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COLLECTOR MANAGED INVENTORY, A PROACTIVE PLANNING APPROACH TO THE COLLECTION OF LIQUIDS COMING FROM END-OF-LIFE VEHICLES

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Collector managed inventory, a proactive planning approach to the collection of liquids coming from end-of-life vehicles

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Abstract

In this article we introduce Collector Managed Inventory (CMI) as the reverse logistics counter part of Vendor Managed Inventory (VMI). The collection company takes responsibility for the inventories of cores or materials to be recycled. Experience in forward supply chain management has shown the potential of VMI by bringing the coordination of transportation and inventory decisions to the same supply chain entity. Using information technology called telemetry, we are able to monitor inventory levels at distance. We introduce a proactive planning methodology based on two types of collection orders: must- and can-orders. Every collection period all must-orders have to be collected, while can-orders are only collected if they can be combined beneficially with the must-orders. The routing problem is solved by a combination of route generation and set partitioning. The system is illustrated in a real-life case study for Auto Recycling Nederland on the collection of liquids coming from end-of-life vehicles, such as coolant and oil. In several scenarios the old reactive approach is compared to the proactive approach resulting in cost savings up to about 19%.

Keywords: closed-loop supply chains, reverse logistics, vehicle routing, set partitioning, distribution planning, information technology, remote monitoring

1. Introduction

Concern for the environment as well as commercial and economic factors have led to increased importance of the area of closed-loop supply chains. Products can be returned at several stages of their life cycle as so called commercial, repairable, end-of-use and end-of-life returns. One of the major issues of closed-loop supply chain management is the dealing

with uncertainty. This paper discusses the application of new IT to enhance the proactive planning of the collection of liquids coming from end-of-life vehicles (ELVs) by Collector Managed Inventory.

1.1 Uncertainty in reverse supply chains

To large extend, the complexity of reverse supply chain management is caused by uncertainty (Fleischmann et al., 2000). Uncertainty in the behavior of the system is caused by the lack of information and control mechanisms regarding quantity, timing and product compositions and quality of returns. Different return types require their own typical closed-loop supply chain and involve different kinds of uncertainty. End-of-life returns result in closed-loop supply chains that primarily make sure that all returned items are collected and processed according to formal prescriptions against minimal cost (Krikke et al., 2004). Liquids coming from ELVs, for example oil, coolant and fuel, pose a serious environmental and safety risk. For that reason, dismantling, storage, collection and transfer to the recovery facility must take place in a closed system. As the value of these returns is low and the recovery takes place on centralized level, the transportation cost pose a significant part of the total reverse supply chain cost. Many so-called control closed-loop supply chains lack good product and inventory data, which causes inefficiencies. Collection Managed Inventory reduces uncertainty and hence reduces transportation cost. Collector Managed Inventory is catalyzed by the introduction of new information technology called telemetry. This enables us to monitor on distance and plan proactively.

1.2 The analogy of Collector Managed Inventory with Vendor Managed Inventory

During the last decades, advances in information technology resulted in breakthroughs in supply chain management. A supply chain, referred to as an integrated system that synchronizes series of inter-related processes (Min and Zhou, 2002), benefits from seamless information interchange. Better information interchange results in better planning and coordination mechanisms within the supply chain. Synchronization or coordination of inter-related processes takes place by collaboration of supply chain partners. In distribution systems, the coordination of inventory and routing decisions is critical, but typically the inventory and routing decisions are taken separately. The supplier is responsible for delivery of the order (routing decisions) while the customer is responsible for the timing and sizing of inventory replenishment orders (inventory decisions). Bringing inventory and routing

decisions in one hand offers the opportunity to quantify the trade-off based on true cost, resulting in a global optimal solution. Concepts like Factory Gate Pricing (Le Blanc et al., 2003) and Vendor Managed Inventory (Disney et al., 2003) intend to do this. To the best of our knowledge these concepts are new the area of closed-loop supply chains. We propose the term Collector Managed Inventory (CMI) as the reverse logistics counterpart of Vendor Managed Inventory.

We focus on low valued recyclables or even waste with negative value due to their environmental impact, where third party recycling or waste processing is applied. Generally, storage capacity for recyclables or waste is limited and often, especially when dangerous materials are involved, timely collection or emptying is critical to the process. In the traditional situation, the waste generator contacts the collection company to report that a collection should take place within a certain time period as agreed in a service level agreement. For collection companies, the occurrence of collection orders seems to be random, resulting in a reactive ad-hoc collection planning. Today, new information and communication technology enables the collection company to monitor the storage capacity left at the waste generator's site. Exploitation of information coming from remote monitoring is likely to have a large impact on the efficiency of the collection planning. In addition, with CMI, the control of inventory and shipments of recyclables and waste is shifted to the collection company. The collection company can now estimate when collection should take place and incorporate this in the collection planning. Thus, the control of the inventory of recyclables or waste is actually transferred from the waste generator to the collection company, aiming at efficiency gains.

Although VMI and CMI seem to be analogous, they are effective in different ways. The increased efficiency in VMI comes from well-balanced trade-off between inventory and transportation cost. In CMI the expected efficiency gains come from foreseeing when collection should take place and actively search for combination possibilities in planning collection trips, reducing the overall amount of transportation cost. The reason for the sole transportation cost focus lies in the low inventory value of returns. In Table 1 the similarities and differences between CMI and VMI are summarized.

3

Type of logistics	Forward logistics	Reverse logistics
Name	Vendor managed inventory	Collector managed inventory
Basic principle	Supplier is responsible for maintaining and replenishing of the inventory of the customer	The collector is responsible for timely collection of recyclables at the generators site
Inventory cost	High inventory holding cost	Low inventory holding cost
Transportation cost	Moderate to low transportation cost compared to value of the product	High transportation cost compared to the value of the product/recyclable
Motivation	Increased availability, cost reduction	Decreased storage capacity shortage, cost reductions
Applications	Industrial gases, soft drinks, fuel, retail industry	Containers, liquid reservoirs

Table 1.   Comparison of VMI and CMI.

1.3 Setup of the paper

Section 2 gives a description of the real-life case in CMI that stems from the research we carried out for Auto Recycling Nederland (ARN), the branch organization that is responsible for end-of-life vehicle (ELV) recycling in The Netherlands. ARN is currently restructuring their processes for the handling of liquids coming from end-of-life vehicles. In this section, the company setting is described to illustrate the system changes needed to create a CMI system for the collection of coolant and oil.

Section 3 explores related literature. Projects described in the existing literature relate to some extend to the problem at hand, however differences at some crucial points force us to adopt a new approach.

Section 4 describes the OR model used to solve the problem. We start with discussing the new planning methodology based on two types of collection orders, namely must-orders and can-orders. Must-orders must be carried out, while can-orders can be used to profitably fill up the remaining vehicle capacity. This profitability is heuristically evaluated based on the cost of inserting the can-order in the route and the closeness in time to triggering a must-order. Hence, the closer the order is to the deadline, the more likely to be selected unless cost are too high. We analyze the effectiveness by simulating the reverse chain processes in a 10-year horizon. For every week, a collection planning is made by route generation and finding the best set of routes by solving a set partitioning problem, in which we minimize the cost of the system. The model is extensively tested to validate and verify.

In section 5 we determine the practical value of information attained by remote monitoring and the adaptation of a CMI strategy in a real-life case of ARN. This case considers the collection of oil and coolant coming from end-of-life vehicles. Policies of different degrees of anticipating on future collection are analyzed and compared to a conventional reactive strategy.

Finally, in section 6, the results are summarized and an outlook to further research is given.

2. The case study: the collection of liquids by Auto Recycling Nederland

In 1993, the Dutch automotive industry decided to act proactively instead of reactively and founded a sector organization for the recycling of ELVs, named Auto Recycling Nederland (ARN). Consumers can hand in their car for free at an ARN-certified dismantler regardless of the brand of the car. This way of organizing end-of-life recycling is very common in The Netherlands and similar sector organizations exist for many end-of-life streams, e.g. white-and-brown good (De Koster et al., 2004), batteries and tires.

In the directive 2000/53/EC, the European Union prescribes guidelines for the legislation on recycling of ELVs in the member states. In 2002, this EU directive has to be implemented by all the member states. Dutch legislation therefore prescribes that wrecks should be dismantled and recycled for at least 85% of the average vehicle weight. C1 materials are hazardous materials that pose a serious threat to safety and environment and have to be dismantled within 10 working days after de-registration in the national vehicle register. Table 2 gives an overview of the C1 materials. The further dismantling process of ELVs is less time critical.

Material	Average amount / wreck	Recovery
Airconditioning refrigerants	Not available yet	Disposal
Batteries	13.3 kg	New batteries
Brake fluid	0.3 liter	New brake fluid
Coolant	3.6 liter	New coolant or solvent in the paint industry
Fuel (petrol / diesel)	5.0 liter	Reuse as fuel
LPG-tanks	0.06 tank	Scrap metal or reuse as LPG-tank
Oil (motor, transmission etc.)	4.9 liter	Lubricating oil
Oil-filters	0.5 kg	
Windscreen washer fluid	1.0 liter	New windscreen washer fluid

Table 2.   Overview of C1-materials.

While vehicles are waiting for removal of the C1-materials, they must be stored at an impermeable floor in order to prevent environmental damage. The old way of drainage did not meet the latest requirements on safety and environment, e.g. because liquids were often accidentally messed. The installation of a new drainage system at 265 ELV dismantlers' sites affiliated to ARN started in 2003. With the new equipment, liquids are siphoned off ELVs to a storage reservoir in a closed system without any chance of spilling. For each liquid a large storage vessel is installed, equipped with remote monitoring.

At the time of the research, collection took place when the collection company received a message from the waste generator that a reservoir was almost full. Using data from the remote monitoring equipment (telemetry) one can foresee this several weeks ahead. This information is valuable and should be exploited. We develop a new procedure where the collection company is responsible for timely collection. In this CMI situation, the collection company periodically (e.g. weekly) retrieves data on the inventory levels of the storage vessels and constructs a collection plan. The tanker trucks used for collection consist of two compartments for different liquids. If the data that stems from the telemetry units indicate that one of the materials needs to be collected, both materials are collected at the same time. Materials collected together are called material groups, not all materials can be collected by one truck. Collections can take place because of two reasons:

- Volume driven, the storage reservoirs are almost full and collection is needed to prevent capacity shortages.
- Time driven, there is a minimal collection frequency that should be respected.

Minimal collection frequencies can be used for materials for which the quality deteriorated over time. For example, oils are hygroscopic (attract water), therefore they should be collected at least once a year to assure sufficient quality for recycling.
In the next section we investigate which models from the literature are useful.

3. Literature

To the best of our knowledge Collector Managed Inventory has never been introduced in the reverse logistics literature as the counter part of Vendor Managed Inventory. While the idea of monitoring the level of refuse or recyclables collected and dynamically scheduling the collection as an alternative for periodic collection systems is mentioned in Beullens (2001), the practical implementation of a CMI system is never investigated.

In the literature on forward logistics, a number of articles have appeared that describe concepts with similar characteristics as discussed here. These papers address so called inventory routing problems. Inventory routing problems involve a set of customers with a certain daily demand to be served from a central depot. The objective is both to minimize cost and to prevent that customers run out of stock (Dror and Ball, 1987). Applications of inventory routing models described in literature are mostly focused on the distribution of industrial gasses and soft drinks.

One of the first articles to address the inventory routing problem is by Bell et al. (1983), describing a project at a supplier of industrial gases. In this problem, the customer inventory levels are forecasted. To avoid shortages in the long term when solving the short term operational planning problem, minimum levels on the inventory of customers at the end of the planning period are defined. Based on forecast information, the actual scheduling process is solved by a mixed integer linear programming model. The programming model selects from the total set of possibilities the best subset of routes to be driven and the amount to be delivered to the customers. The set of possible routes is limited because of the small number of customers on a trip and many practical restrictions on the routes. All logical routing possibilities are enumerated explicitly and fed to the programming model.

All inventory routing models have to incorporate the long-term effects of decisions taken in the current operational planning period. Dror and Ball (1987) reduce the long term horizon by considering penalty cost expressing the long term effects of decisions made in the operational planning period. Only full replenishment of inventories is considered. The resulting planning problem is now solved in a three-phase approach. In phase 1 the customers are assigned to days. In phase 2, the vehicle routing problem is solved using a Clark and Wright savings algorithm. In phase 3, the solution obtained for phase 2 is improved by considering exchanges. Dror and Levy (1986) give a description of how these improvement methods work for inventory routing.

Dror and Trudeau (1996) investigate the inventory routing problem from a cash flow perspective. Customers are billed immediately with each delivery. In this way, payment for the goods is received much faster, which compensates the cost of increased frequency of delivery. Dror and Trudeau (1996) do not discuss the operational routing problem. The cost of delivering to a customer is simply estimated by a fixed fee for each delivery.

Herer and Levy (1997) notice the disregard of an appropriate treatment of inventory holding cost in the above literature. They model the problem by incorporating inventory holding cost by so-called *temporal distances*. Customers who are spatially close tend to be on the same route if they are also temporally close, meaning that the optimal delivery periods are not too far apart. The effects of short-term decisions on the long-term holding, shortage and fixed ordering cost are incorporated in the temporal distances. Temporal distances are defined as the minimal cost of bringing two customers to a common delivery period. The temporal distances are used in the savings calculation of the Clark and Wright algorithm.

Ong et al. (1996) discuss an application for servicing and re-supplying vending machines in the soft drink industry. These machines need to be visited frequently to collect coins and to re-supply the vending machines. Routing is only discussed for the replenishment crew and not for the service crew and is based on clustering first, route second. Clustering is done following a sweep method. The routing is based on ranking the profits and then applying a first fit algorithm. Improvement of the routing takes place by local tour improvement procedures. The objective is the maximization of profit. Inventory holding cost and cost of lost sales are ignored in the routing step.

Campbell et al. (1999) describe an application in the distribution of industrial gases. The planning is solved in a rolling horizon in a two-phase approach. In the first step, an integer programming is used to determine which customers are visited and how much is delivered. Clustering and aggregation techniques are used to make the integer programming solvable. In the second step, an insertion heuristic combined with several improvement heuristics is used to determine the actual delivery routes. Inventory holding cost are not considered.

In essence, the problem setting described above is similar to the reverse logistics setting as described in this paper. Instead of delivering gases or soft drinks one delivers storage space for oils and fuels. Nevertheless, the setting of ARN has some characteristics that are different and justify a new model. Due to the low or sometimes even negative value of the cores or materials to recycle, the inventory holding cost is irrelevant. Collecting as much as possible in one visit is the device, thereby minimizing transportation cost. Since inventory cost does not matter and the supply rate of the liquids is low, the time between two consecutive visits is long in contrast to the applications described in the literature above. The demand for the goods and gasses described above is unknown and sometimes difficult to estimate; consider for example the demand for heating oil, which depends on the weather. In our problem setting, we have the opportunity to obtain accurate information on the levels of fluids at the waste generators, due to the online monitoring of the fill-rate of the reservoirs. In the next section we describe our method of solving the problem in the reverse logistics setting.

4. Model

4.1 Planning methodology

The planning methodology is of a periodic nature. We assume a periodic review of inventory levels. After retrieval of the data with the telemetry units, a collection plan is constructed for the coming review period. An order triggered either by volume or by time, must be performed in the coming planning period. We call these orders must-orders. We also consider the possibility to visit dismantlers that not directly need a collection but are close to triggering one and can be inserted in the route at low marginal cost. These orders are called can-orders. Can-orders are used to profitably fill up the remaining capacity of collection trucks and can never initialize a new collection trip. An additional difference is that can-orders can be performed partially, meaning not fully emptying the storage reservoir but only as far as capacity left in de truck allows, while must orders must fully empty the storage reservoir.

In Figure 1 a conceptual overview of the must-order level, can-order level, the must-order time and the can-order time is given for a given storage reservoir at a dismantlers site. At the beginning of each collection period, in the base scenario weekly, the inventory levels are monitored. When a dismantler passes one of the must-order lines, a must-order is generated that will be part of a route, if a can-order line is passed, but not a must-order line a can-order is generated, for possible insertion in a must-driven route. If one of the materials in a material group triggers an order, the order is generated for the whole material group.
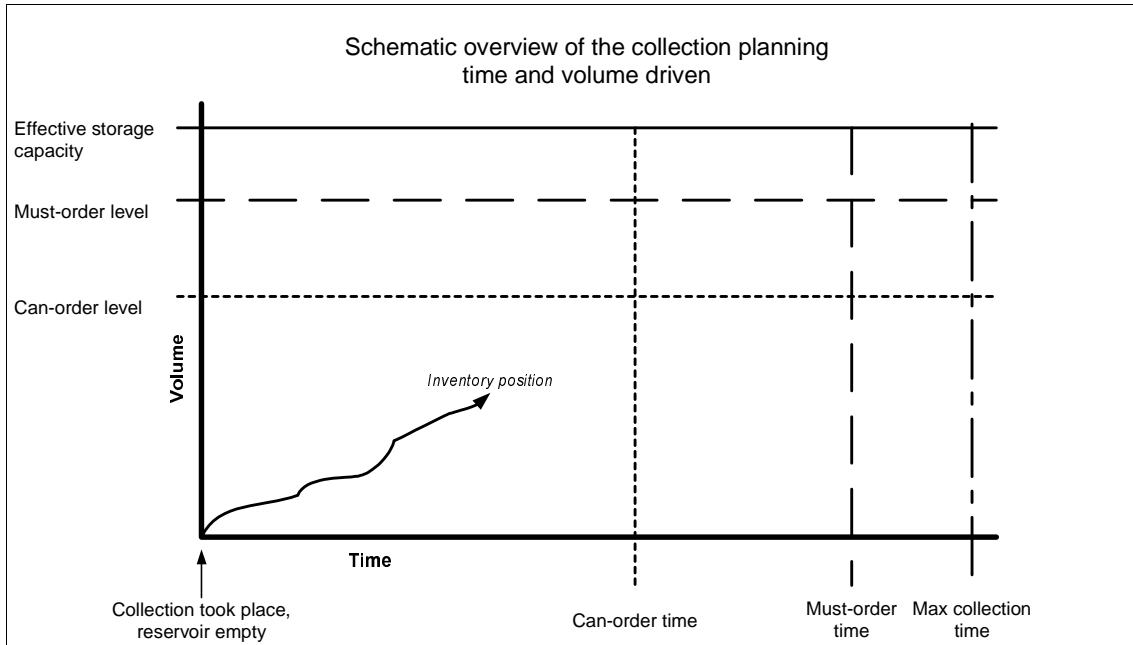
Figure 1. **Conceptual overview of the collection planning.**

The must-order level is defined analogously to the reorder-point in inventory management theory, see e.g. Silver et al. (1998). Assume that the material collection for material mat of dismantler ed is normally distributed with mean $\mu_{ed,mat}$ and variance $\sigma^2_{ed,mat}$. The effective storage capacity for material mat of dismantler ed is given by $cap_{ed,mat}$. The length of the planning period or review period is denoted by rp. The collection takes place within the planning period, so the response time is at most rp days; we assume that the response time is uniformly distributed.

The must-order level, $mo\_level_{ed,mat}$ for dismantler ed and material mat is given by equation [1].

$$mo\_level_{ed,mat} = cap_{ed,mat} - 1\tfrac{1}{2} \cdot rp \cdot \mu_{ed,mat} - k_{ed,mat} \cdot \sqrt{rp \cdot \left(1\tfrac{1}{2} \cdot \sigma^2 + \tfrac{1}{12} \cdot \mu^2 \cdot rp\right)} \qquad [1]$$

Here $k_{ed,mat}$ denotes a safety factor. The safety factor is used to capture the uncertainty within the collection period. The safety factor can easily be calculated using the standard normal distribution and the desired service level. The can-order levels $co\text{-}level_{ed,mat}$ are calculated according to equation [2].

$$co\_level_{ed,mat} = mo\_level_{ed,mat} - \alpha_{ed,mat} \cdot rp \cdot \mu_{ed,mat} \qquad [2]$$

Here, $\alpha_{ed,mat} \in \{0,1,2,\ldots\}$ expresses the number of planning periods that we look forward for can-orders driven by volume. The parameter $\alpha_{ed,mat}$ equal to zero for all dismantlers and materials corresponds to a policy without can-orders. The must-order time, $mo\_time_{ed,mat}$, is based on the maximum allowed number of days between two collections, max collection time, resulting in equation [3].

10

$$\text{mo\_time}_{\text{ed,mat}} = \text{max collection time} - \text{rp} \qquad\qquad\qquad [3]$$

The can-order time is calculated using $\beta_{\text{ed,mat}} \in \{0,1,2,\dots\}$, expressing the number of planning periods we look forward for can-orders driven by time. This results in equation [4].

$$\text{co\_time}_{\text{ed,mat}} = \text{mo\_time}_{\text{ed,mat}} - \beta_{\text{ed,mat}} \cdot \text{rp} \qquad\qquad\qquad [4]$$

At the beginning of each collection period, the inventory positions for all storage reservoirs for all dismantlers are retrieved. Based on this information the must-orders and can-orders are generated and a collection plan for the coming period is made. This plan is constructed by generation of feasible routes and selecting the optimal combination of routes by solving a set partitioning problem. Herewith we ascertain the optimality of the solution to the planning problem. This is of great value for comparison of different scenarios, since differences cannot be caused by the randomness of a heuristic.

Section 4.2 will show the details of the generation of routes, while section 4.3 will give insights in constructing and solving the resulting set partitioning problem. Finally in section 4.4 the verification and validation process is discussed.

4.2 Route generation

In the route generation, every possible route is generated. If the route is found feasible, it is written to the set partitioning tableau. A route is feasible if the maximum time allowed for one day or the maximum capacity of one of the reservoirs is not exceeded. Since the number of orders considered per period is relatively small and the number of orders that fit in a route is limited, explicit enumeration of all possible routes is possible. The difficulty in route generation is to enumerate all combinations in a systematic and efficient way. Our route generator consist of two main procedures that are recursively used: *MustOrderInsertor* and *CanOrderInsertor*. These procedures aim to add respectively an unplanned must- and can-order to the route. If a route is found feasible, it is written to the set partitioning tableau and an attempt is made to add another order. If a route is found to be infeasible, the last added order is removed from the route and a new attempt is done to add the next order in the list. In Figure 2 an overview of these two main procedures is given. The route generation process starts with an empty route and a call to the procedure *MustOrderInsertor*.

During the route generating process, the cost of the route is calculated and corrected for the cost of insertion of can-orders. This cost correction as shown in [5] is based on the difference between the cost of insertion in the current route and the cost of a separate route for this order (linehaul), corrected for the amount of material. This correction is used to quantify the

advantage of adding a can-order to the existing route and acts as the selection mechanism for can-orders, similar to the temporal distance of Herer and Levy (1997). The same correction is used for must-orders in non-empty routes, because combining must-orders as much as possible in a route reduces the total number of routes to be driven. This correction for must-orders is necessary, since otherwise driving two routes with one must-order in each route, combined with a number of can-orders, would be evaluated better than driving one route with both must-orders.

$$cost\_correction_{ed} = insertion\_cost_{ed}$$

$$- \frac{linehaul\_cost_{ed}}{\sum_{mat} linehaul\_volume_{ed,mat}} \cdot \left(\sum_{mat} inserted\_volume_{ed,mat} \right) \qquad [5]$$

```
Function MustOrderInsertor

FOR (MOrder in UnplannedMustOrderList) DO
        RouteFeasible = MustOrderInsertInRoute(MOrder)
        Remove MOrder from UnplannedMustOrderList
        IF(RouteFeasible) THEN
                WriteRouteToSP
                MustOrderInsertor
                CanOrderInsertor
        ENDIF
        MustOrderRemoveFromRoute(MOrder)
        Add MOrder to UnplannedMustOrderList
ENDFOR

Function CanOrderInsertor

FOR (COrder in UnplannedCanOrderList) DO
        RouteFeasible = CanOrderInsertInRoute(COrder)
        Remove COrder from UnplannedCanOrderList
        IF(RouteFeasible) THEN
                WriteRouteToSP
                CanOrderInsertor
                ENDIF
        CanOrderRemoveFromRoute(COrder)
        Add COrder to UnplannedCanOrderList
ENDFOR
```

Figure 2.   Outline of the route generator.

4.3 The route selection problem: set partitioning

We formulate the problem of finding a collection of routes such that all must-orders are fulfilled with minimal cost as a linear integer programming problem. After the introduction of some notation, this problem is given in equations [6] to [10] below.

Variables

$X_{r,vd}$ = 1 if route r is not chosen for vehicle-day combination vd, 0 otherwise.

sc_{co} = 1 if can-order co is not fulfilled in the chosen routes, 0 otherwise.

sv_{vd} = 1 if vehicle-day combination vd is not used to fulfill the chosen routes, 0 otherwise.

Parameters

c_r = the cost of route r, corrected for can-orders and multiple must-orders in the route.

$a_{mo,r}$ = 1 if must-order mo in route r, 0 otherwise.

$a_{co,r}$ = 1 if can-order co in route r, 0 otherwise.

The route selection problem

$$\min \quad \sum_r \sum_{vd} c_r \cdot X_{r,vd} \qquad\qquad\qquad [6]$$

$$\text{s.t.} \quad \sum_r \sum_{vd} a_{mo,r} \cdot X_{r,vd} = 1 \qquad\qquad \forall mo \qquad [7]$$

$$\sum_r \sum_{vd} a_{co,r} \cdot X_{r,vd} + sc_{co} = 1 \qquad\qquad \forall co \qquad [8]$$

$$\sum_r X_{r,vd} + sv_{vd} = 1 \qquad\qquad \forall vd \qquad [9]$$

$$X_{r,vd} \in \{0, 1\} \qquad\qquad \forall r, vd \qquad [10]$$

$$sc_{co} \in \{0, 1\} \qquad\qquad \forall co \qquad [12]$$

$$sv_{vd} \in \{0, 1\} \qquad\qquad \forall vd \qquad [13]$$

Equation [6] describes the objective function of the optimization problem, which is of course total cost minimization of the collection plan. Equation [7] represents the constraints assuring that each must-order is executed exactly once. Equation [8] represents the constraints assuring that each can-order is inserted at most once. Equation [9] assures that each vehicle-day combination has at most one route. Equation [10] bounds the domain of the variables. The variables sc_{co} and sv_{vd} in constraints in [8] and [9] serve as slack variables to make the problem a pure set partitioning problem, otherwise these would be smaller or equal equations.

Set partitioning has the benefit above generic integer programming that the problem structure can be exploited to solve the problem more efficiently (Balas and Padberg, 1976). To solve the set partitioning instances, we use a solver developed by Van Krieken et al. (2003). The main building blocks of the solver are lagrangean relaxation for determining the lower bounds and branch and bound for finding the optimal solution (Fleuren, 1988).

Furthermore, several problem reduction techniques are used to reduce the number of variables and constraints in the problem, for details see Van Krieken et al. (2003). The solver is very effective in solving the set partitioning instances under consideration, even if the amount of variables grows very large. Problems with over 5 million variables are solved in a couple of minutes on a normal desktop computer. Generic solvers like the well-known CPLEX solver are not able to exploit the special structure of set partitioning problems such that they take much more time on average to solve these instances.

In many instances the number of vehicle days available exceeds the number of must-orders. In these cases the vehicle-day combination becomes irrelevant, because there will never be more routes than must-orders. When this is the case, the number of variables can be reduced proportionally to the number of vehicle-day combinations.
In some cases the generated set-partitioning problem is infeasible, because the available capacity (vehicle-day combinations) is too small to fulfill all the must-orders. To overcome this, we have added a dummy route for each must-order. This dummy route covers only one must-order and the cost of this route is equal to a certain factor times the cost of a linehaul. This cost represents the cost of an emergency order and assures that the dummy route will only be chosen if it is not possible to fulfill the order on a vehicle-day combination.

4.4 Validation and verification

We have performed extensive tests on the model validating and verifying its correctness. In the verification process we have analyzed the internal consistency of the model in particular by pushing the parameters to the extremes of the spectrum. In this way, the behavior and outcome of the models are checked on logic.
In the validation process we have tested the external correctness of the model: does the model give representative descriptions of the real world system? We have compared the results with data coming from collection companies. Furthermore, logistic specialists of ARN have examined the outcomes of the model and compared them with their expectations.

5. Results

5.1 Scenario data

We simulate a horizon of ten years. In the base scenario we use a collection period of a week, so in total we simulate 522 collection periods. Collection should take place at least once a year; i.e. all ELV-dismantlers are visited at least ten times in the simulation. The initial inventory at the first collection period for each of the 267 ELV-dismantlers was generated randomly. We use the same initial situation in order to make a fair comparison for each run.

For the collection of oil and coolant a tanker truck with a capacity of 7600 liter for oil and 5700 liter for coolant is rented. The collection company rents these tanker trucks including the driver to different customers, therefore ARN is only charged for the amount of usage, expressed in the number of hours and kilometers driven: 60 euro per hour, 0.38 euro per kilometer driven. A regular workday consists of 450 minutes, after that the charge per hour is doubled for the next 240 minutes. The starting and unloading point is the current depot for oil and coolant, located in Lelystad, in the Netherlands.

5.2 Base scenario with partial and full collection of can-orders

The situation with a reactive planning coincides with the situation with where can-order level $\alpha_{ed,mat}$ and can-order time $\beta_{ed,mat}$ are both 0, see equation [2] and [4]. A proactive approach coincides with can-order level $\alpha_{ed,mat}$ and can-order time $\beta_{ed,mat}$ larger than 0. We varied $\alpha_{ed,mat}$ and $\beta_{ed,mat}$ between 0 and 6, where we did not differentiate in ELV-dismantlers or materials. The results for different can-levels and can-times are shown in Table 3.

We observe that a possible cost reduction up to 18.9% it realized by adopting a forward-looking strategy. The number of routes necessary for collection, which is equal to the number of vehicle days, as well as the average distance traveled within each route is reduced. The total number of kilometers driven per year is reduced by about 18,700. Consequently, it is no surprise that the load-factor, defined as the maximum fraction of capacity of the truck used in a route, is increased from 0.67 to 0.93.

In the base scenario described above, we assumed that partial execution of can-orders is allowed. Table 4 gives the results of a scenario where we restrict the model to allow only full collection of can-orders. In this scenario, a significant cost reduction of 10.5% opposed to 18.9% is possible when we adopt the same proactive strategy. The load-factor is increased up to 0.80, which is significantly less than in the situation where we allow for fractional can-

orders. In Figure 3 and Figure 4 we illustrate the collection cost and load-factor for both scenarios; the intervals in Figure 3 indicate the 90% confidence intervals. The figures illustrate the decrease of the marginal cost savings by extending the forward-looking horizon. A forward looking period of 3 weeks ($\alpha_{ed,mat} = \beta_{ed,mat} = 3$) seems to be enough to fully exploit the saving potential.

α (can-order level)	0	1	2	3	4	5	6
β (can-order time)	0	1	2	3	4	5	6
Average cost per week	€ 3,084	€ 2,759	€ 2,644	€ 2,582	€ 2,538	€ 2,515	€ 2,502
Average number of must-orders per week	7.17	5.50	4.98	4.66	4.53	4.45	4.43
Average number of can-orders per week	0.00	2.13	2.80	3.28	3.47	3.61	3.67
Average number of routes per week	3.95	3.41	3.34	3.27	3.26	3.23	3.23
Average route distance (km)	345.1	337.7	326.2	320.6	315	313	310.9
Average route duration (min)	541	562	556	556	551	552	550
Average load-factor	0.671	0.84	0.883	0.909	0.923	0.927	0.931
Number of kilometers driven per year	71,091	60,178	56,824	54,758	53,613	52,709	52,387
Cost per year	€ 160,992	€ 144,041	€ 138,021	€ 134,784	€ 132,460	€ 131,301	€ 130,601

Table 3. Results for oil and coolant with fractional collection of can-orders.

α (can-order level)	0	1	2	3	4	5	6
β (can-order time)	0	1	2	3	4	5	6
Average cost per week	€ 3,084	€ 2,982	€ 2,927	€ 2,862	€ 2,841	€ 2,808	€ 2,759
Average number of must-orders per week	7.17	6.20	5.64	5.38	5.22	5.08	4.98
Average number of can-orders per week	0.00	1.00	1.63	1.98	2.26	2.47	2.65
Average number of routes per week	3.95	3.69	3.58	3.54	3.45	3.42	3.39
Average route distance (km)	345.1	348.7	348.1	342.2	344.6	341.6	337
Average route duration (min)	541	558	563	560	568	568	566
Average load-factor	0.671	0.707	0.733	0.754	0.773	0.781	0.800
Number of kilometers driven per year	71,091	67,090	65,025	63,239	62,062	60,976	59,582
Cost per year	€ 160,992	€ 155,646	€ 152,789	€ 149,372	€ 148,284	€ 146,581	€ 144,044

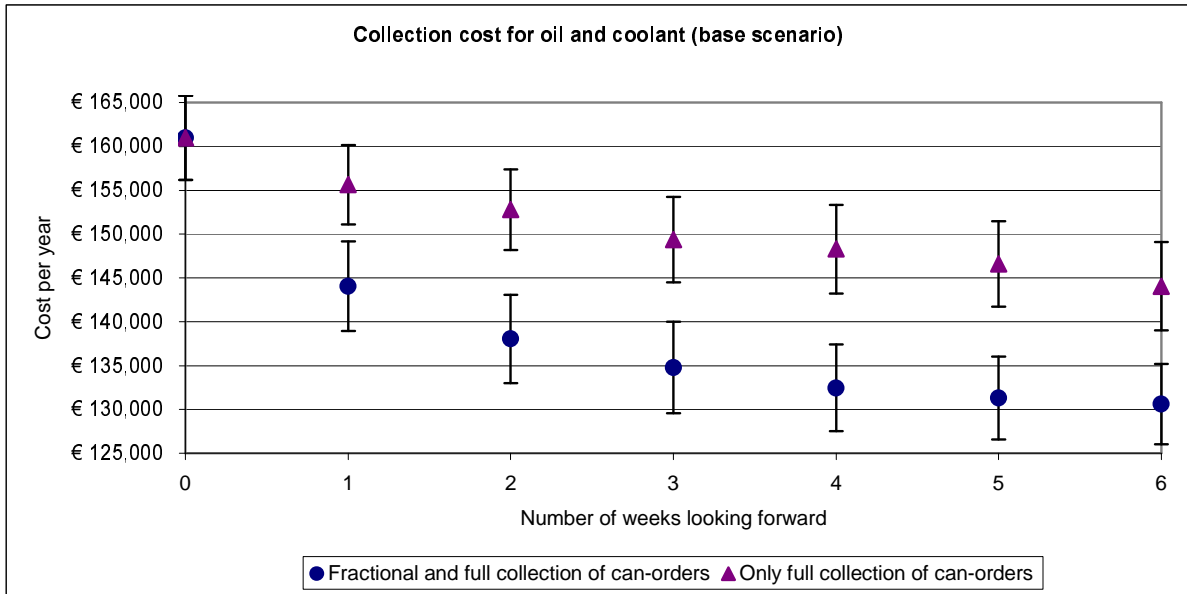**Table 4.** Results for oil and coolant with full collection of can-orders.

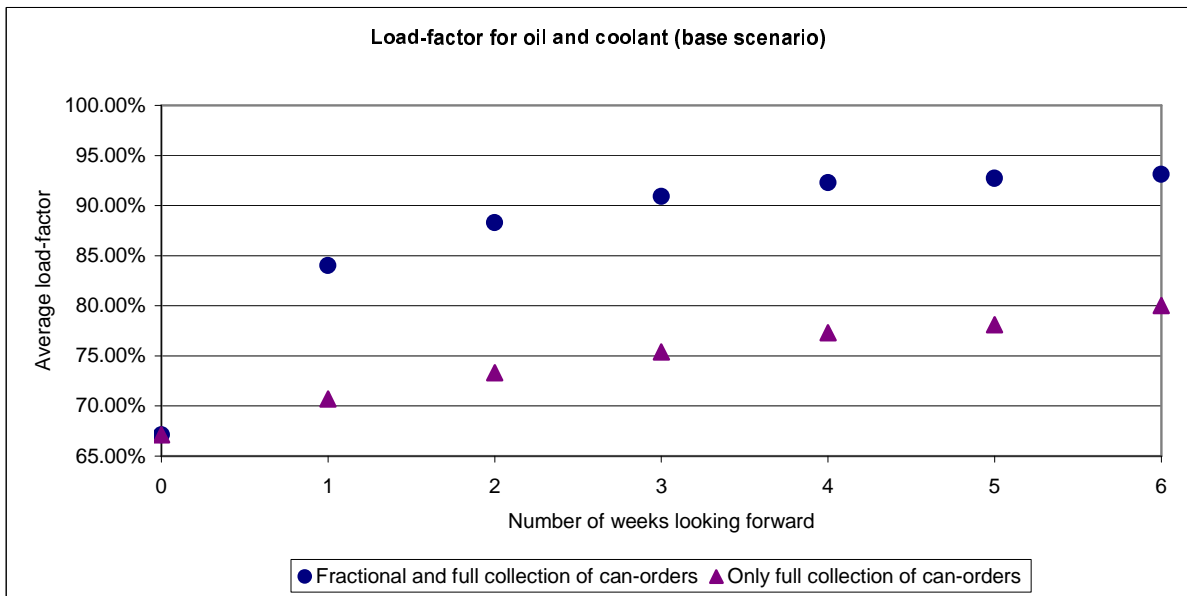**Figure 3.** **Overview yearly collection cost in case of fractional and full collection of can-orders.**

Figure 4. **Overview of the average load-factor in case of fractional and full collection of can-orders.**

5.3 Sensitivity analysis on the length of collection period

The choice for the weekly gathering of data of the telemetry units and constructing the collection planning is a somewhat arbitrary management decision. If this frequency is

increased, we expect that the performance increases as well, since we can plan the trips more frequently, using more actual data. However, when the length of the planning period is larger, we have more possibilities to combine orders and create more efficient routes. This is illustrated by Figures 5 and Figure 6, where we depict the cost and the load factor for different lengths of the collection period. In the reactive strategy, longer collection periods perform better, which is caused by the effect that we have more combination possibilities. However, when we adopt a proactive strategy, we have already better combination possibilities by looking forward. In summary: the more proactive, the higher the planning frequency should be. However the relative improvement of changing the planning frequency is small, compared to the shift from reactive to proactive planning. Since collection periods of one week are more convenient, this justifies the management decision with a proactive strategy.
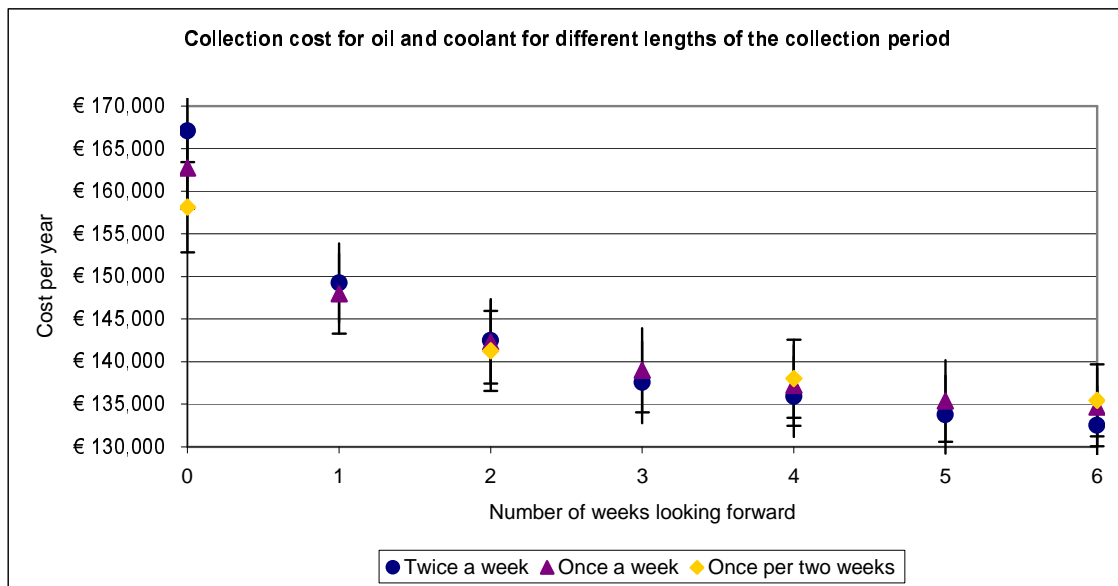

Figure 5. **Overview yearly collection cost for different lengths of the collection period.**
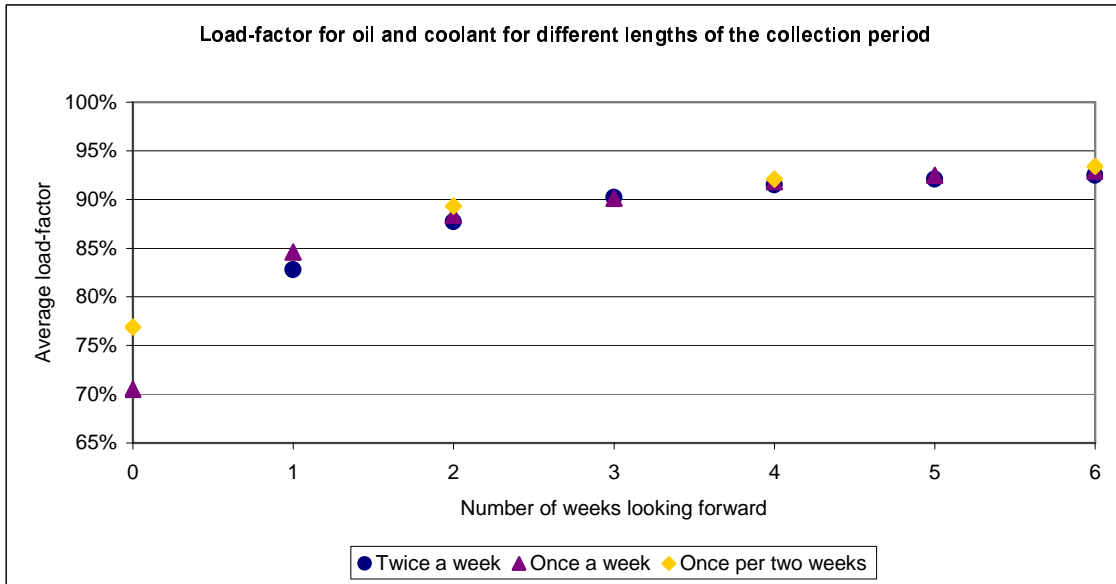
Figure 6   Overview of the average load-factor for different lengths of the collection period.

6. Discussion and conclusion

In this paper, we discussed an application of remote monitoring of inventory levels in reverse logistics. We examined the possibilities of Collector Managed Inventory (CMI), the reverse logistics counterpart of Vendor Managed Inventory (VMI). A planning methodology is developed to support the collection company in constructing operational planning schedules. From the information coming from the telemetry units placed at the waste generator's site, it is possible to foresee when collection should take place and actively search for combination possibilities in planning collection trips, thereby reducing the transportation cost. Two types of transportation orders are considered: must- and can-orders. Must-orders have to be collected in the current period, while can-orders are only collected if they can be combined beneficially with the must-orders. This offers the opportunity to plan orders proactively and save on the transportation cost. The potential is illustrated in a real-life project for the collection of oil and coolant at Auto Recycling Nederland. Cost savings amount to 18.9% when we compare proactive collection planning with the traditional reactive collection planning. The system will be implemented in 2004 together with a similar system for the collection of fuel and windscreen washer fluid. The outcomes of this study justify more research on proactive distribution or collection planning and the use of telemetry in forward as well as reverse supply chains.

The logistic concept of Collector Managed Inventory is not essentially different from Vendor Managed Inventory. However, from a modeling perspective, the focus in forward supply chains is on balancing inventory and transportation cost, while in reverse supply chains for end-of-life returns the focus is merely on reducing transportation cost by finding better combination possibilities. Due to the absence of inventory holding cost and relatively low supply rate of liquids, collection intervals are typically several months; this in contrast to forward applications with typically weekly deliveries. These differences justify the development of new models for the reverse supply chain setting.

Research on a wider application of the CMI concept for other types of returns in closed-loop supply chains is of interest. The telemetry units that measure the amount of liquids in a reservoir are well developed and became cheaper during the last decade (Campbell et al., 1999). This makes application in the reverse logistics setting attractive. In forward supply chain accurate data on inventory levels is obtained from the information system, in reverse supply chains these information systems are usually absent. Telemetry helps in reducing the uncertainty that characterizes and complicates closed-loop supply chain management. Similar applications of the use of telemetry units in reverse logistics are not well developed yet, despite of the great opportunities for applying the concepts described in this paper in other settings. For example consider press containers that are used to collect garbage. Depending on the "resistance" on the press, the load of the container can be determined and sent to the collection company by the telemetry unit. With the decreasing cost of information and telecommunication technology this will be within reach soon as it is today in forward supply chains. This will increase possibilities for optimization in reverse logistics, therefore support of the OR community will be of growing importance.

Finally, it is not only the cost benefit illustrated in the case study, that makes the remote monitoring and a proactive planning approach so attractive. The new system also reduces the environmental burden caused by transportation emissions as well as road congestion. In our case, the total number of kilometers driven can be reduced by 26.3% compared to the conventional reactive planning methodology. This is something we all benefit from.

Acknowledgement

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