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Innovative Applications of O.R.

Transportation planning in freight forwarding companies Tabu search algorithm for the integrated operational transportation planning problem

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A B S T R A C T

The integrated operational transportation planning problem extends the traditional vehicle routing and scheduling problem by the possibility of outsourcing a part of the requests by involving subcontractors. The purpose of this paper is to present the integrated planning problem and to propose an approach for solving it by a tabu search heuristic. Existing approaches from literature which discuss vehicle routing combined with outsourcing regard only one specific type of subcontracting. This paper describes and explores the complex situation where an own fleet and several types of subcontracting are used for request fulfillment. As the approach contains new aspects, unknown to the literature so far, tabu search is extended to special types of moves. On the basis of computational results the cost structure is analyzed in order to investigate the long-term planning question whether and to what extend it is profitable to maintain an own fleet.

1. Introduction

External procurement, also known as vertical division of work, means that a company purchases some items, such as vendor parts or services, from a third party (Grochla, 1980). However, the decision is not reduced to 'either-or' in the sense of 'make-or-buy' for each article or service within an isolated comparison by predetermined criteria. Instead, the traditional 'make-or-buy' decision evolves into a reference analysis among the items involved (Wellenhofer-Klein, 1999). A major impact of such an analysis is noticed in the level and the structure of costs in the outsourcing enterprise (Zäpfel, 2000).

In particular, the 'make-or-buy' decision also applies to the transportation branch. Most freight forwarding companies reduce the capacity of their own vehicle fleet far under the varying total demand limit. Additional outside carriers are involved in order to gain enough transportation resources for covering the demand. In effect, freight forwarding enterprises have to plan the fulfillment of their requests not merely by routing and scheduling their own fleet but also by selecting transportation tasks to be sourced out by entrusting external independent freight carriers with their execution. Using own vehicles for the execution of tasks is called self-fulfillment, while involving an external carrier is called subcontraction. Together with engaging an external carrier, the rules of payment for its service (type of subcontraction) are defined. The problem investigated in this paper consists in constructing a fulfillment plan with the lowest fulfillment costs, assuming a fixed limited size of the own fleet and predefined types of subcontraction. This problem is called the integrated transportation planning problem (ITPP).

In this paper the ITPP, supported by a practical analysis is presented and a tabu search algorithm for problem solving is proposed. The problem has been tested for several sizes of the own fleet, in order to investigate long-term questions concerning the available vehicle capacity. Section 2 outlines the practical motivation for the problem. Section 3 briefly presents existing approaches to the problem. Section 4 introduces our approach to the problem and presents a mathematical model for the problem followed by the solution methodology in Section 5 and computational results in Section 6. Section 7 gives conclusions and recommendations for future research.

2. Operational planning in a freight forwarding company

We have analyzed a medium-sized freight forwarding company using its own vehicles and external subcontractors for its operations in several regions of Germany. The forwarding company receives less-than-truckload shipments from its clients. The analysis has shown that only about 30% of the requests are fulfilled by the company's own fleet (Kopfer et al., 2006). Apart from the usage of the own fleet the company hires subcontractors on a long-term basis and forwards remaining requests to independent

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external carriers. The planning decisions are made hierarchically by the schedulers who are only supported by planning software for the pure vehicle routing problem without subcontraction. The manual planning process is performed in the following way:

At first the most attractive requests are assigned to the own vehicles. The attractiveness of a request is estimated on the basis of its proportionate profit contribution. For the own vehicles, stationed in one depot, round routes are constructed, which contain pickup and delivery locations of the requests. The costs of the own fleet consist of two blocks: variable costs and fixed costs. The variable costs depend on the tour length. They are calculated on the basis of a constant cost rate per travel unit. Fixed costs contain amongst others amortization costs, taxes, and the payment for drivers. These costs are outstanding (Fig. 1a), while the marginal variable costs for a request are considerably low. Thus, it is aimed to utilize the own fleet to a maximal extent.

Next, the requests which are not planned to be performed by self-fulfillment are forwarded to subcontractors. There are subcontractors which are frequently engaged by the forwarder and are nearly exclusively employed by him. Clusters of requests, which build complete tours can be shifted to these subcontractors. Consequently, the exclusively employed subcontractors receive full-truckload shipments from the forwarder. The set of exclusively employed subcontractors is split into two groups with different types of subcontraction. For the first group the payment for a tour with a full-truckload shipment is calculated on tour basis using an agreed tariff rate per travel unit and the length of the transferred tour. The tariff rate per travel unit is higher than the corresponding cost rate of an own vehicle as it covers a part of the fixed costs of the subcontractor (Fig. 1b). For the forwarder, there are no fixed costs connected with the shifting of tours. The advantage of this type of subcontraction is that costs only arise when a vehicle is really used, and that the costs are proportional to the amount of its utilization.

The second type of subcontraction is applied for the second group of exclusively employed subcontractors. It consists in paying freight carriers on a daily basis. In this case an external carrier can be occupied up to an agreed limit for travel distance and time. He gets a daily flat rate and has to fulfill all the received requests of a transferred tour. The costs for the forwarder are constant irrespectively to the amount of vehicle utilization (Fig. 1c) and they only arise if a vehicle of the subcontractor is used at all. The related costs are relatively high, therefore, the break-even point cannot be reached unless the daily limit is actually utilized. In practice, this subcontraction type is used to execute requests which do not fit into efficient vehicle routes or run into directions where no favorable clustering is possible.

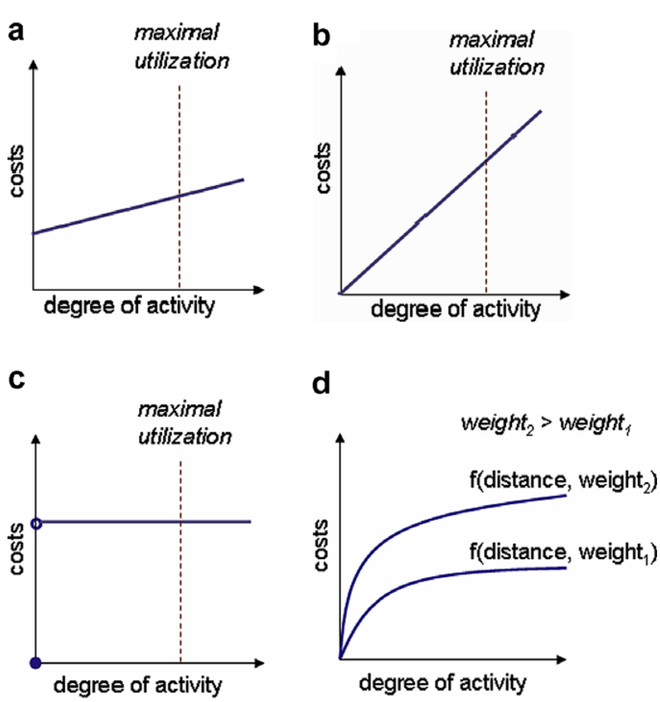

Fig. 1. Fulfillment costs for: (a) a vehicle from own fleet, (b) a vehicle from subcontractor paid on tour basis, (c) a vehicle from subcontractor paid on daily basis and (d) requests forwarded to an independent carrier.

The third type of subcontraction is applied for independent subcontractors which are not employed exclusively. This type of subcontraction is called freight consolidation. For freight consolidation the amount of payment depends on the service of the external carrier and not on the usage of its resources. This is appropriate for subcontractors who usually combine less-than-truckload shipments of different shippers to a single tour. Each shipper pays the subcontractor on the basis of the flow of cargo induced by his own requests and not on the basis of travel distance, because the length of the entire tour resulting from the requests of different shippers is not known to a single shipper. Such a freight calculation on the basis of freight flows had to be applied in Germany at the time of the state-controlled price regulation until 1994 and remains of highest practical relevance till now (Kopfer and Krajewska, 2007). Similar to vehicle routing, the costs for executing requests by means of freight consolidation are determined for each vehicle separately. This causes a grouping of requests which is analogous to the clustering of requests in vehicle routing. To make the difference between vehicle routing and freight consolidation more distinct, the subsets of requests for freight consolidation are called bundles instead of clusters. Instead of routes of a cluster, flows of a bundle are considered for freight calculation. As in vehicle routing, the entire transported loading must not exceed the vehicle capacity, because the requests of one bundle are intended to be transported by a single vehicle. Bundling reflects the cost savings which can be achieved by assigning several requests of one shipper to one vehicle of a carrier. A bundle of requests forwarded on the basis of freight consolidation usually yields a less-than-truckload shipment, but a large bundle may also constitute a full-truckload shipment. The flows of one bundle must ensure that the cargo of each request of this bundle gets from its source (pickup location) to its sink (delivery location). The flow of cargo of a single request can be diverted to locations of other requests of the same bundle and then be combined with them to joint flows on common arcs, while the cargo of each request must reach its sink by a suitable flow. Thus, for each request r_i there must exist a path $P_i(i^+, i^-)$ from the pickup location of r_i to the delivery location of r_i. The path P_i identifies the arcs which are used by the flow of goods of r_i on their way from the pickup to the delivery location. The flow on one single arc consists of the cargo of all requests whose path use that arc. Freight consolidation denotes the process of building bundles and constructing admissible flows for each bundle while the total freight has to be minimized. The calculation of the amount of the freight is performed on the basis of the flows on single arcs. For each arc between two locations the fee is computed in dependence of the length of the arc and the amount of goods flowing on this arc.

The total freight of a bundle of requests corresponds to the sum of the fee of all arcs which are needed to bring the cargo of the bundle from the source locations to the sink locations. In case of a simple Vehicle Routing Problem (VRP) (comp. e.g., Bräysy and Gendreau, 2005), minimizing the costs of a single bundle consists in finding a minimal spanning tree of the complete graph containing all nodes of the bundle. Spanning trees are the only admissible solutions, because the node of each customer must be connected to