adequate systems and infrastructure to collect the items at their end-of-life stage (Sustainable Packaging Coalition, 2011). One way to achieve closed-loop material chain in packaging activities is using returnable transportation items (RTIs) which are in fact reusable packaging material designed and aimed to be used several times in the same form, unlike the traditional cardboard boxes (Kroon & Vrijens, 1995). Examples of RTIs are given in Figure 1. RTIs are usually made of wood, plastic or metal replacements (Rogers and Tibben-Lembke, 1999). This solution has several advantages but also some drawbacks.

Figure 1: *Examples of RTIs (retrieved from gs1.org)*

1.2 Research question and goal

My research thesis aims at answering the following question: "how to adapt the model of Iassinovskaia, Limbourg and Riane (2017) about inventory-routing problem of returnable transport items with time windows and simultaneous pickup and delivery in closed-loop supply chains to additional constraints encountered by organizations?" The goal of this adaptation is to improve the modeling of RTIs management to better stick to the reality.

1.3 Methodology

To try to answer the research question, the first step was to understand properly the initial model of Iassinovskaia et al. (2017) and to figure out which were the aspects that were not taken into account (for example loading, volumes). The second step was reading the Master thesis of Martin (2016) in order to understand the conditions and environment in which the companies actually manage their RTIs. This thesis enables to discover how the main constraints encountered by companies and missing in the model are represented in reality and to see how they could be modeled and integrated in the initial model through some modifications. I also had the opportunity to meet some people working for the supply chain department of two of the organizations analyzed by Martin (2016) and to visit some warehouses. Some constraints were more straightforward to model and to integrate in the existing model of Iassinovskaia et al. (2017) than others. This is the case for the maximum ceiling and minimum threshold constraints. Then, the article of Geyer, Van Wassenhove and Atasu (2007) about the limited component durability and finite product life cycle was analyzed and combined with the model of Iassinovskaia et al. (2017) in order to model three different aspects: the durability, resale and loss of RTIs. This was more complex and involved some modifications within the initial model.

1.4 Thesis structure

The first chapter after this **chapter of introduction** of the thesis is the literature review. It is divided into 3 parts: the first one is about the concept of returnable transportation item (RTI), the second one describes the initial model of Iassinovskaia et al. (2017) and the last one describes the model of Geyer et al. (2007). Then, the **third chapter** is the main one and concerns the contributions of this Master thesis. It begins with the main contribution, which consists in the improvement of the initial model on the durability, resale and losses aspects. The first subsection introduces the subject and raises the reader's interest in the three aspects developed in this improved model. Then the second subsection describes the model. The third one analyzes it by firstly stating the input data and then by analyzing and comparing the initial and modified models firstly in a case with only one customer and then with several customers. The fourth subsection consists in a parametric study where the influences of the two main parameters are studied. Then, the last subsection is about conclusions on the three aspects. The second improved model is the maximum ceiling model. It is introduced, described and then analyzed. The analysis consists in first stating the input data and then comparing the costs obtained with and without the maximum ceiling constraints. The conclusions section is the last subsection. The minimum threshold section has the exact same structure as the maximum ceiling section. Finally, general conclusions are drawn in the **penultimate chapter** and some insights are suggested in the **last chapter**. An extra chapter is also written to deal with the project management aspects of the Master thesis but it is presented in the first Appendix.

2. Literature review

2.1 Returnable Transportation Item (RTI)

According to the International Council for Reusable Transport Item (IC-RTI) (2003), an Returnable Transportation Item (RTI) consists of any reusable mean to gather products for handling, transportation, storage and protection in a supply chain that returns these items for further use. Glock and Kim (2015) define the RTI as a particular type of reusable packaging material, aimed and designed to be used several times in the same form. Pallets, railcars, crates, containers, boxes can be different sorts of RTIs that are used in various industries today (IC-RTI, 2003).

First of all, the term RTI that will be used throughout this Master thesis is also known in the literature under different other names: Reusable Shipping Containers (Saphire, 1994), Returnable Container (Kroon & Vrijens, 1995), Returnable/Reusable Logistical Packaging or Returnable Shipping Container (Rosenau, Twede, Mazzeo & Singh, 1996), Reusable Transport Item (International Council for Reusable Transport Items (IC-RTI, 2003) Reusable Transport Packaging (Kärkkäinen, Ala-Risku & Herold, 2004).

It is only in recent years that the management of returnable transport items has often been a subject of research (Glock & Kim, 2015). Since the subject has lately started to attract researchers' attention, the number of published articles over this theme has considerably risen since 2006, as shown on Figure 2, revealing the growing importance of a more efficient management of RTIs in closed-loop supply chains (Glock, 2017).

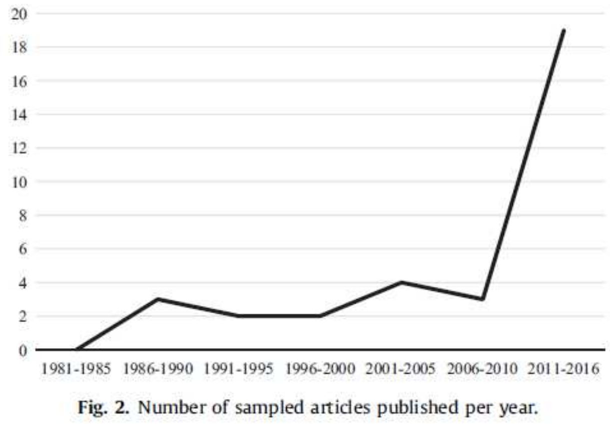

Figure 2: *Evolution of the number of articles about the management of RTIs published per year (retrieved from Glock, 2017, p.3)*

The literature about RTIs before 2006 is very limited. In the late 90s, Fleischmann, Bloemhof-Ruwaard, Dekker, Van der Laan, Van Numen, Van Wassenhove (1997) notice that the scientific literature on the interaction between forward and reverse flows in the context of RTI management was very limited. However, Rosenau et al. (1996) observe that, in practice, RTIs such as containers, pallets, crates, glass bottles and cylinders, had concretely seen the popularity of their usage increase over the last decades. Nowadays, RTIs are frequently used in practice (Glock & Kim, 2015).

According to Rogers and Tibben-Lembke (1999), who shortly introduce the management of RTIs in their work about reverse logistics networks, the drivers of the switch from disposable packaging to returnable ones are environmental, economic and legislative. De Brito, Dekker and Flapper (2005) investigate the reasons behind reverse logistics and come to the conclusion that continents have also an influence on them. Indeed, North American enterprises use RTIs for economic reasons, while it is more the legislation that drives European companies.

Among the advantages of RTIs, we can cite the improved transportation and storage efficiency (Glock & Kim, 2015) and the improved handling and protection of the packaged goods (Kärkkäinen et al., 2004). Using RTIs also enables to avoid repeated purchase of new transportation materials, reducing this way the waste and disposal cost (Glock & Kim, 2015). Indeed, Rogers and Tibben-Lembke (1999) state that even though RTIs are costlier to procure than disposable materials, they are eventually cheaper because the investment cost is amortized through numerous reuses. In the same perspective, Saphire (1994) also demonstrates the economic and environmental advantages of RTIs, such as the decrease in disposal and packaging costs, the prevention from waste and resource conservation (raw materials and energy). Some additional cost-saving in freight, storage, labor and handling costs can also appear in the long-term (Saphire, 1994). In the case study carried out by Silva, Santos Renó, Sevegnani and Serrra Truzzi (2013) comparing disposable and returnable transport items, the reusable items consumes 18% less material than the disposable one, which means that RTIs enable to achieve a decrease in cost at this level. Protection of goods is also improved and waste generation is minimized at the customer (Silva et al., 2013). Concerning the environmental aspect of the use of RTIs, the paper of Glock and Kim (2015) confirms that RTIs lead to waste reduction levels required by some regulations and by customers, who are more and more environmentally-conscious. According to Goellner and Sparrow (2014), reusable containers can lead to a 75% decrease of CO_2 emissions over their lifecycle, in comparison with single-use containers.

However, these statements are to balance. According to Lammers, Lange and Luzyna (1993) (cited by Kroon and Vrijens, 1995) the ability of RTIs to decrease environmental impact compared to traditional transport items is only true when they are used a minimal number of times, since the production, return flows and disposal of such reusable items need to be taken into account. Moreover, return shipments might produce a substantial amount of CO_2 emissions, especially when the partners of the supply chain are located far apart from each other (Glock & Kim, 2015; Glock, 2017). And according to Glock (2017), specific characteristics of the materials composing these reusable items might also be at the disadvantage of RTIs compared to one-way packaging materials. Regarding the cost aspect, the situation is quite similar to the environmental aspect: RTIs are not systematically synonym of lower costs. Indeed, according to Glock (2017), the use of returnable transport material comes at a cost because it needs a large initial investment that may not be completely amortized as well as operations for empty containers. In addition, some replacement or repair costs have to be taken into account if some units are getting lost or damaged (Glock, 2017).

Rogers and Tibben-Lembke (1999) synthesizes in some ways the advantages and drawbacks of RTIs by listing the success factors of an efficient RTIs management:

- Transportation distances: *"The shorter the distance that containers are hauled, the lower the cost"* (Rogers and Tibben-Lembke, 1999, p. 132).
- Delivery frequency: When the time between deliveries decreases, the quantity of containers accumulated between trips will decrease as well. Then, if there is less accumulation, fewer containers will have to be bought, involving less space required for storage. In addition, losses and damage will more likely happen if the containers are kept longer at the customers'.
- Number of parties involved: When there are fewer partners, it is easier to keep track of containers and fewer losses are likely to happen.
- Number of sizes needed: A large range of sizes of containers enables a better cube exploitation, leading to lower transportation costs. However, it is also synonym of a greater quantity of containers that have to be purchased in order to ensure availability. Also, more containers have to be stored and handled at every location.

In the same perspective, Saphire (1994), who is one of the first authors to write a paper dedicated to RTIs (Martin, 2016), identifies the challenges and opportunities encountered by organizations that implement RTIs. Based on case studies, the author points out the success factors and obstacles to the use of RTIs by organizations. Then, insights to foster the use of this kind of reusable items by governments and industries are described (Saphire, 1994).

- Four success factors of the use of RTIs are determined: the first three are identical to the first three ones identified by Rogers and Tibben-Lembke (1999) and the last one refers to *"company-owned or "dedicated" distribution vehicles"* (Saphire, 1994, p.7). If company-owned trucks are used or if the company chooses to work with trucking enterprises that dedicate part or all of their fleet to ship to and from a single customer, return shipping will not be charged (Saphire, 1994).
- Five hindrances to adopting RTIs are identified. Firstly, the initial capital investment is significant (1), some tracking and accounting costs are to incur (2), as well as a cost for returning items to the point of origin (3). Then, empty RTIs require some storage space but the company may lack room in its infrastructures (4). Finally, some partners such as customers and suppliers may show some resistance to this change (5) (Saphire, 1994).
- Seven options to encourage the use of RTIs are suggested to overcome the difficulties and obstacles. Firstly, RTIs can be leased by a third-party (1) (Saphire, 1994) and, similarly, Hariga, Glock and Kim (2016) find out that RTIs rental is particularly beneficial if both the probability of late returns and the shortage cost are high. Then, standardization in the whole industry should be promoted (2) and some cooperative efforts between the different collaborators of the supply chain should be put in place (3). RTIs should be designed so that they can be stored and stacked more easily (4) (Saphire, 1994). Then, *"adopting more frequent and direct delivery systems"* (Saphire, 1994, p.2) would foster the switch to reusable items (5). Finally, concerning the government, some support programs such as tax credits and low-interest loans could help expand the use of RTIs (6), as well as some procurement guidelines (7) (Saphire, 1994).

Some authors also discuss one of the drawbacks related to the use of RTIs that organizations most frequently suffer: losses. According to Breen (2006) (cited by Martin, 2016 and Glock & Kim, 2015), who conducts a study in several industry sectors in the United Kingdom (UK) about RTIs, 15% of pallets in circulation vanish and 20% of packaging are not given back by customers or other kinds of third-parties because they use them for their own purpose. Aberdeen Group (2004) also leads a survey about this topic, indicating that 25% of the responding organizations claim losing at least 10% of their RTIs fleet annually, with 10% of them losing more than 15%. In the same way, Glock and Kim (2015) report that several studies show that the annual loss rate of RTIs lies between 9% and 15% (Ilic et al., 2009; Carrasco-Gallego and Ponce-Cueto, 2010; Mason, Shaw & Al-Shamma'a, 2012), meaning that the material should be replaced after on average 6 to 11 utilizations. More generally, Buchanan and Abad (1998) consider that the quantity of RTIs sent back during a given time span is a stochastic function of the total quantity of RTIs available on the spot. Another variable impacts indirectly the number of lost RTIs according to Glock and Kim (2015). They state that shipment frequency of goods influences the number of RTIs needed in the system, hence its impact on the number of RTIs that get lost. Losses can finally consist in a substantial issue because, according to Grimes-Casey et al. (2007), companies do not have any incentive anymore to use RTIs if customers' return rate is not high enough.

To cope with this loss issue without eradicating it, Kelle and Silver (1989, quoted by Glock & Kim, 2015) state that if one determines how many RTIs will likely be needed in the future as well as the number of RTIs that will probably be lost, then it is possible to calculate the date and size of replacement orders. Then, Kim and Glock (2014) discuss a solution that could decrease the number of non-coming back RTIs. The use of the Radio Frequency Identification (RFID) technology can ease the tracking, inducing partners to heed more the return of RTIs. It can also ameliorate the predictability of RTIs flows. However, the use of RFID may not improve the performance of the system in every case. One element against the use of this technology is the higher container purchase cost (Glock, 2017). Kim and Glock (2014) study under which conditions its use can be beneficial for the system. They come up with calculations giving a threshold price, "*the reservation price*", under which the price of an RFID-tagged RTI should be to allow a beneficial use of the RFID system. Otherwise, traditional non-tagged RTIs are preferred. Another result obtained in this paper is about the factors influencing the benefits of an RFID system. These factors are the effects of the RFID system "*on the mean return rate and on the reparability of returned containers*" (Kim & Glock, 2014, p.25). Indeed, when these elements increase, the reservation price increase as well. In the same way, Johansson and Hellström (2007) discuss the possible benefits of asset visibility in the management of RTIs. They state that tracking the asset costs less to enterprises than tracking the product and that losses happening because of wrong placement or shrinkage could decrease thanks to the tracking of the fleet of RTIs. They carry out a case-study illustrating better RTI visibility and observe a resulting decrease in costs of 34%. In another paper, Hellström and Johansson (2010) deal with RTIs systems, closed-loop supply chain and tracking by studying the consequences of various control strategies on the overall management of RTIs systems.

Regarding durability, Silva et al. (2013) consider in their article the limited lifespan of reusable items and list the lifetime in terms of trips of some returnable packaging materials, such as metallic rack and plastic tray. The article of Geyer et al. (2007) that will be discussed later also proposes a table with the lifespans of different items, expressed in terms of cycles. This table is displayed in Figure 3. Saphire (1994) also takes into account the lifetime of RTIs since he considers the number of times a plastic container can be used in his cost comparison.

Table 2 Maximum Number of Lives *n* for Some Product Components

Product	Component	Characteristic component life	Characteristic product use	*n*	Source
Car tire	Casing	500,000 km.	150,000 km.	3	Ferrer (1997b)
Computer	Chip	80,000 hrs.	20,000 hrs.	4	Keeble (1998)
Single-use camera	Camera core	6 cycles	1 cycle	6	Kodak (1999)
Glass bottle	Whole product	25 cycles	1 cycle	25	UBA (1996)
Wooden pallet	Whole product	50 cycles	1 cycle	50	UBA (1996)
Crates for bottles	Whole product	120 cycles	1 cycle	120	UBA (1996)

Figure 3: *Maximum number of lives for some product components (Retrieved from Geyer et al., 2017, p. 91).*

As this thesis is about inventory routing problems for the management of RTIs, we can note that some authors also study RTIs problems related to inventory and routing. Pollaris, Braekers, Caris, Janssens and Limbourg (2016) conduct some research about the capacitated vehicle routing problem taking into account axle weight constraints and sequence-based pallet loading. The limitations in terms of axle weight are an important challenge for transportation firms because they risk fines for two main reasons. Overloaded trucks can be a threat for the road users' safety and for the road integrity. The conclusions drawn by the authors indicate that the consideration of axle weight constraints in such a problem is possible and even necessary. A feasible route planning requires the incorporation of these axle weight constraints in the vehicle routing model.

Soysal (2016) studies closed-loop inventory routing problem (CIRP) for RTIs and exposes a probabilistic mixed-integer linear programming model which takes into account both forward and reverse logistics operations, demand uncertainty, multiple products and fuel consumption. The author illustrates the possible application of the model thanks to a real-life case study in a soft drink enterprise. The conclusions of the article show that the model developed can make the company achieve substantial savings in the total cost and gives some improved support for decision-making (Soysal, 2016).

2.2 Initial model

The article of Iassinovskaia et al. (2017) tackles *"the pickup and delivery inventory-routing problem within time windows (PDIRPTW) over a planning horizon"* (Iassinovskaia et al., 2017, p.1). The model developed considers a system made up of, on the one hand, a producer based at a depot and on the other hand, a set of customers that have a demand for each period. The partners (i.e. the producer and the customers) are represented by a set of nodes on a directed graph. Distances between the different partners are calculated as Euclidean distances. The producer's role is to deliver his goods thanks to RTIs to the different customers. It is thus a two-stage supply chain. Yet the customers are not available at any time of the day. They determine a time window wherein the producer can bring its products. The RTIs used are either brand-new ones purchased from an RTI supplier or reused ones collected from the various customers. Then, when the products are at the customer's location, they are unpacked from RTIs. These empty RTIs are collected by the producer so that they can be reused again in the following production cycle. Both the producer and the customers have two storage areas for empty and loaded RTIs, which have given maximum storage capacities and given initial levels. Products are distributed by a fleet of homogeneous vehicles which can transport both empty and loaded RTIs at the same time and that is characterized by a unique vehicle capacity for the whole loading and an average speed in km/h. Each vehicle completes a tour per period, going from the depot to a subset of customers. The vehicle visits each customer exactly once per period.

The aim of the producer is to minimize the total cost, i.e. the sum of the transportation, storage, maintenance, purchase and penalty costs. The transportation cost includes a fixed part and a variable part. The fixed part is a cost per km whereas the variable one is a cost per ton km. The storage cost is an inventory holding cost per unit incurred by each partner and at each period of time. The unit inventory holding costs are different depending on either they relate to empty or loaded RTIs and they are lower at the depot thanks to the greater inventory capacity that implies economies of scale. The maintenance cost encompasses a cleaning cost and an inspection cost. The maintenance cost is incurred each time an RTI is filled at the depot. The purchase cost is the cost to buy new RTIs. RTIs are bought at the producer. The penalty cost is actually a penalty cost per unit of time that is computed for the time length of the itinerary and that thus reduces the temptation of the vehicle to wait at one of the customer until the time window of the following customer opens. If it nevertheless does so, a penalty cost is incurred (Iassinovskaia et al., 2016).

To address the PDIRPTW, the authors develop a mixed-integer linear program that is tested on small-scale instances. The version 12.5 of IBM ILOG CPLEX with default parameters is used to solve the instances. The inventory routing problem (IRP) is acknowledged to be a NP-hard problem. This implies that the authors have used a clustering algorithm to solve the instances of a more businesslike scale. This enables to diminish the scale of the problem before executing the branch-and-cut algorithm (Iassinovskaia et al., 2016).

Appendix 2 displays the initial model of Iassinovskaia et al. (2017). It will also be largely explained in the model about durability, resale and losses since it is based to a great extent on this initial model.

2.3 Limited Durability

Geyer, Van Wassenhove and Atasu (2007) contribute to the literature about economics of remanufacturing, which is designated as *"value recovery from collected end-of-use products through reusing their durable components for the manufacturing of a product with the original functionality"* (Geyer et al., 2007, p.88). Their research takes place in the frame of closed-loop supply chains, which has gained substantial interest in recent years because of the environmental challenges that have influenced business practices. The focus of the article is on return flows of goods that have reached their end-of-use cycle but that still constitute an important source of value, as it is the case for components that have the potential to be reused for manufacturing the same products. When products cannot be reused one more time, it is said that they have reached their end-of-life. In this case, they can still be valuable through energy recovery or material recycling. Sometimes, it is even also possible to reuse the components for products that have fewer requirements (Geyer et al., 2007).

The authors study, thanks to basic analytical models, the profitability of remanufacturing under the basic supply-loop constraints, as for example the technical feasibility of remanufacturing (limited component durability), the accessibility of end-of-use products (collection rate) and market demand for remanufactured products (finite product life cycle). They also investigate the interactions of these constraints with each other and also *"with the cost structure of a production system with remanufacturing"* (Geyer et al., 2007, p.89). They also give some examples of the maximum number of lives for some products components that can actually be used as RTIs (as illustrated in Figure 3). A wooden pallet can be used 50 times, a glass bottle 25 times, and a crate for bottles 120 times (Geyer et al., 2007).

The authors consider an original equipment manufacturer that has the possibility to collect goods and remanufacture them once they have reached their end-of-use phase. The products remanufactured are perfect substitutes for the brand-new ones, meaning that both types of products provide the customers with the exact same utility, at the same price. The original equipment manufacturer has control over the production system and can satisfy demand with any combination of remanufactured and brand-new items (Geyer et al., 2007).

They develop an economic model of production systems where the products are taken-back after their use phase and are used to remanufacture perfect substitutes. However, some collected items cannot be remanufactured because of the limited durability of the reusable constituents. The model is divided into four main groups of operation: firstly manufacturing, then collection, remanufacturing and finally disposal (Geyer et al., 2007).

A given percentage c of the marketed products is collected at the end of their current utilization (Geyer et al., 2007). The collection rate c is most of the time inferior to 1 for several reasonable explanations. Firstly, *"the collection network does not cover all areas where products could be collected"* (Geyer et al., 2007, p.89). Then, users might not return the product and dispose of it. And finally, some third parties may collect the products at the end of their useful lives for some other remanufacturing networks. So the RTIs that are not collected are assumed to be lost. Figure 4 depicts this functioning. The authors state that if the collection rate is low or if the used product is returned only after the end of the life cycle, it does not make sense to invest in more durable goods, even if the cost to manufacture a new product is greater than the cost of remanufacturing (Geyer et al., 2007).

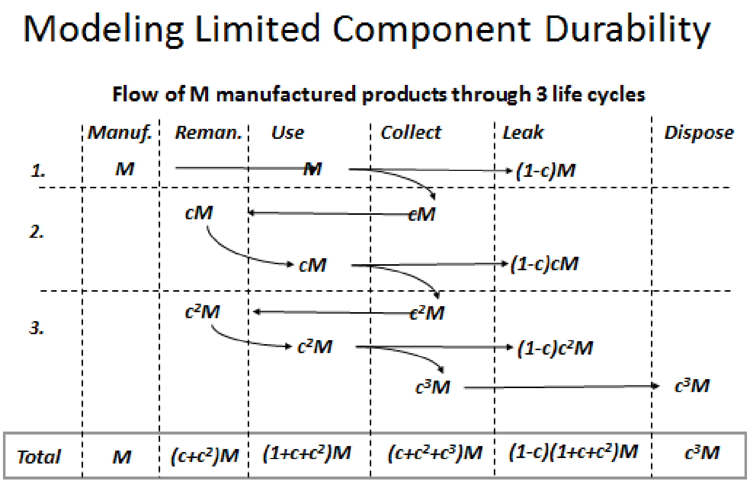

Figure 4: *Flow of M manufactured products through 3 life cycles (Retrieved from Limbourg, n.d.)*

In the model developed by Geyer et al. (2007), the collection process also encompasses an inspection aimed at determining the percentage *r* of the collected items that can be remanufactured. The remanufacturing process transforms the end-of-use products to mint condition, which means that customers get the same utility from remanufactured and brand-new items. This proportion *r* takes into account technical constraints as well as the sufficient market demand. The organization have to dispose of the proportion *(1-r)* of gathered products that cannot be remanufactured, which implies some disposal costs that can however be reduced thanks to energy or materials recovery. Then, combining the collection rate *c* with the remanufacturing yield gives the remanufacturing rate *rc* which "*indicates the efficiency of product take-back based on remanufacturing*" (Geyer et al., 2007, p.90). Remanufactured products are perfect substitutes of the newly manufactured items on the market. Both can be used without any distinction to satisfy the total market demand *Q*. Geyer et al. (2007) then exposes the total cost function of satisfying the demand *Q*:

$$C_{reman}^{total} = (1 - rc)QC_{man} + rcQC_{reman} + cQC_{coll} + (1 - r)cQC_{disp}$$

Where:

C_{man} = the cost of manufacturing an item thanks to first-hand components,

C_{coll} = the collection and inspection cost of an end-of-use item,

C_{reman} = the remanufacturing cost of a collected end-of-use item ($<C_{man}$),

C_{disp} = the disposal cost of an item that cannot be remanufactured.

The authors can then quantify the cost-savings that can be made in a system that collects, remanufactures and remarkets goods. Since remanufacturing is likely to be cheaper than manufacturing, opting for the remanufacture can decrease the cost if the remanufacturing yield is higher than a critical value. The conclusions drawn from the results show the importance of harmonizing carefully the production cost structure, life cycle of the item, the component durability and finally the collection rate to be able to achieve and even maximize cost-savings because some nonlinearity is introduced in the production cost functions by the limited durability and the finite life cycle aspects. The necessary coordination makes the problem more complex. This could be one of the reasons why closed-loop supply chain is not adopted by the majority of original equipment manufacturers (Geyer et al., 2007).

3. Contribution

3.1 Durability, resale and losses

3.1.1 Introduction

3.1.1.1 Durability of RTIs

In reality, companies face the deterioration of their RTIs, which is simply due to their more or less intense use, like for any asset. Indeed, the maintenance that is laid down by the companies examined by Martin (2016) demonstrates that they are aware of the depreciation of RTIs due to repeated utilization. RTIs have a certain lifetime that depends, on the frequency of utilization (being itself tributary on activities of the company) and on the type of RTI.

According to Martin (2016), AGC Glass Europe[1] estimates that their stillages make on average between 40 and 50 rotations during a lifetime of 15 years, Bidvest[2] uses rolls that lasts at least 5 years during which they make a hundred of trips per year, and Bubble Post[3]'s boxes achieve 70 to 80 rotations during a lifetime of 6 to 8 months. To demonstrate the diversity in terms of RTIs and of businesses, Bubble Post is a company specialized in the ecological "first-and-last-mile" transport that uses polystyrene boxes, whereas AGC Glass Europe is a leader in flat glass that uses only stillages and Bidvest is an international enterprise in the services, trading and food distribution sectors that uses euro-pallets, plastic pallets, rolls, plastic tray and pallet heighteners (Martin, 2016).

3.1.1.2 Resale of RTIs

Then concerning the resale, Trafic[4] is sometimes able to resell its defective pallets when they are not good anymore to transport goods. This is possible because Trafic own most of its

1 AGC Glass Europe is the leader in flat glass for the automotive and construction industries and for solar applications. Returnable stillages are always used for the road mode and they are used only with serious and important customers for overseas mode. RTIs represent 50% of the overseas selling volume. The fleet size amounts to about 600 returnable stillages (Martin, 2016).

2 Bidvest is an international firm that operates in trading, services and food distribution. Bidvest provide the companies with all kind of products enabling cooking activities. RTIs are present since the beginning at Bidvest for goods transport and the company buys new kinds of RTIs to adapt to new customers that have specific requirements and constraints (Martin, 2017).

3 Bubble Post is a Belgian company whose concept is about ecological "first-and-last-mile" transport. The choice of RTIs has come recently with the arrival of new customers in the HORECA sector. The ecological, protection and economical aspects drove this choice. The RTIs are actually polystyrene boxes that enable keeping cold temperatures (Martin, 2016).

4 Trafic is a Belgian integrated chain specialized in discount and non-food distribution. The enterprise has used RTIs from its beginning and uses them more and more often. Trafic uses euro-pallets, plastic boxes and pallet heighteners. It has two logistic centers where it receives the merchandise coming from the suppliers. Orders for the 82 non-franchised stores are then prepared in RTIs (Martin, 2016).

RTIs. However some organizations do not have the possibility to fall back on resale or have a limited possibility to resell, since they use RTIs that they do not own. For example, some RTIS used by Trafic come from its suppliers or from its suppliers' RTIs provider Commonwealth Handling Equipment Pool (CHEP). Bidvest owns its rolls and plastic boxes but receive the pallets loaded with goods from the suppliers. Once emptied, the pallets have to be returned to the supplier where they are taken back by CHEP (Martin, 2016). Appendix 3 displays a graph retrieved from Martin (2016) about the ownership of RTIs.

3.1.1.3 Losses of RTIs

The vast majority of companies interviewed by Martin (2016) report facing losses of RTIs. Example of losses are also illustrated by the fact that some of these organizations, such as Bidvest, Bubble Post and Colruyt[5], register sometimes finding RTIs of their competitors. So this issue seems to be quite widespread, even among companies that were not analyzed by Martin (2016). Some companies also experience losses inside their own stores. For example, since Trafic is an integrated chain, it has not set any guarantee system and it does not invoice nor record the RTIs; but it knows that some of its stores use some RTIs for other purposes than transporting goods. One of the problems faced by Trafic is actually the lack of traceability, which leads to the loss of RTIs (Martin, 2016). But Mr. Plumer from Trafic shared with me that the firm cannot quantify the number of losses because, by experience, managers know that an annual inventory would cost them more in terms of energy, time and money that what they actually lose. The CHU[6] Logistic Center also faces the issue of non-coming back RTIs and one of the reasons may also be the fact that internal clients, i.e. the care units in the hospitals, use the plastic boxes as storage devices (Martin, 2016). Ms. Limbourg, when visiting Bubble Post, Baxter and the CHU, also had the opportunity to realize how serious the problem of lost RTIs was for these organizations operating in different fields and using different types of RTIs.

To tackle this phenomenon, some organizations have set up some measures, as for example a guarantee system. AGC Glass Europe, Bidvest and Colruyt use this system as an incentive for

[5] Colruyt is a Belgian supermarket chain that has become an important player in the distribution sector of four countries. It has always used RTIs (pallets, rolls and plastic trays) for storage, handling and protection reasons.

[6] The CHU Logistic Center is the logistic center of the only academic hospital complex of Wallonia. It is new and has a storage capacity of almost 7,000 m². It has switched to the use of RTIs recently for some items and for a long time (e.g. rolls) for some others. The use of rolls is imposed by the infrastructure constraints of the hospitals. Its customers are actually care units of hospitals (Martin, 2016).

customers to return the RTIs. Other methods such as a penalty system, a clause in a contract or a tracking system can also be used. Baxter[7] for instance uses barcodes for its most expensive returnable items. The implementation of a RFID system could also reduce the number of lost RTIs. For instance, Trafic does not use the RFID technology but managers pay close attention to it because they that think it could be very interesting for the traceability and it could also increase the productivity. Having the name of the company on the RTI however does not seem to be sufficient because some organizations sometimes find some RTIs with names of partners or competitors on them (Martin, 2016).

As seen in the literature review, it seems according to various authors and studies that the loss rate ranges between 9% and 20%. Bubble Post reports that only 1 to 2% of their boxes get lost after an 8-month cycle. The CHU, Baxter and AGC Glass Europe as for them estimate their annual loss rate to amount to 10% (Martin, 2016). Martin (2016) resumed the information she obtained from her survey thanks to the graph displayed in Appendix 4: the majority of the organizations are confronted to a loss rate inferior to 5%, a bit more than one third lose between 6 and 10% of their RTIs and less than one fifth face a loss rate of minimum 10% (Martin, 2016).

3.1.2 Description of the model

This adaptation of the initial model enables to take into consideration three main specificities existing in organizations managing RTIs: durability, resale and losses. Firstly, an RTI does not have an unlimited lifespan. Each time it is used, it gets a bit more deteriorated, until the moment it cannot be used anymore. Then, the company has to get rid of this unusable RTI. Depending on the type of RTI, the company will either be able to resale it and get some money from it or it will have to get the RTI out of the system by paying a certain amount of money. It is also possible that taking this RTI out of the system does not cost anything nor bring in some money. Finally, losses are a quite frequent problem encountered by organizations that deal with RTIs. These three specificities have been thought by having a look at what happens in practice in organizations thanks to the Master thesis of Martin (2016) and by drawing some inspiration from the durability and collection aspects developed in the article of Geyer et al. (2007). As explained in the literature review, this article studies a

[7] Baxter is worldwide healthcare enterprise whose core business is about developing, manufacturing and manufacturing pharmaceutical products. It uses euro-pallets, rolls, plastic boxes, plastic trays and wheeling plastic pallets.

remanufacturing system through collection of used products. Yet, the remanufacturing aspect is not present in the issue at hand. Indeed, the model developed in the thesis considers that RTIs, which are used to pack goods for their distribution from a producer at the depot to the set of customers, can be collected until they have been used l times, l being the maximum number of lives. Moreover, RTIs are only resold when they reach their end of life and resale is assumed to take the form of a raw materials recovery in our model, whereas, in the paper of Geyer et al. (2007), resale is described as a possible recovery from the disposal costs of collected items that cannot be remanufactured. Compared to the cost function used in the model of Geyer et al. (2007), our cost function only takes into account the disposal cost, which is actually in our case a disposal revenue because end-of-life RTIs are assumed to be resold at a certain price a. So the product of the number of RTIs disposed and the resale price a is subtracted from the objective function to minimize. The collection cost as for it does not exist in our model because it is assumed that the collection of used RTIs is the norm (losing RTIs being the exception) and does not involve any effort and cost.

Then, a great part of the model of Iassinovskaia et al. (2017) can be picked up to formulate the modified model:
"The PDIRPTW problem is defined on a directed graph $G = (N, A)$ where N is the set of nodes indexed by $i, j \in \{0, \ldots, n\}$ and $A = \{(i, j): i, j \in N, i \neq j\}$ is the arc set. Node 0 represents the producer location and the set $N_0 = N \backslash \{0\}$ denotes the customer locations. Each customer i has a demand u_{it} at period t. Moreover, each customer and the producer incur unit inventory holding costs per period ($\forall i \in N$), h_i^L for the loaded RTI and h_i^E for the empty RTI, with inventory capacities C_i^L for the loaded RTI and C_i^E for the empty RTI. Inventories are not allowed to exceed the holding capacity and must be positive. The length of the planning horizon is p with discrete time periods $t \in T = \{1, \ldots, p\}$" (Iassinovskaia et al., 2017, p.5).

A fleet of identical vehicles $v \in V = \{1, \ldots, \boldsymbol{f}\}$ of a capacity Q is used for the transport. The capacity Q is expressed in terms of number of RTIs. Empty and loaded RTIs are assumed to take the same place in a vehicle. Then, a fixed cost per km α and a variable cost per tonne.km β are incurred. The average speed of the vehicle is s km/h. *"An empty RTI weights w_E, and a loaded RTI weights w_L. Each vehicle is able to perform a route per period, from the producer to a subset of customers. At the customer's gate, a fixed time in hours, g is incurred. A* *distance d_{ij} is associated for all $(i, j) \in A$. The service of a customer $i \in N_0$ can begin within a time window $[e_i, l_i]$. The vehicle cannot arrive earlier than time e_i and no later than time l_i.*

The producer is assumed to have sufficient inventory and capacity to perform all of the pickups and deliveries during the planning horizon. The cost to buy a new RTI is b; the production cost per RTI is c, including inspection and cleaning costs incurred at the producer and is proportional to the number of RTIs used at the producer" (Iassinovskaia et al., 2017, p.5).

Each RTI has a level of utilization $k \in K = \{0, \ldots, l\}$. An RTI is said to have been used once when a customer i $(i \neq 0)$ empties it after having satisfied its demand. The degree of utilization of the RTI increases each time this action occurs at the customer. So, an RTI with a degree of utilization of *0* is an RTI that has never been used and the level of utilization *l* corresponds to the end-of-life level. When an RTI reaches this degree of utilization *l*, it is resold at a price *a* and it is thus taken off from the company. If *l* was set to 1, the model would not reflect an RTI management anymore since it would mean that the items are only used once and then resold, i.e. they would lose their returnable nature and become disposable items. The subset $\mathrm{K}_0 = \mathrm{K}\backslash\{0\}$ indicates the levels of actual utilization (i.e. excluding the level "never used") and this notation will be used in the model.

"*At the beginning of the planning horizon, the producer knows current inventory levels: I_{ik0}^{L} of the loaded RTI and I_{ik0}^{E} and receives information on the demand u_{it} of each customer i for each period t"* (Iassinovskaia et al., 2017, p.5). However, the level of utilization *k* of the RTIs used to satisfy this demand is not known. So the decision variable $\tilde{u}_{ikt}$ is created as a way to determine which RTIs (i.e. with which level of utilization) are used to satisfy the known demand u_{it}.

It is also assumed that only a proportion γ of the empty RTIs returned from the customers are collected at the producer. It is indeed assumed that the rest of the empty RTIs returned *(1- γ)* is assumed to have got lost.

"*The objective of the problem is to minimize the total cost while satisfying the inventory level constraints for each customer in each period. It is assumed that every customer can only be* *visited exactly once. Moreover, a penalty cost per unit of time ε, is added for the time length of the route, δ_{vt}.*

Decision variables used in the formulation are a set of binary variables y_{ijvt} equal to 1 if and only if arc (i,j) is used on the route of vehicle v in period t; the integer variables are listed as follows:" (Iassinovskaia et al., 2017, p.5).

I^L_{ikt} inventory level of loaded RTIs with a degree of utilization k, at customer i, at the end of period t;

I^E_{ikt} inventory level of empty RTIs with a degree of utilization k,at customer i, at the end of period t;

q_{ikt} quantity of loaded RTIs with a degree of utilization k delivered to customer i in period t;

r_{ikt} quantity of empty RTIs with a degree of utilization k returned from customer i in period t;

x_{ijkt} quantity of loaded RTIs with a degree of utilization k transported from customer i to customer j in period t;

z_{ijkt} quantity of empty RTIs RTIs with a degree of utilization k transported from customer i to customer j in period t;

p_{kt} quantity of RTIs with a degree of utilization k filled at the depot in period t;

n_t new RTI quantity bought and filled from the producer in period t;

$\tilde{u}_{ikt}$ quantity of RTIs with a level of utilization k used to satisfy the demand of customer i in period t;

and the real variables are:

m_{ivt} arriving time of vehicle v to customer i in period t

δ_{vt} the time length of the route.

The PDIRPTW with durability constraints is then formulated as follows:

$$\text{minimize} \sum_{i\in N}\sum_{j\in N}\sum_{t\in T}\left(\alpha \sum_{v\in V} y_{ijvt} + \beta \sum_{k\in K}(w_L x_{ijkt} + w_E z_{ijkt})\right) d_{ij}$$
$$+\sum_{i\in N}\sum_{t\in T}\sum_{k\in K}(h_i^L I^L_{ikt} + h_i^E I^E_{ikt}) + \sum_{t\in T} c\, p_{kt} + \sum_{t\in T} b\, n_t + \sum_{v\in V}\sum_{t\in T}\varepsilon\, \delta_{vt} - a\sum_{t\in T} I^E_{0lt}$$

(1)

Subject to:

$\sum_{k\in K}(x_{ijkt} + z_{ijkt}) \leq Q \sum_{v\epsilon V} y_{ijvt}$	$\forall\,(i,j) \in A, \forall t \in T$	(2)
$I^L_{ikt} = I^L_{ikt-1} + q_{ikt} - \tilde{u}_{ikt}$	$\forall i \in N_0, \forall\ t \in T, \forall k \in K$	(3)
$I^E_{ikt} = I^E_{ikt-1} - r_{ikt} + \tilde{u}_{ik-1t}$	$\forall i \in N_0, \forall\ t \in T, \forall k \in K_0$	(4)
$I^E_{i0t} = I^E_{i0t-1} - r_{i0t}$	$\forall i \in N_0, \forall\ t \in T$	(4')

$I_{0kt}^{L} = I_{0kt-1}^{L} + p_{kt} - \sum_{i \in N} q_{ikt}$ $\quad \forall\, t \in T, \forall k \in K$ (5)

$I_{0kt}^{E} = I_{0kt-1}^{E} - p_{kt} + \gamma \sum_{i \in N} r_{ikt}$ $\quad \forall\, t \in T, \forall k \in K_0 \backslash \{l\}$ (6)

$I_{00t}^{E} = I_{00t-1}^{E} - p_{0t} + n_t + \gamma \sum_{i \in N} r_{i0t}$ $\quad \forall\, t \in T$ (6')

$I_{0lt}^{E} = \gamma \sum_{i \in N} r_{ilt}$ $\quad \forall\, t \in T$ (6")

$0 \leq \sum_{k \in K} I_{ikt}^{L} \leq C_i^L$ $\quad \forall i \in N, \forall\, t \in T$ (7)

$0 \leq \sum_{k \in K} I_{ikt}^{E} \leq C_i^E$ $\quad \forall i \in N, \forall\, t \in T$ (8)

$p_{kt} \leq I_{0kt-1}^{E}$ $\quad \forall\, t \in T, \forall k \in K_0 \backslash \{l\}$ (9)

$p_{0t} \leq I_{00t-1}^{E} + n_t$ $\quad \forall\, t \in T$ (9')

$\sum_{i \in N, i \neq j} (x_{ijkt} - x_{jikt}) = q_{jkt}$ $\quad \forall\, j \in N_0, \forall\, t \in T, \forall k \in K$ (10)

$\sum_{i \in N, i \neq j} (z_{ijkt} - z_{jikt}) = r_{jkt}$ $\quad \forall\, j \in N_0, \forall\, t \in T, \forall k \in K$ (11)

$\sum_{i \in N, i \neq j} y_{ijvt} - \sum_{i \in N, i \neq j} y_{jivt} = 0$ $\quad \forall j \in N, \forall v \in V, \forall t \in T$ (12)

$\sum_{i \in N} \sum_{v \in V} y_{ijvt} \leq 1$ $\quad \forall j \in N_0, \forall t \in T$ (13)

$\sum_{j \in N_0} y_{0jvt} \leq 1$ $\quad \forall v \in V, \forall t \in T$ (14)

$r_{ikt} \leq I_{ikt-1}^{E}$ $\quad \forall i \in N_0, \forall\, t \in T, \forall k \in K$ (15)

$q_{ikt} \leq I_{ikt}^{L}$ $\quad \forall i \in N_0, \forall\, t \in T, \forall k \in K$ (16)

$\gamma \sum_{i \in N} r_{ikt} \leq I_{0kt}^{E}$ $\quad \forall\, t \in T, \forall k \in K$ (17)

$\sum_{i \in N} q_{ikt} \leq I_{0kt-1}^{L}$ $\quad \forall\, t \in T, \forall k \in K$ (18)

$e_i \sum_{j \in N, j \neq i} y_{ijvt} \leq m_{ivt} \leq l_i \sum_{j \in N, j \neq i} y_{ijvt}$ $\quad \forall i \in N, \forall v \in V, \forall\, t \in T$ (19)

$m_{ivt} + y_{ijvt}\left(g + \frac{d_{ij}}{s}\right) - \max_{i \in N} l_i\ (1 - y_{ijvt}) \leq m_{jvt}$

$\forall i \in N, j \in N_0, i \neq j\ \forall v \in V, \forall\, t \in T$ (20)

$0 \leq \delta_{vt} \leq \max_{i \in N} l_i$ $\quad \forall v \in V, \forall\, t \in T$ (21)

$m_{ivt} + y_{i0vt} * \left(g + \frac{d_{i0}}{s}\right) - \max_{i \in N} l_i\ (1 - y_{i0vt}) \leq \delta_{vt}$

$\forall i \in N, \forall v \in V, \forall\, t \in T$ (22)

$\sum_{i \in N} \sum_{v \in V} \sum_{t'=t_1}^{t_2} y_{ijvt} \geq \left\lceil \frac{\sum_{t'=t_1}^{t_2} (u_{jt'} - C_j^L)}{min\{C_j^L, Q\}} \right\rceil$ $\quad \forall j \in N_0, \forall\, t_1, t_2 \in T, t_1 \geq t_2$ (23)

$I_{ikt}^{L}, I_{ikt}^{E}, q_{ikt}, r_{ikt}, x_{ijkt}, z_{ijkt}, n_t, p_{kt}, \tilde{u}_{ikt} \in \mathbb{Z}^+$ $\quad \forall\, i, j \in N, \forall t \in T$ (24)

$y_{ijvt} \in \{0,1\}$ $\quad \forall\, (i,j) \in A, \forall v \in V, \forall t \in T$ (25)

$\sum_{k \in K \backslash \{l\}} \tilde{u}_{ikt} = u_{it}$ $\quad \forall\, t \in T, \forall i \in N_0$ (26)

"The objective function (1) minimizing the total cost. The first sum of the objective function corresponds to transportation costs, the second sum corresponds to the inventory costs of empty and loaded RTIs at both customer locations and the depot, the third sum is the production cost, the fourth sum represents the cost to buy new RTIs, the fifth term is the penalty cost due to the driver's waiting time" (Iassinovskaia et al., 2017, p.6) and the last term is the resale of RTIs that have reached a level of utilization *l* and that are back at the depot, whatever the period of time.

"*Constraints (2) state that the vehicle capacity is not exceeded. Constraints (3) state the inventory conservation condition for the loading of RTIs over successive periods*" (Iassinovskaia et al., 2017, p.6). The inventory of RTIs with a degree of utilization k in period t is the inventory held at the end of the previous period, plus the loaded RTIs quantity of a level of utilization k delivered from the producer minus the quantity of RTIs of level k used to satisfy the demand. Similarly, for empty RTIs, constraints (4) express the inventory conservation conditions over successive periods. The inventory of RTIs of a degree k in period t is the inventory held at the end of period $t-1$, minus the quantity of empty RTIs of level k returned plus the quantity of RTIs of level $k-1$ that have been used to satisfy the demand. The demand term here has a degree of utilization $k-1$ because of the definition of utilization. Indeed, an RTI is assumed to have been used once when a customer i ($i \neq 0$) empties it after having satisfied the demand. This constraint is actually the one enabling the transition from one level of utilization k to the following. Constraints (4') describe the particular case of constraints (4) for $k = 0$, i.e. for RTIs that have never been used. So, since the demand term expresses precisely the utilization, it is logically not present in these constraints. Concerning the inventory conservation conditions over successive periods at the depot, constraints (5) state that the inventory of loaded RTIs of a degree of utilization k in period t is the inventory held in period $t-1$, plus the quantity of RTIs of degree k filled, minus the number of loaded RTIs sent to customers. Likewise, constraints (6), (6') and (6'') state the inventory conservation conditions for the empty RTIs situated at the producer. Constraints (6) express that, for $0<k<l$, the inventory in period t is equal to the inventory held in the previous period, minus the number of RTIs filled by the producer, plus the number of empty RTIs that customers return and that have been collected at the depot (i.e. that have not got lost). Constraints (6'), for $k = 0$, are similar to constraints (6), except that the term n_t is added in the right member of the constraints. Indeed newly bought RTIs can only have a degree 0 of utilization, hence the appearance of this term here. Constraint (6'') state that, for $k = l$, the inventory of empty RTIs at the producer is only composed of empty RTIs that have been returned by customers and that have been collected at the depot (i.e. that have not got lost). Indeed, once RTIs of degree l are back at the producer, they are directly resold and do not appear anymore in the firm at the following period of time. The model actually assumes that the resale can only take place at the producer. "*Constraints (7) and (8) define the bounds on the inventory of loaded (7) and empty RTIs (8) held by each customer throughout all periods*" (Iassinovskaia et al., 2017, p.6).

Constraints (9) ensure that, for *k = 0*, for *0<k<l*, the quantity of RTIs that the producer fills in period t is not superior to the quantity of empty RTIs held in the inventory in the previous period. In the same way, for *k = 0,* constraints (9') state that the quantity of RTIs that the producer fills in period t is not superior to the quantity of empty RTIs held in the inventory in the previous period plus the quantity of newly purchased RTIs. The term n_t only appears for *k = 0* because new RTIs can only have a degree of utilization of *0*. "*Constraints (10) indicate that loaded RTI quantities are delivered and constraints (11) that the empty RTIs are returned.*

Constraints (12), (13), (14) and (20) ensure that the proper vehicle routes are constructed. Constraints (12) stipulate if a vehicle v *visits customer j in period* t*, it has to leave customer j in period* t*. Constraints (13) ensure that at the most, a vehicle visits a customer per period. Constraints (14) ensure that vehicles leave the producer only once per period or stay at the depot.*

Constraints (15-18) ensure the closed-loop chain" (Iassinovskaia et al., 2017, p.6). Constraints (15) guarantee that the number of empty RTIs returned was held in the inventory of the previous period. Constraints (16) state that the quantity of loaded RTIs delivered is held in the inventory. Constraints (17) express that the number of empty RTIs of degree of utilization *k* returned to and collected at the producer (i.e. that have not got lost) is held in its inventory. Constraints (18) ensure that the quantity of loaded RTIs of degree of utilization *k* delivered to the customers was held in the inventory of the producer during the previous period.

"*Constraints (19) ensure that at each customer location, the vehicle arrives within the time window. Constraints (20) ensure that the arrival time at customer j has a greater value than arrival time at customer i in one route. Those constraints do not need to be satisfied when the vehicle v does not travel from node i to node j in period t. Constraints (21) ensure that the waiting time is lesser than the maximum arrival time and constraints (22), combined with the objective function, guarantee that the vehicle returns to the depot directly after serving the last customer.*

Based on Coelho and Laporte (2014), the valid inequalities (23) are related to whether the demand of customer j for period $[t_1, t_2]$ *is greater than its inventory capacity then a visit is* *required"* (Iassinovskaia et al., 2017, p.6). These constraints make the running time needed to prove optimality decrease and thus, have a positive impact on solving the instances. Then, constraints (24) and (25) respectively express non-negativity and binary conditions on the different variables. Lastly constraints (26) are added to make the link between the decision variable $\tilde{u}_{ikt}$ and the data matrix u_{it}. Only the RTIs that can be used further, at least one more time, to satisfy demand are considered here ($K \setminus \{l\}$).

The approach is based on a mixed integer linear program and the model is tested on small-scale instances. IBM ILOG CPLEX 12.5 is used with the default parameters to resolve the instances.

3.1.3 Analysis

This section aims at explaining and analyzing the results obtained from the model described in the previous section by considering two situations: a situation with one customer and a situation with several customers. First, the input data that are common for both situations are given. Then, the input data that differ are given in the respective subsections. For the subsection with one customer, the initial and new model are described and illustrated thanks to schemes. Then, a comparison is made between the two models. The subsection about the situation with the multiple customers is more straightforward since the main explanations have already been given in the case with one customer and the two models are also compared.

3.1.3.1 Input data

Firstly, the parameters set for the following computations were chosen in order to enable the optimization within a reasonable running time. A trade-off had to be made between the values of *l*, *p* and *n*, i.e. the respective maximum values of *k*, *t* and *i*. The instance built is very similar to one of the instances used in the article of Iassinovskaia et al. (2017). It considers a planning horizon of 4 periods, a fleet of 2 vehicles; and introduces 2 levels of utilization.

Then, the following data are taken from the instance used as an illustration in the paper of Iassinovskaia et al. (2017):

- *"Each vehicle has a capacity Q=25 RTIs,a fixed transportation cost α=0.8€/km, a variable cost β=0.02€/(km.item),we assume that the difference between an empty RTI* *weights and a loaded RTI is not significant and each vehicle has an average speed s=50 km/h;*

- h_0^L *= 0.015€ /(day.item);* h_0^E *0.01€ /(day.item) ;* h_i^L *= 0.035€ /(day.item) ;* h_i^E *= 0.03€ /(day.item) ;*
- *the maintenance cost is c=0.02€/item;*
- *the cost to buy a new RTI is b=10€;*
- *a penalty cost: ε=0.01€/min;*
- *the time needed at the customer's gate: g=10min"* (Iassinovskaia et al., 2017, p.7).

Then, for the new model, the following parameters are added:

- The price to resell an RTI is *a* and is set to 5;
- the collection rate is γ and set to 0.5.

The distances are also taken up from the article of Iassinovskaia et al. (2017):

"A set of spatial coordinates of customers is randomly generated as integers in a square of 100 units, and the location of the depot is at (0.0) in the center of the square. Distances between depot and customers and between each customer are calculated as Euclidian distances" (Iassinovskaia et al., 2017, p.7).

Table 2
Distance matrix.

km	Depot	C1	C2	C3	C4	C5	C6	C7
Depot	0	24	64	57	25	34	45	36
C1	24	0	43	79	33	22	33	60
C2	64	43	0	122	75	58	30	98
C3	57	79	122	0	53	76	101	31
C4	25	33	75	53	0	23	65	46
C5	34	22	58	76	23	0	56	66
C6	45	33	30	101	65	56	0	74
C7	36	60	98	31	46	66	74	0

Figure 5: *Distance matrix (retrieved from Iassinovskaia et al., 2017, p.7).*

Finally, concerning the time windows:

"We assume that each driver can operate 420 min (7 h) per day and that the day begins at time 0. All customers have a time window in minutes $[e_i, l_i]$ *= [0,420]. But some customers may have a tight time window, that is why, we randomly select two customers for which one of these two time windows [0,100] or [150,250] is assigned"* (Iassinovskaia et al., 2017, p.7)

3.1.3.2 Model with one customer

This section aims at illustrating the differences between the functioning of the initial model and the modified model. Although the consideration of only one customer does not represent a pickup and delivery problem, it enables a better understanding of the mechanism of two models and of the modifications that have been brought.

3.1.3.2.1 Input data – Complement

This model obviously considers a value of n of 1. For the new model, resale price a has been set to 5€ and the collection rate γ to 0.5. The maximum degree of utilization l is set to 2. Then, concerning the demand of this customer, it is assumed to be constant over time and set to 10. The inventory capacity is set to 30 for both the producer and the customer. Then, for the initial model, the initial inventory level for loaded RTIs is set to 10 at the depot and to 20 at the customer. For the empty RTIs, it is set to 0 at the depot and to 10 at the customer. For the modified model however, since one should take into account that RTIs of different level of utilization are available in the initial inventory, the inventory levels chosen for the initial model have been split into two between the degree of utilization 0 and 1. Yet at the depot they stay the same.

3.1.3.2.2 Initial model

The goal of this section is to illustrate the functioning of the initial model in order to better understand it and to make the comparison with the modified model easier.

Firstly, the costs generated when running the initial model with one customer and with the data above-mentioned are exposed in Table 1. It can be observed that the transportation cost represents the greatest part the total cost and amounts to 48.52% of the total cost. Then the cost to purchase new RTIs equals 48.13% of the total cost which is quite a lot. The rest of the costs combined only reach 3.35% of the total cost, which is not significant. It is also the reason why they are considered in one set; taking them into account separately would not make sense.

Total cost (€)	Transportation cost (€)	Inventory holding cost (€)	Maintenance cost (€)	New RTIs cost (€)	Penalty cost (€)	Running time (s)
207.75	100.8	5	0.4	100	1.55	0.92

Table 1: *Details of the costs of the initial model with one customer.*

Then, Figure 7 enables to understand what actually happens in the inventories of both the producer and the customer, as well as what are the flows and interactions. For the sake of clarity, this scheme is presented in this section because it is much easier to represent the RTIs inventories and flows when considering only one customer. Figure 6 is the key that will be used for both this scheme and the one of the modified model.

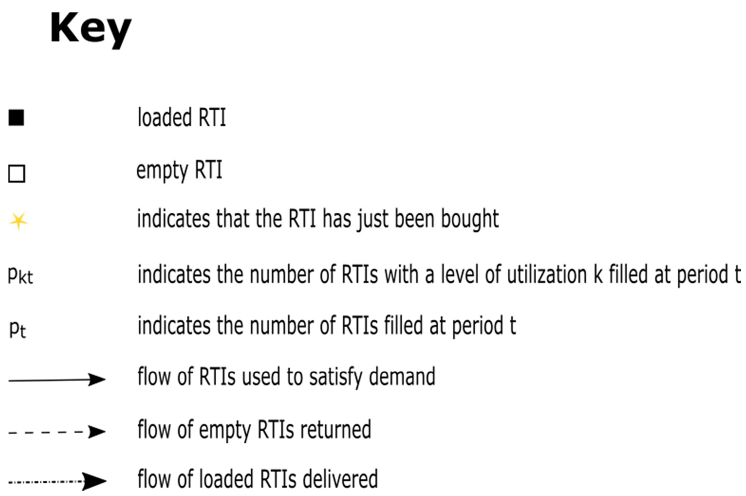

Figure 6: *Key of the schemes of the initial and new models*

At time 0, the inventories of both the producer and the customer are the ones that have been described in the input data section since these are given data. The inventory of loaded RTIs at the producer equals 10 and there is no inventory for empty RTIs. Then, for the customer, the inventory of loaded RTIs is equal to 20 and the one of the empty items is equal to 10. Then, at period 1, 10 brand-new RTIs are bought at the depot. These are automatically filled. At the customer's, the demand of 10 RTIs (the demand being constant over time) of period 1 is satisfied, which means that 10 of the loaded RTIs of period 0 find themselves emptied in period 1. Then, at period 2, several flows can be observed: the 20 loaded RTIs that were at the depot at period 1 are delivered to the customer and the 20 empty RTIs that were at the customer's at period 1 are returned to the producer. The demand of period 2 is satisfied, which means that 10 RTIs that were loaded at period 1 are now emptied. At period 3, the only flow consists in the demand satisfaction. However, 10 empty RTIs are filled at the depot.

Finally, at the last period, the demand is satisfied and 10 loaded RTIs are sent by the producer to the customer. The final inventory levels are thus constituted of 10 empty RTIs at the depot and 30 empty RTIs and 10 loaded RTIs at the customer's.

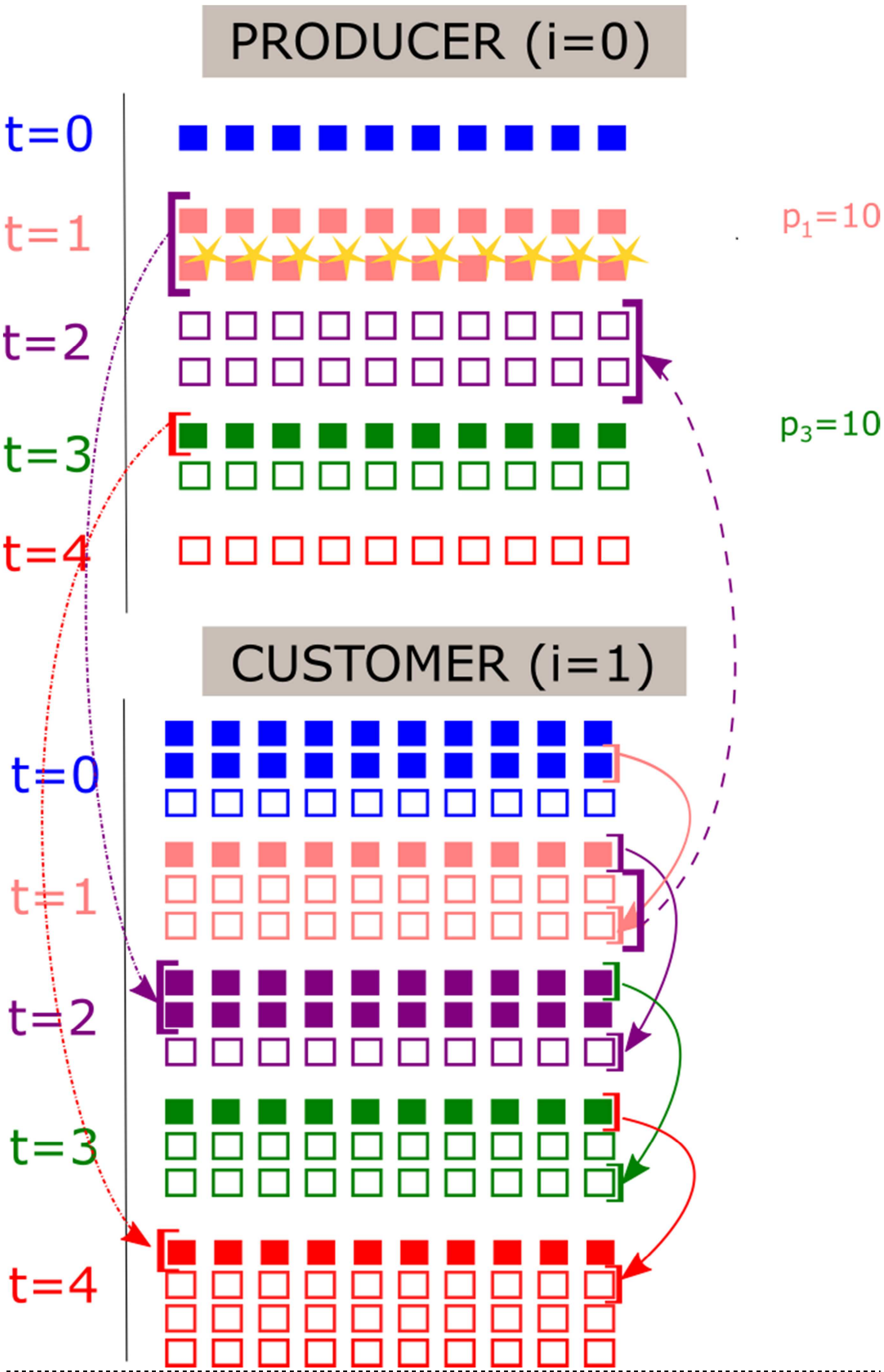

Figure 7: Scheme of the initial model when considering several customers

3.1.3.2.3 New model

The aim of this section is very similar to the previous one, except that it is about the modified model, and the same structure will be followed.

Table 2 gives the values of the different terms composing the total cost function of the modified model. The total cost function of this model presents a particularity: one of its terms is a revenue and is thus introduced by a minus sign, having a negative impact on the total cost. The main two costs are again the transportation cost and the cost to buy new RTIs. The resale revenue stands at -12.74% of the total cost. The other types of cost have significantly less impact on the total cost.

Total cost (€)	Transportation cost (€)	Inventory holding cost (€)	Maintenance cost (€)	New RTIs cost (€)	Penalty cost (€)	Resale Revenue (-) (€)	Running time (s)
196.21	104.64	4.62	0.4	110	1.55	25	1.20

Table 2: *Details of the costs of the new model with one customer.*

Then, in the same manner as Figure 7, Figure 8 enables to explain what actually occurs in the inventories of both the customer and the producer and what are the flows and interactions between them and inside of their own inventory. Figure 6 is also the key used for this scheme.

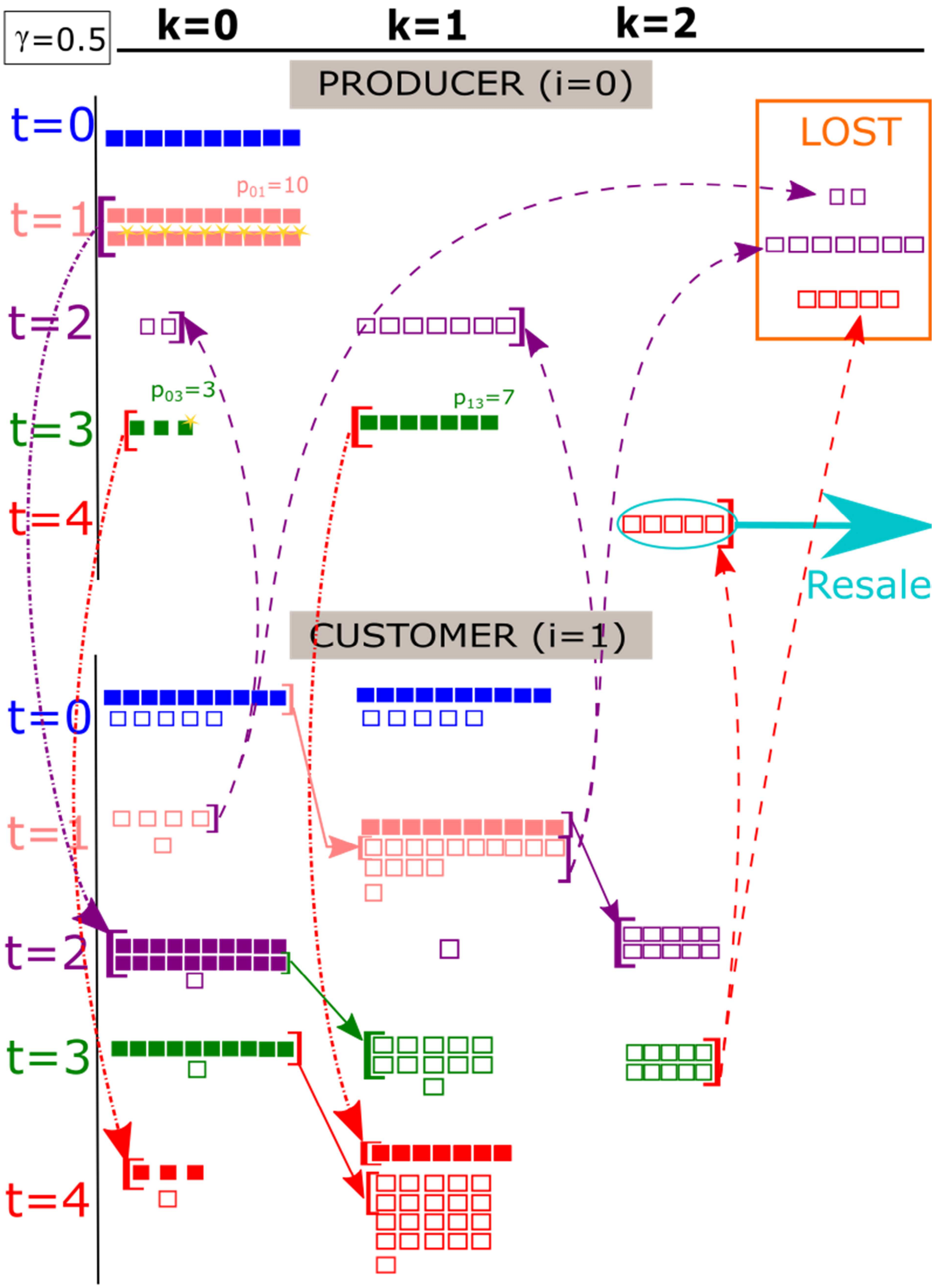

Figure 8: *Scheme of the new model when considering only one customer.*

At period 0, the inventory levels of the producer and of the customer are the ones set in the input data, as it was the case in the scheme of the new model. At the depot, the inventory of loaded RTIs that have never been used is equal to 10 and this is the only kind of inventory available at the producer's. At the customer's, there are, for both the degrees of utilization $k=0$ and $k=1$, 10 loaded RTIs and 5 empty RTIs. At time 1, 10 new RTIs are purchased (at the depot). These RTIs, as they are brand-new, have a degree of utilization $k=0$. They are automatically filled. At the customer's, the demand of period 1 is satisfied by using the loaded RTIs that were available at period 0 and that have never been used. It is the model that has chosen to use RTIs with this degree of utilization. It could have chosen the ones with a degree of utilization $k=0$. According to the definition of the utilization, since these RTIs are used to satisfy the demand, they go from the level of utilization $k=0$ to the following ($k=1$). So these RTIs undergo 3 modifications and it is always the case for the demand satisfaction in this model: they see their degree of utilization increase by 1, they are emptied and we can find them in the inventory of the next period. Then, at period 2, different interactions happen. Firstly, 20 loaded RTIs that were at the depot at period 1 are delivered to the customer. Then, the demand is satisfied by emptying 10 loaded RTIs with a degree of utilization $k=1$. These items therefore go from a level of utilization $k=1$ to $k=2$. Finally, 4 empty RTIs with $k=0$ and 14 with $k=1$ are sent from the customer to the producer. However, once at the producer, only the half of them remains: 2 with $k=0$ and 7 with $k=1$. The other half has got lost. The proportions of collected and lost items are due to the collection rate which was set to 0.5. Period 3 does not witness a lot of interactions: only the demand satisfaction, as already described for other periods. Moreover, one RTI is bought (and obviously appears in the inventory of unused RTIs) and is directly filled. The other 2 empty RTIs that were present at the previous period with a degree $k=0$ are also filled. In addition to these 3 RTIs filled, the 7 empty RTIs with a degree $k=1$ that were present at period 2 are also filled. Finally, at period 4, the three kinds of movement appear. The demand satisfaction occurs, according to the definition of utilization. Then, loaded RTIs of level of utilization $k=0$ (3 items) and $k=1$ (7 items) are sent to the customer. And some empty RTIs are sent back to the depot. Half of them disappear and the other half can be found at the inventory of the depot. These RTIs have a degree of utilization $k=2$, which means that the ones that are collected are all going to be resold once they arrive at the producer's, at a price set to 5€. Indeed, if the model presented a fifth period of time, one would notice that these RTIs do not appear anymore in the producer's inventory of empty RTIs for $k=2$, neither in another one. Yet a remark can also be made: the fact that RTIs are in different inventories according to their level of utilization only aims at making the scheme clearer. It is not the case in real life. Contrarily, the initial model, due to the inventory capacity constraints, seems to assume that loaded and empty RTIs at both the producer's and the customers' are stored in different locations. And this constraint has not been modified in this new model.

3.1.3.2.4 Comparison between the two models

When comparing the two models, one can directly notice that the total cost is lower for the new model. This can seems surprising since adding constraints is supposed to increase the total cost. However, one of the terms of the objective function is revenue, which can reduce the total cost. In addition, as it will be shown in the parametric study, depending on the values of a and γ and on the data encoded, it is possible to have a lower total cost for the new model. This happens when the resale revenue is high enough to compensate for the increase in the other costs. And this is actually what can be observed here in the new model. Each cost has either increased or remained equal and what makes this total cost decrease under the total cost of the initial model is the resale revenue.

	Total cost (€)	Transportation cost (€)	Inventory holding cost (€)	Maintenance cost (€)	New RTIs cost (€)	Penalty cost (€)	Resale Revenue (-) (€)	Running time (s)
Model without durability, resale and losses	**207.75**	100.8	5	0.4	100	1.55	/	0.92
Model with durability, resale and losses	**196.21**	104.64	4.62	0.4	110	1.55	25	1.20

Table 3: *Comparison of the costs of the initial and new models for one customer.*

A first point of similarity is the fact that the total costs of both models are composed by roughly the same proportion of the different costs. Indeed, the two main costs composing the total cost at nearly 50% each are the transportation cost and the purchase cost. In addition, both models show the same maintenance cost and penalty cost. Concerning the maintenance cost, it will be shown in the parametric study that it seems to depend only on the demand and initial inventory levels. Since these data are the same for the two models, the maintenance cost is the same as well.

Then, when comparing the running time, the one of the new model is a bit longer than the one of the initial model, which looks logical. Indeed, a model containing additional constraints and an additional dimension will likely take more time to run. The augmentation of the running time amounts to 30.43%.

When comparing the two diagrams, one can notice that in the two schemes, the same types of movement of items happen during a given period of time. Indeed at period 0, no flow can be observed. The only difference concerning period 0 consists in the number of RTIs in inventories, since for the customer, empty and loaded RTIs are split between the levels of utilization $k=0$ and $k=1$. Then, at periods 1, 10 new RTIs are bought and filled in both schemes and the demand of 10 RTIs is satisfied. The only difference at this point is about the definition of utilization, since RTIs that are used and emptied for satisfying the demand see their level of utilization grow. For period 2, three flows of RTIs can be discerned in both schemes, but the returning flows, for the new model, get split into two flows since half of the RTIs get lost and the other half get found at the depot. The other difference is again about the level of utilization. Period 3 highlights very similar interactions in schemes since there is only one movement of RTIs. The difference is again the changing level of utilization when satisfying the demand. Yet a new RTI is also purchased. Finally, for period 4, the difference is more visible. Indeed, the second scheme depicts an additional interaction: a returning flow of RTIs, from which half gets lost. The ones that are found at the depot actually have a degree of utilization $k=2$, *w*hich means that they are resold and disappear from the inventory. The augmentation of the level of utilization also happens at time 4 when satisfying the demand.

In addition, the scheme enables to understand some of the modifications brought to the set of costs. One RTI is bought, which explains the augmentation of the purchase cost by 10. Then, 5 items are resold, which corresponds to the resale revenue that appeared in the new model. Concerning the inventory holding cost, it is lower for the new model, simply because there are less empty RTIs in the inventories: on the one hand, some RTIs get lost and do not arrive at the producer's inventory, and on the other hand, the number of empty RTIs at the customer's during the last period is also lower because the new model generates a flow of returning RTIs that did not exist in the initial model. More generally, the flows are not the same on the two schemes, which implies some differences in the inventories. The difference of empty RTIs at the depot is 26 when comparing the two schemes. At the customer, this difference amounts to 4 RTIs. Since the inventory holding cost for one empty RTI is 0.01€ at the producer's and 0.03€ at the customer's, this results in a decrease in the inventory holding cost of 0.38€. Finally, the increase in the transportation cost can also be explained by the modifications in flows. Some empty RTIs are returned to the depot during time 4, whereas it was not the case in the initial model. This might be explained by the fact that there is an incentive to return these RTIs. Indeed, the model wants to resell these RTIs which have reached their end-of-life before the end of the planning horizon because the additional transportation cost necessary to make the resale possible will definitely be lower than the resale revenue generated.

The fact that some RTIs get lost when returning to the depot does not seem to disturb a lot the system. Indeed, with 14 lost RTIs one could think that the model would have to compensate for these losses by purchasing brand-new items. However, we can notice that it is not the case because only one new RTI is bought, compared to the situation of the initial model. The number of new RTIs purchased would probably increase if the planning horizon was longer. Then, the same reflection is valid for the resale: it would most likely involve the purchase of new RTIs if the time scope was longer since these resold items disappear from the system. But for a narrow planning horizon like we have here, the resale is only synonym of revenue.

3.1.3.3 Model with several customers

3.1.3.3.1 Input data – Complement

This illustration of the model with several customers actually considers 7 customers, i.e. a value of *n* of 7. For the modified model, the collection rate has been set to 0.5, the resale price to 5€, and the maximum level of utilization to 2.

Then, concerning the demand, the values of the initial model are kept. "*The customer's demand for each period t is* a random number generated between 1 and 9." (Iassinovskaia et al., 2017, p.7). It is also assumed that every customer's demand is constant throughout the planning horizon (Iassinovskaia et al., 2016). The values are set to :
" $u_{1t} = 2;\ u_{2t} = 8;\ u_{3t} = 8;\ u_{4t} = 8;\ u_{5t} = 6;\ u_{6t} = 5;\ u_{7i} = 2\ \ \forall t \in T$ " (Iassinovskaia et al., 2017, p.7).

Finally, concerning inventory capacities and initial inventory levels, the rule applied in the instance of the article is also applied here: *"The capacities at the depot are* C_0^L *=* C_0^E *= 10n·2;* C_i^L *=* C_i^E *=* $2u_{it}$ *for the customers. The initial inventory levels of loaded RTIs are equal to the customers' demand for half of the customers and to the demand for the other customers doubled, whereas initial inventory levels of empty RTIs are equal to the demand"* (Iassinovskaia et al., 2017, p.7). However, for the modified model, modification have been brought to the initial inventory levels of both empty and loaded RTIs in order to take into account the possibility to have initially RTIs of different degrees of utilization. That is the reason why, for each customer, these inventory levels have been divided into two between the degrees of utilization 0 and 1. The inventory levels at the depot are not affected by this adaptation: it is 0 for empty RTIs and 10*n* for loaded RTIs.

3.1.3.3.2 Comparison between the two models

The same comparison as the one done for one customer is going to be made in order to see the effects of the addition of customers on the difference between the two models. Then, in the parametric study, the values of *a* and *γ* will be modified in order to stick as much as possible to the initial model and a comparison between the models will be made.

	Total Cost (€)	Transportation Cost (€)	Inventory Holding Cost (€)	Maintenance Cost (€)	New RTIs cost (€)	Penalty cost (€)	Resale Revenue (-) (€)	Time (s)
Model without durability, resale and losses	**1124.45**	1011.5	17.37	1.36	80	14.23		201
Model with durability, resale and losses	**1288.56**	947.42	16.84	1.36	380	12.94	70	151

Table 4: *Comparison of the costs of the initial and new models for several customers.*

What stands out from the cost comparison in Table 4 is the fact that the total cost of the new model is higher than the one of the initial model. As explained previously, this seems to be logical given the additional constraints introduced in the modified model. This increase in the total cost is due to the net increase in the purchase cost. The number of RTIs bought has considerably increased, which is due to the lost and resold RTIs that have to be replaced in order to be able to satisfy the demand of each customer properly. The number of additional new RTIs (30) is more than 2 times higher than the number of resold items (14). Unlike the comparison for one customer, the revenue generated from the resale is not important enough to compensate for the augmentation of the new RTIs cost. Then, the inventory holding cost is also lower, due to the fact that lost and resold RTIs do not have to be stored anymore. Contrary to the analysis with one customer, the transportation cost has decreased in the modified model. This modification depends on the changes in terms of flows that have occurred. The decrease in transportation cost may be due to the fact that the company globally hinders the empty RTIs to return to the depot because it knows that a part of them will get lost. However, as it has been said for the analysis with one customer, it may generate a returning flow at the end of the period for empty RTIs that have reached their maximum number of lives in order to get some resale revenue, but this seems to have a lower impact than the fear of losing RTIs throughout the planning horizon. So, all the types of cost either decrease or remain constant in the modified model, except the purchase cost that skyrockets because of the lost and resold RTIs that have to be replaced. This important increase largely compensate for all the small decreases and for the resale revenue generated.

Then, considering the running time, it is lower for the new model, which seems strange since an additional dimension and additional constraints are supposed to increase the running time. However, as it will be shown in the appendices related to the parametric study, a collection rate of 0.5, for any value of the resale price, is particular in that it needs very few minutes to run, compared to other values of the collection rate. Indeed, the majority of the values of the collection rate do not enable to reach the optimal solution within a reasonable running time.

3.1.4 Parametric study

3.1.4.1 Input data and gap

The parametric analyses are based on the same set of data as the one used for the model with several customers. For running the following cases, a limitation on the gap[8] has been set on IBM ILOG CPLEX. A gap of 5% is accepted if no optimal solution is found within the first 10 minutes of running time. It has even been reduced to 2% for the graph of Figure 16. This

[8] The relative Mixed Integer Programming (MIP) gap is the relative difference *"between the best integer objective and the objective of the best node remaining"*. The gap is computed in the following way: "*|bestnode-bestinteger|/(1e-10+|bestinteger|)*" (IBM, s.d.).

enables to avoid a too long running time and to estimate how far the solution found is from the optimal one. On the following graphs, optimal solutions are recognizable thanks to a purple asterisk. Actually, optimal solutions have been reached for only two values of the collection rate: γ = 0.5 and γ = 1. Since the IRP is a NP-hard problem, it is not reasonable to evaluate and fix a necessary running time instead of a gap, based on only some values of *a* and γ. Indeed, some values may generate an optimal solution after a very short running time whereas some others may need a considerable time. In addition, only even collection rates will be taken into account in some of the graphs because two odd collection rates (0.7 and 0.9) do not reach a tolerable gap within a reasonable running time. Indeed, they do not even reach a gap of 10% after nearly 24 hours of running time. A possible solution to solve such cases is the development of heuristics.

3.1.4.2 Effects of the collection rate

The first analysis that can easily be made consists in examining, for a given resale price per RTI *a*, the total cost as a function of the collection rate γ. Figures 9 express the total cost as a function of the collection rate for $a = 5$. Not surprisingly, the total cost strictly decreases when the collection rate increases. The points $\gamma = 0.7$ and $\gamma = 0.9$ are missing in Figures 9, 10 and 11 due to the too long running time and to the too poor gap reached. Solutions are optimal for $\gamma = 0.5$ and $\gamma = 1$.

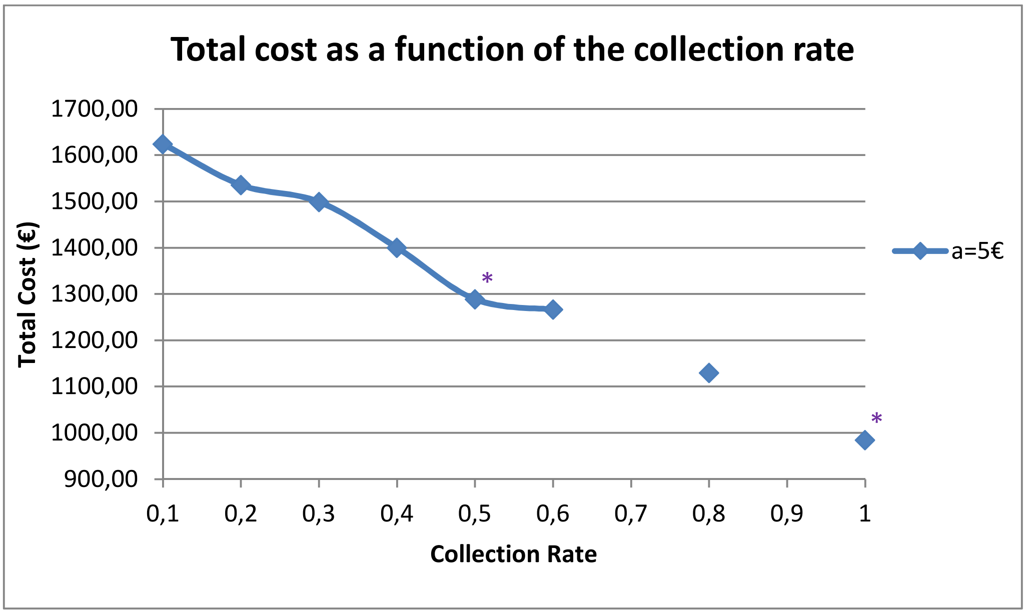

Figure 9: Total cost as a function of the collection rate for a = 5€.

Intuitively, we can imagine that the greater the collection rate, the fewer the new RTIs needed to compensate for the lost RTIs. Another reflection could be the following: the resale revenue increases when γ increases because if fewer RTIs get lost throughout the periods, the number of RTIs reaching the last degree of utilization l will be greater. This second causal relation is nevertheless likely to be weaker because we can suppose that the revenue arising from this resale is globally lower than the new RTIs cost and because the resale revenue has to be nuanced by the probable need to replace resold RTIs with new items. Figure 10 depicts the trends of the total cost, the cost to buy new RTIs and the resale revenue for $a = 5€$ and largely bears out the above reflection. When the collection rate increases, there are two elements that push the total cost to decrease. The first one is the effect of the new RTIs cost because less RTIs have to be bought if the organization is able to get a large portion of them. Then, the second element is the effect of the resale because, for a fixed resale price, more RTIs reach the condition at which they are sold. However, this graph does not confirm the above intuition when it comes to the superior value of the purchase cost over the value of the resale revenue. Indeed, when no RTI gets lost, the resale revenue is higher than the cost to purchase new RTIs. However, this is only true for values of a that are strictly greater than 2, as it will be explained further in the subsection about the effects of the resale price.

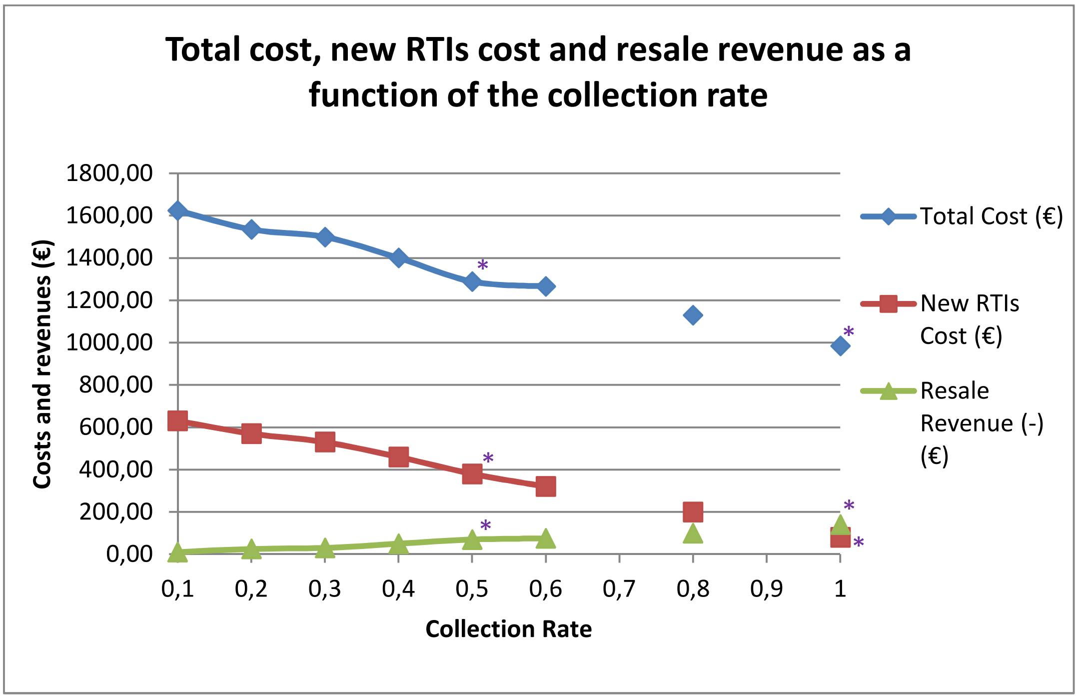

Figure 10: *Total cost, new RTIs cost and resale revenue as a function of the collection rate (for a = 5€).*

Figure 11 shows that the fluctuations of both the penalty and inventory holding costs are not substantial and are not even visible on this graph. Therefore, they do not have any sizable impact on the evolution of the total cost. Concerning the transportation cost, it does not vary a lot. For $\gamma=0.6$, the transportation cost increases a bit and this is precisely the point for which, in Figure 10, the curve of the new RTIs cost was not showing parallelism with the curve of the total cost. So for this point, a link appears to exist between the transportation cost and total cost. Moreover, the transportation cost seems to globally decrease when the collection rate decreases. This may be due to the fact that the model hinders the return of empty RTIs in order not to lose them during the way back. The maintenance cost is not represented on this graph but, as it will be explained later, it is equal to 1.36 for any value of a and γ. Thus this graph demonstrates that the transportation, penalty and inventory holding costs do not influence the evolution of the total cost as a function of the collection rate and for a given value of the resale price. Consequently, only the resale revenue and the new RTIs cost have a considerable impact on the evolution of the total cost, except for some particular points.

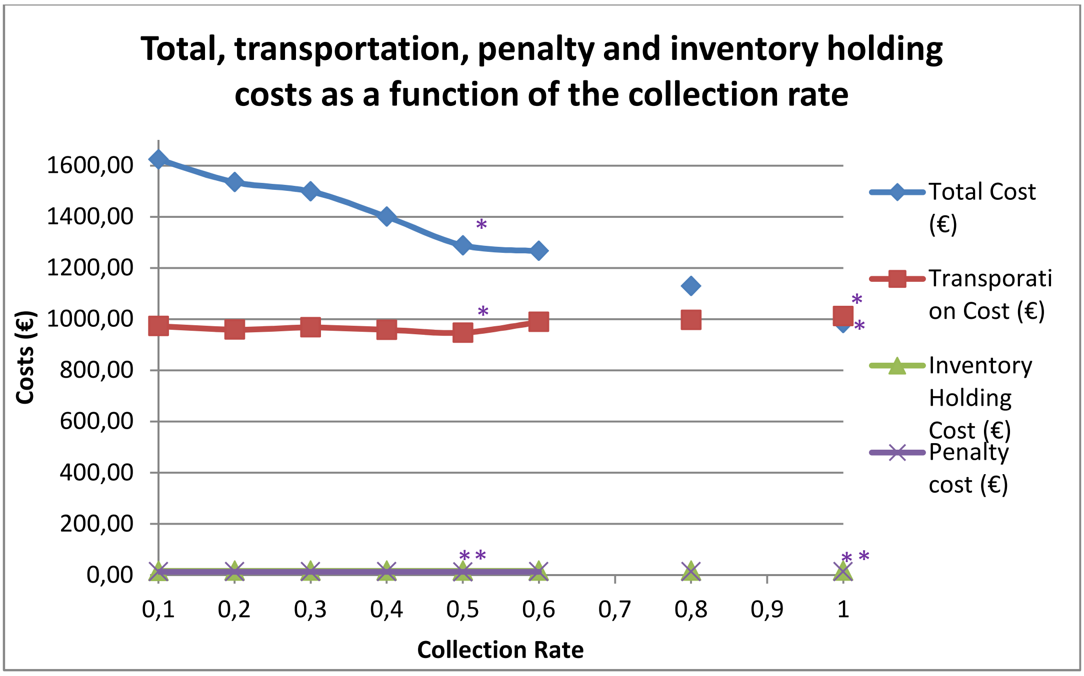

Figure 11 : *Total cost, transportation cost, inventory holding cost and penalty cost as a function of the collection rate (for a = 5€).*

The resale price a has been set to 5 to illustrate an average price, but it also represents properly the global trend that emerges from the other values of a, since the elements constituting the total cost do not vary a lot according to a, as it will be shown later. Therefore, another value of *a* could have been chosen for building these two graphs without any substantial difference.

The detailed data generating the graphs of this subsection are available in Appendix 5.

3.1.4.3 Effects of the resale price

Another type of analysis is based on the variation of the resale price *a*, for a given collection rate *γ*. The total cost is a decreasing function of the resale price, as shown in Figure 12. At first glance, one can notice that the total cost is globally a linear decreasing function of the resale price, even though the trend looks a bit broken for negative values. This is confirmed when looking at the minimization function of the total cost. The resale term, i.e. the only term on which the resale price *a* has an impact, is introduced by a minus sign and basically is the product of the resale price and the number of RTIs at the depot that have reached their end-of-life. The value *"a = -2€"* should be understood throughout this parametric study as the fact that the resale revenue becomes a disposal cost (cost of 2€ per RTI thrown away). Contrarily, the curve of the total cost as a function of the collection rate (Figure 9) is much less straight because the collection rate impacts several elements of the objective function.

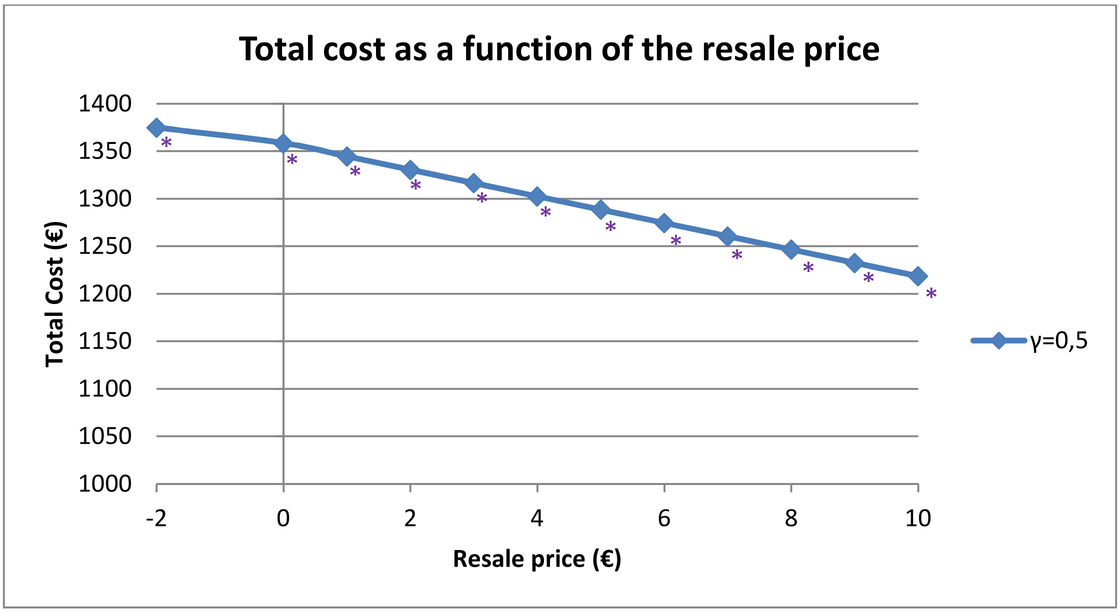

Figure 12: *Total cost as a function of the resale price for γ = 0.5*

The logic is straightforward and is the following: the higher the resale price for a given quantity of resold RTIs, the lower the total cost. Indeed, it will be shown in the next subsection that the quantity of resold RTIs, for positive values of *a*, is only influenced by the collection rate. Being able to resell at a higher price could also be a good reason for the model to push RTIs to reach the level *l* of utilization, but as it will be discussed in the next subsection, this supposition should be discarded. In addition, if it was the case, there would not be any linearity. It is actually what seems to happen for *a* = *-2*. The model probably tries to limit the number of RTIs that the company must get rid of, since it represents an additional cost. It would maybe also be the case for a resale price higher than the purchase price. Indeed, the model would not worry anymore about making the items reaching their end-of-life since the cost to replace them by new ones would definitely be compensated by the resale revenue. But this situation does not make sense in real life: used objects are usually not resold at a higher price than brand-new ones.

Figure12, representing the total cost, purchase cost and resale revenue as a function of *a* for *γ* = 0.5, shows on the one hand that the cost to buy new RTIs, since it remains stable for any value of *a*, does not influence at all the trend of the total cost. On the other hand, the graph confirms the reflection explained above: the increase in the resale revenue seems to fill in perfectly the decrease in the total cost for non-negative values of *a* and this can be easily confirmed by the source data in Appendix 6.

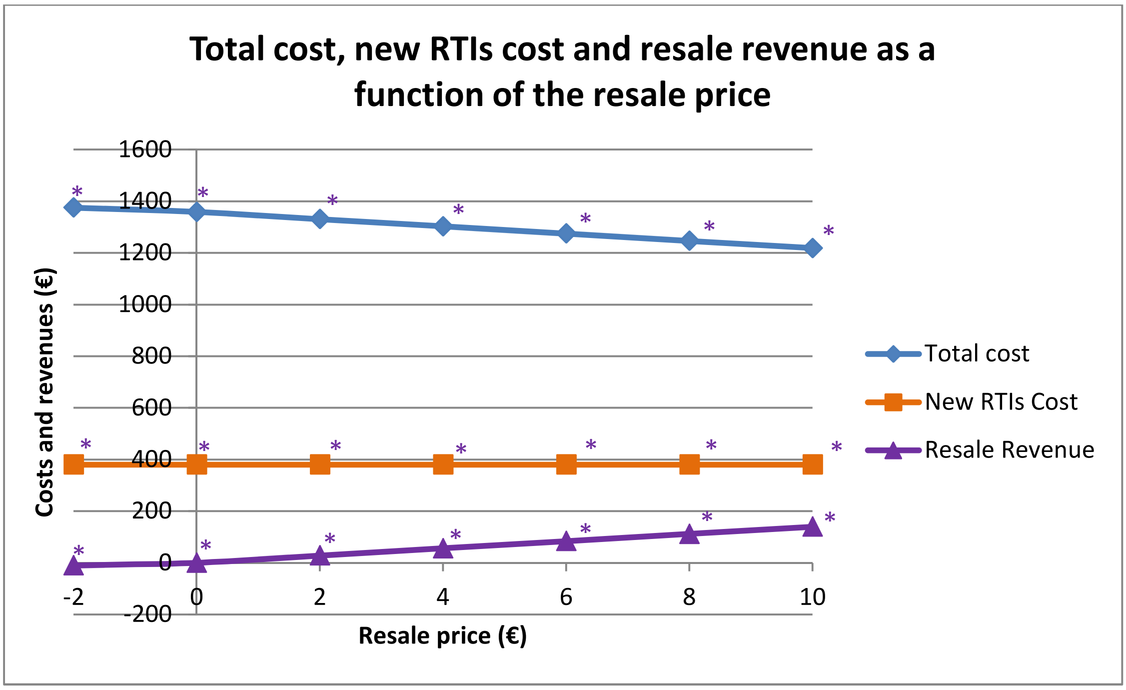

Figure 13: *Total cost, new RTIs cost and resale revenue as a function of the resale price (for γ = 0.5).*

Figure 14 confirms that the evolution of the total cost is largely impacted by the resale revenue because the graph shows that the transportation, penalty and inventory holding costs remain quite stable for any value of the resale price. Thus, they have no influence on the decrease of the total cost. It can be noticed, when taking a deeper look at the values on which the figure has been formed in Appendix 6, that the values of these 3 types of costs are exactly identical for all the values of *a* represented on the graph, except for *a* = *-2* for which the values differ a bit. These results are thus even more radical than the ones obtained for the Figure 11, which is the equivalent graph when studying the influence of the collection rate for a fixed resale price instead of the impact of the resale price for a fixed collection rate.

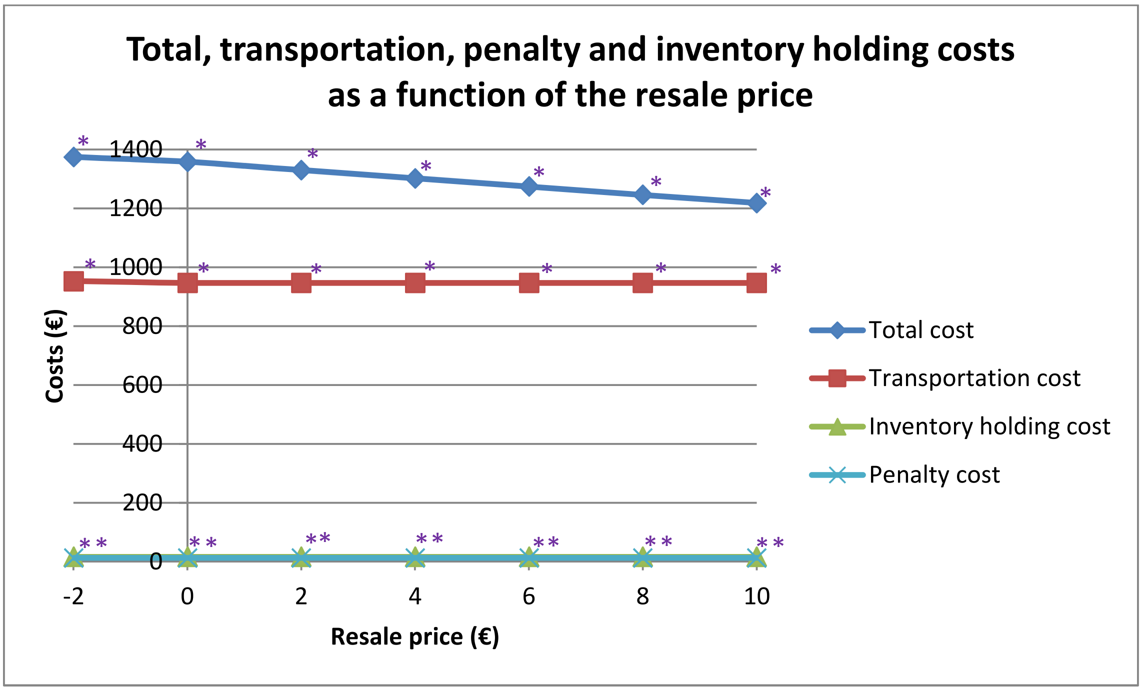

Figure 14: *Total cost, transportation cost, inventory holding cost and penalty cost as a function of the resale price (for γ = 0.5).*

The detailed data generating the graphs of this subsection are available in Appendix 6.

3.1.4.4 Effects of the collection rate and the resale price

3.1.4.4.1 Comparison between the two models

This model is not exactly a generalization of the initial model. Indeed, when applying a resale price per RTI *a* of 0 and a collection rate γ of 1 to stick the most possible to the assumptions of the initial model, the resulting total cost is slightly (0.2€) lower than the one of the initial model. Actually, the difference comes from the inventory holding cost. Since the RTIs with a degree of utilization *k* are thrown away (that is what is implicitly deducted by a resale price of 0) when they arrive at the depot, there is no more inventory holding cost incurred for these RTIs after they exit the company. Contrarily, the initial model assumes that they remain forever in the company. In our case here, 2 RTIs are thrown away at period 2 and 16 at period 3. Considering a constant inventory holding cost for empty RTIs at the depot of 0.01€, these RTIs would have respectively cost the company in the initial model *0.01€*2*(4-2)* and *0.01€*16*(4-3)* for being hold in the inventory for the remaining periods of time. Table 5 gives the detailed values obtained. Solutions obtained for both models are optimal.

	Total Cost (€)	Transportation Cost (€)	Inventory Holding Cost (€)	Production Cost (€)	New RTIs cost (€)	Penalty cost (€)	Resale (€)	Time (s)
Initial model *	**1124.45**	1011.5	17.37	1.36	80	14.23	/	201
New model, with γ=1 and a=0€ *	**1124.25**	1011.5	17.17	1.36	80	14.23	0	500

Table 5: *Comparison between the initial and new model for γ = 1 and a = 0.*

This comparison with the initial model also enables to examine the differences in terms of the running time. The new model takes 8 minutes and 20 seconds to run, which is 5 more minutes than the initial model, which only needs 3 minutes and 20 seconds. This represents an increase of the running time of 56%, which can be explained by the introduction of a new dimension *k* and new constraints.

3.1.4.4.2 Total cost

Figure 15 confirms that the same trend as the one observed in the Figure 9 can be noticed for other values of *a*: the total cost decreases when the collection rate gets closer to 1. The order of the curves follows the following rule: the higher the value of the resale price, the lower the total cost. The reason behind this fact lies on the total resale revenue. Indeed, for a given collection rate, the resale revenue increases when the resale price increases, which leads to a decrease in the total cost. In addition, it can also be observed that the difference between the values of the total cost obtained for each curve get bigger when the collection rate increases. This can easily be explained by the fact that a higher collection rate implies more RTIs reaching the level of utilization l at which the producer resells them. Then the unequal resale prices accentuate this difference. Indeed, the only element of the cost function that is impacted by the parameter a is the resale revenue term. As it has been explained in the subsection about the effects of the collection rate, there are only two components of the total cost that really influence the total cost: the purchase cost and the resale revenue.

Then, the red point on the graph of Figure 15 represents the total cost reached by the initial model (1124.45€) and is placed for $\gamma = 1$ since the initial model implicitly considers that there is no RTI that gets lost. We can see that all the curves get lower than this total cost when $\gamma = 1$. Indeed, as explained in the comparison of the previous subsection, the total cost of the initial model is a little bit higher than the one of the modified model when the resale price is null. It is therefore logical that it is also the case for positive values of a. For the highest values of a, the total cost is lower than the one of the initial model even for lower values of the collection rate (0.8).

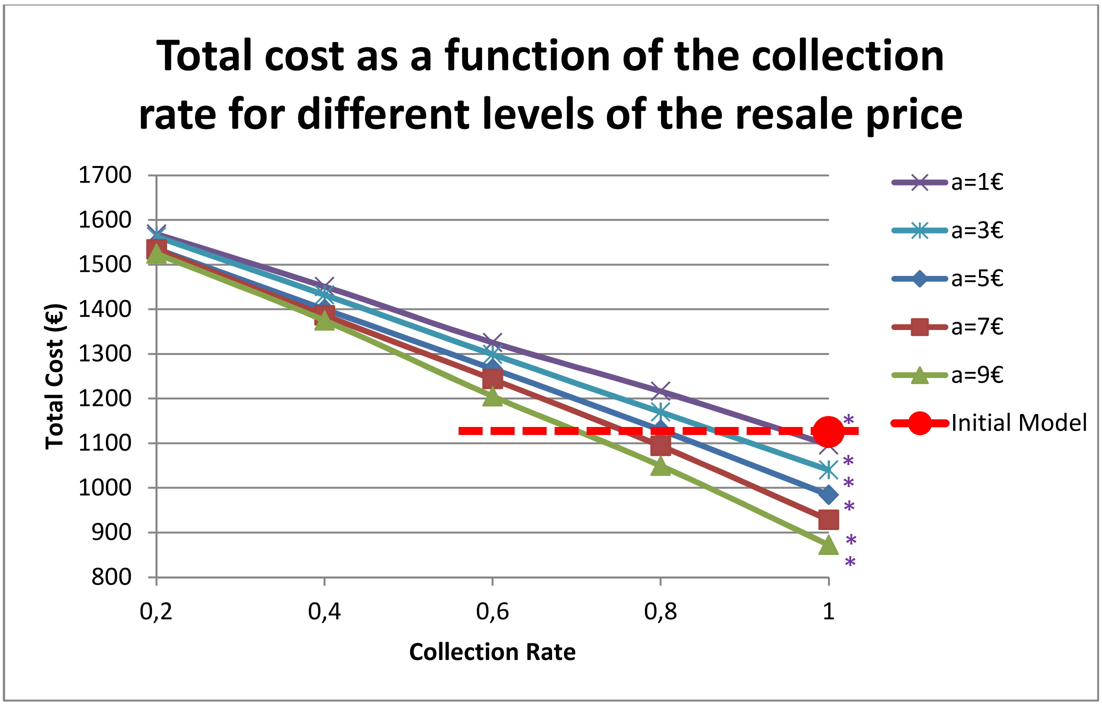

Figure 15: *Total cost as a function of the collection rate for different levels of a.*

Figure 16 shows that the evolution of the total cost as a function of the resale price is represented by decreasing curves for different values of γ. The curves are linear for non-negative values of a. This confirms the trend of Figure 12. Indeed, the higher the resale price, the higher the resale revenue and thus the lower the total cost. It can also be noticed that the higher the value of the collection rate, the lower is the curve on the graph because, as already explained, a high collection rate means that more RTIs are collected and therefore, more RTIs are likely to reach the last degree of utilization at which they are automatically sold by the producer. This means a higher revenue and consequently a lower total cost for each value of *a*. However, the three curves of the graph do not have the same slope: the higher the collection rate, the steeper the slope. The reason behind that is the mix between the two effects: for high values of *a* and γ, more RTIs are resold and they are resold at a higher price. Thus the combination of both effects defines the slope. In addition, for the negative value of *a*, the same phenomenon as the one already noticed in Figure 12 seems to happen also for other values of the collection rate. The solutions of Figure 16 are optimal for $\gamma = 1$ and $\gamma = 0.5$ and the gap has been set to 2% for $\gamma = 0.1$.

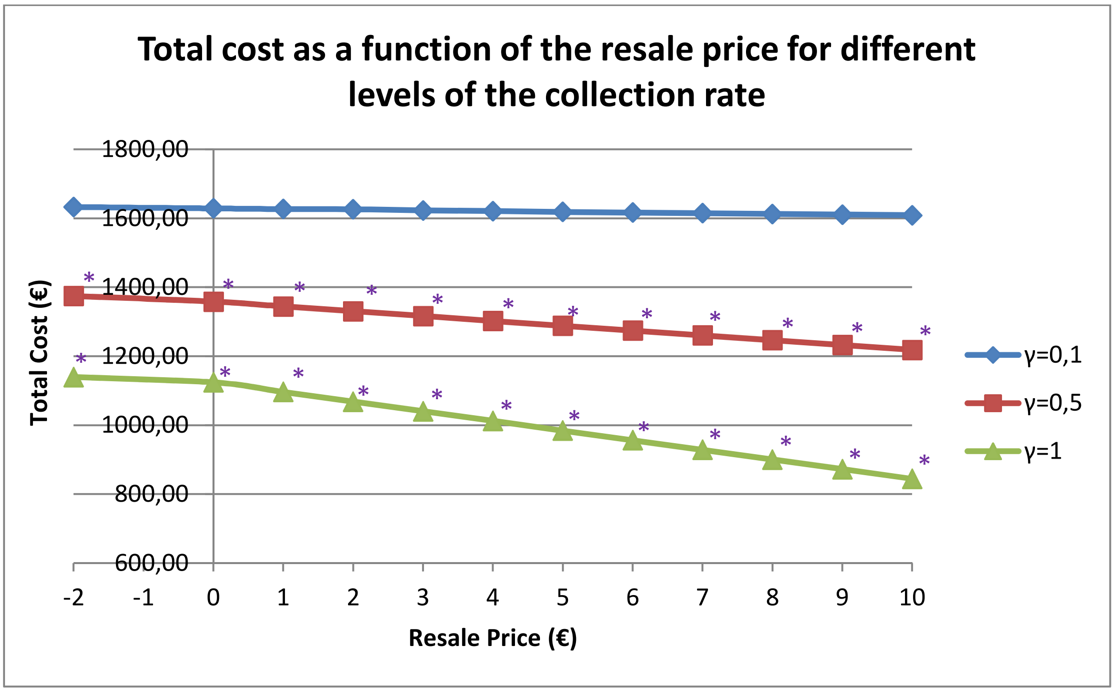

Figure 16: *Total cost as a function of the resale price for different levels of* γ.

3.1.4.4.3 Number of RTIs resold

Then, when observing the number of RTIs resold on Figure 17, one can notice that for positive values of *a*, it is only dependent on the value of the collection rate γ since the curves representing a positive value of *a* coincide with each other. These curves are increasing: the higher the collection rate, the higher the number of RTIs resold. This is due to the fact that the number of RTIs reaching their end-of-life increases when γ increases, as it has already been discussed. So for these values of *a*, the number of RTIs resold is not influenced at all by the value of the resale price *a*. This means that the quantity of RTIs that reach their end-of-life condition and need to be resold stays the same for a given *γ*, whatever the value of *a*. One could have thought that the lower the value of *a*, the more the model would prevent the RTIs from reaching the level of utilization *l*, but it does not seem to be the case for positive values. However if seems to be the case for null and negative values of *a* because the curves for negative values are globally lower than the others. This leads us to believe that the model tries to restrict the number of RTIs that the company must get rid of because it either does not make any money from the disposal (*a = 0*) or it has to pay for it (*a = -2*), and because, in addition, resold RTIs implies replacement. A good way to limit this number could for example be the anticipative purchase of brand-new items from the beginning of the planning horizon to expand the fleet of RTIs that can be used, thus hindering the utilization of each RTI. Yet, this supposition is not confirmed. Indeed Figure 13 depicts a constant purchase cost, which means a constant number of new RTIs bought since the buying price per RTI, *b*, does not vary.

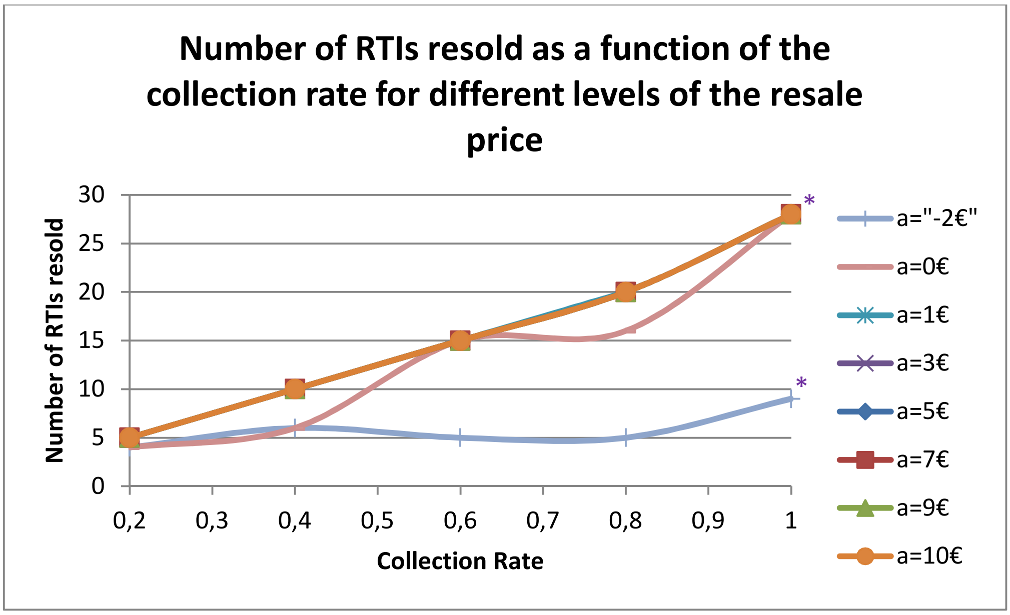

Figure 17: *Number of RTIs resold as a function of the collection rate for different levels of a.*

3.1.4.4.4 Maintenance cost

Moreover, it can also be shown that, whatever the value of *a* and *γ*, the maintenance cost is always exactly the same (1.36€). This means that the same number of RTIs has to be filled at the depot, i.e. $\sum_{k\in K}\sum_{t\in T} p_{kt}$ is always the same for any *a* and *γ*. And this seems to be simply due to the demand and initial inventory levels that stays the same for all the possible values of *a* and *γ*.

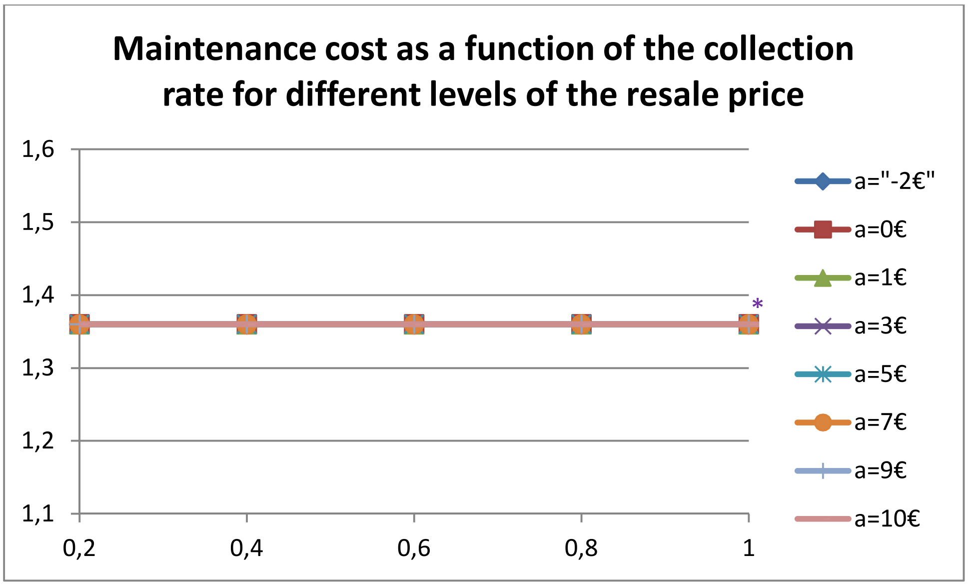

Figure 18: *Maintenance cost for different values of a and γ.*

3.1.4.4.5 Collection rate of 1

For the specific value *γ=1*, we can notice some particular behaviors. Firstly, as briefly mentioned earlier in the subsection about the effects of the collection rate, the resale revenue becomes higher than the cost to buy new RTIs when *a* equals 3€ or more. Figure 19 shows that the curve of the resale revenue passes above the line of the purchase cost just before the point corresponding to *a=3*. This line is constant for any value of *a*, as it was the case in Figure 13 for *γ=0.5*. This overtaking happens because no RTI gets lost, and only for a certain level of *a*. Indeed, if no RTI gets lost, the need to purchase new ones is reduced. This cost of purchase can then be exceeded by the resale income, if the price per RTI resold is high enough, knowing now that, for positive values of the resale price, the number of RTIs resold does not depend on the resale price but only on the collection rate.

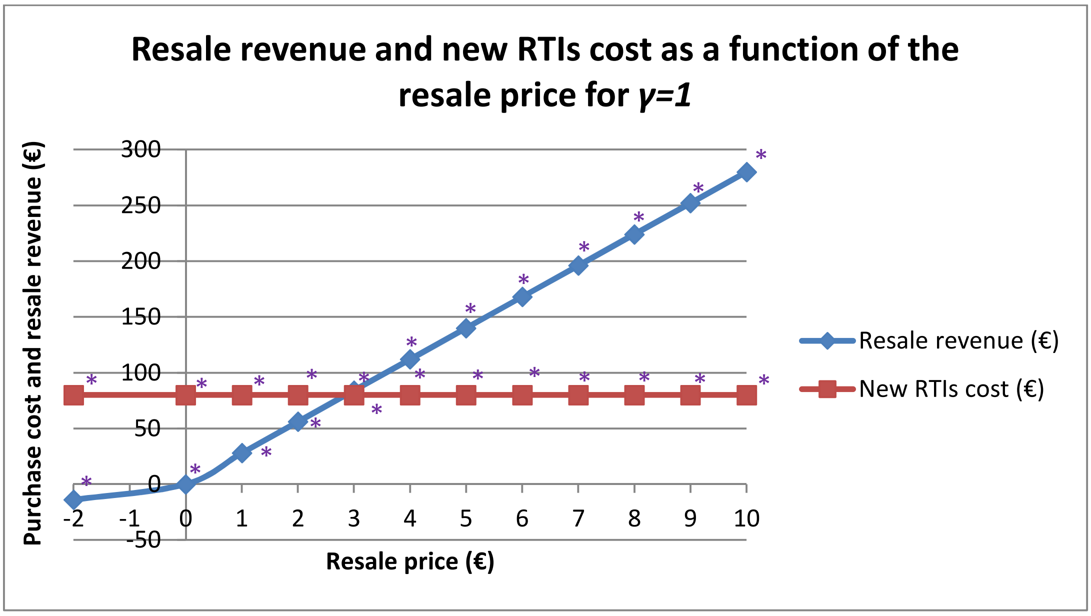

Figure 19: *Resale revenue and new RTIs cost as a function of a for γ = 1.*

Similarly, one can observe on Figure 20 that for $\gamma=1$, the value of the total cost is lower than the value of the transportation cost, for a strictly greater than 4. This means that the revenue obtained thanks to the resale of RTIs is big enough to compensate for the set of inventory holding cost, new RTIs cost, penalty cost and maintenance cost and even for a small part of the transportation cost. In addition, we can notice that the transportation cost is a constant function of a, as it was the case in Figure 14 for $\gamma=0.5$.

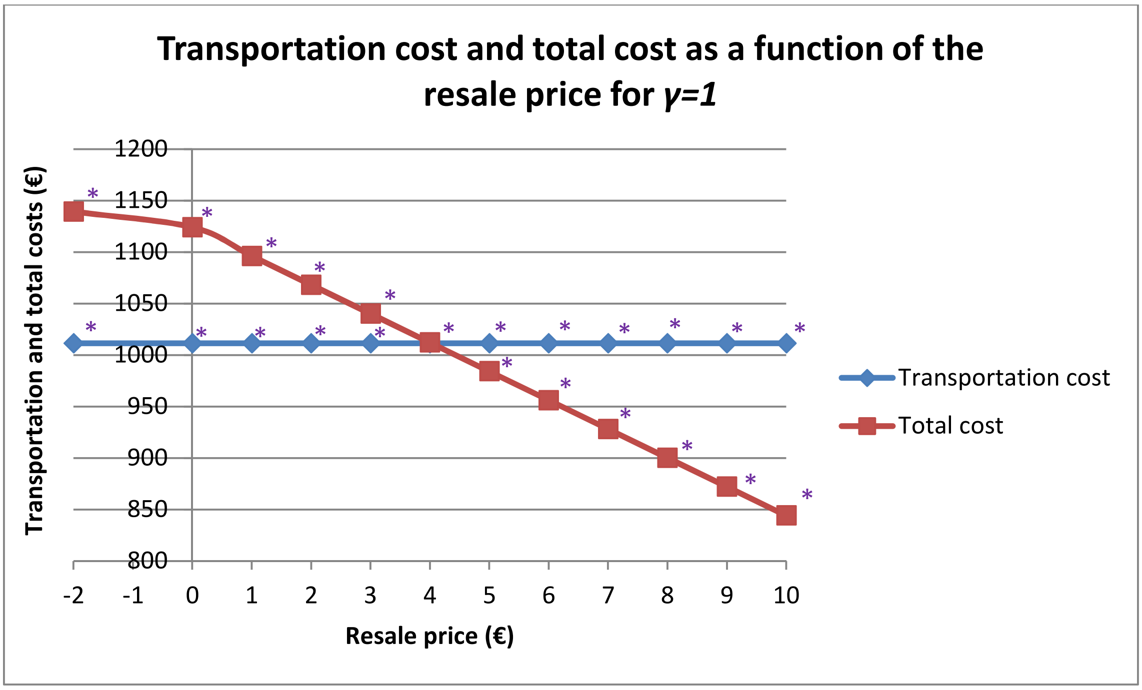

Figure 20: *Total cost and transportation cost as a function of a for γ = 1.*

The data on which these figures have been built can be found in Appendix 7.

3.1.5 Conclusions

3.1.5.1 Durability of RTIs

The addition of a new dimension *k* for the durability is necessary to be able to record information about the level of utilization, if the goal is to resale or get rid of RTIs that do not fit for use anymore. This dimension works as a counter of the number of utilization. However, in real life, each utilization of an RTI is not recorded. Indeed, as illustrated in the thesis of Martin (2016), most organizations do not track their RTIs. RTIs are more likely to be labelled as not acceptable anymore when they are inspected or when a problem occurs because of their poor condition. But this additional dimension could be helpful for enterprises already using a tracking system such as the RFID technology or when implementing it, as wished by Trafic or the CHU for example (Martin, 2016).

The definition of utilization that has been chosen for the model seems plausible. Indeed, it is assumed that an RTI has been used once when it has been used at the customers' to satisfy demand. To illustrate, if customers in fact represent actual stores of the company, RTIs get to the next level of utilization when they are emptied in the shelves of the store. This definition implies that the RTI is said to have been used once when it has been loaded at the producer, then transported to the customer and emptied to satisfy its demand. It implicitly expresses all the steps that are encountered before an RTI can finally be defined as used. However, other definitions could have been chosen, since this one is not the most straightforward. For example, assuming that an RTI has been used once when it has been sent from the producer to the customer might be seen as a less complicated way to think about utilization. But in this case, it would involve that the inventories of loaded and empty RTIs at the customers' locations should not have any RTI with a degree of utilization 0. Indeed, if these RTIs have arrived at the customer, it means that they have been transported at least once from the producer to the customer. So, this would have to be taken into account when creating the initial dataset.

Then, concerning the number of periods of the planning horizon and the durability of an RTI that were set for the computations, they may be underestimated compared to what occurs in organizations for most types of RTIs. Figure 3 in the literature review displays a table of the number of lives for some products components retrieved from Geyer et al. (2007). For example, wooden pallets, according to Geyer et al. (2007), can be used during 50 cycles, each use corresponding to one cycle, before they need to be taken off from the company. This involves considering a period of time greater than 50 to be able to witness the pallets reaching their end-of-life. The number of cycles of an RTI depends a lot on the type of RTI but also on how and for which purpose the company uses these items, as illustrated earlier with the number of rotations that RTIs of AGC Glass Europe, Bubble Post and Bidvest make. For the analysis, the data that have been used in the instance have been chosen to allow a reasonable running time. The number of periods being of 4, the number of cycles had to be reduced too. However, the model allows introducing more realistic data that are closer to realistic problems happening in enterprises. If we want to integrate the case of Bubble Post in the model, whose boxes achieve 70 to 80 rotations during a lifetime of 6 to 8 months, it would mean that a utilization happens on average every 3 days. This would mean that periods of time of 1 day could be considered, as well as a planning horizon of 8 months, i.e. 240 days, to be able to see the resale.

Finally, the use of a new decision variable $\tilde{u}_{ikt}$ can be justified by the need to track which RTIs (i.e. with which degree of utilization) are used to satisfy demand. More especially, when they are emptied right after satisfying the demand, they go from one level of utilization to the next one, in accordance with the definition of utilization. In addition, it is not reasonable to consider $\tilde{u}_{ikt}$ as known data. Indeed, in real life, there is no reason to have information about the degree of utilization of the RTIs that will be used to satisfy the demand. We know the demand of each customer at each period and the model gives us the number of RTIs of each possible degree of utilization that it has decided to use to satisfy this known demand. This is why $\tilde{u}_{ikt}$ is introduced in the model as a decision variable.

3.1.5.2 Resale of RTIs

Concerning the resale, the model assumes that it can only take place at the producer, which seems quite reasonable. Indeed, if the nodes $i \neq 0$ are real customers of the node $i = 0$, there is no reason for them to be in charge of its resale. And if these nodes are stores, it seems logical that the RTIs are first centralized at the depot to be resold in group.

Then, it is also assumed that the RTIs sent back at the warehouse and that have reached a level *l* of utilization are directly, i.e. at the same period, sold and taken off from the system. However, in the real life, companies may want to reach a certain quantity of RTIs of degree *l* before selling them. Or the resale procedure may take some time and RTIs of degree *l* may be resold some periods after they arrived at the depot. Meanwhile, the RTIs are not used and simply wait at the depot. In addition, the fact that the model assumes that RTIs are only resold when they reach their lifespan seems quite reasonable since it is not the core business of this kind of company to sell RTIs. So they sell them only when it is not possible anymore to make use of them in the organization.

Finally, the model generally considers a positive price of resale *a*. This can be justified for some types of RTIs by the remaining value of the item. For example, pallets may not be appropriate anymore in a company to transport goods after a certain number of cycles, but can be interesting to use as salvage wood or as firewood. This is even more visible nowadays with the growing trend and interest for recovery and re-creation. Do-it-yourself tutorials on the Internet easily demonstrate how pallets can be transformed in garden furniture for example. However, other RTIs may require the company to pay to get rid of them. So in this case, it is not a revenue but an additional cost that is incurred by the enterprise. And the model can easily be adapted to take into account this cost because *a* can take negative values as well. In addition, the parameter analysis was done by varying values of *a* between -2 and 10, 10 being the value set for the cost to purchase a brand-new RTI. The value -2 can be considered as a reasonable value to illustrate the situation where an organization has to pay to get rid of old RTIs. Indeed, studying a disposal cost higher than one fifth of the price of a new RTI is maybe not judicious because it may not represent the majority of the cases existing in real life. Then, concerning the maximum value of the parametric variation, this makes no sense to consider values higher than 10 because reselling used RTIs at a more expensive price than the brand-new ones is not plausible. The value 10 has nevertheless been studied to check if it leads to some particular behaviors.

3.1.5.3 Losses of RTIs

Concerning the loss of RTIs, the assumption behind the model is that RTIs get lost once they arrive at the depot because it is only in the inventory levels of the producer that the losses can be noticed. Indeed, the losses do not come from the customers because they send back all the empty RTIs that need to be returned. This assumption can be justified if the depot is very big, implying that RTIs can get lost from the truck to the storage area. In addition, this assumption has the advantage to make sure that losses happen only after the demand is well satisfied and that only empty RTIs are concerned with losses. Although the fact to consider only the losses of empty RTIs may be a bit too idealistic, it enables to ensure that the demand can be satisfied. It is indeed more realistic to think that if some thefts occur, loaded RTIs would more likely be the target of the thief. A second assumption, maybe describing more usual situations, could have been losing RTIs at the customers'. Indeed we can imagine that RTIs get lost in the infrastructures of the customers after having satisfied the demand and been emptied. It can be the case if the customers do not return the totality of the RTIs for example because they use them for some other usages and purposes than the ones intended, as illustrated in the study carried out by Breen (2006) (cited by Martin, 2016 and Glock & Kim, 2015) mentioned in the literature review and as experienced by the CHU and by Trafic in its stores (Martin, 2016). One can also imagine that the customer is actually a store and that the demand is satisfied in the shelves of the store. Some empty RTIs may get lost in the different departments of the store or customers may take some of them back home. A third assumption could also have been that RTIs get lost on their way back to the producer. Indeed it is probable to loose RTIs after they have been picked up from the different customers because the truck driver sometimes have to handle the empty RTIs at the different nodes of the journey to place some other RTIs in the truck. During these manipulations, some RTIs may be forgotten. The plausibility of this assumption is confirmed by the discussions I had with Mr. Colline from the CHU and with Mr. Sullon from Trafic. Both have already seen this kind of oversight from the truck driver.

The model assumes that a constant proportion γ of RTIs is collected at each period, implicitly meaning that a constant proportion $1- \gamma$ gets lost at each period. The fact that this parameter is constant throughout the planning horizon is not very realistic since there is no logical and valid reason to justify the same number of losses each month. Indeed, the issue of lost RTIs usually involves a random character. The constant rate is more to understand as an average because companies are likely to experience variable losses from one period to another, depending for example on the period of the year. Moreover, according to the definition of the period, some companies may not have time to notice and record the losses engendered. It seems also more logical to catalogue the RTIs at the end of a given period of time, for instance at the end of the average lifetime, and note the number of missing RTIs at that moment. For example if a company purchase a new fleet of RTIs and know their approximate lifespan, it can decide to check after this period of time if all the RTIs that were bought at the same moment are still available in the company. Besides, most companies interviewed by Martin (2016) that suffer losses gave her a percentage of loss at the end of the average lifetime of the RTIs or an annual loss rate.

The values of the collection rate γ that have been considered range between 0.1 and 1 in order to base analysis on plausible values, although, in practice it seems to be more around 1 than around 0.1. Indeed, as mentioned in the introduction, organizations seem to be generally confronted to a loss rate close to 10%. In addition, this value is not a proportion of RTIs getting lost at each period of time, as discussed in the previous paragraph, but rather an annual rate. So, the value of γ that should have been considered for the model should have been even higher than 0.9. However, the value 0.5 has been used in order to be able to show a marked difference with the initial model. Then, a value of γ of 0 would not make a lot of sense since it would mean that every single RTI gets lost. In reality, it can happen once if an incident occurs but considering a stable value of 0 over the planning horizon would be insane. A value superior to 1 could happen too if, by mistake, some RTIs from partners or competitors get found in the company. This actually reflects what sometimes happens by Bidvest, Bubble Post and Colruyt (Martin, 2016). Finally, a value lower than 0 would simply make no sense.

3.2 Maximum ceiling

3.2.1 Introduction

Trafic is a very good example of a company that has defined a maximum threshold constraint. The company has established some rules regarding the management of returning RTIs, one of them being the maximum ceiling (Martin, 2016).

During my visit at the Trafic of Grivegnée, I had the opportunity to ask more practical and concrete questions to Mr. Sullon. The first rule established by Trafic to optimize the space utilization is that the stores must accumulate pallets in stacks of exactly 10 to be allowed to send them back to the warehouse. So, one stack of 10 pallets actually accounts for one pallet on the ground since it will take the place of one pallet on the floor of the truck. Depending on the loading of a loaded RTI, the ratio of the volumes of a loaded and empty pallet can be very important.

A second rule states that the truck driver is allowed to take back on average 60% of what he has just delivered, in terms of pallets on the ground. This rule comes from two main facts. Firstly, Trafic operating according to a pickup and delivery system, the truck driver does not deliver one store at a time but visits on average 2.4 stores during its tour and aims at manipulating the merchandise as little as possible. In contrast, the store's goal is to send back as many empty RTIs as possible to the logistic centers when the store does not need them anymore. This situation represents two opposite objectives. If the first store visited wants to give back as many RTIs as received in terms of surface or volume, it will make the truck driver remove these empty RTIs to be able to reach the goods to be delivered to the second store. Secondly, quantities that have to be returned are sometimes much bigger than quantities that have just been delivered, due to seasonality. To illustrate the combination of these two rules, if the store receives 10 pallets loaded with merchandise, i.e. 10 pallets on the ground, it will be allowed to return up to 6 pallets on the ground, i.e. 6 stacks of 10 pallets. However, if the store is the first one to be delivered, the truck driver will likely take back less than 60%. If it is the last one, he will likely take back more RTIs. In order to simplify the situation, Trafic has decided that this percentage is 60% in all the cases.

Trafic also uses plastic boxes and pallet heighteners. Traffic uses euro-pallets as a basis to transport goods. Indeed either pallet heighteners are fixed on pallets to form a big wooden box or foldable plastic boxes are placed on pallets. Sometimes, a mix is also possible: some plastic boxes can be placed in the wooden boxes constituted with a pallet and five pallet heighteners, with other non-reusable cartons. But this last possibility will be discarded since it is not only about reusable items. The three types of RTIs used can be analyzed separately.

Concerning plastic boxes, four plastic boxes can exactly hold on the surface of one euro-pallet, i.e. 120 cm x 80 cm. The boxes have respectively the following length, width and height:

- When unfolded: 60 cm x 40 cm x 30 cm
- When folded: 60 cm x 40 cm x 6.5 cm

When folded, a height of 25 boxes can be placed on a pallet, which means that in total 100 folded boxes can hold on a euro-pallet. When unfolded, the height is reduced to 3 boxes, which means that in total 12 unfolded boxes can be placed on a euro-pallet. The first configuration is obviously the one used for the backward shipments and the second one is used for the forward shipments, when boxes do contain products. Thus one pallet of folded plastic boxes leaving a store contains 100 boxes for a place on the ground corresponding to one euro-pallet, i.e. 120 cm x 80 cm. In contrast, one pallet of boxes leaving the store contains 16 boxes on this same surface. So for a same surface in the truck, 100 boxes can be taken back when 16 are delivered. If less than 16 are delivered, they still need one euro-pallet to be transported and this pallet can be completely filled with folded boxes for the return.

Concerning the pallet heighteners, there are most of the time five pallet heighteners of 20 cm high fixed on a pallet to form a wooden box with a length, a width and a height of respectively 120 cm x 80 cm x 14.4 cm (including the height of the pallet itself). These wooden boxes are used to provide the stores with heterogeneous goods. For the backward shipping, they can be used to contain elements that need to go back to the warehouse, such as defective products, hangers, waste, cellophanes or cardboards. Folded pallet heighteners are also returned to the logistic center in wooden boxes. The pallet heighteners used by Trafic have on purpose six hinges, so that they can be folded to fit in a wooden box. Appendix 8 displays a picture of such a pallet heightener. In such a box, it is possible to lay four rows of folded heighteners within the 80 cm width and 25 heighteners within the 100 cm height. Indeed, if we do not include the height of the pallet, we have a height of the box of 5 x 20 cm. Then, the thickness of the wood is one centimeter and, when folded, the heightener has four times this thickness at the ends, hence a height of a folded heightener of 4 cm. Thus, in such a wooden box, it is possible to place 100 pallet heighteners in total. And if we take into account the heighteners forming the box, this number increases to 105. So for a same surface in the truck, 105 pallet heighteners can be taken back when 5 are delivered.

Finally, some kinds of RTI can neither take less space when stacked, nor be folded. It is for example the case of the returnable polystyrene boxes used by Bubble Post.

3.2.2 Description of the model

One of the first insights of improvement of the initial model was about the dimensions of RTIs. Indeed, it assumes that the loaded and empty RTIs take the same space in the truck in a backhaul system[9]. Yet in reality, most RTIs do not take the same space when emptied. Some RTIs can actually be folded or piled up when emptied. A company using these kinds of RTIs can take advantage of a better space utilization for empty RTIs.

Thus the truck capacity constraint, which links the number of empty and loaded RTIs transported, should take into account an equivalence factor to express this difference in the space utilization:

$$x_{ijt} + z_{ijt} \leq Q \sum_{v \epsilon V} y_{ijvt} \quad \text{becomes} \quad \theta * x_{ijt} + z_{ijt} \leq Q \sum_{v \epsilon V} y_{ijvt}$$

$$\forall (i,j) \in A, \forall t \in T.$$

Where x_{ijt} and z_{ijt} represents the quantity of respectively loaded and empty RTIs transported from customer i to customer j in period t, where Q represents the truck capacity, where θ is the equivalence factor and where y_{ijvt} is a binary variable that "*is equal to 1 if and only if arc (i,j) is used on the route of vehicle v in period t" (Iassinovskaia et al., 2016).*

In order to avoid decimals in the equivalence factor, this factor will express the number of empty RTIs that a loaded RTI can replace in terms of space utilization. This way, the constraint is expressed in terms of empty RTIs, which means that the value of the truck capacity, Q, should be adapted too to be expressed in terms of empty RTIs as well.

Concerning the inventory capacity of both empty and loaded RTIs at the customers' and at the producer's, the initial model does not include a capacity constraint that links both inventories, as it is done for the truck capacity. This can be due to the fact that requirements to store empty and loaded RTIs are different, for example if the goods in the RTIs have to be kept at a specific temperature. In such a case, empty and loaded RTIs would most likely be stored in different rooms. Therefore, no modification is necessary for the inventory capacity constraints.

Then, when the customer receives the goods from the producer, the RTIs from the precedent delivery may also be taken back. The aim is often to densify as much as possible what is sent back in order to have the least RTIs on the ground possible. So, during a tour, the truck driver goes to the first customer and delivers the part of the goods in the truck that is intended for

[9] A backhaul system is a system where the same truck is used for transporting RTIs containing goods and for returning empty RTIs (Glock & Kim, 2015).

this customer. The customer, in exchange, gives back some empty RTIs to the truck driver. Then, the driver goes to the next customer and gives him his intended loaded RTIs. However, to be able to have access these loaded RTIs, the truck driver may have to manipulate the empty RTIs that have been returned by the first customer. This leads to unproductive manipulations and waste of time.

Thus, to tackle this issue, some organizations have established a rule according to which only a certain percentage of the quantity of loaded RTIs delivered at a given period can be returned at the same period. For example, if this percentage is 50%, this means that if 10 loaded RTIs are delivered to a customer at a given period, this customer cannot give back more than 5 empty RTIs (among the empty RTIs waiting in the inventory) to the truck driver at this same period. Yet, some enterprises, for some specific reasons, may prefer to set a maximum quantity of empty RTIs to be returned, rather than a percentage of the arriving loaded RTIs.

This constraint can be modelled easily:

$$r_{it} \leq \lfloor \varphi * q_{it} \rfloor \qquad \forall t \in T, \forall i \in N_0$$

Where r_{it} represents the number of empty RTIs returned from node i in period t, where q_{it} represents the loaded RTIs quantity delivered to node i in period t and where φ represents the percentage of RTIs that can be returned from any customer and at any period of time. The value is rounded down because it is what is done in practice in stores.

This constraint implicitly implies that loaded and empty RTIs take the same place in the truck. It should therefore be modified to take into account the same equivalence factor (θ) as the one used for the capacity constraint, r_{it} and q_{it} representing the same flows:

$$r_{it} \leq \lfloor \varphi * q_{it} \rfloor * \theta \qquad \forall t \in T, \forall i \in N_0$$

Nevertheless, it is important to note that the first equation is correct if r_{it} represents the number of empty RTIs *on the ground* returned from node i in period t.

Then, some organization, in order again to optimize the space utilization in the truck, may set some rules in order to make the stores or customers return as many RTIs per RTI on the ground as possible. Indeed, it seems pertinent, if one empty RTI takes θ times less space than a loaded one, to take advantage of the space available and place θ empty items where one loaded item could stand. A variable k_{it} can be introduced in order to constraint the model to only consider piles of θ RTIs to be returned. This number of piles depends on the period of time and on the customer, hence the indices i and t. So, here is the constraint that can easily be added to the initial model of Iassinovskaia et al. (2017):

$$\begin{cases} r_{it} \leq \lfloor \varphi * q_{it} \rfloor * \theta \\ r_{it} = \theta * k_{it} \end{cases} \quad \forall t \in T, \forall i \in N_0, \forall k_{it} \in \mathbb{N}$$

Where r_{it} represents the number of empty RTIs returned from node i in period t, where q_{it} represents the loaded RTIs quantity delivered to node i in period t, where φ represents the percentage of RTIs that can be returned from any customer and at any period of time, where θ is the equivalence factor and where k_{it} is a decision variable that represents the number of piles of RTIs returned from customer i at period t.

3.2.3 Analysis

3.2.3.1 Input data

The same data as the one used for the analysis of the initial model with several customers in the section "Durability, resale and losses" is reused here, except for some elements. Indeed, the demand has been divided by 2 for each customer. The inventory capacities of empty RTIs have been changed and set to 20 for every customer; but remains identical at the depot.

Then, the truck capacity Q that was set to 25 in the section about durability, resale and losses is set to 220. Indeed, as already explained, Q has to be adapted to be expressed in terms of empty items, hence the multiplication by 10. However, it is more suitable, if we assume, like in the initial model, that the vehicles are 30-foot trucks, to consider that 22 loaded pallets can hold in the truck. This means that a vehicle can contain 22 stacks of 10 empty pallets, which equals to 220 empty pallets. Indeed, 30-foot trucks can contain up to 22 pallets positioned in two horizontal rows, according to Pollaris et al. (2016).

Then, concerning the new parameters φ and θ, they are respectively set to 0.6 and 10. They are chosen to reflect the situation of Trafic when dealing only with simple pallets. If pallet-heighteners or foldable plastic boxes were considered, θ would respectively equal 21 or 6.25. The constraints are thus the following:

$$10 * x_{ijt} + z_{ijt} \leq 220 \sum_{v \in V} y_{ijvt} \quad \forall (i,j) \in A, \forall t \in T$$

$$\begin{cases} r_{it} \leq \lfloor 0{,}6 * q_{it} \rfloor * 10 \\ r_{it} = 10 * k_{it} \end{cases} \quad \forall t \in T, \forall i \in N_0$$

3.2.3.2 Comparison between the two models

The first element of comparison here is not exactly the initial model of Iassinovskaia et al. (2017). It is rather this model but with the modified truck capacity constraint (Model 1). The other element of comparison takes in addition into account the maximum ceiling constraints (Model 2). This way, it is possible to focus only on the effects of the maximum ceiling constraints and to analyze their impacts in terms of costs.

When comparing the different costs generated by these two models, displayed in Table 6, we can notice that the second model costs in total more than the first one. Indeed, an increase of 7.76% is observed. Since some constraints are added in the second model, it is reasonable to have a higher total cost. The augmentation of the transportation cost is actually the only reason behind this increase because all the other costs either remain stable or decrease. This increase is due to the fact that more RTIs per return leave the customers. The inventory holding cost decreases in the second model, which may seem a bit unexpected given the 60% rule. It is actually not this rule, but rather the stacking rule that makes the inventory holding cost decrease in this case because the first model was already respecting the 60% rule without even being constrained to. Another set of data could have shown the opposite results. Therefore here, compared to the first model, more RTIs per return leave the customer in the second model because it imposes that empty RTIs are transported by batch of 10. The first model contrarily makes smaller quantities return. Storing an item at the depot being cheaper than storing it at the customer’s, the inventory holding cost decreases in the second model. In addition, the running time of the second model is slightly higher, which is logical since it contains only a few additional constraints.

	Total Cost (€)	Transporation Cost (€)	Inventory Holding Cost (€)	Maintenance Cost (€)	New RTIs cost (€)	Penalty cost (€)	Time (s)
Model 1	**357.20**	333.9	17.72	0	0	5.58	6.56
Model 2	**384.91**	363.3	16.48	0	0	5.13	7

Table 6: *Cost comparison for maximum ceiling constraints*.

3.2.4 Conclusions

Although the analysis was very limited since it aimed at illustrating the addition of these maximum ceiling constraints in a single specific case, establishing such a rule seems to cost the company. Indeed, the total cost has increased in our small example. However, as already mentioned, it consists in some economy of time and effort for the truck driver, and therefore, it can still be beneficial for the company in terms of management. One should keep in mind that costs are not the only element that organizations try to control in their RTIs management, and this is in general true for any management.

Then, the assumption that loaded RTIs are never stacked in the truck, (meaning that the number of RTIs received equals the number of RTIs on the ground) neglects the possibility for pallets with pallet-heighteners to be stacked on one another. Indeed, as an example, Trafic uses wooden-boxes made of one pallet and 5 pallet-heighteners with a cover at the top that can provide stability and enables the stacking of another similar wooden box on its top. So the capacity of a 30-foot truck is 22 pallets on the ground, but when stacking is possible, it is possible to put until 44 wooden boxes.

Finally, the value of φ is assumed to be constant over time and does not vary from one customer to another. This appears reasonable because the organization is likely to first study the management of its RTIs and then determine an adequate constant percentage. It is also a way to act fairly towards the customers because important customers will be delivered with more loaded RTIs and will then be allowed to return more empty RTIs too.

3.3 Minimum threshold

3.3.1 Introduction

AGC Glass Europe constitutes a good example of an organization facing a minimum threshold constraint in its RTIs management. The company requests the customer to accumulate 10 stillages in storage before returning them to the stillage manufacturer in Belgium for verification and maintenance or to another factory abroad if needed. The stillages have to be repackaged, loaded and sent by the customer in a container, respecting the procedure of AGC since the cost of a stillage is quite high (around 1,300 euros according to Iassinovskaia et al. (2017) and to Martin (2016)). The number of RTIs is in this situation determined by the maximum number of stillages that can fit in a container. So this rule has been set up in order to maximize the use of available space in a container (Martin, 2016).

3.3.2 Description of the model

The approach of the minimum threshold model is similar to the one of the maximum ceiling, although it expresses the opposite constraint. First of all, the modification of the truck capacity constraint is also applicable here for the same reasons.

Then, the customer needs to wait for a certain number of empty RTIs to be collected before being allowed to send them back because of space optimization constraints:

$$r_{it} \geq \lambda * k_{it} \qquad \forall t \in T, \forall i \in N_0, \forall k_{it} \in \mathbb{N}$$

Where r_{it} represents the number of empty RTIs returned from node *i* in period *t*, where k_{it} is a decision variable representing the number of vehicles of empty RTIs returned from customer *i* at period t and where λ represents the number of empty RTIs that must be reached to be allowed to return a vehicle, from any customer and at any period of time.

3.3.3 Analysis

3.3.3.1 Input Data

The same data as the one used for the analysis of the maximum ceiling model is reused here, except for some values. θ takes the value 1 because we will assume that an empty RTI takes exactly the same place as a loaded one. Thus the initial vehicle capacity constraint is restored. Then, the maximum vehicle capacity Q is set to 10 stillages. Finally, concerning the new parameter λ, it is actually equal to Q when, like AGC Glass Europe, the company wants to optimize the space utilization as much as possible. Consequently, the inequality symbol becomes a simple equality symbol.

So the constraints are then the following in this case:

$$x_{ijt} + z_{ijt} \leq 10 \sum_{v \epsilon V} y_{ijvt} \qquad \forall (i,j) \in A, \forall t \in T$$

$$r_{it} = 10 * k_{it} \qquad \forall t \in T, \forall i \in N_0$$

3.3.3.2 Comparison between the two models

The first element of comparison here is the initial model of Iassinovskaia et al. (2017) (Model 1). The other element of comparison takes in addition into account the minimum threshold constraint (Model 2). So the focus is only on the effects of the minimum threshold constraint.

Table 7 displays the different costs generated by these two models. We can observe that the second model costs in total more than the first one. The difference between the total costs amounts to 3.22%. Since a constraint is added in the second model, this result seems consistent. It is the transportation cost that justifies this increase because all the other costs either remain stable or decrease. It increases because the size of the returning batches increases. In the same way as the maximum ceiling model, the inventory holding cost decreases in the second model because the second model imposes that empty RTIs are transported by batch of 10 whereas the first model was generating smaller batches. And since storing an item at the depot is cheaper than storing it at the customer's, the inventory holding cost decreases in the second model.

	Total Cost (€)	Transportation Cost (€)	Inventory Holding Cost (€)	Maintenance Cost (€)	New RTIs cost (€)	Penalty cost (€)	Time (s)
Model 1	**520.05**	494.18	17.5	0	0	8.37	370
Model 2	**536.79**	511.7	16.72	0	0	8.37	33

Table 7: *Cost comparison for minimum threshold constraint.*

3.3.4 Conclusions

So establishing a minimum threshold rule seems to cost the company since the total cost has increased in our small example. Yet, great care should be taken because the analysis was very limited. Indeed, the goal was to illustrate one specific case.

Then, it is important to remind that some companies have no choice but establishing this kind of rule because of the type of RTI or vehicle they need to use or because of the global management constraints they face. In addition, the cost of a journey with a vehicle might be so expensive in reality that the minimum threshold rule could decrease the total cost on the long run. Indeed the managers of the organization may fear that the vehicle comes back with too few empty RTIs compared to what a journey with the vehicle costs. Only companies with a rather important fleet of RTIs can afford to make the empty (and thus potentially available) RTIs wait at the customers' inventory, which implies that the company has to be able to afford investing in enough RTIs. AGC Glass Europe requires that the quantity of empty RTIs returned is exactly a multiple of the capacity of the vehicle but some organizations may only require at least reaching a certain quantity which is lower to the quantity needed to completely fill the vehicle. The situation faced by AGC Glass Europe might seem a bit particular but such specific constraints happen more often than it might be expected.

4. Conclusion

Returnable transportation items are used by organizations for three key reasons. Firstly, some regulations promoting RTIs goad companies to switch from disposable items to returnable items. Then, RTIs can enable the company to reduce its environmental impact, which is in addition a valuable argument for customers becoming more environmentally-conscious. Last but not least, economic benefits can be achieved thanks to the use of such items. Then, there are various ways to manage RTIs and research efforts are made in different related fields, such as production planning and control, warehouse layout, tracking, scheduling, IRP. This latter has been tackled by Iassinovskaia et al. (2017) who developed a PDIRPTW for the management of RTIs. Yet, this model does not take some real-life aspects into account. The aim of this Master thesis is to adapt this model to additional constraints encountered by organizations. To do so, understanding the initial model properly and figuring out the missing aspects was overriding. Then, the Master thesis of Martin (2016) describes the conditions in which organizations manage their RTIs, and therefore implicitly gives some insights about the possible adaptations that can be brought to the initial model. Visiting the warehouses of some of the analyzed companies eases the understanding of real-life management conditions of RTIs. Thereafter, the article of Geyer et al. (2007) enables to better figure out how to execute the adaptation of the initial model to some realistic aspects. The contribution is exposed in three different sections corresponding to the three different proposed modifications of the model: firstly durability, resale and losses, then maximum ceiling and finally minimum threshold.

The main finding regarding the first contribution is the fact that the model is closer to what happens in real life. Indeed, the limited lifespan of RTIs (including the different possible ways for RTIs to quit the company: resale revenue, disposal cost) and the possibility of losses are taken into account. It seems that the total cost of such a model is most of the time higher than the total cost of the initial model. This increase in cost is mainly due to the increase in the cost to purchase new RTIs, since the resold and lost items have to be replaced. However, the higher the collection rate and the resale price, the lower the total cost. This means that managers have to put in place some measures to limit losses as much as possible. An RFID system can be envisaged in some cases, as discussed in the literature review. Then, manager should try their best to find ways to resell the RTIs that cannot be used anymore rather than just dispose of them. Finding good opportunities to resell at the best price possible is even more interesting. Yet, a tradeoff should be made between the cost in terms of time of such research and the benefits in terms of revenue. Managers could also maybe take this criterion into account when comparing the different sorts of RTIs when switching from disposable to reusable items. Indeed, some RTIs are more prone to have some second hand value at the end of their life whereas companies will have to pay to dispose of some other kinds of RTIs. Another criterion to consider when choosing a type or brand of RTI is the maximum number of times it can be used. A tradeoff has to be made between durability and investment cost. A manager who would choose to invest in more durable, but also more expensive, RTIs would have to make sure that the loss rate is minimized and that the items can be maintained correctly.

Concerning the maximum ceiling and minimum threshold aspects, although adding such constraints increase the total cost, some non-financial reasons drive the organizations to put them in place. Managers should think carefully about the pros and cons of such constraints before establishing them. The value of the threshold or ceiling must also be chosen judiciously according to the characteristics of the RTIs and vehicles, but also according to external factors. In addition, considering the fact that empty and loaded RTIs do not take the same place in a truck enriches the model, since it is a reality for a lot of types of RTIs.

To conclude, in a personal perspective, building up these models made me realize how a model can be subjected to assumptions. Indeed, this confirms that modelling all the characteristics and constraints of a model, whatever the scenarios, is a bit utopian. In addition, these assumptions have to be thought carefully so that they do not contradict each other. Also, obtained results may sometimes contradict the expected outcomes and this can be very confusing.

5. Insights

Then, an insight of improvement would be to mix the durability, resale and losses model with one of the two other models in order to also take into account in the main model developed in this thesis the fact that empty and loaded RTIs may not take the same place in the truck and that some limits can be established by the company (maximum ceiling, minimum threshold). Mixing the three models has not been done in this Master thesis because of two main reasons. Firstly, most organizations only encounter one of the three situations described by the models. Then, the second reason is related to clarity. Dealing with one model at a time enables to observe and analyze the impacts of the different models independently.

The improvement could even go further by assuming that the inventories of empty and loaded RTIs are linked, which is the case if, for example, empty and loaded RTIs are located in the same storage area. The same type of constraint as the truck capacity constraint would then be modeled for the inventories at the depot and at the customers'. Similarly, the weights of empty and loaded RTIs could also be taken into consideration in the truck capacity constraint of the main model.

A deeper study could be conducted regarding the maximum ceiling and minimum threshold models. Indeed, the results developed here are very limited to specific cases. A generalization would enable to get a better understanding and a more reliable view of the impacts of such constraints. For the maximum ceiling model, an insight of improvement would be to take the possibility of stacking into account. This would be more complex than just adding some constraints to the initial model. It would probably need to modify some constraints of the initial model itself. For the minimum threshold model, analyzing the impacts of the variation of the cost of a new RTI and of the unit transportation cost could be interesting. This way we could see if such a constraint can decrease the total cost if the transportation cost is too high. We could also observe how a high purchase cost can hinder the model to have fleet large enough to enable the execution of such a rule.

Appendices

Appendix 1 – Extra Chapter: Project Management

The relevance of this chapter might be a bit blurred since my Master thesis is not a project-thesis aimed at bringing a solution to a given issue faced by an enterprise in the frame of an internship. Indeed, in this kind of thesis, the student is in charge of a real project, which is about the analysis of a global management problem for an organization. Also, organizations implement change through projects, which leaves place to several ideas of project for this kind of partnerships between a business and a Master student. In this perspective, they have to deal with a real scope, budget, stakeholders and time frame, either within a team or by themselves, to deliver an argued solution or insights of solutions. They are facing the real environment of a company with its constraints and consequences. In this context, it is much easier to make links with the seminar given by Professor Jean-Pierre Polonovski from l'Ecole des Sciences de la Gestion of the University of Quebec in Montreal that students in the Master of Business Engineering had the opportunity to attend at the very beginning of the academic year. This seminar was focused on the management of a portfolio of projects within a company. And indeed, some students have faced in their project-thesis a portfolio of projects to manage. Some others have experienced achieving a project in a team, including in this case the team management aspect. The negotiation aspect might also have been present when dealing with stakeholders, in order to come to a win-win situation. Some have come up with solutions but, in addition, had to incidentally implement them. In this last case, they might also face both execution and control parts, the two parallel phases in a project management, as seen during the beginning of the seminar.

A research thesis by contrast does not take place in the frame of an internship where the student is in the conditions of a company project. It is usually about the analysis of a global management problem that is translated into research questions. A research thesis can sometimes be very theoretical, with very few links and applications to the business world. In this case, it is even less obvious to see connections with project management, especially as addressed during the seminar.

However, in most research thesis treated by students in Management, the company aspect is present. And in the case of my thesis especially, links to the business world are clearly existent. Indeed, my contribution was based on two previous works on the subject, with a strong emphasis on the organizational context. Firstly, the initial model developed by Iassinovskaia, Limbourg and Riane (2017) was the main document on which I have based my analysis. It takes into account some actual facts and constraints of RTI management in the business world, such as the time windows constraint. Then, the qualitative Master thesis done last year by Martin (2016) is the second resource I have used. Based on interviews and surveys, this research thesis intends to describe and analyze the management of RTIs within Belgian organizations. Thus, based on these two documents business-oriented documents, my research thesis could only have this company aspect as well. The topic of my research thesis is not only theoretical, but rather purports to reflect issues and constraints encountered by real organizations in their daily management of RTIs, to model them and in some cases, to propose corresponding insights of solutions. In this perspective, I had the opportunity to visit some of the enterprises interviewed for last year research thesis to better visualize and figure out how they were actually handling, transporting, storing, maintaining their RTIs; in one word, managing RTIs. The people who welcomed me shared with me their current issues, projects and expectations concerning RTI management. All this makes my research thesis be a bit more project-oriented, without forasmuch becoming a project-thesis as it is for some other students in internship in one single organization. It is a bit like having a global project for different enterprises, with some parts of the project concerning more certain companies than others. This involves a certain need to think about some real constraints that can exist inside such enterprises and to take them into account, so that the model can more easily be adopted by the interested companies. Interests of the different stakeholders have to be imagined, if no visit in the companies is possible. In this way, a research thesis with a strong business side can be more similar to a project management, compared to a very theoretical research thesis. However, without being immersed in a company, it is difficult to deal with elements of project management such as budget, stakeholders, team management and other constraints specific to the corporation.

Nevertheless, writing a Master thesis in general, either with or without a business aspect, can be related to managing a project. Indeed, it can be seen as a project to achieve throughout the last year of Master thanks to tools acquired during the previous years of university degree. Carrying out a thesis requires resources, knowledge, time and sometimes also a budget, exactly like managing a project.

Firstly, I think project management implicitly includes time management. Indeed, a project always has a time frame and an end, as explained by Mr. Polonovski. This limited lifetime is actually one of the central characteristic of a project. Besides, it is because of this limited duration that there are a lot of consultants in the project management field. Definitely, planning and scheduling was an important part of the project management of my Master thesis. From the very beginning, I had to think about how to manage my time. Indeed, since I chose the subject of my Master thesis, i.e. during the second semester of the first year of the Master degree, I have tried to set up a vague scheduling method to work progressively and in a fairly constant fashion. My first goal was to work at least one afternoon a week during the first semester of the following academic year because I had courses (implying among others lectures, individual and group works) and extracurricular activities to handle as well. I had the same objective concerning the internship period. Then, my planning after the internship was practically totally dedicated to the thesis but I left some time for some personal activities, for some job research and for the oral defense of the internship. I have more or less managed to stick to the schedule during the first semester and I have also had time for additional work between the two exam periods. Then, it was much more difficult to work on the thesis during the internship period, but I could still devote one afternoon each week-end to the thesis, except when the deadlines related to the internship got closer. After the internship, I realized that the planning was too optimistic. Indeed, I had a lot of personal things to do that I could not handle during the internship period. In addition, as I will explain a bit further, I did not take some unexpected changes into account when I did the planning. I should have included more important safety margins. The point here is that, in the frame of a project management as much as in the frame of a Master thesis, time management is important and difficult and should definitely not be neglected.

Then, resources management is also a focal point between project management in a company and conducting a Master thesis. Undeniably, resources are a central point of a Master thesis and one cannot conduct such a work without any foundations. Resources can be information obtained thanks to surveys conducted either previously by researchers or by oneself. It can also be articles, books and papers about the same subject or about closely related topics. Academic sources are especially important in the frame of a Master thesis since references to theoretical concepts, as well as the use of reliable documents, preferably reviewed by peers, are essential. This is also a way to exercise critical thinking in the choice of the sources, which is a skill that is indispensable in every day’s life, and not only during studies.

Resources can also be the expertise of qualified people. For a Master thesis, it is of course the promoter, but it can also be other teachers or experts in the field, either academicians or practitioners. In the case of a company-oriented thesis, resources can also come from relevant companies. These companies may want to help in order to better beneficiate from the conclusions of the thesis, expecting a win-win partnership. In comparison, in the case of a project management, resources are information on which to base the project and decisions on or the expertise of internal and external people. Information can be for instance surveys, reports or studies. Internal people can be employees and workers from the different departments of the corporation, whereas external people can be for example consultants or external service providers.

Another important aspect of project management is related to challenges. Indeed it is important for a research thesis to be able to challenge what has been done so far, either by other people in the field or by oneself. The researcher is the one who define the objectives. But is important to recall, despite challenges, that this kind of thesis involving modelling requires some trade-offs between sticking to the reality of a particular case encountered in a company and generalizing. Indeed, the very essence of a model is to be a simplified representation of the reality. Its goal is to make it possible to draw conclusions and interpret results thanks to assumptions, experiments and observations. So the challenge here is not to completely stick the reality of one specific case.

Throughout the year, I have realized that some of the approaches that I was investigating were not interesting to build a real contribution on. So several times, after checking the outcomes with my promoter, I had to start back and find another approach to explore. This is not very positive to keep the spirits up because you sometimes feel like having done a considerable amount of work for nothing. However, I have still kept track of the reflections conducted and corresponding results obtained because they might be useful further in the quest. A research thesis can sometimes be frustrating but it is how research works: exploring several ways for eventually keeping and deepening only a few or even just one. And this changing environment is also present in the frame of a project management. Indeed, when a company is undergoing a project, it still has to continue to run at the same time. The project is thus not managed in a fixed context, with static constraints and inputs. This constitutes one of the main challenges and difficulties of project management.

During the research, when going for something precise, and when investigating and exploring it, other elements draw one's attention. Sometimes these elements are worth being analyzed deeper and can bring prominent insights, but it is important not to lose the track of what was at first examined. Indeed, such an approach can create a lot of ramifications and the researcher can end up with too many elements to look at or too much information. Keeping in mind the global goal of the research in order not to lose too much time in some less relevant insights is necessary. Here again, the time component of a project management appears, as well as the corresponding trade-offs. One should be able to judge what could be interesting or not. This process takes time and, in my opinion, it is part of the learning of a research thesis. Indeed, the approach of a research thesis involves making some choices and experiments by oneself. It is different from a group or individual work due for a course and for which the teacher usually states beforehand what is expected or at least builds a frame. However, it is sometimes by going off the point that great ideas and opportunities appear. So, at times, it can also be worth daring to go a bit further. This tendency to be tempted to look at different directions when investigating insights is also responsible for the instability and uncertain character of the approach.

A difference between project management and a research thesis pertains in my opinion to the work atmosphere. Indeed, a project is most of the time managed within a group, or at least, requires the contribution of several people. In the frame of project-thesis, students are either placed in a project team or work alone on the project. But in both cases, they work in the offices of the company and can, to a certain extent, easily reach out to people who could help them with some information or expertise. Of course other employees work on their own projects and may not have a lot of time to allocate to the students, but it is usually possible to make an appointment at some point to discuss about the project in hand. Nevertheless, for a research thesis, it is not the same work environment. Indeed, except the promoter and sometimes the readers, the student works most of the time alone. If the research-thesis is company-oriented, the student may also have some contacts with people from some organizations, but these remain only punctual occasions. Indeed, these people have less interest to devote time to the student since the project is not of primary importance for them. The reason is that the project is not brought by the organization in question, involving that it is usually not targeting one of its specific problems and that the student is not working for the company, neither evaluated by them. So the student may sometimes feel left to their own devices. But on the other hand, they do not have to deal with team management matters, as students with a project-thesis would probably have to.

To conclude, several concepts of project management can be applied to the project that Master students face during their last year of studies, i.e. the Master thesis. The applications are more obvious in the case of a project-thesis but valid for a research thesis too.

Appendix 2 – Initial model of Iassinovskaia et al. (2017)

"The PDIRPTW problem is defined on a directed graph $G = (N, A)$ *where* N *is the set of nodes indexed by* $i, j \in \{0, \dots, n\}$ *and* $A = \{(i, j): i, j \in N, i \neq j\}$ *is the arc set. Node 0 represents the producer location and the set* $N_0 = N \setminus \{0\}$ *denotes the customer locations. Each customer* i *has a demand* u_{it} *at period* t*. Moreover, each customer and the producer incur unit inventory holding costs per period (* $\forall i \in N$*),* h_i^L *for the loaded RTI and* h_i^E *for the empty RTI, with inventory capacities* C_i^L *for the loaded RTI and* C_i^E *for the empty RTI. Inventories are not allowed to exceed the holding capacity and must be positive. The length of the planning horizon is* p *with discrete time periods* $t \in T = \{1, \dots, p\}$*. A set of vehicles* $v \in V = \{1, \dots, k\}$ *are available, each with a capacity* Q *in terms of number of RTIs without distinction between empty and loaded RTIs, with* α*, a fixed cost per km;* β *a variable cost per tonne.km and with an average speed* s *in km/h. An empty RTI weights*w_E*, and a loaded RTI weighs* w_L*. Each vehicle is able to perform a route per period, from the producer to a subset of customers. At the customer's gate, a fixed time in hours,* g *is incurred. A distance* d_{ij} *is associated for all* $(i, j) \in A$*. The service of a customer* $i \in N_0$ *can begin within a time window*$[e_i, l_i]$*. The vehicle cannot arrive earlier than time* e_i *and no later than time* l_i*. The producer is assumed to have sufficient inventory and capacity to perform all of the pickups and deliveries during the planning horizon. The cost to buy a new RTI is* b*; the production cost per RTI is* c*, including inspection and cleaning costs incurred at the producer and is proportional to the number of RTIs used at the producer. At the beginning of the planning horizon, the producer knows current inventory levels:* I_{i0}^L *of the loaded RTI and* I_{i0}^E *and receives information on the demand* u_{it} *of each customer* i *for each period* t*. The objective of the problem is to minimize the total cost while satisfying the inventory level constraints for each customer in each period. It is assumed that every customer can only be visited exactly once. Moreover, a penalty cost per unit of time,* ε*, is added for the time length of the route,* δ_{vt}*.*

Decision variables used in the formulation are a set of binary variables y_{ijvt} *equal to 1 if and only if arc (i,j) is used on the route of vehicle* v *in period* t*; the integer variables are listed as follows:*

I_{it}^L *inventory level of loaded RTI at customer* i *at the end of period* t*;*
I_{it}^E *inventory level of empty RTI at customer* i *at the end of period* t*;*
q_{it} *loaded RTI quantity delivered to customer* i *in period* t*;*
r_{it} *empty RTI returned from customer* i *in period* t*;*

x_{ijt} *loaded RTI quantity transported from customer i to customer j in period t;*
z_{ijt} *empty RTI quantity transported from customer i to customer j in period t;*
p_t *RTI quantity filled from the producer in period t;*
n_t *new RTI quantity bought and filled from the producer in period t;*
and the real variables are:
m_{ivt} *arriving time of vehicle v to customer i in period t*
δ_{vt} *the time length of the route.*

The inventory routing problem with Simultaneous Pickup and Delivery in a closed-loop (PDIRPTW) is then formulated as follows:

$$minimize \sum_{i\in N}\sum_{j\in N}\sum_{t\in T}\left(\alpha\sum_{v\in V} y_{ijvt} + \beta(\,w_L x_{ijt} + w_E\, z_{ijt})\right) d_{ij} + \sum_{i\in N}\sum_{t\in T}(h_i^L\, I_{it}^L + h_i^E\, I_{it}^E) + \sum_{t\in T} c\, p_t + \sum_{t\in T} b\, n_t + \sum_{v\in V}\sum_{t\in T} \varepsilon\, \delta_{vt} \quad (1)$$

Subject to:

$x_{ijt} + z_{ijt} \le Q\sum_{v\epsilon V} y_{ijvt}$ $\forall\,(i,j)\in A, \forall t\in T$ *(2)*

$I_{it}^L = I_{it-1}^L + q_{it} - u_{it}$ $\forall i\in N_0, \forall\ t\in T$ *(3)*

$I_{it}^E = I_{it-1}^E - r_{it} + u_{it}$ $\forall i\in N_0, \forall\ t\in T$ *(4)*

$I_{0t}^L = I_{0t-1}^L + p_t - \sum_{i\in N} q_{it}$ $\forall\, t\in T$ *(5)*

$I_{0t}^E = I_{0t-1}^E - p_t + n_t + \sum_{i\in N} r_{it}$ $\forall\, t\in T$ *(6)*

$0\le I_{it}^L \le C_i^L$ $\forall i\in N, \forall\, t\in T$ *(7)*

$0\le I_{it}^E \le C_i^E$ $\forall i\in N, \forall\, t\in T$ *(8)*

$p \le I_{0t-1}^E + n_t$ $\forall\, t\in T$ *(9)*

$\sum_{i\in N, i\ne j}(x_{ijt} - x_{jit}) = q_{jt}$ $\forall\, j\in N_0, \forall\ t\in T$ *(10)*

$\sum_{i\in N, i\ne j}(z_{ijt} - z_{jit}) = r_{jt}$ $\forall\, j\in N_0, \forall\ t\in T$ *(11)*

$\sum_{i\in N, i\ne j} y_{ijvt} - \sum_{i\in N, i\ne j} y_{jivt} = 0$ $\forall j\in N, \forall v\in V, \forall t\in T$ *(12)*

$\sum_{i\in N}\sum_{v\epsilon V} y_{ijvt} \le 1$ $\forall j\in N_0, \forall t\in T$ *(13)*

$\sum_{j\in N_0} y_{0jvt} \le 1$ $\forall v\in V, \forall t\in T$ *(14)*

$r_{it} \le I_{it-1}^E$ $\forall i\in N_0, \forall\, t\in T$ *(15)*

$q_{it} \le I_{it}^L$ $\forall i\in N_0, \forall\, t\in T$ *(16)*

$\sum_{i\in N} r_{it} \le I_{0t}^E$ $\forall\, t\in T$ *(17)*

$\sum_{i\in N} q_{it} \le I_{0t-1}^L$ $\forall\, t\in T$ *(18)*

$e_i\sum_{j\in N, j\ne i} y_{ijvt} \le m_{ivt} \le l_i \sum_{j\in N, j\ne i} y_{ijvt}$ $\forall i\in N,\ \forall v\in V, \forall\, t\in T$ *(19)*

$$m_{ivt} + y_{ijvt}\left(g + \frac{d_{ij}}{s}\right) - max_{i\in N} l_i \; (1 - y_{ijvt}) \; \leq m_{jvt}$$

$$\forall i \in N, j \in N_0, i \neq j \;\; \forall v \in V, \forall t \in T \qquad (20)$$

$$0 \leq \delta_{vt} \; \leq \; \max_{i\in N} l_i \qquad \forall v \in V, \forall t \in T \qquad (21)$$

$$m_{ivt} + y_{i0vt} * \left(g + \frac{d_{i0}}{s}\right) - \max_{i\in N} l_i \; (1 - y_{i0vt}) \; \leq \delta_{vt}$$

$$\forall i \in N, \forall v \in V, \forall t \in T \qquad (22)$$

$$\sum_{i\in N}\sum_{v\in V}\sum_{t'=t_1}^{t_2} y_{ijvt} \geq \left\lceil \frac{\sum_{t'=t_1}^{t_2}(u_{jt'} - C_j^L)}{min\{C_j^L, Q\}} \right\rceil \qquad \forall j \in N_0, \; \forall t_1, \; t_2 \in T \;, \; t_1 \geq \; t_2 \qquad (23)$$

$$I_{it}^L, I_{it}^E, q_{it}, r_{it}, x_{ijt}, z_{ijt}, n_t, p_t \in \mathbb{Z}^+ \qquad \forall i, j \in N, \forall t \in T \qquad (24)$$

$$y_{ijvt} \in \{0,1\} \qquad \forall (i,j) \in A, \forall v \in V, \forall t \in T \qquad (25)$$

The objective function (1) minimizing the total cost. The first sum of the objective function corresponds to transportation costs, the second sum corresponds to the inventory costs of empty and loaded RTIs at both customer locations and the depot, the third sum is the production cost, the fourth sum represents the cost to buy new RTIs, and the last term is the penalty cost due to the driver's waiting time. Constraints (2) state that the vehicle capacity is not exceeded. Constraints (3) state the inventory conservation condition for the loading of RTIs over successive periods: they define the inventory in period t *as the inventory held in period* $t-1$*, plus the loaded RTI quantity delivered minus the demand. In the same way, constraints (4) state the inventory conservation condition for empty RTIs over successive periods: they define the inventory in period* t *as the inventory held in period* $t-1$*, minus the empty RTI quantity returned plus the demand. Constraints (5) ensure inventory conservation conditions for the loading of RTIs over successive periods at the depot: the inventory in period* t *as the inventory held in period* $t-1$*, plus the RTI quantity filled from the producer minus the loaded RTI quantity delivered to customers. In the same way, constraints (6) ensure inventory conservation conditions for the empty RTIs over successive periods at the depot: the inventory in period* t *as the inventory held in period* $t-1$*, minus the RTI quantity filled from the producer, plus the newly bought RTIs plus empty RTIs returned from customers. Constraints (7) and (8) define the bounds on the inventory of loaded (7) and empty RTIs (8) held by each customer throughout all periods. Constraints (9) guarantee that the number of RTIs filled from the producer in period* t *do not exceed the number of empty RTIs held in the inventory in period* $t-1$ *plus the number of bought RTIs. Constraints (10) indicate that loaded RTI quantities are delivered and constraints (11) that the empty RTIs are returned. Constraints (12), (13), (14) and (20) ensure that the proper vehicle routes are constructed.*

Constraints (12) stipulate if a vehicle v visits customer j in period t, it has to leave customerj in period t. Constraints (13) ensure that at the most, a vehicle visits a customer per period. Constraints (14) ensure that vehicles leave the producer only once per period or stay at the depot. Constraints (15-18) ensure the closed-loop chain. Constraints (15) state that the quantity of empty RTIs returned is held in the inventory. Constraints (16) state that the quantity of loaded RTIs delivered was held as inventory in the previous period. Constraints (17) state that the quantity of empty RTIs returned to the producer is held in its inventory. Constraints (18) state that the quantity of loaded RTIs delivered to the producer was held in the inventory in the previous period. Constraints (19) ensure that at each customer location, the vehicle arrives within the time window. Constraints (20) ensure that the arrival time at customer j has a greater value than arrival time at customer i in one route. Those constraints do not need to be satisfied when the vehicle v does not travel from node i to node j in period t. Constraints (21) ensure that the waiting time is lesser than the maximum arrival time and constraints (22), combined with the objective function, guarantee that the vehicle returns to the depot directly after serving the last customer. Based on Coelho and Laporte (2014), the valid inequalities (23) are related to whether the demand of customer j for period $[t_1, t_2]$ *is greater than its inventory capacity then a visit is required. These constraints (23) have a very positive impact on solving the ten instances included in Table 5 since the running time taken to prove optimality is reduced by half on average. This result corroborates the conclusion of Coelho and Laporte (2014). Finally, constraints (24) and (25) define non-negativity and binary conditions on the variables“* (Iassinovskaia et al., 2017, pp.5-7).

Appendix 3 – Ownership of RTIs

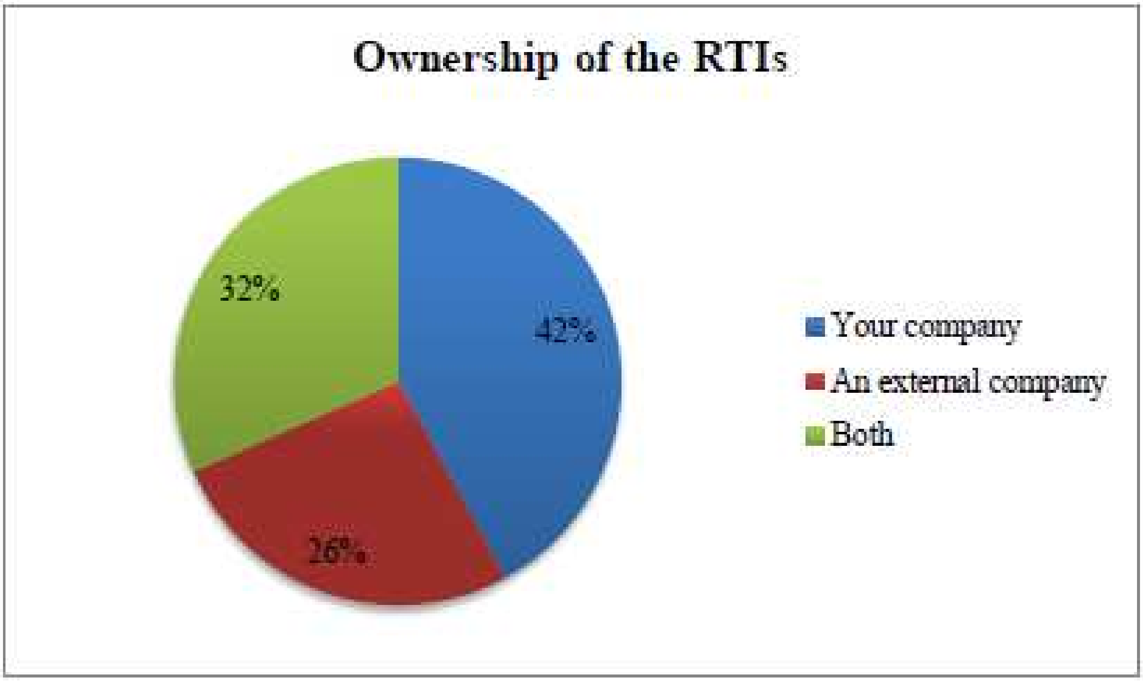

Figure 12: Ownership of the RTIs

Retrieved from Martin (2016, p.42).

Appendix 4 – Loss rate graph

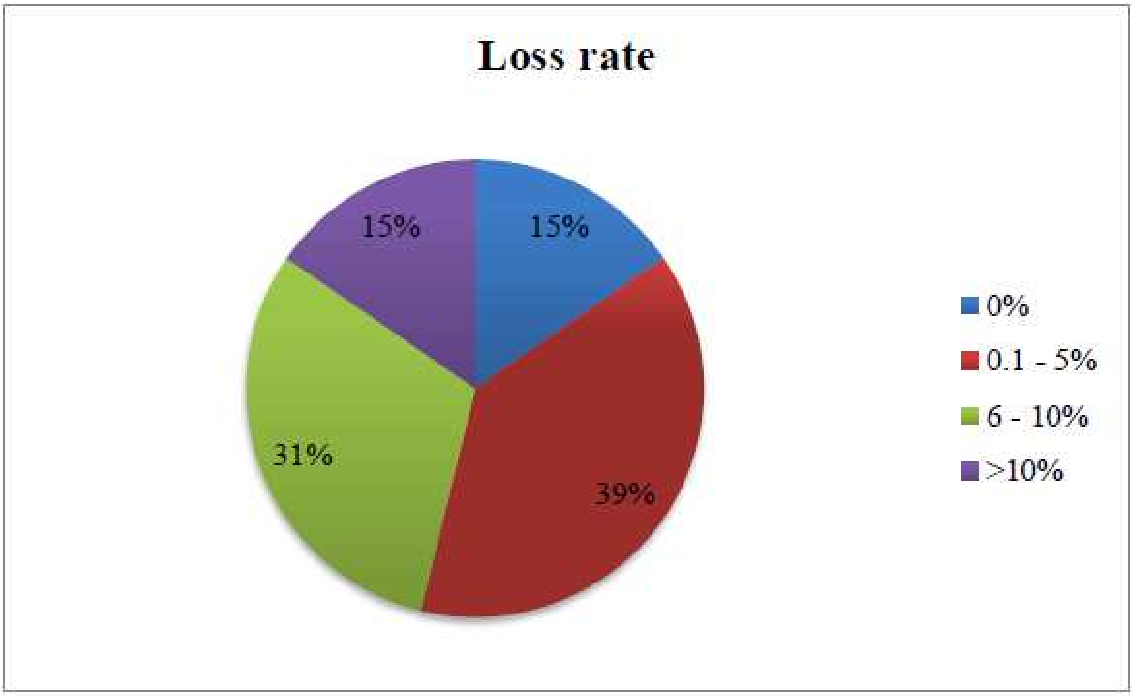

Figure 16: Loss rate

Retrieved from Martin (2016, p.46).

Appendix 5 – Data used for the graphs illustrating the effects of the collection rate

Figure 9

a = 5€			
γ	Total Cost(€)	Running Time (s)	Optimal solution
0.1	1624.25	90	
0.2	1535.42	123	
0.3	1499.15	11702	
0.4	1400.07	107	
0.5	1288.56	151	X
0.6	1266.44	351	
0.7			
0.8	1129.48	509	
0.9			
1	984.29	489	X

Figure 10

γ	Total Cost (€)	New RTIs Cost (€)	Resale Revenue (-) (€)	Running Time (s)	Optimal solution
0.1	1624.25	630.00	10.00	90	
0.2	1535.42	570.00	25.00	123	
0.3	1499.15	530.00	30.00	11702	
0.4	1400.07	460.00	50.00	107	
0.5	1288.56	380.00	70.00	151	X
0.6	1266.44	320.00	75.00	351	
0.7					
0.8	1129.48	200.00	100.00	509	
0.9					
1	984.29	80.00	140.00	489	X

Figure 11

γ	Total Cost (€)	Transportation cost Cost (€)	Penalty cost (€)	Inventory holding cost (€)	Running Time (s)	Optimal solution
0.1	1624.25	972.82	13.58	16.49	90	
0.2	1535.42	958.96	13.32	16.78	123	
0.3	1499.15	967.64	13.08	17.07	11702	
0.4	1400.07	958.32	13.32	17.07	107	
0.5	1288.56	947.42	12.94	16.84	151	X
0.6	1266.44	989.24	13.51	17.33	351	
0.7						
0.8	1129.48	996.94	13.78	17.40	509	
0.9						
1	984.29	1011.50	14.23	17.17	489	X

Appendix 6 – Data used for the graphs illustrating the effects of the resale price

Figure 12

γ=0.5			
a (€)	Total Cost (€)	Running time (s)	Optimal solution
-2	1374.96	156	X
0	1358.56	178	X
1	1344.56	142	X
2	1330.56	172	X
3	1316.56	189	X
4	1302.56	175	X
5	1288.56	151	X
6	1274.56	91	X
7	1260.56	262	X
8	1246.56	130	X
9	1232.56	99	X
10	1218.56	137	X

Figure 13

γ=0.5					
a (€)	**Total cost (€)**	New RTIs Cost (€)	Resale Revenue (€)	Running time (s)	Optimal solution
-2	**1374.96**	380	-10	156	X
0	**1358.56**	380	0	178	X
2	**1330.56**	380	28	172	X
4	**1302.56**	380	56	175	X
6	**1274.56**	380	84	91	X
8	**1246.56**	380	112	130	X
10	**1218.56**	380	140	137	X

Figure 14

γ=0.5						
a (€)	**Total cost (€)**	Transportation cost (€)	Inventory holding cost (€)	Penalty cost (€)	Running time (s)	Optimal solution
-2	**1374.96**	953.18	17.21	13.21	156	X
0	**1358.56**	947.42	16.84	12.94	178	X
2	**1330.56**	947.42	16.84	12.94	172	X
4	**1302.56**	947.42	16.84	12.94	175	X
6	**1274.56**	947.42	16.84	12.94	91	X
8	**1246.56**	947.42	16.84	12.94	130	X
10	**1218.56**	947.42	16.84	12.94	137	X

Appendix 7 – Data used for the graphs illustrating the effects of both the resale price and collection rate

Figure 15

	Total cost (€)					
c	*a* = 1€	*a* = 3€	*a* = 5€	*a* = 7€	*a* = 9€	Optimal solutions
0.2	1568.59	1562.46	1535,42	1533.99	1524.60	
0.4	1451.04	1432.44	1400,07	1386.18	1374.91	
0.6	1325.25	1298.94	1266,44	1243.3	1205.25	
0.8	1216.16	1169.48	1129.48	1093.66	1049.48	
1	1096.29	1040.29	984.29	928.29	872.29	X

Figure 16

a (€)	*γ=0.1*		*γ=0.5*		*γ=1*	
	Total cost (€)	Running time (s)	Total cost (€)	Running time (s)	Total cost (€)	Running time (s)
-2	1632.85	90	1374.96	156	1139.48	199
0	1628.85	84	1358.56	1	1124.29	500
1	1626.85	104	1344.56	142	1096.29	242
2	1626.31	122	1330.56	113	1068.29	337
3	1622.86	88	1316.56	189	1040.29	329
4	1620.85	77	1302.56	118	1012.29	349
5	1618.85	90	1288.56	107	984.29	489
6	1616.85	74	1274.56	91	956.29	280
7	1614.85	122	1260.56	262	928.29	463
8	1612.85	91	1246.56	113	900.29	266
9	1610.85	77	1232.56	99	872.29	230
10	1608.85	83	1218.56	137	844.29	468
Optimal solutions			X		X	

Figure 17

	Number of resold RTIs							
γ	*"a=-2€"*	*a=0€*	*a=1€*	*a=3€*	*a=5€*	*a=7€*	*a=9€*	Optimal solutions
0.2	4	4	5	5	5	5	5	
0.4	6	6	10	10	10	10	10	
0.6	9	15	15	15	15	15	15	
0.8	8	16	20	20	20	20	20	
1	7	28	28	28	28	28	28	X

Figure 18

		Maintenance cost (€)								
		"a=-2€"	*a=0€*	*a=1€*	*a=3€*	*a=5€*	*a=7€*	*a=9€*	*a=10€*	*Optimal solutions*
γ	0.2	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	
	0.4	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	
	0.6	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	
	0.8	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	
	1	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	X

Figure 19

a (€)	Resale revenue (€)	New RTIs cost (€)	Running time (s)	Optimal solution
-2	-14	80	199	X
0	0	80	500	X
1	28	80	242	X
2	56	80	337	X
3	84	80	329	X
4	112	80	349	X
5	140	80	489	X
6	168	80	280	X
7	196	80	463	X
8	224	80	266	X
9	252	80	230	X
10	280	80	468	X

Figure 20

a (€)	Transportation cost (€)	Total cost (€)	Running time (s)	Optimal solution
-2	1011.5	1139.48	199	X
0	1011.5	1124.29	500	X
1	1011.5	1096.29	242	X
2	1011.5	1068.29	337	X
3	1011.5	1040.29	329	X
4	1011.5	1012.29	349	X
5	1011.5	984.29	489	X
6	1011.5	956.29	280	X
7	1011.5	928.29	463	X
8	1011.5	900.29	266	X
9	1011.5	872.29	230	X
10	1011.5	844.29	468	X

Appendix 8 – Foldable pallet heightener with 6 hinges

Retrieved from TER-Industry (s.d.).

Bibliography and Webography

Aberdeen Group. (2004). RFID-enabled logistics asset management benchmark report. TKR Consulting Associates, June**.**

Accenture. (2014). *Circular Advantage*. Accenture Strategy, 14-3357.

Akçalı, E., Çetinkaya, S. (2011). Quantitative models for inventory and production planning in closed-loop supply chains. *International Journal of Production Research*, *49*(8), 2373–2407. doi: 10.1080/00207541003692021

Buchanan, D. J., & Abad, P. L. (1998). Optimal policy for a periodic review returnable inventory system. *IIE Transactions, 30*(11), 1049–1055.

Garrasco-Gallego, R., & Ponce-Cueto, E. (2010). A management model for closed-loop supply chains of reusable articles: defining the issues. In *Proceedings of the 4th International Conference on Industrial Engineering and Industrial Management*, (pp. 63-70). San Sebastián.

De Brito, M. P., Dekker, R., Flapper, S.D.P. (2005). Reverse logistics: A review of case studies. In *Distribution Logistics* (pp.243-281). Springer Berlin Heidelberg.

Dowlatshahi, S. (2000). Developing a theory of reverse logistics. *Interfaces, 30*(3), 143-155.

European Environment Agency [EEA]. (2016). Circular economy in Europe. *EEA Report*, *2*.

European Parliament and Council. (1994). *European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste*. Amended in 2004, 2005, 2009, 2013. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3Al21207#amendingact

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E., Van Numen, J., Van Wassenhove, L. (1997). Quantitative models for reverse logistics: a review. *European journal of operational research*, *103*(1), 1-17.

Geyer, R., Van Wassenhove, L. N., & Atasu, A. (2007). The Economics of Remanufacturing Under Limited Component Durability and Finite Product Life Cycles. *Management Science*, *53*(1), 88-100. doi: 10.1287/mnsc.1060.0600

Guide, V. D. R., Harrison, T. P., & Van Wassenhove, L. N. (2003). The Challenge of Closed-Loop Supply Chains. *Interfaces*, *33*(6), 3-6.

Glock, C. H. (2017). Decision support models for managing returnable transport items in supply chains: A systematic literature review. *International Journal of Production Economics, 183,* 561-569. doi:10.1016/j.ijpe.2016.02.015

Glock, C. H., & Kim, T. (2015). A joint economic lot size model with returnable transport items. *International Journal of Integrated Supply Management*, *9*(3), 202–224.

Goellner, K. N., & Sparrow, E. (2014). An Environmental Impact Comparison of Single-use and Reusable Thermally Controlled Shipping Containers. *The International Journal of Life Cycle Assessment*, *19*(3), 611-619.

Grimes-Casey, H. G., Seager, T. P., Theis,T. L., & Powers, S. E. (2007). A game theory framework for cooperative management of refillable and disposable bottle lifecycles. *Journal of Cleaner Production*, *15*(17), 1618–1627.

GS1, (s.d.). *Returnable Transport Items.* Retrieved from *http://www.gs1.org/1/tlkeys/index.php/p=asset/aid=43*

Hariga, M., Glock, C. H., & Kim, T. (2016). Integrated product and container inventory model for a single-vendor single-buyer supply chain with owned and rented returnable transport items. *International Journal of Production Research, 54*(7), 1964-1979. doi:10.1080/00207543.2015.1071896

Hellström, D., Johansson, O. (2010). The impact of control strategies on the management of returnable transport items. *Transportation Research Part E: Logistics and Transportation Review***,** *46*(6), 1128-1139.

Iassinovskaia, G., Limbourg, S., & Riane, F. (2017). The inventory-routing problem of returnable transport items with time windows and simultaneous pickup and delivery in closed-loop supply chains. *International Journal of Production Economics, 183,* 570-582. doi:10.1016/j.ijpe.2016.06.024

IBM. (s.d.). *Relative MIP gap tolerance.* Retrieved from https://www.ibm.com/support/knowledgecenter/SS9UKU_12.5.0/com.ibm.cplex.zos.help/Parameters/topics/EpGap.html

IC-RTI (2003). *Reusable Transport Items (RTI) – Organizational Recommendations*. Retrieved from http://ecr-all.org/wp-content/uploads/pub_2003_RTI_organizational_recommendations.pdf.

Ilic, A., Ng, J.W.P., Bowman, P., & Staake, T. (2009). The value of RFID for RTI management. *Electronic Markets*. *19*(2-3), 125–135.

Johansson, O., Hellström, D. (2007). The effect of asset visibility on managing returnable transport items. *International Journal of Physical Distribution and Logistics Management, 37*(10), 799-815.

Kärkkäinen, M., Ala-Risku, T., Herold, M. (2004, February). Managing the rotation of reusable transport packaging – a multiple case study. In *Thirteenth International Working Seminar on Production Economics.*

Kim, T. & Glock, C. H. (2014). On the use of RFID in the management of reusable containers in closed-loop supply chains under stochastic container return quantities. *Transportation Research Part E: Logistics and Transportation Review, 64*, 12–27.

Kroon, L., Vrijens, G. (1995). Returnable containers: an example of reverse logistics. *International Journal of Physical Distribution & Logistics Management*, *25*(2), 56-68.

Limbourg, S. (s.d.). *Distribution Management.* Lecture Notes, University of Liège.

Martin, A. (2016). *An analysis of the management of returnable transport items.* Unpublished Master thesis, University of Liège, Liège.

Mason, A., Shaw, A., & Al-Shamma'a, A. (2012). Peer-to-peer inventory management of returnable transport items: A design science approach. *Computers in Industry*, *63*(3), 265–274.

Pollaris, H., Braekers, K., Caris, A., Janssens, G.K., Limbourg, S. (2016). Capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints. *EURO Journal on Transportation and Logistics*, *5*(2), 231-255. doi: 10.1007/s13676-014-0064-2

Rogers, D. S., Tibben-Lembke, R.S. (1999). Going backwards: Reverse logistics trends and practices.

Rosenau, W. V., Twede, D., Mazzeo, M. A., & Singh, S. P. (1996). Returnable/Reusable logistical packaging: A capital budgeting investment decision framework. *Journal of Business Logistics*, *17*(2).

Saphire, D. (1994). *Delivering the goods: Benefit of reusable shipping containers*. INFORM.

Silva, D. A. L, Santos Renó, G.W., Sevegnani, G., & Serrra Truzzi, O. M. (2013). Comparison of disposable and returnable packaging: a case study of reverse logistics in Brazil. *Journal of Cleaner Production*, *47*, 377-387.

Soysal, M. (2016). Closed-loop inventory problem for returnable transport items. *Transportation Research Part D: Transport and Environment*, *48*, 31-45.

Sustainable Packaging Coalition. (2011). *Definition of sustainable packaging.* Retrieved from http:// sustainablepackaging.org/uploads/Documents/Definition%20of%20Sustainable %20Packaging.pdf

TER-Industry. (s.d.). *Wooden Pallet Risers.* Retrieved from http://www.ter-industry.com/rent/wooden-pallet-risers/product-pallet-collars-of-wood

Table of Figures

Table of Tables

Table of Abbreviations

CHEP: Commonwealth Handling Equipment Pool

CHU: Centre Hospitalier Universitaire

CIRP: Closed-loop Inventory Routing Problem

CLSC: Closed-loop supply chain

EEA: European Environment Agency

IC-RTI: International Council for Reusable Transport Items

IRP: inventory-routing problem

MIP: Mixed Integer Programming

NIMBY: Not In My Back Yard

PDIRPTW: pickup and delivery inventory-routing problem within time windows

RFID: Radio Frequency Identification

RTI: Returnable Transport Item

UK: United Kingdom

Table of Content

Executive Summary

This Master thesis proposes some modifications of the model developed by Iassinovskaia, Limbourg and Riane (2017) related to Pickup and Delivery Inventory Routing Problem with Time Windows (PDIRPTW) for the management of Returnable Transport Items (RTIs). The aim of these modifications is to better reflect the reality of the management of RTIs in organizations.

The first improvement provided to the model refers to durability, resale and losses. The durability aspect relates to the fact that RTIs have a finite lifetime, which means that they can be used only a limited number of times. Then, the company has to dispose of these items and one interesting way to proceed is to resell them, hence the resale aspect which is strongly linked to the durability feature. Finally, the loss of RTIs is a frequent problem faced by companies. Both durability and losses generate the need to purchase more RTIs.

The second and third modifications are about maximum ceiling constraints and minimum threshold constraints that are added to the initial model of Iassinovskaia et al. (2017). Some companies have to establish this kind of rules for some managerial or organizational reasons, although they result in some additional costs.

These three main parts of the thesis are illustrated by some real-life situations drawn from the Master thesis of Martin (2016) and from the visits of different companies. Then, the models are developed and explained. After that, some analyses are performed and some conclusions are finally drawn.

Key words: Returnable Transport Item (RTI), pickups and deliveries, durability constraints, maximum ceiling constraints, minimum threshold constraints.