How to include the durability, resale and losses of returnable transport items in their management?

Sabine Limbourg
HEC-Liege Management School
QuantOM
Liege, Belgium
sabine.limbourg@ulg.ac.be

Myriem Pirotte
HEC-Liege Management School
f *QuantOM*
Liege, Belgium
myriem.pirotte@student.ulg.ac.be

***Abstract*—Reducing environmental nuisances, related regulations and the pursuit of economic advantages are the main reasons why companies share their returnable transport items (RTIs) among the different partners of a closed-loop supply chain. However RTIs have a finite lifetime, which means that they can be used only a limited number of times. Moreover, 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.**

***Index Terms*—Returnable Transport Item (RTI), pickups and deliveries, durability constraints, closed-loop supply chain, inventory routing problem.**

I. Introduction

Enterprises want to make their supply chains greener but the environmental aspect only makes sense if additional economical value is considered. The development of reverse logistics took place in this frame. According to [1], 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 [2]. Reverse logistics also includes reverse distribution, which refers to the flow of information and goods in the opposite direction from traditional logistic activities [3]. 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 [2].

All these elements have set the stage for the concept of closed-loop supply chain (CLSP). According to [4], CLSP consists of both the forward supply chain and the counterpart reverse supply chain. 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).

The CLSC field gives rise to several areas of research and various opportunities. Some of them are related to packaging activities. Sustainable packaging has to be effectively recovered and utilized in biological or industrial closed loop cycles [5]. 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 [5]. 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. The next section of this paper is the literature review. Then, in section 3, improve and the the pickup and delivery inventory-routing problem within time windows (PDIRPTW) over a planning horizon model developed by [6] on the durability, resale and losses aspects. Section 4 consists in a parametric study where the influences of parameters are studied. Finally, general conclusions are drawn and some insights are suggested in the last section.

II. Literature review

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. [7] 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).

It is only in recent years that the management of returnable transport items has often been a subject of research [7]. 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 1, revealing the growing importance of a more efficient

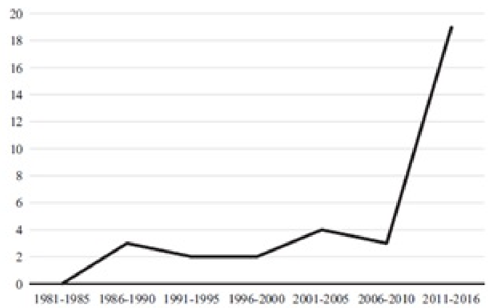

Fig. 1: Evolution of the number of articles about the management of RTIs published per year (retrieved from [8], p.3).

management of RTIs in closed-loop supply chains [8].

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, [9] 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 [7].

According to [10], 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. [11] 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 [7] and the improved handling and protection of the packaged goods [12]. Using RTIs also enables to avoid repeated purchase of new transportation materials, reducing this way the waste and disposal cost [7]. Indeed, [10] 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, [13] 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 [13]. In the case study carried out by [14] 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 [14]. Concerning the environmental aspect of the use of RTIs, the paper of [7] confirms that RTIs lead to waste reduction levels required by some regulations and by customers, who are more and more environmentally-conscious. According to [15], 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 [3]) 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 CO2 emissions, especially when the partners of the supply chain are located far apart from each other ([7]; [8]). And according to [8], 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 [8], 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 [8].

[10] synthesizes in some ways the advantages and drawbacks of RTIs by listing the success factors of an efficient RTIs management: transportation distances, delivery frequency, number of parties involved, and number of sizes needed.

In the same perspective, [13] 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.

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 [16] and [7]), who conducts a study in several industry sectors in the United Kingdom 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. [17] 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, [7] 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; [18], meaning that the material should be replaced after on average 6 to 11 utilizations. More generally, [19] 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 [7]. 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 [20], 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 [7]) 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, [21] 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 [8]. [21] 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 [21]. Indeed, when these elements increase, the reservation price increase as well. In the same way, [22] 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, [23] 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.

As this paper 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. [24] 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.

[25] studies closed-loop inventory routing problem 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.

III. Modelling approach

Companies face the deterioration of their RTIs, which is simply due to their more or less intense use. Indeed, the maintenance that is laid down by the companies examined by [16] 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 [16], a flat glass company estimates that their stillages make on average between 40 and 50 rotations during a lifetime of 15 years. An international firm in the services, trading and food distribution sectors, uses rolls (among RTIs such as euro-pallets, plastic pallets, plastic tray and pallet heighteners) that lasts at least 5 years during which they make a hundred of trips per year, and a company dealing with ecological first-and-last-mile transport has polystyrene boxes that achieve 70 to 80 rotations during a lifetime of 6 to 8 months.

Some companies that own their RTIs are able to resell their defective RTIs when they are not good anymore to transport goods. Moreover, the vast majority of companies interviewed by [16] report facing losses of RTIs. This issue seems to be quite widespread. To tackle this phenomenon, some organizations have set up some measures, as for example a guarantee system. Other methods such as a penalty system, a clause in a contract or a tracking system can also be used. The implementation of a RFID system could also reduce the number of lost RTIs. As seen in the literature review, it seems according to various authors and studies that the loss rate ranges between 9% and 20%.

A. Limited durability

The focus of the article [26] 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. The authors give some examples of the maximum number of lives for some products components that can actually be used as RTIs. A wooden pallet can be used 50 times, a glass bottle 25 times, and a crate for bottles 120 times. 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. A given percentage of the marketed products is collected at the end of their current utilization. The not collected RTIs are assumed to be lost.

B. PDIRPTW with limited durability, resale and losses

As the model developed by [6], we consider a system made up of a producer based at a depot and 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.

However, 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.

RTIs, 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, at a certain price a, when they reach their end of life and resale is assumed to take the form of a raw materials recovery. 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 during the planning horizon being the exception) and does not involve any effort and cost.

That is why, the model developed by [6] is improved with a level of utilization $k \in K = \{0, ..., l\}$ for each RTI. 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 $K_0 = K = \{1, ..., l\}$ indicates the levels of actual utilization (i.e. excluding the level never used) and this notation will be used in the model. The integer variables, $\widetilde{u}_{ikt}$, are 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 $(1 - \gamma)$ is assumed to have got lost. The following integer variables are thus added to the [6] model:

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

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 node j in period t;

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

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

The objective function becomes:

$$\min \sum_{i\in N}\sum_{k\in K}\sum_{t\in T}(h^L_i I^L_{ikt} + h^E_i I^E_{ikt}) + \sum_{t\in T} cp_t + \sum_{t\in T} bn_t + \sum_{i,j\in N;t\in T}\left(\alpha \sum_{v\in V} y_{ijvt} + \beta \sum_{k\in K}(w_L x_{ijkt} + w_E z_{ijkt})\right) d_{ij} + \sum_{v\in V}\sum_{t\in T}\varepsilon\delta_{vt} - a\sum_{t\in T} I^E_{0lt} \quad (1)$$

where 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.

The constraints related to the quantity of RTIs become:

$$x_{ijkt} + z_{ijkt} \leq Q \sum_{v\in V} y_{ijvt} \qquad \forall i,j \in N, \forall t \in T \quad (2)$$

$$I^L_{ikt} = I^L_{ikt-1} + q_{ikt} - \widetilde{u}_{ikt} \qquad \forall i \in N_0, \forall t \in T, \forall k \in K \quad (3)$$

$$I^E_{ikt} = I^E_{ikt-1} - r_{ikt} + \widetilde{u}_{ikt} \qquad \forall i \in N_0, \forall t \in T, \forall k \in K_0 \quad (4)$$

$$I^E_{i0t} = I^E_{ikt-1} - r_{i0t} \qquad \forall i \in N_0, \forall t \in T \quad (5)$$

$$I^L_{0kt} = I^L_{0kt-1} + p_{kt} - \sum_{i\in N} q_{ikt} \qquad \forall t \in T, \forall k \in K \quad (6)$$

$$I^E_{0kt} = I^E_{0kt-1} - p_{kt} + n_t + \gamma \sum_{i\in N} r_{ikt} \qquad \forall t \in T, \forall k \in K_0 \backslash \{l\} \quad (7)$$

$$I^E_{00t} = I^E_{00t-1} - p_{0t} + n_t + \gamma \sum_{i\in N} r_{i0t} \qquad \forall t \in T \quad (8)$$

$$I^E_{0lt} = \gamma \sum_{i\in N} r_{ilt} \qquad \forall t \in T \quad (9)$$

$$0 \leq \sum_{k\in k} I^L_{ikt} \leq C^L_i \qquad \forall i \in N, \forall t \in T \quad (10)$$

$$0 \leq \sum_{k\in k} I^E_{ikt} \leq C^E_i \qquad \forall i \in N, \forall t \in T \quad (11)$$

$$\sum_{i\in N, i\neq j}(x_{ijkt} - x_{jikt}) = q_{jkt} \qquad \forall j \in N_0, \forall t \in T, \forall k \in K \quad (12)$$

$$\sum_{i\in N, i\neq j}(z_{jikt} - z_{ijkt}) = r_{jkt} \qquad \forall j \in N_0, \forall t \in T, \forall k \in K \quad (13)$$

$$\sum_{k\in K\backslash\{l\}} \widetilde{u}_{ikt} = u_{it} \qquad \forall i \in N_0, \forall t \in T \quad (14)$$

Constraints 2 state that the vehicle capacity, Q, is not exceeded. Constraints 3 state the inventory conservation condition for the loading of RTIs over successive periods. 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 5 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 6 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 7, 8 and 9 state the inventory conservation conditions for the empty RTIs situated at the producer. Constraints 7 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 8, for $k = 0$, are similar to constraints 7, 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 9 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 10 and 11 define the bounds on the inventory of loaded 10 and empty RTIs 11 held by each customer throughout all periods. Constraints 12 indicate that loaded RTI quantities are delivered and constraints 13 that the empty RTIs are returned. Lastly constraints 14 are added to make the link between the decision variable $\widetilde{u}_{ikt}$ and the demand 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.

IV. Parametric study

Data are taken from the instance used as an illustration (case 8) in the paper of [6]. Then, for the new model, the following parameters are added: the price to resell an RTI is $a = 5$; the collection rate γ is set to 0.5, and The maximum degree of utilization l is set to 2. 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 $10n$ for loaded RTIs

What stands out from the cost comparison in table I is the fact that the total cost of the new model is higher than the one of the initial 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.

TABLE I: Comparison of the costs (in €) taking durability, resale and losses into account or not

Durability Resale Losses	Total cost	Transportation cost	Inventory holding cost	Maintenance cost	New RTIs cost	Penal-ty cost	Resale revenue (-)
Yes	1124.45	1011.50	17.37	1.36	80	14.23	
No	1288.56	947.42	16.84	1.36	380	12.94	70

For running the following cases, a limitation on the gap (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—) 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 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: = 0.5 and = 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 . 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. 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. Figure 2 depicts the trends of the total cost, the cost to buy new RTIs and the resale revenue 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 2 and 3 due to the too long running time and to the too poor gap reached. Solutions are optimal for $\gamma = 0.5$ and $\gamma = 1$. 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 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. There is an 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, there is the effect on 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.

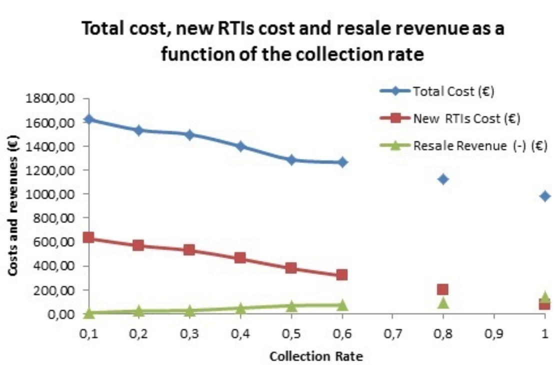

Fig. 2: Total cost, new RTIs cost and resale revenue as a function of the collection rate for $a = 5$ €.

Figure 3 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 2, 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.

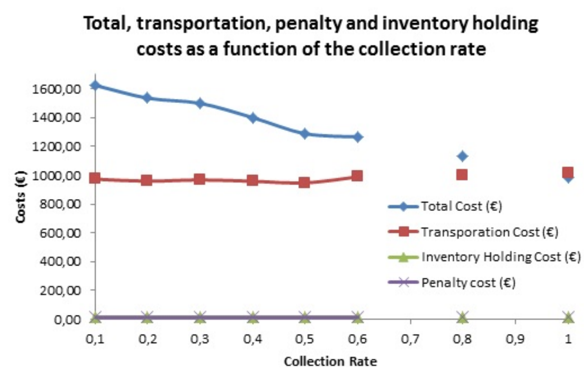

Fig. 3: Total cost, transportation cost, inventory holding cost and penalty cost as a function of the collection rate for $a = 5$€.

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.

B. 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 4. 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).
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. Being able to resell at a higher price could also be a good reason to push RTIs to reach the level l of utilization during the planning horizon. It is actually what seems to happen for $a = -2$. The number of RTIs that the company must get rid of is limited since it represents an additional cost. Figure 4 also 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. The evolution of the total cost is largely impacted by the resale revenue because the transportation, penalty and inventory holding costs seem to have no influence on the decrease of the total cost.

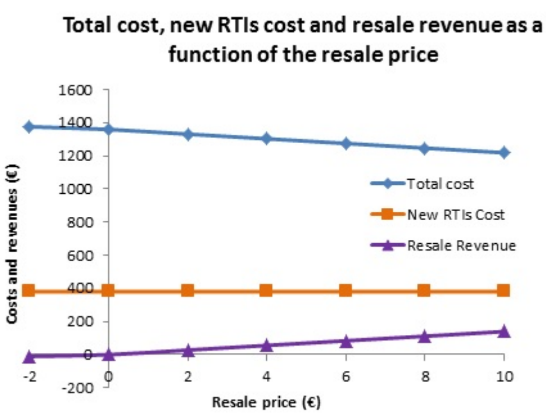

Fig. 4: Total cost, new RTIs cost and resale revenue as a function of the resale price for $\gamma = 0.5$

C. Effects of the collection rate and the resale price

Figure 5 confirms that the same trend as the one observed in the figure 2 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. 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. Then, the red point on the graph of figure 5 represents the total cost reached without any limitation $l = \infty$ on the level of utilization and is placed for $\gamma = 1$. We can see that all the curves get lower than this total cost when $\gamma = 1$ due to the resale price.

For the specific value $\gamma = 1$, we can notice some particular behaviors. Firstly, the resale revenue becomes higher than the

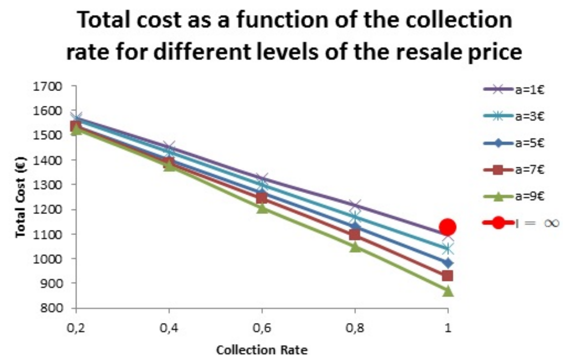

Fig. 5: Total cost as a function of the collection rate for different levels of a

cost to buy new RTIs when $a \geq 3$ €. Figure 6 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 overtaking happens because 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 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.

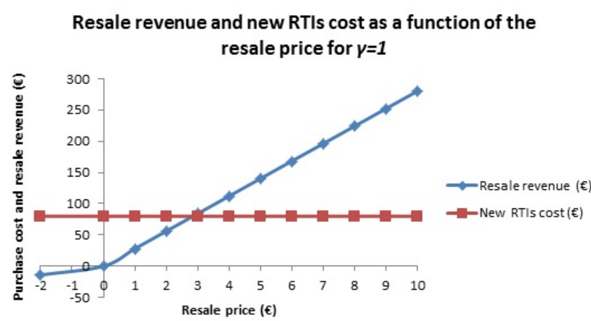

Fig. 6: Resale revenue and new RTIs cost as a function of a for $\gamma = 1$

V. Discussion

A. 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, 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. 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. The literature review displays a table of the number of lives for some products components retrieved from [26]. For example, wooden pallets, according to [26], 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. 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.

B. Resale of RTIs

Concerning the resale, the model assumes that it can only take place at the producer, which seems quite reasonable. 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.

C. 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. 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 [16] and [7]) mentioned in the literature review. 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 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 period of time. 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 that suffer losses know 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. 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. Finally, a value lower than 0 would simply make no sense.

VI. Conclusions and perspectives

The contribution is to take into consideration 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 in the PDIRPTW. Results show how the increase in the cost to purchase new RTIs (since the resold and lost items have to be replaced) is related to the collection rate and the resale price. This allows to quantify the cost to put in place some measures (such as RFID) to limit losses as much as possible and to resell the RTIs. 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.

References

[1] V. D. R. Guide, T. P. Harrison, and L. N. Van Wassenhove, "The challenge of closed-loop supply chains," *Interfaces*, vol. 33, no. 6, pp. 3–6, 2003.

[2] S. Dowlatshahi, "Developing a theory of reverse logistics," *Interfaces*, vol. 30, no. 3, pp. 143–155, 2000.

[3] L. Kroon and G. Vrijens, "Returnable containers: an example of reverse logistics," *International Journal of Physical Distribution & Logistics Management*, vol. 25, no. 2, pp. 56–68, 1995.

[4] E. Akçalı and S. Çetinkaya, "Quantitative models for inventory and production planning in closed-loop supply chains," *International Journal of Production Research*, vol. 49, no. 8, pp. 2373–2407, 2011.

[5] Sustainable Packaging Coalition, "Definition of sustainable packaging," 2011. [Online]. Available: http://sustainablepackaging.org/uploads/Documents/Definition%20of%20Sustainable%20Packaging.pdf

[6] G. Iassinovskaia, S. Limbourg, and F. Riane, "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*, vol. 183, pp. 570–582, 2017.

[7] C. H. Glock and T. Kim, "A joint economic lot size model with returnable transport items," *International Journal of Integrated Supply Management*, vol. 9, no. 3, pp. 202–224, 2015.

[8] C. H. Glock, "Decision support models for managing returnable transport items in supply chains: A systematic literature review," *International Journal of Production Economics*, vol. 183, pp. 561–569, 2017.

[9] W. V. Rosenau, D. Twede, M. A. Mazzeo, and S. P. Singh, "Returnable/reusable logistical packaging: a capital budgeting investment decision framework," *Journal of Business Logistics*, vol. 17, no. 2, pp. 139–165, 1996.

[10] D. S. Rogers and S. Ronald, "Going backwards: reverse logistics trends and practices," 1999.

[11] M. P. De Brito, R. Dekker, and S. D. P. Flapper, "Reverse logistics: a review of case studies," in *Distribution Logistics*. Springer, 2005, pp. 243–281.

[12] M. Kärkkäinen, T. Ala-Risku, and M. Herold, "Managing the rotation of reusable transport packaging–a multiple case study," in *Thirteenth International Working Seminar on Production Economics, Igls, Austria*, 2004.

[13] D. Saphire, *Delivering the goods: benefits of reusable shipping containers*. INFORM, 1994.

[14] D. A. L. Silva, G. W. S. Renó, G. Sevegnani, T. B. Sevegnani, and O. M. S. Truzzi, "Comparison of disposable and returnable packaging: a case study of reverse logistics in brazil," *Journal of Cleaner Production*, vol. 47, pp. 377–387, 2013.

[15] K. N. Goellner and E. Sparrow, "An environmental impact comparison of single-use and reusable thermally controlled shipping containers," *The International Journal of Life Cycle Assessment*, vol. 19, no. 3, pp. 611–619, 2014.

[16] A. Martin, "An analysis of the management of returnable transport items," 2016.

[17] Aberdeen Group, "RFID-enabled logistics asset management benchmark report," June 2004.

[18] A. Mason, A. Shaw, and A. Al-Shamma'a, "Peer-to-peer inventory management of returnable transport items: A design science approach," *Computers in Industry*, vol. 63, no. 3, pp. 265–274, 2012.

[19] D. Buchanan and P. Abad, "Optimal policy for a periodic review returnable inventory system," *IIE transactions*, vol. 30, no. 11, pp. 1049–1055, 1998.

[20] H. G. Grimes-Casey, T. P. Seager, T. L. Theis, and S. E. Powers, "A game theory framework for cooperative management of refillable and disposable bottle lifecycles," *Journal of Cleaner Production*, vol. 15, no. 17, pp. 1618–1627, 2007.

[21] T. Kim and C. H. Glock, "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*, vol. 64, pp. 12–27, 2014.

[22] O. Johansson and D. Hellström, "The effect of asset visibility on managing returnable transport items," *International Journal of Physical Distribution & Logistics Management*, vol. 37, no. 10, pp. 799–815, 2007.

[23] D. Hellström and O. Johansson, "The impact of control strategies on the management of returnable transport items," *Transportation Research Part E: Logistics and Transportation Review*, vol. 46, no. 6, pp. 1128–1139, 2010.

[24] H. Pollaris, K. Braekers, A. Caris, G. K. Janssens, and S. Limbourg, "Capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints," *EURO Journal on Transportation and Logistics*, vol. 5, no. 2, pp. 231–255, 2016.

[25] M. Soysal, "Closed-loop inventory routing problem for returnable transport items," *Transportation Research Part D: Transport and Environment*, vol. 48, pp. 31–45, 2016.

[26] R. Geyer, L. N. Van Wassenhove, and A. Atasu, "The economics of remanufacturing under limited component durability and finite product life cycles," *Management science*, vol. 53, no. 1, pp. 88–100, 2007.