European Journal of Operational Research 236 (2014) 863–878

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Many-to-many location-routing with inter-hub transport and multi-commodity pickup-and-delivery

Julia Rieck *, Carsten Ehrenberg, Jürgen Zimmermann

Clausthal University of Technology, Institute of Management and Economics, Operations Research Group, Julius-Albert-Str. 2, 38678 Clausthal-Zellerfeld, Germany

ARTICLE INFO

Article history:
Available online 21 December 2013

Keywords:
Location-routing
Inter-hub transport
Multi-commodity pickup-and-delivery
Mixed-integer linear programming
Fix-and-optimize
Genetic algorithm

ABSTRACT

In this paper, we consider a variant of the many-to-many location-routing problem, where hub facilities have to be located and customers with either pickup or delivery demands have to be combined in vehicle routes. In addition, several commodities and inter-hub transport processes are taken into account. A practical application of the problem can be found in the timber-trade industry, where companies provide their services using hub-and-spoke networks. We present a mixed-integer linear model for the problem and use CPLEX 12.4 to solve small-scale instances. Furthermore, a multi-start procedure based on a fix-and-optimize scheme and a genetic algorithm are introduced that efficiently construct promising solutions for medium- and large-scale instances. A computational performance analysis shows that the presented methods are suitable for practical application.

1. Introduction

Trading, industrial, and commercial service companies, as well as logistic service providers operate in *transport networks* that connect supply and delivery points. Particularly, when a company is launched, or decides to expand its operations, the *efficient design* of a transport network is an important key factor for business success. In order to configure a network such that all transport needs may be satisfied at the lowest transportation costs, companies usually decide to route shipments through a *hub-and-spoke system*. Instead of driving with partially loaded vehicles from supply to delivery points, full vehicles are sent to central transhipment facilities (hubs), where shipments are sorted and consolidated for further transport. In particular, strategic network design decisions comprise the determination of the numbers and locations of hub facilities, as well as the allocation of supply and delivery points to one or more hubs in order to specify possible transportation paths between pairs of origins and destinations (location-allocation problem). Once facilities are located, routes have to be planned for vehicles moving within the network (vehicle routing problem).

Location-allocation problems typically consider the positioning of facilities while taking into account serving customer locations on a straight-line trip between facility and customer. However, the assumption of direct transports rather than vehicle routes leads to less realistic transportation cost estimations. In order to compensate for that shortcoming, *location-routing problems* consist of determining the location of facilities and defining the routes for vehicles such that customer demands are satisfied, vehicle capacities are not exceeded, and the minimization of facility fixed and operating costs, as well as of routing costs is realized.

Location-routing problems (LRPs) usually occur in practice when customer locations are known in advance and therefore stable vehicle routes can be constructed. For example, Or and Pierskalla (1979) presented a study focusing on regionalization of blood banking systems. Jacobsen and Madsen (1980) considered a newspaper printing and distribution system in Denmark. Nambiar, Gelders, and Van Wassenhove (1989) investigated the problem of locating central rubber processing factories to process smallholder's rubber, collected daily from a number of stations in Malaysia. Kulcar (1996) considered a project dealing with waste collection management, and Wasner and Zäpfel (2004) developed an optimal network structure for an Austrian parcel delivery service.

Various classification schemes have been presented for LRPs, where the differentiation is generally based on hierarchical levels, nature of demand or supply, number of facilities or vehicles, facility layers, and objectives (cf. e.g., Laporte, 1988; Min, Jayaraman, & Srivastava, 1998; Nagy & Salhi, 2007). In this paper, we consider a three layer network configuration consisting of supply and delivery points on the one hand and hub facilities to be located on the other hand. Supply and delivery points are situated at known locations and each point has a given demand that must be picked up or delivered (deterministic data). For hub facilities a set of potential locations is given. In order to meet the long-term characteristic

* Corresponding author. Tel.: +49 5323 727647.
E-mail addresses: julia.rieck@tu-clausthal.de (J. Rieck), carsten.ehrenberg@tu-clausthal.de (C. Ehrenberg), juergen.zimmermann@tu-clausthal.de (J. Zimmermann).

0377-2217/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2013.12.021

of the location problem, we study one aggregate, representative planning period (static problem). To cope with the lack of reliable information on how conditions might change in future, as well as to allow decision-makers to explore the consequences of their decisions, appropriate scenarios are designed, where cost and demand variations are considered.

In Section 2, we describe the underlying location-routing problem and a possible application area. Since the problem contains problem components known from the literature that have not been considered in combination before, related literature is presented. In Section 3, we introduce a mixed-integer linear model for the problem. In order to strengthen the according formulation, Section 4 describes valid inequalities that may be added within the optimization process. Sections 5 and 6 are devoted to a multi-start procedure and a genetic algorithm that efficiently construct near-optimal solutions. The results of extensive computational experiments, where instances with problem-specific structural characteristics are considered, are given in Section 7. Finally, conclusions are presented in Section 8.

2. Problem description and related research

The location-routing problem under consideration is derived from a real-world application in the *timber-trade industry*. In order to exemplify the problem, a possible network configuration including routing decisions is depicted in Fig. 1 using a layer diagram (cf. Laporte, 1988) with three layers. The layers are identified as supply points (layer 1), potential hubs (layer 2), and delivery points (layer 3), i.e., a many-to-many network structure is considered. Starting from an established hub (here h_1, h_2, or h_3), vehicles perform pickup and delivery routes visiting each supply and delivery point precisely once. Routes may be pure pickup, pure delivery, or "mixed", where some pickup locations have to be visited before the first delivery location can be served. The consideration of mixed routes is of practical importance and saves costs if the products involve a lot of handling effort, pickup and delivery locations are close together, and pickup and delivery quantities can be aggregated to almost full truckloads. Section 7 contains computational results which show in detail the impact that allowing mixed routes has on the total network costs. Inter-hub routes, i.e., routes that go from one hub to another and back, are traversed in order to obtain synergy effects by consolidating products in full truckloads. Thereby, products with different origins and different destinations are transported together over the line-haul portion of the network.

We distinguish between several products (*commodities*). Consequently, each supply as well as each delivery point is associated with a vector containing either surpluses or deficits of the different products (multi-commodity pickup-and-delivery problem; cf. e.g., Hernández-Pérez & Salazar-González, 2009; Rodríguez-Martín & Salazar-González, 2011).

The many-to-many location-routing problem involves the following three interdependent subproblems:

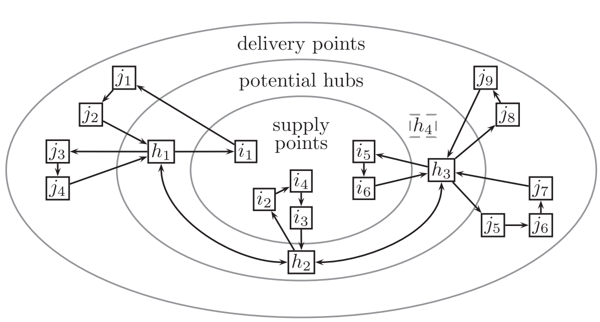

Fig. 1. Layer diagram with three layers.

(1) How many hub facilities are required and where should they be located?
(2) Is it beneficial to combine supply and/or delivery points to form vehicle routes, where every route starts and ends at an assigned hub?
(3) Which inter-hub routes must be established?

The overall network operating costs are composed of fixed costs for establishing and maintaining hub facilities, and variable costs for handling and transporting products on routes.

A practical application of the considered problem can be found in the timber-trade industry. A timber-trade company picks up wooden products (e.g., beams, pallets, door and window frames) from sawmills and wood-manufacturers (supply points), and serves a number of distributors or wood-processing businesses (delivery points). Supply points usually do not act as a full-range provider. Particularly, sawmills are specialized in processing different kinds of wood, e.g., spruce, maple, and pine, and wood-manufacturers are specialized in manufacturing wood for construction purposes, fences, or indoor equipment. The delivery points periodically require more or less the same mixture of products (e.g., ply wood, panels, and OSB-boards) for their production or retail activities. Hence, pickup and delivery locations and their product quantities can be assumed to be known in advance.

Nowadays, an increasing number of companies in the wood sector works in a *just-in-time environment*, and tries to avoid extensive stock holding (cf. e.g., Klassen, 2000; Madzanai, 2012). Therefore, aggregating product amounts over time and then performing full truckloads from one origin to one destination is not required. Consequently, timber-trade companies aggregate products within the network and provide their pickup and delivery services using hub-and-spoke systems. Employing this network structure, economies of scale and scope can be realized by consolidating freight through one or more hubs.

Since material handling at hub facilities is especially difficult for large-sized, heavy, and non-standardized wooden products, the number of intermediate hubs on a transportation path is typically limited to no more than two. Hence, inter-hub vehicles perform replenishment routes, where products are carried from one hub (e.g., hub h_1 in Fig. 1) to another hub (e.g., hub h_2) and other products are transported from h_2 to h_1. However, routing all freight through a hub is not always the best option. If vehicles are fully loaded with all products required by one or a few adjacent destinations, direct transports between supply and delivery points can lead to cost efficiency. In practice, delivery points place recurrent orders in small quantities. High capacity utilizations may then be achieved by aggregating pickup and delivery activities. As several organizational aspects (e.g., driver-vehicle combinations, equipment assignments) have to be considered, routes start and end at an assigned hub location. Wooden products differ in size, quality, weight, or handling requirements, and therefore the consideration of one homogenous good is not acceptable. In order to take different product characteristics into account, we specify several product classes in accordance with their distinctive features. The determination of different commodities lasts to offer enough flexibility for a detailed planning on the operational level in which fixed pickup and delivery pairs have to be considered. For each commodity, the quantities of products are measured in abstract transport units which may, for example, be calculated from the dimensions of an individual product.

To sum up, the problem under consideration typically occurs, when transport networks for companies who handle large, non-standardized products (e.g., timber, glass, or steal) have to be designed. The problem involves dealing with subproblems (1)–(3) and may be identified as an extension of the well-known location-routing problem. In addition, a many-to-many network