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Single allocation *p*-hub median location and routing problem with simultaneous pick-up and delivery

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ABSTRACT

We introduce the single allocation *p*-hub median location and routing problem with simultaneous pick-up and delivery based on observations from real life hub networks. The aim of our problem is to minimize the cost of transferring the flow between hubs and routing the flow in the network. We propose several mixed integer programming formulations and two heuristic approaches based on multi start simulated annealing and ant colony system to solve these problems. Extensive results demonstrate that using our methods good solutions can be found despite the computationally challenging nature of the problem.

1. Introduction

In various many-to-many distribution networks, including airlines, cargo/postal delivery services, and telecommunication networks, hub facilities serve as sorting, transshipment and consolidation points. The aim of a hub location problem is to find the location of the hubs and allocation of the non-hub nodes to the hubs in order to minimize costs. It is generally assumed that there are economies of scale due to the accumulation of large amounts of flow at the hub facilities. This economy of scale is approximated using a constant discount rate for the travel costs between every hub pair.

Hub location problems can be categorized in terms of the objective functions of the mathematical models. In the literature, hub location problems with total transportation cost objectives (median), min-max type objectives (center), and covering type objectives have been well studied Alumur et al. (2012). The interested reader is referred to the reviews by Campbell (1994), Alumur and Kara (2008), and Campbell and O'Kelly (2012).

Although the basic structure of the flow movement is the same in hub location problems, each application network has its different requirements and specifications. In this study, we focus on the operational characteristics of a leading cargo company in Turkey. Through interviews with this company, it was determined that the cargo firms' main objective is to satisfy customers. To guarantee customer satisfaction in this sector, companies have started to pay more attention to service levels. Recently, cargo companies have started to offer "delivery within the same day in the city," "next day delivery," or "delivery within 24 h" guarantees to their customers in Turkey. "Next day delivery" or "delivery within 24 h" has been a target for a long time for the cargo companies operating in Turkey. For this purpose, cargo companies have investigated the costs and advantages of using airlines in their hub networks Alumur et al. (2012). Apart from that, the "delivery within the same day in the city" service offer is a fairly recent application for cargo companies. In particular, one of the leading cargo companies has started offering this service to its customers. Therefore, this company has started to investigate a cost-minimizing hub location and routing network structure in Istanbul. We note

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here that this service is usually preferred by companies that dispatch products to their dealers within the same day, such as banks that forward documents across their branch offices.

Motivated by the "delivery within the same day in the city" application, we extend the uncapacitated single allocation p-hub median problem to include vehicle routing with simultaneous pick-up and delivery. Although we explain the operating characteristics of the motivating example in the following, our aim with this paper is not to focus on this particular application and it will not consider all of the idiosyncrasies of this company. Instead we are interested in extensions of the existing model and formulations, how solution algorithms scale, and the structure of the solutions obtained when allowing vehicle routing with simultaneous pick-up and delivery.

To explain the operating structure of the service network in detail, consider that there are two types of nodes in the *same city*: branch offices (*non-hub nodes*) and operation centers (*hubs*). Initial contact with the customers is made at the branch offices, where parcels are picked-up from the customers. The branch offices also act as delivery points, where parcels are given to the consignees. Operation centers are major sorting centers where incoming parcels are collected and rerouted to their destinations. In such networks, each branch office is customarily allocated to a single operation center, mainly owing to ease of management (Serper and Alumur, 2016). In the "delivery within the same day in the city" application, the company accepts the parcels at the branch offices no later than 11 a.m. in order to distribute them by 6 p.m. on the same day. We note here that this service is available only for documents and small packages. After all the parcels are collected at the branch offices, each vehicle starts its first route from its respective operation center, travels across the branch offices while picking-up and delivering the flows at each branch office along the route, and returns back to the same operation center. The parcels that will be sent to the other branch offices start their journey from the first operation center to the final operation center. At the final operation center, each vehicle performs its second route *just* by delivering the flows at each branch office that originated from branch offices that belong to different vehicle routes, and the route ends when the vehicle returns back to the operation center. In their second route, vehicles only perform delivery because the flows that originated at each branch office were already collected in the first route.

With these considerations, the problem we consider in this paper is to design a hub location-routing network. We refer to this as the single allocation p-hub median location and routing problem with simultaneous pick-up and delivery, denoted by pHMLRP-SPD throughout this paper. It includes locating p hubs, assigning each non-hub node to exactly one hub and forming the vehicle routes. In our problem branch offices are modelled as nodes, also called demand centres, some of which may be selected as operation centers (hubs). Since a single allocation scheme is adopted, each non-hub node must be served by exactly one vehicle.

We assume that the hubs and vehicles (in the hub network and routes) are uncapacitated. Although vehicle capacity constraints can be easily incorporated into our models, because this service is only available for documents and small packages, it is assumed that the capacity of any vehicle is sufficient to transfer the traffic flows. We also assume that the number of vehicles based at each hub is fixed and limited. The fixed costs of using links and vehicles that might depend on traversed distance and driver costs, respectively, are not considered in our formulation. However, these features could easily be incorporated into our models, if required.

Traditionally in the p-hub median problem, it is assumed that one vehicle is available between each demand center and hub. Especially if a cargo company employs a hub location network in big cities, such an approach results in higher transportation costs as well as traffic congestion, because it forces the use of separate vehicles. By allowing vehicle routes we allow companies to determine the best network design for a fixed investment budget specified in terms of the number of hubs and vehicles to be used.

Our primary concern with this study is to propose effective models for the p-hub median location and routing problem based on well-known modeling ideas with three-index (Ernst and Krishnamoorthy, 1996) and four-index variables (Campbell, 1994) from the hub location literature, which can be essentially simple but give a strong basis for easy extension to other constraints; these include hub/vehicle capacity and/or time/distance constraints. Moreover, we intend this paper to contribute to the hub location and routing literature by following as closely as possible the "radial", i.e., single/multiple allocation p-hub median model, to what degree ideas and solution algorithms from this extensive part of the literature can be extended to a case where the access network involves vehicle routes.

In most of the studies in the hub location and routing problem literature, the majority of the papers focus on minimizing total transportation costs (e.g. Rieck et al., 2014; Karimi and Setak, 2014). These costs generally include the total costs of establishing hubs and allocating demand centers to hubs, and the cost of flow through the network. However, the routing costs for a vehicle that starts and ends at the same hub are calculated only as a function of distance Cetiner et al. (2010) or a function of total demand plus total supply for a node Camargo et al. (2013). Even though the proposed models are realistic representations of the hub location and routing problem concerning the specific applications, none of them consider the costs as a function of distance traversed and the flow. Recognizing such a need for a real-life application, in this paper, we propose a more consistent objective function, in which the transportation costs in all parts of the network, both between hubs and between non-hub nodes, is proportional to both the distance and the amount of flow volume carried through the links.

The structure of our problem is illustrated by Fig. 1, which shows a hub location-routing solution for a network with three hubs and seven vehicles in total.

In airline companies, if separate aircraft and separate air staff are assigned to each flight, they incur high investment and operating costs. For passenger airlines, the number of legs is a significant factor as travelers prefer shorter, more direct flights. However, for star access networks traffic congestion occurs at the hub airports. Hence, many parcel delivery companies that use air transport do not connect every demand node directly to a hub (Bowen, 2012).

This problem may also appear frequently in railway and maritime transportation applications. Furthermore, similar networks are used in the military logistics sector where personnel and equipment are picked-up and delivered simultaneously at each regional center.