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Inventory sharing strategy and optimization for reusable transport items

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ABSTRACT

Reusable transport items (RTI), as a sustainable solution to the increasing packaging wastes generated along with the ever-growing globalized supply chains, create both challenges and opportunities to organizations for their management. A trend of organizations outsourcing their RTI activities explains the rapid emerging of a third-party RTI pooler. Yet few research studies have been conducted from the perspective of the RTI pooler for optimizing their customer allocation, and few on the decision support model for a practical case in the developing economies. This research intends to fill in this gap. Motivated by a case study of a leading RTI pooling company in China, this research proposes to implement a sharing strategy into the daily planning operation of distribution and routing. A decision support framework is developed to optimize the distribution flows and dispatching vehicle routes by the use of a two-stage solution process. Empirical results demonstrate an economic savings of 28.1% in the transportation costs along with environmental and social advantages implicated by the shortened travel distance of vehicles.

1. Introduction

Flowing through all echelons of global supply chains are the raw materials, components, parts, semi-finished products and finished products, along with their packaging (Babader et al., 2016). Packaging is indispensable in every stage of supply chain, for it enables the storage, protection, handling, transportation and marketing of the materials and products (Bortolini et al., 2018; Glock and Kim, 2016). With the increasing demands of global consumer products and the shifting consumption pattern towards online transactions, incurred is the booming packaging requirement for handling and distributing the materials and the products, with an industry outlook of a projected market value of $1trillion in 2020 (Gardas et al., 2019; Meherishi et al., 2019). This industry prosperity comes with a price. Eurostate office has reported an annual production of 163 kg of packaging waste per capita in EU-28 (the 28 member states of the European Union), which is up to 80% of global production in 2017 (Bortolini et al., 2018). The increased packaging wastes created along the supply chain have been causing heavy strains on the environment and society (da Cruz et al., 2014; Meherishi et al., 2019). As a countermeasure, EU introduces directives on packaging and packaging waste, holding the producer responsible for the entire life cycle of their packaging (Berger and Nagase, 2018; da Cruz et al., 2014; Iassinovskaia et al., 2017). Similar regulations are either implemented or drafted in both industrialized economies and emerging economies (Rubio et al., 2019). Under the pressure imposed by the government legislation and the ever growing public concerns raised over waste and pollution problems, organizations strive to seek for sustainable packaging system solutions (Babader et al., 2016; Iassinovskaia et al., 2017; Sarkar et al., 2019a).

One sustainability enabler can be the environmentally conscious product design and product reuse of packaging (Hariga et al., 2016; Sarkar et al., 2017). Packaging is commonly recognized in three levels: primary, secondary, and tertiary. The primary-level packaging contains consumer products and has direct contact with the end consumer. The secondary-level packaging contains one or more primary packages to facilitate the unitized transport between the supply chain stages before the delivery to the end consumer. The tertiary-level packaging groups the secondary packages together for the bulk movement of materials and products between the supply chain players (Dang and Chu, 2016; Davis, 2019; Meherishi et al., 2019). The secondary-level and/or tertiary-level packaging are called as the transport packaging (Fan et al., 2019b; Iassinovskaia et al., 2017; Soysal, 2016). Reusable transport item (RTI), the study subject of this paper, is designed to be made of more durable materials than the disposable one, which lasts multiple cycle of use in the same form over a lifespan of several years (Accorsi et al., 2019; Ech-Charrat et al., 2017; Fan et al., 2019b; Glock and Kim, 2016; Limbourg and Pirotte, 2018). Reuse of RTIs guarantees a high volume of waste reduction by cutting down the need for purchasing new packaging materials (Accorsi et al., 2019; Babader et al., 2016; Bortolini et al., 2018; Hariga et al., 2016; Glock,

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2017; Limbourg and Pirotte, 2018; Ross and Evans, 2003; Sarkar et al., 2017, 2019b; Silva et al., 2013). Environment incentives from RTI would be more convincing for organizations to adopt it if it comes with additional economic values (Iassinovskaia et al., 2017; Limbourg and Pirotte, 2018). Comparative studies show that implementing RTIs brings organization more economic advantages, since the unit cost of RTI would be eventually cheaper as the higher initial investment cost is amortized through the numerous reuse cycles compared to the one-way packaging (Accorsi et al., 2014; Silva et al., 2013). Considering packaging accounts for 10%–40% of the product price, which reflects total system cost caused by supply chain activities, the cost savings from using RTIs are substantial (Sarkar et al., 2019b). Some researchers also suggest to use a balanced combination of reusable and disposable ones, since reusable packaging does require additional reverse flow to collect them for reuse (Accorsi et al., 2019; Bortolini et al., 2018; Glock, 2017). In addition, the standard and modular design of RTI not only improves the operational efficiency but also provides effective work ergonomics (Gardas et al., 2019; Iassinovskaia et al., 2017; Meherishi et al., 2019; Ren et al., 2019). Stackable RTI enables a high warehouse space utilization (Babader et al., 2016; Gardas et al., 2019; Glock, 2017). Empty RTIs can be nested or collapsed during the transportation, which can significantly reduce the truck loading volume and cut down backhaul trips reducing CO_2 emissions (Gardas et al., 2019; Glock, 2017; Sarkar et al., 2019b).

RTI program presents environmental, economical and operational benefits to organizations (Fan et al., 2019a; Sarkar et al., 2019a; Tornese et al., 2019). Yet the complexity to design and manage it is much higher as compared to the one-way program, as RTI undergoes both forward flow and backward flow of items whereas the disposable one involves solely forward flow in the supply chain (Accorsi et al., 2019; Bortolini et al., 2018; Elia and Gnoni, 2015; Wang and Zhao, 2018). Two common strategies for managing RTIs are: 1) direct or deferred exchange; 2) asset pooling (Accorsi et al., 2019; Bottani et al., 2015; Bottani and Casella, 2018; Ren et al., 2019; Roy et al., 2016). The first strategy implements the exchanges of RTIs along with their ownership between supply chain players either on the spot or at a deferred time. The latter strategy suggests a service provider who owns the RTIs and is responsible for supplying, storing, collecting and maintaining RTIs for the supply chains (Accorsi et al., 2019; Bottani and Casella, 2018; Iassinovskaia et al., 2017; Tornese et al., 2018). The pooling model allows the possibility of outsourcing RTI management to a third party and the supplier players rent RTIs from this party (Carrano et al., 2015; Elbert and Lehner, 2019; Glock, 2017; Tornese et al., 2018). This leased pooling model grows popularity exemplified by the emerging specialized companies, such as Euro Pool System, the Commonwealth Handling Equipment Pool, etc. (Glock, 2017; Hariga et al., 2016; Tornese et al., 2018). This model enables the supply chain players to focus on their core activities, while offers higher logistical efficiency and cost advantages to the pooler which can reduce environment impacts by consolidating shipments and enhancing truck capacity utilization (Accorsi et al., 2019; Bottani et al., 2015; Carrano et al., 2015; Ren et al., 2019). RTI management demands rigorous judgment on strategic level decisions like the locations and capacities of the pooling facilities. It is equally crucial for the pooler to make tactical and operational level decisions like the distribution flow, the safety stock level at the facilities, the transport routes of RTIs, etc. (Accorsi et al., 2019; Iassinovskaia et al., 2017).

Significant research efforts on RTIs have been conducted in the four areas: comparative studies of RTI systems and strategies, forecasting RTI returns, purchasing decisions of RTIs, and managing RTI systems, according to a review conducted by Glock (2017). It is recommended that further researches take into consideration that RTIs are often rented in practice and decision support models for RTIs be developed explicitly referring to a practical case to improve the applicability of the proposed model, and research efforts in the developing economies to be accelerated (Glock, 2017; Meherishi et al., 2019). Intended to fill this research gap, this paper, motivated by a practical case of a leading RTI pooler in China, propose a decision making tool to optimize the distribution flow of RTIs from the pooler facilities to supply chain customers and the routing decision among the customers afterwards, with a goal to reap economic benefits and minimize the environmental impacts. This study can be used to showcase the applicability of incorporating a decision support tool implemented with the inventory sharing strategy into a RTI pooling company's daily planning operations providing sustainable solutions to the company.

The reminder of this paper is structured as follows. Section 2 reviews the relevant literature on RTIs and identifies the observed research gap. Section 3 provides a detailed description on a studied case and presents the mathematical model to support the distribution and routing decisions. The solution method is also explained. Section 4 discusses the empirical results of the case study and the implications to logistics managers and industrial practitioner. Finally, Section 6 concludes the paper with remarks.

2. Literature review

The most recent review (Meherishi et al., 2019) can be found on a broad scope of the sustainable packaging for supply chain management including primary, secondary, and tertiary level packaging over the last 18 years. Yet the focus of this literature review is bound to the decision making models developed for RTIs in the field. Glock (2017) has given a thorough review on this topic summarizing published papers up to July 2015. This review hence intends to discuss the relevant work published afterwards to avoid repetitions. The alternative terms for RTI used in the literature are returnable/reusable transport item, reusable/returnable logistical packaging, and reusable transport packaging. Since pallet is a common form of the transport packaging, the keyword of pallet is also used in the literature search along with other interchangeable terms of RTI.

Many decisions are involved along the life cycle of the RTI management. The first important decision in the early phase is whether to adopt the RTI packaging solutions or not. Practitioners can find clues from some conducted researches. For example, González-Boubeta et al. (2018) used a case of Spanish agro-food company to analyze three kinds of packaging solutions (i.e., disposable, reusable, and reusable on lease) on the measures of economic and environmental impacts adopting the life cycle assessment method. Katephap and Limnararat (2017) investigated the sustainable advantages of using returnable packaging under three reverse logistics arrangements with the export requirements as compared to the disposable ones for an Asia auto parts company. Bengtsson and Logie (2015) compared the environmental performances of reusable pallets with those of the disposable pallets used in China and Australia context. Once the decision on using reusable packaging is made, it may be worthwhile to know the critical success factors of establishing the RTI system by referring to a study in the manufacturing industry by Gardas et al. (2019). Some researchers also summarized the important factors to consider when developing the logistics systems for RTIs (Zvirbule et al., 2016).

It is then pending to choose the RTI management strategy and decide the ownership of the RTIs. RTIs can be owned and used within each supply chain player, called a dedicated use in this case. Or the ownership of the RTIs can be exchanged between supply chain players, called transfer of ownership or buy/sell in different literatures. Or the supply chain can consolidate RTIs using a separate pooling function practicing a shared mode. This pooling function can be outsourced to a third party who owns RTIs, called the leased RTI pooling strategy. Some researchers addressed how to choose an appropriate pallet management strategy (dedicated use of pallets, transfer of pallet ownership, pallet rental) by the use of simulation from the supply chain cost perspective (Ren et al., 2019). Zhang et al. (2015) compared the impacts of implementing two different RTI management modes (the dedicated mode and the shared mode) to the total cost for auto parts companies. Carrano et al. (2015) explored the environmental impacts of employing the three strategies (disposable, buy/sell, and leased pallet pooling) or a mix of these strategies considering the life cycle of pallets. Roy et al. (2016) also analyzed three pallet management strategies (disposable, buy/sell, and leased pallet pooling) but implemented in the push and pull inventory systems. Accorsi et al. (2019) evaluated the performances of two pallet management strategies (buy/sell and pooling) used in different network infrastructures in terms of logistical and environmental indicators.

Each RTI management strategy has drawn researchers' attention because of their unique operational characteristics. Elia and Gnoni (2015) simulated two alternative pallet exchange policies (direct exchange and deferred exchange) within different network configurations to evaluate their performances based on a set of cost and time indicators. Some researchers found the influential factors to enabling the smooth functioning of the pallet exchange system (Elbert and Lehner, 2019).

RTI pooling has gained popularity in industry and the pooler faces strategic-level facility location decisions in the need of designing their network configuration. Some researchers integrate the distribution flow decisions with the network configuration design. Amin et al. (2018) examined a pallet network of suppliers, plants, distributors, customers and recycling centers. A MIP model is developed to determine the best locations for the plants, the distributors, and the recycling centers, and to optimize the distribution flows between the network players in order to gain the largest economic benefits in a case of a Canada pallet network. Zhou and Song (2019) proposed the locations of pallet service centers and determined the flows between the pallet supply points, the service centers and the demand points to achieve the minimum total cost considering random demands. Bortolini et al. (2018) studied a fruit and vegetable supply chain, a closed loop network including both forward product flow and reverse flow of RTIs. A MIP model is used to decide the suitable packaging mix including both disposable packaging and reusable packaging, the storage and handling node locations and the flow allocation between the network nodes, which balances the economic and environmental impacts. Tornese et al. (2018) examined the effects of the pallet repair facility location and two re-positioning policies (cross-docking and take-back) along with the pallet handling and loading conditions on the key performance indicators. Some researchers assume pre-determined network structure and analyze the flows within the network devotedly. RTI procurement decision is involved here as well to ensure sufficient RTI supplies to support demands. Ech-Charrat et al. (2017) sought for an environmental friendly solution for a network of warehouses and clients, deciding the distribution and collection flows within the network. Ren et al. (2017) analyzed a network consisting of pallet service depots, supply points, and customer points. Decisions were made on the distribution flows of RTIs from the service depots to the customers, the re-positioning flows from the supply points to the demand points, and the recovery flows from the supply points to the depots under stochastic supply scenarios at the depots.

Distribution planning triggers more operational level decision making like routing. Some researches can provide some insights on this subject for practitioners. Soysal (2016) considered a closed loop supply chain with a single vendor and a set of customers, modeled as a closed loop inventory routing problem (CIRP) and determined the routes for the forward delivery to the customers and the reverse travel collecting the empty RTIs from the customers to the vendor assuming changing demands. Iassinovskaia et al. (2017) addressed a special case of CIRP. In this case, customers defined a time window wherein the delivery service from the vendor can begin. Limbourg and Pirotte (2018) extended the work by Iassinovskaia et al. (2017) considering the durability and the resale value of RTIs. For a review of the sustainability aspects in the inventory routing operations with RTI as one of three major subject areas, practitioners can refer to the work by Malladi and Sowlati (2018).

In the daily operation of the RTI management, practitioners encounter RTI losses often caused by misplacement. Some researchers proposed an investment in the staff training and demonstrated a reduction in the total supply chain cost (Fan et al., 2019a,b). The unexpected RTI loss is one of the sources causing the uncertainty of RTI returns. Researchers attempt to find solutions for the mismatch between the supply and the demand of RTIs caused by the uncertain returns. Alternative safety measures against this mismatch include the procurement and renting of RTIs and the establishment of safety stock. Jami et al. (2016) studied a logistics chain between a supplier and a manufacturer with both players making procurement decisions. The supplier can buy the disposable containers to fulfill a part of demand if it does not receive sufficient re-positioned reusable containers from the manufacturer and the manufacturer also has options to buy reusable containers but with lot size requirement. Researchers analyzed the suitable conditions for triggering separate purchasing decisions. Hariga et al. (2016) considered the stochastic RTI return time in a single vendor and single retailer network given the vendor is allowed to rent RTIs. It was found that renting RTIs is especially beneficial in case that both shortage cost and risk of late RTI returns are high. Some researchers examined different scenarios to analyze the trade-offs between purchasing new pallets either on a standard order or an urgent order and retrieving them from the customers in terms of economic and environmental performance indicators (Bottani et al., 2015; Bottani and Casella, 2018). Glock and Kim (2016) investigated the optimal safety stock level and safety return time for RTIs to reduce stockout risks.

Another decision in the regular management of RTIs is the re-manufacturing and repair of RTI. Tornese et al. (2019) studied the tradeoff between truncating the useful life of pallet components and consolidating transportation to the pallet re-manufacturing facility when a preemptive repair policy is implemented from environmental and economic perspective. Tornese et al. (2016) quantified the carbon emission associated with pallet re-manufacturing operations considering different loading and service conditions under two pallet re-positioning scenarios (cross-docking and take back).

Some relevant researches are on the interactions between the transported materials and RTIs considering joint decisions for both. For example, Wang and Zhao (2018) analyzed the retail pricing of the product adjustable according to RTI parameters under the carbon tax policy for the retailer in a supply chain. Sarkar et al. (2019a) considered a closed loop supply chain with single-setup multi-delivery policy for suppliers and manufacturers. The retail pricing, production and delivery decisions were made to maximize the profit and minimize carbon emission while determining the RTI requirement. Some researchers investigated a closed loop supply chain including product re-manufacturing possibilities. RTIs, owned by the third party, circulate within the network, transporting the product. The pricing and inventory decisions for the products are planned to achieve economical and/or environmental objectives along with the decision on the right capacity for RTIs (Sarkar et al., 2017, 2019b). SteadieSeifi et al. (2017) studied a horticultural supply chain to plan the transportation strategy for the perishable products using RTIs. Decisions included transportation modes and schedules, vehicles for each mode, the flow and the re-positioning of RTIs to balance tradeoff between the product freshness and the costs.

Significant research efforts have been devoted to the decision making encountered in the RTI management ranging from strategic level to operational level. However, some research gaps still exist. This paper intends to develop a decision support tool planning the distribution flow and vehicle routing for a RTI pooler adopting a sharing policy and apply this model to a practical case in China. As Glock (2017) pointed out, few researches have the practical assumption that RTIs are rented except for the studies of González-Boubeta et al. (2018), Hariga et al. (2016), Ren et al. (2019), Sarkar et al. (2019b) and Sarkar et al. (2017). But their focus is not on optimizing the distribution flow and routes from the pooler's perspective. Studies by Ren et al. (2017), Zhou and Song (2019) assumed pallet pooling mode and attempted to optimize the network configuration and/or the distribution flows within the network. Yet both of them do not consider the imminent routing decision. This paper intends to fill in this gap and further study the impact of these operational decisions.

3. Case description and mathematical model

This research is motivated by an industrial case in the B2B market of China. A leading RTI pooling company, Company A, provides green packaging solutions (foldable containers) to the domestic market with customers from various industries such as automotive, food, etc. Company A has developed a service and transportation network over the years to dispatch leased empty containers to its customers and collect the empty containers from them. Company A, as the RTI owner, is also responsible for procurement, storage and maintenance of containers. The service network of Company A consists of about 40 Container Management Centers (CMC) with more than 10,000 containers flowing within this network. Everyday each CMC dispatches trucks to send empty containers to its customers (an upstream supply chain player) fulfilling the customer orders. Once receipt by the customers, the containers flow into the customers' operational processes. Then the customers transport the finished parts in the containers to its customers (a downstream supply chain player), which may be located miles away from the upstream player (Accorsi et al., 2019; Iassinovskaia et al., 2017). After the containers have been emptied by the downstream player, they are sent back to a CMC. Returned containers are inspected, maintained, and then put into the storage for future dispatching requirements in the CMC.

The current policy practiced by Company A is that each CMC has a collection of dedicated customers to serve. A closed loop flow of containers is also enforced, meaning the emptied containers collected at the downstream player need to be reverted back to their originated CMC. With this policy in place, it may take up to a month for the containers to return to their home CMC. Each CMC hence runs with a possibility of stockout disrupting the supply chain flow due to a fluctuating on-stock level of containers and its customers' changing requests. Stockout can cost Company A prohibitively high contract penalty since their supply chain customer employs zero tolerance on the container shortage caused by their competitive industry nature (Jami et al., 2016). To safeguard against the potential stockout, each CMC then maintains a large volume of safety stocks causing high inventory costs. Additionally, the closed loop flow incurs non-value-added backhauls of containers to their home CMC in the commonly observed scenario that a nearby CMC may have customers' orders for these containers (SteadieSeifi et al., 2017).

The transportation costs remain Company A's topmost operational costs. As a result, Company A's profit growth meets stagnancy, even though their market has been growing rapidly. The company demands a more sustainable and operable solution. This research proposes an inventory sharing strategy that removes the dedicated mode of customer to CMC and returns the empty containers at the downstream player to the closest CMC instead of the home CMC forming a open loop flow of containers. Figs. 1 and 2 illustrate how containers flow within the network including both CMCs and supply chain players under current dedicated mode and the proposed sharing mode. CMC is shown as triangular and its customer (the upstream player) as circle and the downstream player as square. The arrow lines represent the directed container flows. The solid lines are the flows to be studied in this research and the dashed ones are outside of the study scope since Company A has no control on how its customers use their containers in their own supply chains. Planning activities operate on a daily basis allocating the returned RTIs in all CMCs to all customers in the whole network based on the daily changing demands and the changing supplies of RTIs.

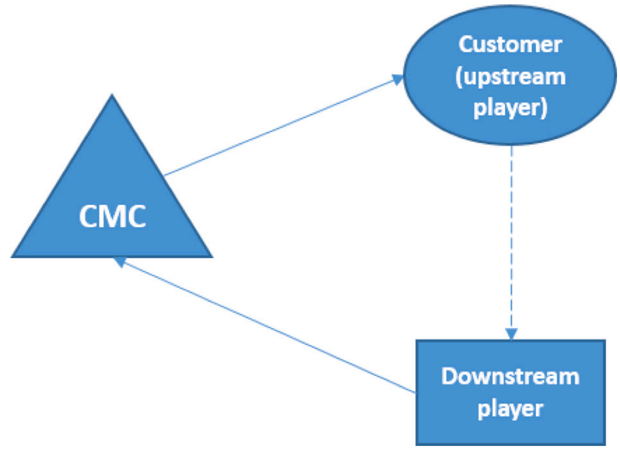

Fig. 1. RTI flow through network echelons under current dedicated mode.

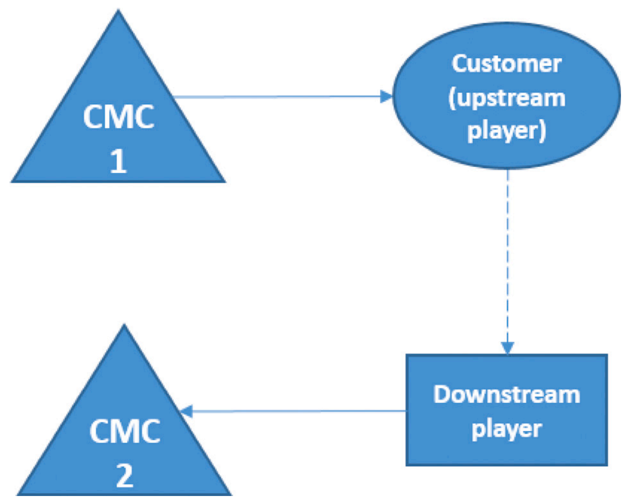

Fig. 2. RTI flow through network echelons under proposed sharing mode.

A decision support model is developed to implement this sharing strategy which optimize the dispatching flows between CMCs and customers, and simultaneously create the optimal plan of the trucking routes. In this integrated model, minimized is the overall transportation cost including not only the long haul costs between CMCs and customers but also the regional trucking costs among the surrounding customers of the CMCs. The transportation quantities from each CMC to customers are driven by the customers' demands but limited by its on-site container supplies. The customers' demands also trigger the trucking routes which are constrained by the loading capacity. Time window set by customer is a widely studied factor in the vehicle routing literatures (Schneider et al., 2014; Karakatič and Podgorelec, 2015). However, it is not a concern in this model, since Company A's customers always place advanced orders following their zero stockout policy and hence there is no operational requirement on this factor. The notations used in the model is given in Table 1.

The problem is formulated as a mixed integer programming model as follows:

$$\text{Min} \sum_{i\in I, j\in J} U_{ij}\cdot R_{ij}\cdot V\cdot x_{ij} + \sum_{i\in I, j, j'\in N^i, k\in K^i} U_{jj'}\cdot R_{jj'}\cdot V\cdot z_{jj'k} \tag{1}$$

s.t.

$$\sum_{i\in I} x_{ij} \geq D_j, \forall j\in J \tag{2}$$

$$\sum_{j\in J} x_{ij} \leq S_i, \forall i\in I \tag{3}$$

Table 1
Notations used in the model.

Sets	Definition
I	Set of CMCs
J	Set of customers
K^i	Set of vehicles deployed at CMC $i \in I$. Two dummy points are created for CMC $i \in I$: 0^i, the starting node; T^i, the ending node for all vehicles deployed at CMC i. Both of them are physically coincided with node $i \in I$.
N^i	$N^i = \{0^i, T^i\} \cup J, \forall i \in I$
N	$N = \cup_{i \in I}\{0^i, T^i\} \cup J$
Parameters	
R_{ij}	Transportation distance from a node $i \in N$ to another node $j \in N$. Note that R_{0^i,T^i}, $\forall i \in I$ is 0.
U_{ij}	Unit transportation cost from a node $i \in N$ to another node $j \in N$
V	Volume conversion factor of a container
D_j	Demand for containers from customer $j \in J$
S_j	Supply of containers at CMC $i \in I$
C	Loading capacity of each vehicle
M	An arbitrary large positive number
ϵ	An arbitrary small positive number
Decision Variables	
x_{ij}	Transport amount of containers from CMC $i \in I$ to customer $j \in J$
$z_{jj'k}$	Binary variable; 1 if vehicle $k \in K^i$ of CMC $i \in I$ travels immediately from node $j \in N^i$ to node $j' \in N^i$, 0, otherwise.
y_{jk}	Vehicle $k \in K^i$'s loads when arrives at node $j \in N^i$
w_{ijk}	Transport amount of containers from CMC $i \in I$ to customer $j \in J$ by vehicle $k \in K^i$
v_{ij}	Binary variable; 1 if $x_{ij} > 0$; 0, otherwise.

$$\sum_{k \in K^i} w_{ijk} = x_{ij}, \forall i \in I, j \in J \tag{4}$$

$$x_{ij} \le M \cdot v_{ij}, \forall i \in I, j \in J \tag{5}$$

$$\epsilon \cdot v_{ij} \le x_{ij}, \forall i \in I, j \in J \tag{6}$$

$$\sum_{j \in N^i \setminus \{T^i\}} z_{juk} = \sum_{j' \in N^i \setminus \{0^i\}} z_{uj'k}, \forall i \in I, k \in K^i, u \in J \tag{7}$$

$$\sum_{j \in N^i \setminus \{T^i\}} z_{juk} \ge v_{iu}, \forall i \in I, k \in K^i, u \in J \tag{8}$$

$$\sum_{j \in N^i \setminus \{T^i\}} z_{juk} \le M \cdot v_{iu}, \forall i \in I, k \in K^i, u \in J \tag{9}$$

$$\sum_{j \in N^i \setminus \{0^i\}} z_{0^i jk} = 1, \forall i \in I, k \in K^i \tag{10}$$

$$\sum_{j \in N^i \setminus \{T^i\}} z_{jT^i k} = 1, \forall i \in I, k \in K^i \tag{11}$$

$$y_{jk} - y_{j'k} + C \cdot z_{jj'k} \le C + w_{ijk}, \quad \forall i \in I, j \in N^i \setminus \{T^i\}, j' \in N^i \setminus \{j, 0^i\}, k \in K^i \tag{12}$$

$$w_{ijk} \le y_{jk} \le C, \forall i \in I, j \in J, k \in K^i \tag{13}$$

$$x_{ij}, y_{jk}, w_{ijk} \ge 0, z_{jj'k}, v_{ij} \in \{0, 1\} \tag{14}$$

The objective function (1) is to minimize the sum of two costs. The first term of (1) is related to the trunk line transportation costs and the second term is related to the regional trucking costs. Since $R_{0^i,T^i} = 0$ $\forall i \in I$, all the unused vehicle $k \in K^i$ will take the shortest route, i.e., from 0^i to T^i. Constraints (2) make sure all customers' demands are fulfilled. Constraints (3) let the total number of containers shipped from CMC i be less than on-hand containers. Constraints (4) link w_{ijk} and x_{ij}. Constraints (5)–(6) define the decision variable v_{ij}. Constraints (7) are the flow-conservation conditions. Constraints (8)–(9) make sure if customer u is covered by CMC i, then at least one vehicle in K^i should visit the customer; on the contrary, if the customer is not covered by CMC i, then no vehicle should visit the node. Constraints (10)–(11) guarantee that any vehicle $k \in K^i$ starts from 0^i and finally visits T^i. Constraints (12)–(13) restrict the load of vehicle as well as to eliminate subtours. Finally, constraints (14) specify the scopes for all decision variables.

During the solution process, it is determined that this integrated model can be decomposed into two-stage sequential solves including the first-stage transportation model and the second-stage vehicle routing model. The reasons are following: (1) It has been found through the preliminary data analysis that the customers are usually clustered within certain regions. This implies that the transportation costs of the trunk lines between CMCs and customers dominate the regional transportation costs among the customer clusters in general. Furthermore, the cost benefits from simultaneously making the transportation and routing decisions are normally offset by the high computational costs caused by solving the large-scale NP-hard combinatorial problem. (2) The order fulfillment decisions and the truck dispatching decisions are managed by different functions in the company. The division of the integrated model enables the users re-adjust the transportation results with minor changes accommodating impromptu operational judgments, such as order consolidation, small order pull-in or push-out, etc.

A decision support framework is thereby developed to implement these two models in the industrialized optimization platform, AIMMS. Two mathematical models, a transportation model and a variation of vehicle routing model, are developed to form the two-stage solution process of this tool. The transportation model in the first stage decides the optimal transportation quantity for every CMC based on its on-site container supplies to meet the customers' demands with an objective to minimize the total transportation costs. The capacitated vehicle routing model in the second stage determines the minimum number of trucks required under the loading limit and the truck routes between the CMC and the served customers to fulfill the transportation quantity allocated in the first stage for every CMC aiming to minimize the total travel distances. Both problems are solved using the standard solver engine, CPLEX12.9, embedded in AIMMS.

All problem parameters are based on historical transaction records from January to June of 2019 except that the distance parameters between the network nodes (CMCs and customers) are calculated using Baidu Maps. The variable transportation cost are driven mainly by the fuel consumption, which is a function of the travel distance, the shipment size, and the loading weight of the truck (Anonymous, 2017b; Iassinovskaia et al., 2017; Sarkar et al., 2017, 2019a; Soysal, 2016). Unit transportation cost is obtained using a regression analysis with observation data of the paid bills on the outbound logistics activities. The regression analysis is used to estimate the cost parameters required for all possible routes between CMCs and customers in the proposed sharing mode, since the paid bills cover only the existing routes between CMCs and their dedicated customers. Even though Company A provides several RTI products for their customers, one particular kind of container captures 80% of the company profit and hence is the study subject in this research in order to create meaningful business impacts for the company. The volume conversion factor is estimated as 0.24 M^3 per piece using this container's physical characteristics. Company A employs a fleet of 7.6-meter trucks for delivery, with a loading capacity of 87.4 M^3. Using the container's physical dimensions, it is estimated that each truck can load up to 336 containers. Additional reference data will be available upon request.

4. Analysis

To evaluate the business values created by the proposed sharing strategy, the historical transaction data is used as a baseline scenario to compare with the results obtained from the proposed framework implementing the sharing strategy. For demonstration purposes, the results from both strategies are presented using one typical day's operation data in this section. Since the distribution decision is driven by the transportation cost which is predominantly determined by the transportation distances between CMCs and customers, the solved distribution flows show a pattern of hub and spoke. For the ease of discussion, the results are subsequently reviewed in three hub regions: the south region, the east region and the north region.

Figs. 3 and 4 show the dispatching flows from CMCs to customers in the south region of China under the current dedicated mode and the proposed sharing mode respectively. The solid blue lines represent the dominating services provided by a CMC to a customer and the dashed lines represent the supporting services of a CMC to a customer if a customer's demand cannot be fully supported by one dominating CMC. It can be observed that there are a couple of distribution swaps and a newly assigned flow between CMCs and customers influenced by the overall transportation costs and the on-hand stocks at CMCs, proposed by the sharing strategy. For example, the distribution flow from CMC1 to Customer2 is removed and replaced by the flow from CMC2 to that customer. CMC4 comes into play and acts as the primary channel for supporting Customer1 and CMC1 as a secondary service provider picks up the unsupported volume of Customer1 left from CMC4. CMC3 replaces CMC2 to support Customer4 and no longer serves Customer5. Customer5 is be served by the northern CMC. The new distribution flows proposed by the sharing mode have reduced the original transportation costs by almost 4.6 times in this region.

Figs. 5 and 6 show the dispatching flows from CMCs to customers in the east region of China under the dedicated mode and the sharing mode respectively. There are two new CMCs assigned to the customers in this region. CMC6 and CMC8 store other RTI products in the current dedicated practice but are now stocked with the returned containers within its proximity in the proposed model. Customer6 switches from receiving a dedicated service from CMC5 to receiving a shared flow from both CMC5 and CMC6 with CMC6 playing the supporting role. The proposed solution suggests that CMC8 collaborate with CMC7 as a secondary service provider to support Customer7 and serve Customer8 by itself replacing CMC7. CMC9 removes the northern CMC10 out of the picture by providing services to Customer9. This proposal causes around 21% reduction in the transportation costs in this region.

Figs. 7 and 8 show the dispatching flows from CMCs to customers in the north region of China under different strategies respectively. A few CMCs are out of the picture with an incoming new one and there are some new assignments between CMCs and customers. CMC3, CMC13 and CMC4 no longer serve the northern customers. CMC12 is assigned to support Customer5 replacing CMC3 located in the south region. CMC11 removes CMC13 from the play by taking over Customer17 from it and starts supporting Customer16 replacing CMC4 in the south region. CMC14 reduces its customer base to Customer13 and Customer14 and leaves Customer15 to CMC15, which is a new assignment. CMC10's operations have been simplified significantly as it no longer supports Customer18 which is now assigned to CMC16 and leaves Customer9 to be served by the eastern CMC. These new arrangements help to reduce the transportation costs by 2.5 times in this region.

Table 2
Comparison of historical and optimized transportation cost in different regions.

Region	Historical data	Optimized cost
South	22,757.97	4,949.61
East	10,545.15	8,347.11
North	23,780.91	9,220.32
Total	57,084.03	22,517.04

Table 2 lists the historical cost records compared with the optimized results in different regions on that typical business day. Both data are the transformed ones using an uniform transforming mechanism with a purpose of concealing the company's operational data. Current planning practice adopted by the company is the use of Excel and planner's experiences. The newly proposed practice is the use of the optimization modeling. It can be expected that this global optimization allocates the customers to the appropriate CMC to minimize the transportation cost.

No historical data has been maintained for the routing decision. In current practice, that decision is left to the truck drivers' discretion. The discussions on the routing results below are for illustration purposes and are based on the distribution flows under the current dedicated mode. Focused in the discussion are top two CMCs in the most demanding east region, which is CMC6 and CMC7, since other CMCs do not present higher complexity in their delivery routes. The exact coordinates of CMCs and customers are used to show the real routes in the regional map of the east. In order not to reveal their exact locations, the resolutions of the below figures are adjusted deliberately.

Fig. 9 shows the proposed delivery routes for CMC7 which handles 10 customers around its proximity region. Different vehicle routes are coded in different colors in the figure. Due to the loading capacity of each vehicle is limited to 336 containers, the company need to run 3 vehicles for their delivery services from CMC7 with the total travel distances of 331.2 KM. The delivery routes for CMC6 is shown in Fig. 10. CMC6 serves 6 customers around its proximity region. Since the transport demand for this CMC is less than that of CMC7, 2 trucks are sufficient to circulate the area delivering the requested containers with the total travel distance of 316.2 KM.

5. Implications

The decision support framework implementing the sharing strategy for Company A has proven to provide more cost efficient results for the distribution flows during the first stage. Even though the transportation costs are calculated on the outbound logistics from CMCs to customers, the inbound backhaul costs are implicitly captured in the optimized outbound flows from CMCs to customers based on the returned container stocks collected from the neighboring downstream supply chain players. That is to say steeper cost deductions would be expected in the results if both inbound and outbound logistical costs were evaluated.

The optimized dispatching flows combined with the optimized truck routes create less environmental burdens by reducing carbon emissions as a result of the shortened travel distances (Sarkar et al., 2019a). In turn it helps Company A to abide by government regulations on the carbon footprint. Reduced logistics poses less threats to the public health (da Cruz et al., 2014). According to a recent report in 2016, "more than 1.6 million people die per year in China from breathing the toxic air" and traffic is one of the biggest pollution drivers (Gustke, 2016; SteadieSeifi et al., 2017). Less commercial trucks traveled on the road reduces also community concerns on the traffic load, their threat to other road users' safety and road integrity (Limbourg and Pirotte, 2018; Malladi and Sowlati, 2018). Recent data shows that commercial trucks are accounted for 30.5% of the automobile accidents in 2016 (Anonymous, 2017a). This tool enables Company A to achieve

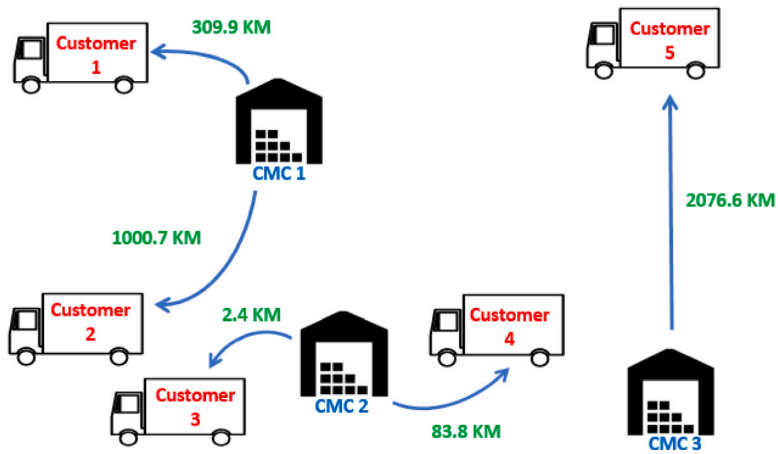

Fig. 3. Current dispatching practices in South region.

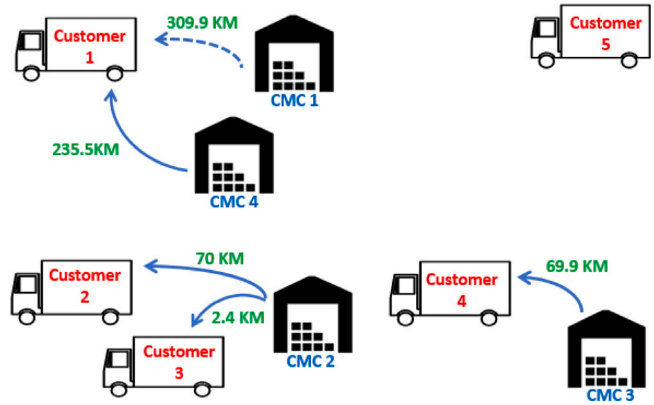

Fig. 4. Proposed dispatching practices in South region.

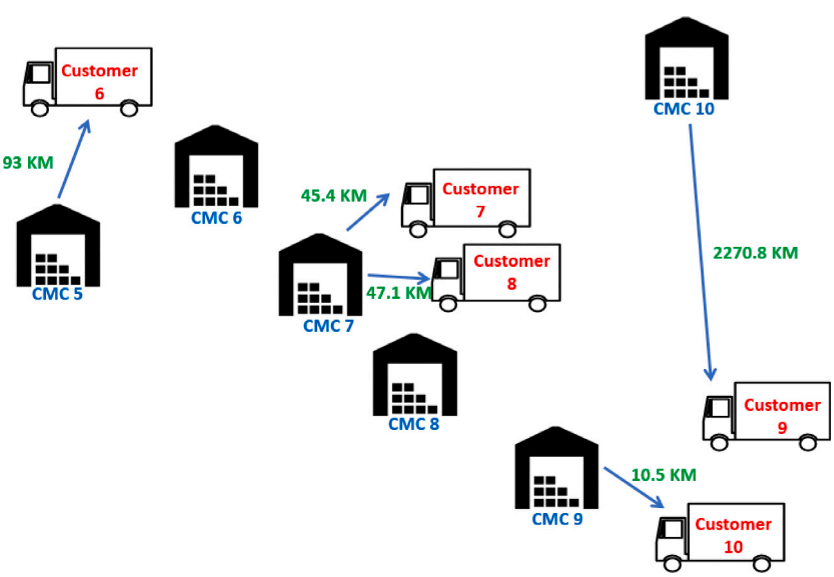

Fig. 5. Current dispatching practices in East region.

sustainability directly or indirectly in economic, environmental and social dimensions (González-Boubeta et al., 2018; Soysal, 2016).

The minimal truck requirements obtained during the second stage can give Company A implications when planning their fleet operations of in-house trucks. For example, when the requirement exceeds the in-house quantity, rental truck service needs to be arranged beforehand. Truck maintenance can be planned when there are less demands for the truck usage. The travel distance obtained can be used as a benchmark for evaluating the delivery activities either performed in-house or outsourced.

Another useful information which could be elicited from the first stage transportation results is the least active CMCs among all CMCs.

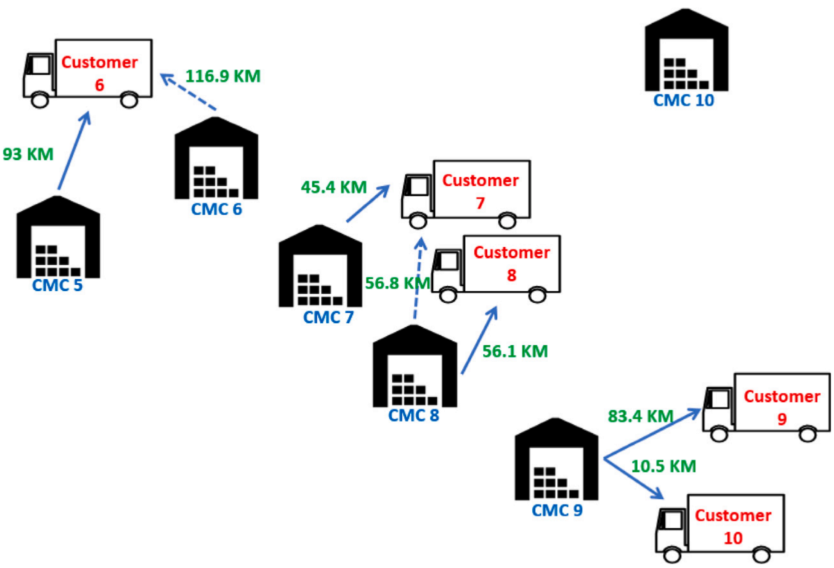

Fig. 6. Proposed dispatching practices in East region.

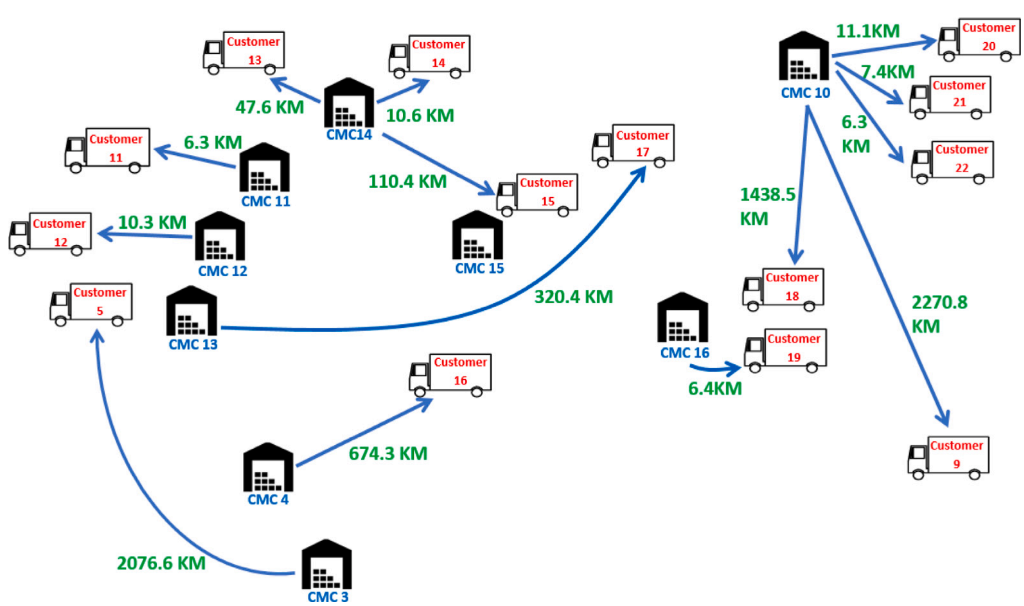

Fig. 7. Current dispatching practices in North region.

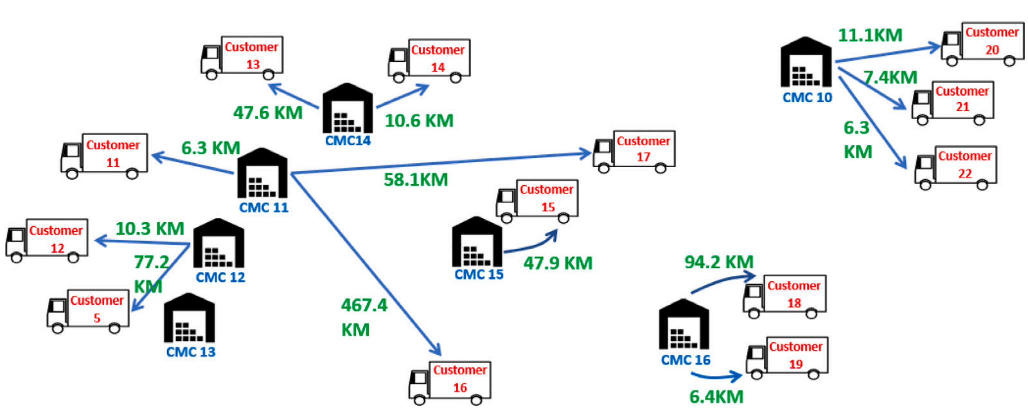

Fig. 8. Proposed dispatching practices in North region.

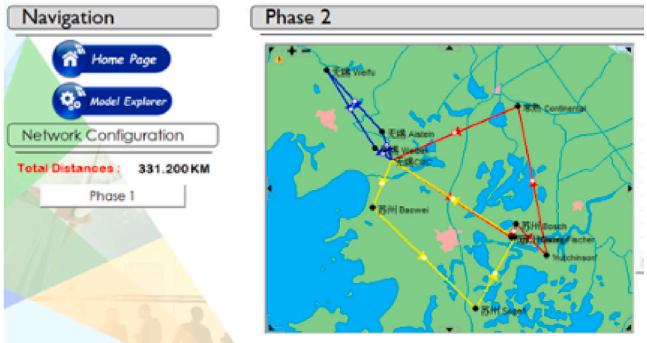

Fig. 9. Truck routes proposed for CMC7.

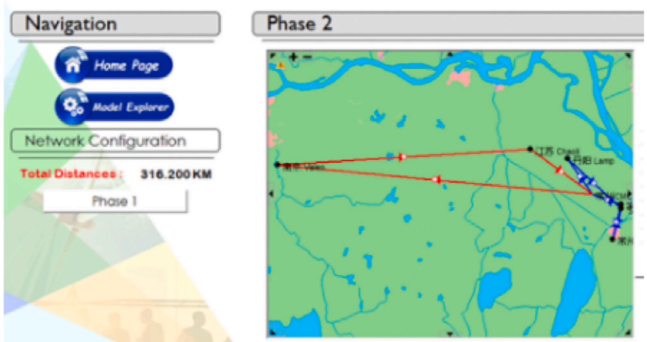

Fig. 10. Truck routes proposed for CMC6.

They are the ones observed from which few dispatching flows are originated. In the first stage transportation model, there is no hard requirement to use all CMCs or to assign at least one customer to one CMC. This is an allowable business scenario since it is highly possible to observe no dispatching operations in some CMCs on a particular day due to the fact that customer demands are intermittent over a period and this tool is for daily planning. Besides, with a purpose of reducing asset liability and activate assets, Company A currently undergoes a process of reconfiguring its supply chain network and attempts to close some redundant CMCs within a certain region and open some new ones in the new market regions. After collecting the resulting data on the inactive CMCs over multiple runs, a removal candidate list of CMC can be established and a final removal decision can be made with scrutiny of other tangible and intangible factors of the candidate CMCs.

The company is advised to run the tool for the daily planning operation and it is expected that the proposed distributing pairings between CMCs and customers properly adjust to the customer demands and the on-stock level of containers at each CMC reflecting the uncertain returns of containers on that day. In the fear of stockout, CMCs reserve at least 20% buffer stock in-house under the current practice discounting the ones in-transit. The total supply of containers at all the CMCs is therefore always larger than the total demand of all the customers, which ensures no infeasibility encountered during the solution process of the first stage transportation problem.

For Company A, the sharing strategy certainly implies additional managerial costs, asks for strong information system support, and is a need of more collaborations between CMCs (Zhang et al., 2015). However, supply chain customers would not worry from where they receive the service as long as the containers are delivered on time with the required quality and quantity. That requests Company A to have standard quality assurance procedures in place across all the CMCs and implement the same level of customer service.

6. Conclusion

Packaging waste problem has been deteriorated by the extended supply chains around the globe catering for the increasing global consumer needs and the significant shift towards e-commence. Government regulations and society concerns press organizations to look for a sustainable packaging solution. Reusable transport items are then adopted by organizations for creating economic, environmental and social benefits. In order to avoid the extra layer of complexity adding to their supply chain management, RTI pooling and outsourcing to a third party becomes a popular option to many organizations.

This research is based on a case study of a leading RTI pooling company in China. A decision support framework is developed to support their daily planning operations adopting a sharing policy and a two-stage solution process is utilized to create the planning proposal. During the first stage, the distribution flows are optimized between CMCs and customers based on the on-stock RTIs collected at each CMC following the sharing policy. During the second stage, the vehicle routes are determined to minimize the total travel distance using minimum vehicles possible for every CMC. Empirical results show that Company A has gained noticeable reductions in the transportation costs in different regions of China. In total, the company is able to reduce their transportation expenses by 28.1% based on transaction accounting records. The reduced travel distance brings significant implications to environment and community.

CRediT authorship contribution statement

Guoquan Liu: Conceptualization, Methodology, Validation, Writing - original draft. **Lei Li:** Formal analysis, Writing - original draft, Writing - review & editing. **Jianghang Chen:** Methodology, Validation, Writing - review & editing. **Fei Ma:** Methodology, Writing - review & editing.

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