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Facility and hub location model based on gravity rule

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ABSTRACT

This paper presents a model for "Domestic Facility and Hub Location" in transportation network. Number of hubs and facilities are unknown and the objective is to minimize the transportation cost, lost demand penalty and facility set up costs. Also the distribution of demand among domestic facilities and hubs adheres to gravity rule. To solve the problem, sequential and integrated approaches were undertaken. In the sequential approach, domestic facilities were allocated and hubs were selected afterwards. However the integrated approach deals with both concurrently, with a more sophisticated steps reaching to the solution. This is mainly because the demand itself is highly dependent to where the facilities are going to be located. Heuristic solutions were employed and was tested in a set of Turkish network and validated by CPLEX software in small cases.

1. Introduction and literature review

This paper presents a transportation model in which an unknown number of domestic facilities are selected and among some are depicted as hubs aiming to minimize transportation, lost demand penalty and facility set-up costs.

Fig. 1 depicts a transportation network which includes 11 nodes (circles) each representing a city having a number of travels between each of origin-destination pairs. Some nodes indicated with triangle is considered as locations in which domestic facilities are going to be built for serving the demands while nodes with square symbol functioning as the hubs. The dotted big circles show the sphere of influence. For example the left circle shows the sphere of influence of node 1 and the right circle is for node 4. It means that if there is no facility in the left or right circle, the flow from node 1 to node 4 is considered as a lost demand. In this figure, some routs just as examples are shown.

Assuming that domestic facilities in the system could be connected to every hub so a flow (passenger/freight) will have a choice to select his hubs and fly through to proceed his journey to destination facility. Also it is assumed that each customer will travel his route through only two hubs. Directing passengers/freight through a hub leads to a higher performance of the designed network, by using the consolidation/break bulk function that lets the flows (passenger or freight) to be aggregated and disaggregated (Campbell & O'Kelly, 2012). In our model, we assume that each flow should go through two hubs. As a brief explanation for this assumption, we can point out to the economy of scale that happens between two hubs in a network that can easily justify enrooting through two hubs, to achieve a lower transportation cost. it is noteworthy that if a flow (passenger/freight) starts from a hub, or ends to a hub, (s)he is already passing two hubs (by taking the direct path from his/her start point to the destination facility) and does not need to go through any extra point. In addition, it is obvious that our model is the general form, and can be easily modified to be a one hub model, considering both start and end hubs to be the same. This assumption has been considered in several articles in the literature due to Alumur and Kara (2008) (see for example: Abyazi-Sani and Ghanbari (2016), Gao and Qin (2016), and Kian and Kargar (2016)). As an example, a demand exists from node 1 to node 4. As there is no facility in each of these nodes; the demand should be transferred to other nodes in which domestic facilities exists and if the distances (between Starting Point to Origin Facility or Destination Facility to Final Destination) are far away, the demand is considered as "lost demand". The route 1–2–3–5–6–4 presents that the flow wishes to travel from Starting Point 1 to Final Destination 4, so from node 1 he moves to Origin Facility 2 and continuing the journey using hub 3 and 5. After that arriving at Destination Facility 6 and reaches to his Final Destination represented by node 4. In this paper we try to locate the facilities and hubs simultaneously aiming to minimize the imposed costs for travels. In this network, if a demand exists from starting point 2 to final destination 6, the route 2–3–5–6 implies that as the

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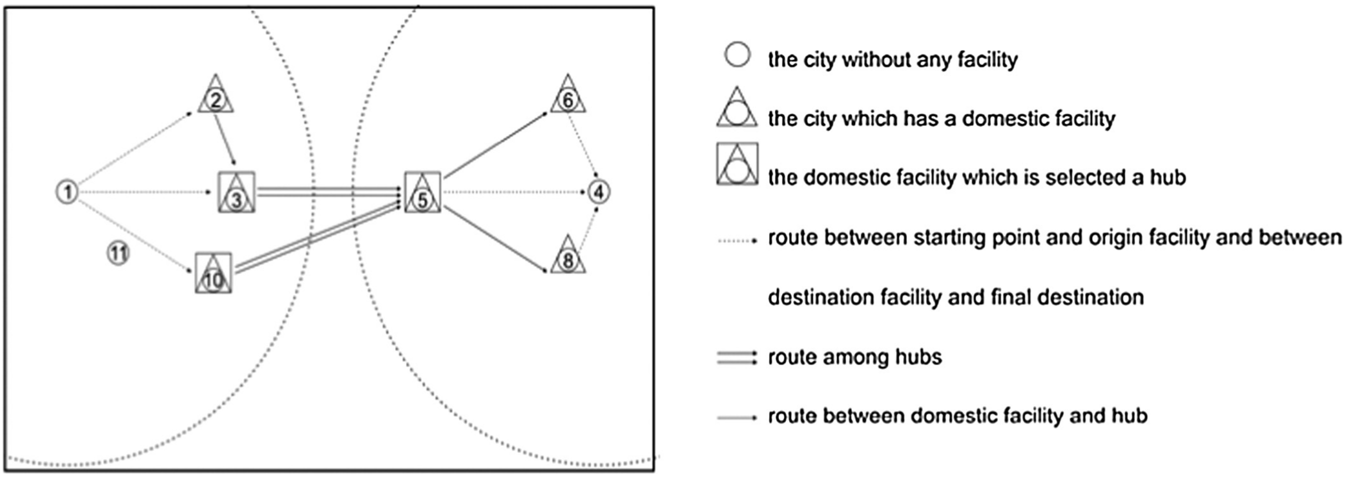

Fig. 1. The schematic representation of nodes in a transportation system.

starting point is finely equipped with facilities, one prefers to use it and after passing hubs 3 and 5 gets to node 6 as his final destination obviously equipped with proper facilities. A real example of this case is the network of domestic airports in a country. In real cases, transportation officials should select in which cities domestic facilities should be established and then which should play as hub nodes. So if a demand exists between two cities which they suffer not having airport facilities, the demand should be transferred to cities which they can support the service.

The first part of this problem is to find the location of domestic facilities similar to p-median problem, in which the effort is to minimize the set-up cost to establish the facilities and part of transportation cost for a flow from his starting point to origin facility and from destination facility to his final destination. The second part of problem, is to find the hub locations based on where the domestic facilities were located in aforementioned part.

Most probably the p-median is the most common location model. To review, please consider Mirchandani (1990) and Drezner and Hamacher (2004). The p-median model selects the p-node to install facilities for servicing a demand distributed in "n" nodes in such a way that the total travel time or distance is minimized. Hakimi (1964) found that the optimal outcome of p-median model will fall into network nodes.

Hub concept exists in many-to-many dispersal networks such as: Cargo, telecommunication, airline. The Hub problem deals with finding the optimal location of hubs and addressing the demand points into the proper one for routing the traffic between origin-destination. Hubs are considered as intermediate facilities to regulate the distribution in many-to-many systems and add value by reducing time and cost. There are two separate assumptions dealing with Hub location problem. (a) Flows should have a route via at least one Hub (b) The graphs among Hubs is a complete one and the cost of transportation between two hubs has a discount factor $(0 \leq \alpha \leq 1)$ (Contreras, Fernández, & Marín, 2009; Eiselt & Marianov, 2009; Silva & Cunha, 2009). O'Kelly and Miller (1994) introduced a problem which the graph among hubs is incomplete. In addition to the said research, Alumur, Kara, and Karasan (2009) defined incomplete version of Hub location problem such as p-Hub median Hub covering and p-Hub center.

In Hub location problem there exists two type of allocation (assignment); single and multiple. In the first one, each non-hub is allocated to A Hub (Contreras et al., 2009; Labbé & Yaman, 2004; Labbé, Yaman, & Gourdin, 2005) while in multiple there is no constraints for allocation to A Hub (Contreras, Cordeau, & Laporte, 2012; Hamacher, Labbé, Nickel, & Sonneborn, 2004; Marín, 2005; Mayer & Wagner, 2002; Nickel, Schöbel, & Sonneborn, 2001). Couple of researchers studied both type of allocation (Campbell, 1994; O'Kelly, Bryan, Skorin-Kapov, & Skorin-Kapov, 1996; Skorin-Kapov, Skorin-Kapov, & O'Kelly, 1996). In classical Hub location problems, the objective function is to minimize the total transportation cost and the fixed cost.

Also space for location of Hub nodes fall into continues or discrete. When continues space is considered, Hubs can be located any point in the region, but when discrete is studied, Hubs can be located as specific and defined points. Most of the time discrete region is considered however some researches were undertaken on continues style (Aykin & Brown, 1992; Campbell, 1990; O'Kelly, 1992). Also capacitated or un-capacitated classification is also addressed in previous literature. Along the above said, some advance problems were introduced among the said literature such as: Stochastic Hub Location (Contreras, Cordeau, & Laporte, 2011; Lium, Crainic, & Wallace, 2009; Sim, Lowe, & Thomas, 2009; Yang, 2009), Dynamic Hub Location (Campbell, 2010; Contreras, Cordeau, & Laporte, 2010) Hub Arc Location (Campbell, Ernst, & Krishnamoorthy, 2005a, 2005b; Campbell, Stiehr, Ernst, & Krishnamoorthy, 2003), Competitive Hub Location (Eiselt & Marianov, 2009; Gelareh, Nickel, & Pisinger, 2010; Lüer-Villagra & Marianov, 2013; Mahmutogullari & Kara, 2016; Marianov, Serra, & ReVelle, 1999; Sasaki & Fukushima, 2001; Wagner, 2008).

O'Kelly (1987) as a pioneer presented a quadratic mathematical model and Campbell (1994) contributed into the subject and made it linear. Skorin-Kapov et al. (1996) commenced on Campbell finding by tight linear relaxation and came up with an exact solution for p-Hub median problem. However Ernst and Krishnamoorthy (1998), presented a mixed-integer linear programming form of the problem with fewer constraints and variables. Hamacher et al. (2004) used polyhedral properties and proposed a new mathematical modelling. For more review see Alumur and Kara (2008), Campbell and O'Kelly (2012), Zanjirani Farahani, Hekmatfar, Boloori, and Nikbakhsh (2013).

In a routine p-median, it is assumed that the closest facility will serve the service and this is called proximity assumption. This assumption in hub location problem means that one will choose a hub to minimize his travel route and time to desired destination. Meanwhile based on proximity rule, the same hub will be selected by passengers traveling between the two airports. But this is not exactly the real world case as one may consider variety of flight offered and selects the best which suits his demand.

Assumptions based on proximity seems logical because it is delegated to user's best interest to use the closest facility. Indeed this