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Opposition-based learning for competitive hub location: A bi-objective biogeography-based optimization algorithm

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ABSTRACT

This paper introduces a new hub-and-center transportation network problem for a new company competing against an operating company. The new company intends to locate p hubs and assign the center nodes to the located hubs in order to form origin–destination pairs. It desires not only to maximize the total captured flow in the market but also aims to minimize the total transportation cost. Three competition rules are established between the companies which must be abided. According to the competition rules, the new company can capture the full percentage of the traffic in each origin-destination pair if its transportation cost for each route is significantly less than of the competitor. If its transportation cost for each route is not significantly less than one of the competitors, only a certain percentage of the traffic can be captured. A bi-objective optimization model is proposed for the hub location problem on hand under a competitive environment. As the problem is shown to be NP-hard, a novel meta-heuristic algorithm called multi-objective biogeography-based optimization is developed. As there is no benchmark in the literature, a popular non-dominated sorting algorithm is utilized to validate the results obtained. Moreover, to enhance the performance of the proposed Pareto-based algorithms, this paper intends to develop a binary opposition-based learning as a diversity mechanism for both algorithms. The algorithms are tuned to solve the problem, based on which their performances are compared, ranked, and analyzed statistically. Finally, the applicability of the proposed approach and the solution methodologies are demonstrated in three steps.

1. Introduction

The hub-and-spoke networks, otherwise known as the hub-and-center, have been widely used in various industrial applications. These networks provide services through a specified set of hub nodes in telecommunications, postal delivery systems, emergency services, computer networks, transportation systems, etc. The hub-and-center network is a fully connected network with material/information flow between any two nodes being processed at a small number of hub nodes and moved through inter-hub links. In other words, instead of establishing direct links between two nodes, the hubs serve as transshipment or switching points for the flows between origin and destination center nodes (non-hub nodes). Flows departing from an origin node are collected in a hub or transferred between hubs if necessary, and then distributed to a destination node by combining flows [1]. As the hubs consolidate and collect the flows, due to the economies of scale concept, a significantly less operating cost can be achieved. Additionally, the origins and destinations are connected with fewer links and therefore the consequential smaller transportation rates reduce the total transportation cost [1].

In the real world, hub locations and allocating center nodes (i.e. *spokes*) for hubs are among the most important issues in hub-and-center network problems. That is why the hub location problem (HLP) has received an extensive attention from researchers and practitioners. For instance, Lin and Chen [2] studied the integration of Taiwanese and Chinese air networks for direct air cargo services in a pure hub-and-spoke network. Moreover, an instance of the hub airport location between 37 cities taken from the Iranian aviation dataset (IAD) is displayed in Fig. 1, in which Tehran and Kerman are active airports acting as the hubs [3].

The work of O'Kelly and Bryan [4] was pioneering in HLP. They applied the economies of scale on trunk lines in an uncapacitated network. Ebery et al. [5] studied several formulations and solution approaches based on the shortest path, for a capacitated HLP. This study was extended by Ebery [6] for two and three hubs. The inte-

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Fig. 1. An instance of a hub-and-center network in Iranian aviation dataset.

gration of Taiwanese and Chinese air networks for direct air cargo services was investigated by Lin and Chen [2] in a pure hub-and-spoke network. Furthermore, Pérez et al. [7] proposed a GRASP path re-linking method to solve an HLP.

A bi-criteria approach in an HLP was described by Costa et al. [8]. They presented two models; the first minimizes the time for processing flows, whereas the second minimizes the maximum service time at the hubs. Camargoa and Miranda [9] presented Bender's decomposition algorithms to solve a HLP. On the other hand, two genetic algorithms were designed by Kratica et al. [1] to solve an un-capacitated HLP problem. Contreras et al. [10] developed a Lagrangean relaxation method to obtain tight upper and lower bounds on the total cost in an HLP. An HLP with stochastic time and service-level constraints was proposed by Sim et al. [11] using mutually independent normal distributions. Ge et al. [12] developed a tree pruning algorithm for a capacitated HLP on the air transportation system using data on passenger flows between the top 20 Chinese cities. Stanimirović [13] proposed a genetic algorithm to solve an HLP in order to minimize the total transportation cost.

Yang et al. [14] studied an HLP with discrete random travel. In addition, Yaman and Elloumi [15] proposed a star HLP in two-level star networks with regard to service quality considerations in order to minimize the total routing costs. Rabbani et al. [16] described an HLP with a combined cost including fixed, health, safety, environmental, energy, and personnel costs. Two mixed-integer programming problems for a HLP were introduced by Yang et al. [17]. They solved the problem using an improved hybrid particle-swarm optimization algorithm by combining genetic operators and a local search. However, they did not account for the capacity restrictions of the hubs in this research. Furthermore, Bashiri et al. [18] proposed a hybrid approach for an HLP using both qualitative and quantitative parameters to minimize the longest travel time. They utilized the fuzzy VIKOR combined with a genetic algorithm to provide a hybrid solution. Interested readers are referred to Farahani et al. [19] for more details on the HLP.

1.1. Literature review on competitive HLP

The vast majority of existing research on HLP addresses the problem of optimally locating hubs for a single company that serves flows between origin and destination center nodes in a region. In many real-world instances, however, companies compete with each other in a specific region in order to capture more market share. In order to minimize transportation costs, companies have to decide on a set of locations to establish facilities for production, service provision, warehousing and so on. In a passenger transportation network, several companies compete in a geographic region to capture the maximum customer traffic, freight shippers, or individual travelers. In this regard, the market share may be measured in terms of the percentage of the passengers, freight, or profit captured. This problem has not yet been investigated in depth. In other words, although it may seem logical to assume an existing competitive environment in the HLP [20,21], the existing studies on HLP have not taken this factor into account in their networks.

The earliest work on the HLP in competitive environments goes back to Marianov et al. [22] who introduced a sequential competitive HLP. Their model located p hubs in order to maximize the flow capture for a company in a network with operating competitors in the market. Wagner [23] extended the hub location model presented by Marianov et al. [22] with optimal solutions for up to 50 nodes and 5 hubs. He assumed that allocating the customers between the two companies is based on the transportation costs. In other words, if the transportation cost of a company is lower than the one of the competitors for any path, then the company would fully capture its flow. In addition, Wagner [23] showed that the implementation of the heuristic approach proposed by Marianov et al. [22] was not correct. Lüer-Villagra and Marianov [24] presented a