Transportation Research Part E 46 (2010) 1071–1085

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Task selection and routing problems in collaborative truckload transportation

Ran Liu, Zhibin Jiang *, Xiao Liu, Feng Chen

Department of Industrial Engineering and Logistics Management, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China

ARTICLE INFO

Article history:
Received 29 August 2009
Received in revised form 8 December 2009
Accepted 18 March 2010

Keywords:
Collaborative transportation
Full truckload
Task selection
Routing
Memetic algorithm

ABSTRACT

This paper introduces the task selection and routing problem in collaborative transportation in which a truckload carrier receives tasks from shippers and other partners and makes a selection between a private vehicle and an external carrier to serve each task. The objective is to minimize the variable and fixed costs for operating the private fleet plus the total costs charged by the external carrier. The mathematical formulation and the lower bound are established. A memetic algorithm is developed to solve the problem. The computational results show that the proposed algorithm is effective and efficient.

1. Introduction

Nowadays, in the trucking industry more and more carriers adopt a new transportation model called collaborative transportation (CT) to improve logistics performance, reduce system-wide inefficiencies and cut down operational costs. In the CT, many collaborative carriers use practices such as group purchasing and capacity and information sharing to increase each partner's profit (Ergun et al. 2007a,b; Agarwal et al., 2009; Liu et al., 2010). For example, transportation tasks are exchanged among various carriers instead of each carrier only using internal vehicle to serve his own tasks. In such situations, a carrier may receive two types of transportation tasks, with one given by shippers, while the other by external carriers. Each first type task (i.e., given by shippers) must be served by one of vehicles of the internal fleet or by an external collaborative carrier. When it is assigned to a collaborative carrier, a penalty cost is incurred which represents all costs associated with this assignment. For each second type task (i.e., given by external partners), the carrier can accept or reject it. Similarly, when an external carrier's task is accepted and served by a vehicle of the private fleet, a compensative payment is given by the external carrier. Thus, a carrier' manager has to decide which tasks are selected to be served by private fleet and to route the internal vehicles. Meanwhile, we find that in most practical CT applications, the carriers are required to move goods between specified pairs of nodes with full truckload, i.e., picking up the goods at one node and delivering the goods at the destination. Therefore, we assume that each carrier provides only full truckload transport in this study. The problem can thus be called the task selection and routing problem with full truckload. In this paper, we address this special optimization problem. The objective is to develop a heuristic algorithm to make a selection of tasks and to route the private vehicles by minimizing a total cost function.

* Corresponding author. Address: Department of Industrial Engineering and Logistics Management, School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dong Chuan Rd., 200240 Shanghai, PR China. Tel./fax: +86 21 34206065.
E-mail address: zbjiang@sjtu.edu.cn (Z. Jiang).

1366-5545/$ - see front matter
doi:10.1016/j.tre.2010.05.003

Although the task selection and routing problem with full truckload is practical and important in the CT, the problem has not been previously studied in the literature. The closely related reference we are aware of is on a VRP with private fleet and common carrier (VRPPC) introduced by Chu (2005), who modeled the problem and solved it through a savings-based heuristic, followed by intra-route and inter-route exchanges. Bolduc et al. (2007) proposed a simple heuristic and generated better results. Bolduc et al. (2008) presented two formulations for the VRPPC, showing that the VRPPC could be formulated as a heterogeneous vehicle routing problem. Meanwhile, they developed a powerful metaheuristic for the VRPPC, which used a perturbation procedure in the construction and improvement phases, and performed a streamlined family of edge exchanges. Experiments results indicated that the proposed algorithm dominated two previous methods. Recently, Côté and Potvin (2009) described a tabu search algorithm for the VRPPC, whose numerical experimental results showed that the tabu search performed well on a set of benchmark instances.

The VRPPC studied in these papers differs from our setting with respect to two main issues. First, in the VRPPC the carrier allocates part of customers to the external carrier, and does not receive outside carriers' tasks. Second, in the VRPPC the carrier serves node-customers, and thus the problem is formulated as a variant of the node routing problem. In this paper, we assume that the carriers are required to move goods between specified pairs of nodes with full truckload. The corresponding problem should be formulated as a variant of the Arc Routing Problem (ARP).

The task selection and routing problem with full truckload is NP-hard since it reduces to the rural postman problem (RPP), another NP-hard problem (Lenstra and Rinnooy Kan, 1976), when all the tasks are served by a private vehicle. Many exact algorithms (Christofides et al., 1986; Corberán and Sanchis, 1994; Letchford and Eglese, 1998; Ghiani and Laporte, 2000) and heuristics (Frederickson, 1979; Pearn and Wu, 1995; Fernández de Córdoba et al., 1998; Corberán et al., 2000; Ghiani et al., 2006; Holmberg, 2010) have been proposed for the RPP and its variations. Although these algorithms have been designed for the RPP, they cannot be applied directly for our problem because of two major differences between the problems. First, in the RPP all the tasks (required arcs or edges) must be served by private vehicle, while in our problem we have to decide which tasks are to be entrusted to external carriers, and which tasks from them will be accepted or rejected. Meanwhile, the RPP is a single-vehicle version of our problem, and it only can be considered as a particular case of our problem.

This paper presents a new heuristic algorithm, based on memetic algorithm (MA), for the solution of the task selection and routing problem with full truckload. MA has been proved to be a successful technique for the solution of related problems such as CVRP (Prins, 2004) and CARP (Lacomme et al., 2004). The proposed algorithm was tested on a range of randomly generated instances and showed being able to tackle practical large-scale problem instances with up to hundreds of transportation tasks.

The rest of this paper is organized as follows. In Section 2, the problem is defined and transformed into an equivalent node routing problem, followed by the resulting mathematical formulation presented in Section 3. Section 4 analyses the lower bound for the problem. Section 5 describes the MA algorithm that was used to solve the problem. Section 6 presents the results from the computational testing of randomly generated problem instances. Section 7 presents our conclusions and future work.

2. Problem definition and transformation

The task selection and routing problem with full truckload is defined as follows. Let $G = (V, A)$ be a directed Euclidean graph, where $V = 0 \cup N$ is the vertex set and A is the arc set. Vertex 0 represents the depot, and the other vertices are the start-points and end-points of the arcs. Each arc $a \in A$ has a non-negative travel distance l_a. Two subsets $A_{.1} \subset A$ and $A_{.2} \subset A$ are two types of tasks needed to be served. Each arc $(i, j) \in A_{.1}$, $i, j \in N$ represents a task given by shippers, i.e., loading the goods at node i, traveling to node j directly and delivering the goods, which is characterized by a penalty cost g_{ij} when it is assigned to an external carrier. Each arc $(i, j) \in A_{.2}$, $i, j \in N$ represents a task outsourced by other carrier, which is characterized by a compensative payment e_{ij} when it is served by the private vehicle. A fleet of identical private vehicles, initially located at the depot, is available to serve the tasks. Each vehicle has a maximal distance span H, and an operating cost, i.e., fixed costs plus variable costs. Suppose a fixed cost f is incurred each time when a vehicle is used, and the vehicle variable costs are equivalent to its travel distance. Each private vehicle starts from the depot, serves many tasks and return to the depot. The objective of the task selection and routing problem with full truckload is to serve all required arcs (tasks) at minimal total cost, i.e., the sum of fixed vehicle costs, variable costs, penalty costs and subtracting compensative payments.

The proposed approach is based on transforming the original problem in graph G into an equivalent node routing problem in graph $G' = (V', A')$. This type of transformation is of interest since it permits to use state-of-art models and algorithms for the VRP to solve the ARP (Baldacci and Maniezzo, 2006; Longo et al., 2006; Tagmouti et al., 2007). In our case, the detailed transformation is the following. First, each arc $a \in A_{.1} \cup A_{.2}$ corresponds to a node a' in graph G' with a travel distance l_a. Each pair of node $(i, j) \in G'$ is connected by an arc $(i, j) \in A'$ with travel distance c_{ij}. The value of c_{ij} is calculated in graph G, equaling the distance from the end node of the first required arc to the start node of the second required arc and includes the second required arc. Let set N' stands for all the nodes in graph G'. Then, the depot node d' is added into graph G'. Let set $V' = d'_{.} \cup N'$ represents all the nodes in G'. The distance from the depot d' to node $a' \in N'$ equals the distance from the depot to the start node of required arc in graph G, and plus the distance of the required arc. The distance from node $a' \in N'$ to d' is equivalent to the distance from the end node of required arc to the depot node in graph G. Finally, each node $a \in N'$ in graph G' is associated with a pair of cost (e_a, g_a), where e_a and g_a are the compensative payment and the penalty cost of node a, respectively. If node