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Closed-loop Inventory Routing Problem for returnable transport items

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A R T I C L E I N F O

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A B S T R A C T

Increasing concerns on supply chain sustainability have given birth to the concept of closed-loop supply chain. Closed-loop supply chains include the return processes besides forward flows to recover the value from the customers or end-users. Vendor Managed Inventory (VMI) systems ensure collaborative relationships between a vendor and a set of customers. In such systems, the vendor takes on the responsibility of product deliveries and inventory management at customers. Product deliveries also include reverse flows of returnable transport items. The execution of the VMI policy requires vendor to deal with a Closed-loop Inventory Routing Problem (CIRP) consisting of its own forward and backward routing decisions, and inventory decisions of customers. In CIRP literature, traditional assumptions of disregarding reverse logistic operations, knowing beforehand distribution costs between nodes and customers demand, and managing single product restrict the usage of the proposed models in current food logistics systems. From this point of view, the aim of this research is to enhance the traditional models for the CIRP to make them more useful for the decision makers in closed-loop supply chains. Therefore, we propose a probabilistic mixed-integer linear programming model for the CIRP that accounts for forward and reverse logistics operations, explicit fuel consumption, demand uncertainty and multiple products. A case study on the distribution operations of a soft drink company shows the applicability of the model to a real-life problem. The results suggest that the proposed model can achieve significant savings in total cost and thus offers better support to decision makers.

1. Introduction

In modern supply chains, companies constantly seeking to reduce costs, increase handling efficiencies and improve sustainability performance through reducing environmental and social externalities. One of the main motivations behind the development of sustainable supply chains is policy measures and strategies devised by governments. Among such regulations are requirements relating to the tracking of products in supply chains. More specifically, enhanced traceability regulations require companies to track both forward product movement and reverse flows of secondary packaging and materials handling equipment associated with product shipment.[1] Additionally, regulations on emission reduction of greenhouse gases that are responsible for global warming, climate change, environmental pollution have led to growing interest

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[1] RTI (Pallet Tagging) Guideline, http://www.gs1.org/sites/default/files/docs/epc/EPC-RTIPalletTagging-ImpGuide-i2.pdf, Online accessed: December 2015.

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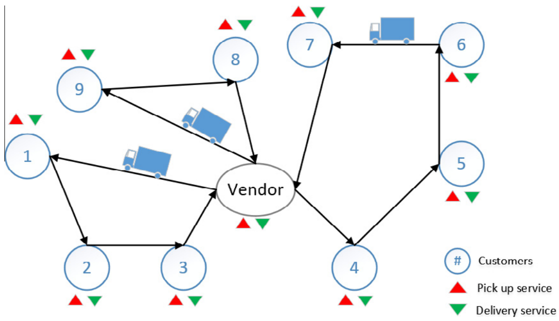

Fig. 1. A generic representation of the Closed-loop Inventory Routing Problem.

in transportation energy efficiency improvement and emission reduction opportunities (see Soysal, 2015). These obligations together with increased economic, environmental and social concerns of stakeholders have given birth to the concept of closed-loop supply chain. Closed-loop supply chains include the return processes besides forward flows to recover the value from the customers or end-users. Here the challenge is development of innovative closed-loop supply chain systems that are able to contribute to the triple bottom line of sustainability: economic, environmental and social aspects.

Vendor Managed Inventory (VMI) systems ensure collaborative relationships between a vendor and a set of customers. In such systems, the vendor takes on the responsibility of product deliveries and inventory management at customers. Product deliveries also include reverse flows of returnable transport items (RTIs) such as pallets, roll cages, returnable plastic containers, tote boxes, ingredients bins, and dollies. Under VMI policy, the vehicle routes are constructed based on the inventory levels observed at the customers rather than the replenishment orders coming from them. The use of VMI system provides opportunity to both parties, i.e., suppliers can better coordinate deliveries to customers and customers do not have to dedicate resources to inventory management (Coelho et al., 2012a; Campbell et al., 1998; Raa and Aghezzaf, 2009). Therefore, VMI systems can contribute to the triple bottom line of sustainability in terms of reducing (i) logistics cost (see Coelho and Laporte, 2014), (ii) transportation energy use or emissions from forward and reverse flows (see Mirzapour Al-ehashem and Rekik, 2013) and (iii) product waste (see Aksen et al., 2012) or packaging waste, i.e., the collection of RTIs removes the need for recycling or recovering packaging and packaging waste. The execution of the VMI policy requires vendor to deal with an integrated problem consisting of its own forward and backward routing decisions, and inventory decisions of customers. This integrated problem is known in literature as a variant of the Inventory Routing Problem (IRP) called the Closed-loop Inventory Routing Problem (CIRP).

The IRP addresses the management of two components of the supply chain: the vehicle routing and the inventory management (Jemai et al., 2013). The tackled IRP here comprises single vendor which provides several product types to a set of customers. As distinct from the basic IRP, CIRP also deals with collecting end-of-life products or RTIs from customers for either reuse or proper disposal. Following the collection operation from the customers, these collected items are returned to the central depot of vendor. Another issue which is worth to be mentioned here is the customer usage rate (demand) is not known in the beginning of the planning horizon. A generic representation of the CIRP is illustrated in Fig. 1. The objective of the problem is to minimize total distribution and inventory costs. The vendor/supplier has to make three simultaneous decisions: (1) when to deliver to each customer, (2) how much to deliver to each customer each time it is served, and (3) how to combine customers into forward and backward vehicle routes. Applications of the CIRP can arise in different logistics systems such as food distribution to supermarket chains, i.e., collection of products which are at the end of their shelf life for proper disposal or collection of RTIs used for packaging to reuse.

The traditional IRP without reverse flows has been extensively studied in the literature. However, there exist a few attempts (e.g., Liu and Chung, 2009; Liu et al., 2015) to formulate and solve the CIRP. Researchers make several assumptions and simplifications in their models which are developed either for traditional IRP or CIRP. Some of these assumptions and simplifications restrict the usage of the proposed models in current logistics systems. These assumptions can be regarded as doubtful from the practical point of view and are summarized as follows. First, studies in the field often disregard reverse logistic operations which leads to missed opportunity to merge forward and backward flows. Second, IRP models often use distance-based cost calculation to estimate distribution cost, whereas fuel consumption and therefore cost can change based on vehicle load which is dependent on the visiting order of the customers (Kara et al., 2007; Kuo and Wang, 2011; Suzuki, 2011; Ligterink et al., 2012). Third, a widespread assumption of in advance known customer usages is restrictive in that this is clearly not the case in reality. Fourth, a widespread tendency is to assume that the problem is subject to single product, whereas vendor might provide more than one product to the same customer set. The aforementioned main weaknesses of the models for the tackled problem have to be improved.

From this point of view, our interest in this study is to enhance the traditional models for the CIRP to make them more useful for the decision makers in closed-loop supply chains. In order to achieve that improvement, we do not rely on the above-listed assumptions and simplifications of the traditional models. Therefore, in our problem setting, forward and reverse flows have to be managed simultaneously, distribution costs between nodes are not known in advance and are not constant, customer usage is not known a priori, and the vendor is responsible for logistics operations of multiple