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A dynamic closed-loop vehicle routing problem with uncertainty and incompatible goods

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ABSTRACT

This study investigates a dynamic closed-loop vehicle routing problem (VRP) with uncertain pickup and deterministic delivery of incompatible goods, which is an extension of the VRP with simultaneous pickup and delivery (VRPSPD) in closed-loop logistics, where the incompatibility between goods of pickup and delivery is considered. The problem involves minimizing transportation cost, incompatibility and number of customers visited twice. A solution method based on variable neighborhood search (VNS) is developed for solving the VRPSPD. The pickup uncertainty is handled in two stages: first, *a priori* routes are generated by solving a VRPSPD whose pickup demands are estimated; second, the *a priori* routes are simulated by dynamically satisfying the pickup demand under incompatibility, and the second-round routes are generated to meet the unmet demands. The effects of considering the incompatibility are examined by experiments. A case of centralized tableware disinfection and logistics services in China's catering industry is used for demonstration. Disinfected tableware for delivery and used tableware for pickup are incompatible because of potential cross-contamination. The experimental results quantitatively provide insights for managers who must solve the dynamic closed-loop VRP with uncertain pickup and incompatible goods. The proposed method also proves competitive for the VRPSPD.

1. Introduction

In closed-loop supply chain and reverse logistics (Karlaftis et al., 2009; Guide and Van Wassenhove, 2009; Souza, 2013), new products and returns are typically stored or transported in the same compartment or container, without consideration of potential mutual incompatibility that may harm production quality and human health. For example, empty beer bottles are collected as full beer bottles are distributed; reusable containers are collected while products are distributed (Duhaime et al., 2001); returns are collected while new products are distributed to retailers (Mihi Ramírez, 2012; Zerhouni et al., 2013). In all such examples, the forward and reverse demands are typically met by a route and a vehicle. As a typical example, incompatible hazardous materials are typically stored in the same warehouse and sometimes transported in the same vehicle (Winder and Zarei, 2000; Hamdi-Dhaoui et al., 2012; Murèa and Demichelab, 2013).

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In the considered closed-loop logistics, pickup demands are uncertain and the collected goods are incompatible with the goods to be delivered in the same vehicle. Pickup demand is estimated based on the goods that have not already been collected. Collecting goods at a customer when goods are delivered to this customer can reduce the stock of goods at customers and reduce the pickup cost. However, the goods to be delivered and collected may have to be transported in the same vehicle, whereas they are incompatible. When the incompatibility is severe, the pickup and delivery demands can be satisfied using two vehicles. In such a strategy, the pickup and delivery demands are met by solving the two isolated capacitated vehicle routing problem (CVRP); the transportation cost is high because the vehicle capacity is not fully utilized; and each customer may be visited twice, potentially reducing the service quality. When each customer's pickup and delivery demands are satisfied simultaneously, the problem refers to a VRP with simultaneous pickup and delivery (VRPSPD). As a compromise strategy, divisible pickup and delivery involves dynamically and selectively pickup based on the realized uncertain pickup demands at customers. The new problem of finding tradeoffs among the logistical cost, the service quality and the incompatibility degree then arises. In terms of the load feasibility constraints that challenge VRPSPD, some effective metrics which capture the load fluctuation of vehicles along their routes (Wassan et al., 2008; Zachariadis et al., 2010), whereas the incompatibility is not considered between the picked-up and delivered goods. Although reverse logistics has been extensively studied (Dethloff, 2001), typically, only the contamination of the environment by the collected items is considered (Hu and Sheu, 2013).

This work contributes to the literature on reverse logistics and VRPSPD. First, the incompatibility between goods to be delivered and collected is incorporated into the routing solution. The incompatibility factor specifies the relationship between the goods collected and to be delivered, and the vacant vehicle capacity. A measure of accumulated incompatibility uses this instant incompatibility factor and the time traveled with the mixed goods collected and to be delivered. Second, a VRP with uncertain pickup and deterministic delivery (VRPUPDD) is specified. The strategies are developed to cope with the uncertainty in pickup demand. Third, a coefficient is used to estimate the uncertain pickup demands, and the estimated demands are then used to schedule *a priori* routes for an instance of the VRPSPD. The *a priori* routes dynamically and selectively meet the realized pickup demands at customers. Fourth, a new control parameter (load ratio) and a routing strategy are developed for the simulation. The load ratio is used to control the limit when deciding to load or not load a pickup demand. The demand of a customer for pickup may not be met by a vehicle on the *a priori* route if the load ratio exceeds the load ratio control parameter after this customer is met; the *a priori* routes may be adjusted to solve a VRP with divisible pickup and delivery (VRPDPD) when the uncertain pickup demand is known. The unmet pickup demands as a whole are then met by the dynamic recourse pickup routes, which are determined by solving a CVRP. This strategy differs from static recourse strategies (Ukkusuri and Patil, 2009; Chen and Miller-Hooks, 2012).

The rest of this paper is organized as follows: Section 2 presents routing problems and variable neighborhood search (VNS) as a method of solving them. Section 3 formulates the problem. Section 4 presents a solution strategy and the details of related procedures. Section 5 elucidates a typical case of incompatibility. Section 6 discusses the computational results of a series of experimental scenarios. Section 7 draws conclusions.

2. Related work

2.1. Incompatible goods in closed-loop logistics

Few studies have addressed incompatibility among transported goods in closed-loop logistics, and especially with respect to the pickup and delivery routing problems. Two streams of research relate to this issue. First, in relation to closed-loop supply chains, reverse logistics, and simultaneous pickup and delivery, the transportation cost is generally a critical objective to be minimized (Dethloff, 2001; Pishvaee et al., 2010; Baldacci et al., 2011), but the incompatibility among delivered and collected goods is seldom addressed. Second, incompatibility among goods is considered in hazardous material management (Winder and Zarei, 2000; Hamdi-Dhaoui et al., 2012; Wang, 2012; Murèa and Demichelab, 2013) but rarely in transportation. The problems of bottle and package forward and reverse logistics that were considered by González-Torre et al. (2004) are strongly related to this work. When the bottles and packages are used to contain food, these problems arise as used bottles and packages contaminate clean ones when they are stored or transported within the same containers. The incompatibility may affect the service perceptions by the consumers. Although direct evidences are not seen in literature, empirical studies can be conducted to examine these types of attitudes to services (Psarros et al., 2011).

2.2. Routing with pickup and delivery

A few studies have considered VRPSPD with uncertain pickup demand and complex relations (e.g., incompatibility) between the picked-up and delivered goods. Related works are categorized below as concerning VRPSPD or VRPDPD, each with uncertainties. The demand or traveling time uncertainties involved in VRP can be alleviated short-term forecasting methods and technologies (Karlaftis and Vlahogianni, 2009; Vlahogianni et al., 2014).

The VRPSPD involves identifying a set of routes such that each route begins and ends at a depot; each customer is visited exactly once by one vehicle; the total vehicle load in any road in the route does not exceed its capacity, and the total routing cost is minimized (Montané and Galvão, 2006). As a critical constraint of the VRPSPD, the pickup and delivery activities must be performed simultaneously by the same vehicle. Min (1989) introduced the VRPSPD. Dethloff (2001) mathematically