SEARCHING OPTIMAL HUB LOCATIONS IN POSTAL LOGISTIC NETWORK

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Abstract

The article deals with the process of searching the optimal locations of logistic hubs in conditions of postal logistic network of Slovak Post. The research adopted in this article uses allocation models within graph theory to obtain results for addressed optimization problem. The optimization is based on demographic and economic characteristics of Slovak republic. Selected allocation models are applied on the road infrastructure with objective to determine the optimal location of postal hubs. The results can serve as a basis for modification of the used model for the simulation of logistic networks in the postal sector.

Keywords: Postal network, allocation models, p-median, fixed charge facility location

1. INTRODUCTION

Appropriate location decision is a key to optimally solve variety of public and private problems, since poor location can result in various negative scenarios. We can consider such decisions as critical, or strategic. In private sector it can lead to increasing costs, loss of competitive advantage and market share. Location theory provides many different approaches, procedures and solution to support decisions of locating facilities, either building new ones or relocating existing. The choice of solution depends exclusively on the nature of the problem, known inputs, decision variables and the outputs we want to achieve. In location models, demands and candidate locations are discretized to simplify the solution. These models also assume that there is an underlying network for the problem, consisting of certain infrastructure, such as transport or other logistic connections The distance between demand nodes and facility locations is not necessarily the physical distance. It could be also the travel time, travel costs, etc.

Postal operation represents an extensive technological system with a considerable degree of integration for different types of services. The main business activity of postal operator is reliable, regular, and fast transport of postal items. The transport is performed among the stationary postal facilities with different levels of postal item processing. Customer demands the delivery time to be minimal and guaranteed under the terms of the universal service and the nature of postal item, respectively. Moreover, the effort of postal operators as business entities is put forth, so that operations are carried out with minimal cost. Apart from the postal item processing technology, transport itself is an equally critical factor of time and cost. Transport is affected by the location of postal facilities and connections among them - the postal logistic network. [1]

The design of a suitable postal logistic system is the most important issue for providing elementary functions of the postal enterprise. A correct technology decision depends on the chosen postal infrastructure model and specific technological methods and processes. The designed model takes into consideration demands of the outside postal environment and requirements of the high level automation equipment in the conditions of postal enterprises. [2]

2. ANALYSIS

On the basis of essential postal technology, terms it is important to analyze main areas, which influencing the whole technological process of the postal items processing. The analysis determines the critical part of the whole optimization process - the choice of suitable construction variant of the postal logistic network.

The most suitable construction variant of the postal logistic network is selected from experiences of the postal enterprises in two European countries, which are comparable to Slovakia in geomorphological character and demographical structure. The chosen countries are Swiss and Denmark. The construction variant of the transportation network that seemed to be the optimum for these countries conditions is hierarchical three-level model of postal logistic network (**Figure 1**). [3]

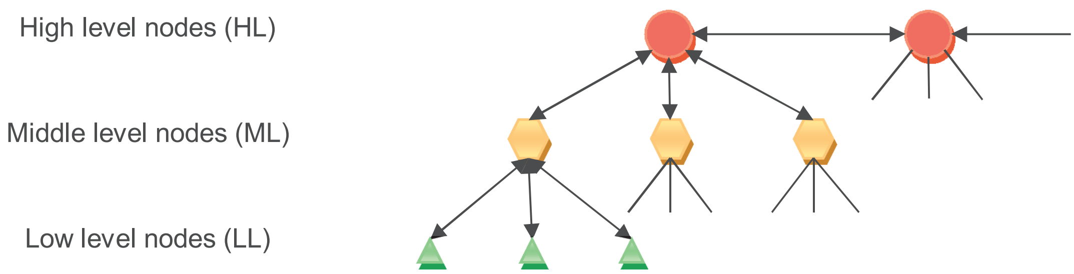

Figure 1 Hierarchical three-level model of postal logistic network [3]

2.1. Analysis of the models suitable for allocation of hubs in postal logistic network

The number and location of postal processing centers in the postal transport network is determined mainly by logistic functions of the entire postal system. The decision on where and how many top-level nodes to be located can be considered as strategic, and, therefore, it needs to be taken based on the results of the optimization process.

The graph theory is highly used in the optimization of transport networks. It enables us to describe and to abstract these networks and formulate different tasks to solve them. One of those tasks is finding the optimal location of facilities. Allocation models can be helpful in this case. The role of such mathematical models is to find answers to these key questions [4]:

- How many facilities need to be located?
- Where should each facility be located?
- How large should the facility be?
- What are the demands or how large is the area to be covered by an individual facility?

Postal transport network centers perform supplying function. To find the location, it is convenient to use discrete network allocation models. One of the basic parameters for solving problems of such type is the very distance between nodes. From this point of view, it is possible to subdivide allocation models into two categories: models based on maximum distance (set covering, maximum covering, p-center) and models based on total or average distance (p-median, maxisum, fixed charge facility location). [5]

Models, based on the total, or covering distance seem to be the most appropriate for the issue addressed in this article. When locating facilities, these models do not take into account the maximum distance between the facility and demand node, but rather the total / average distance between the facilities and all demands. They ensure that the average distance between any vertex and facility location will be minimum possible. Thus, we decided to use the p-median allocation model and uncapacitaed fixed charge facility location model.

The p-median problem is one of the basic questions of location theory and is as follows: The spatial distribution and the amount of demand for a certain service or facility are known. The task is to find locations for a given number of facilities that satisfy the demand. The facility locations are optimal, if the weighted travel efforts from the demand points to the nearest facilities are minimized. The problem is uncapacitated, which means that a facility can match any amount of demand necessary. [6]

The objective of the uncapacitated fixed charge location problem is to minimize total facility and transportation costs. In so doing, it determines the optimal number and locations of facilities, as well as the assignments of demand to a facility. [7]

3. OBJECTIVE AND METHODOLOGY

After choosing the construction model of the logistic network, it is necessary to determine the number and placement of each node at all levels of the postal network. That is the main objective of this article. For reasons to reach the real results, the postal optimization process is realized in conditions of the Slovak postal enterprise - Slovak Post.

The existence of logistic network of Slovak Post determined to use methodology based on variant-oriented optimization process. Therefore, a two-phase optimization method has to be created, which at first (optional phase) re-evaluates existence of middle level nodes and after (second phase) suggest the number and placement of the highest level nodes of the postal logistic network - hubs.

We can search optimal position of hubs in the existing postal network in the Slovak republic or we can create new postal logistics network based on main demographic and geographic data. There is a three-level structural variant of postal network implemented. The lowest level consists of regular post offices. These are connected only to the middle-level modes. The middle-level nodes perform function of mail concentrator and ensure a certain degree of mail processing. The postal items are then forwarded to high-level nodes, which are connected to each other. The process works similarly in the opposite direction - from higher to lower level nodes. [8] This process ensures the covering of the whole territory of Slovakia. In this article we will try to find the location of hubs in existing postal logistic network of national postal operator in Slovakia - Slovak Post, a.s. and we will use second phase of optimization only.

The underlying infrastructure can be represented by simplified model of a postal network, abstracted by a graph G=(V, E, c, w). The set of vertices (nodes) V consists of all 41 existing middle-level nodes. The set of edges E represents road connections between nodes. The labels of edges c(e) have value of the shortest distance in kilometers or travel time in minutes (we will use only value - distance in km). When determining the weight of nodes w(v), we use the demographic and geographic characteristics of individual nodes and the covering region which they serve. We consider the following attributes: number of villages (or cities) in the middle-level region, number of villages (or cities) with postal offices in the middle-level region, number of citizens in the middle-level region total area of the middle-level region, total distance between the middle-level region center and each village (or city) in the middle-level region and total distance between the middle-level region center and each village (or city) with postal office in the middle-level region. [9,10]

Above mentioned input data are applicable for almost any type of allocation model. The uncapacitated fixed charge location model uses another two specific characteristic variables, which are necessary to be set prior to obtaining the final solution. One of those are fixed costs for the location and build of facility at certain node. We consider the standardized model of postal sorting center, which would have the same construction for all locations. The basic value is set to 800 000 EUR, which resulted from similar projects implemented in practice in recent past. Another required input variable is the cost coefficient per distance unit per demand unit. It is necessary to determine the weight of demand and transport costs. Analyzing the available internet resources, we set the final value of required coefficient is 0.04873 EUR per kilometer per demand unit. [11]

4. RESULTS

The p-median model locates p facilities to minimize the demand-weighted average distance resulting in minimizing of total costs. The cost of serving demands at specific node is given by the demand at node and the distance between demand node and the nearest facility to that node. The task of the uncapacited fixed charge location model is to find the number and location of high-level nodes in the network while minimizing the costs of building the facilities and serving the demands of network. When we applied this to models on postal logistic network we obtained these results.

4.1. P-median model

By application of p-median location model we found out that the minimum number of facilities (hubs) for given input values are achieved when locating three facilities at nodes representing the covering regions of cities Trnava, Martin and Prešov. The establishment of this set of high-level nodes in these locations ensures that the all demands / requirements of the nodes of the entire Slovak territory will be satisfied. The final solution for p-median model are presented below (**Figure 2** and **Table 1**)

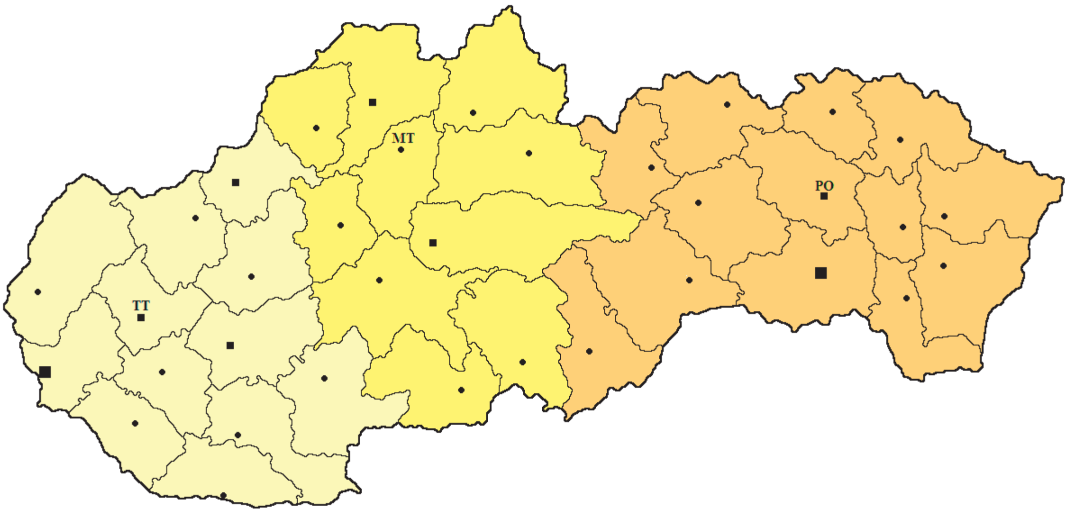

Figure 2 Results of p-median allocation model [11]

Table 2 Obtained solution for p-median model

Final results of model					
Number of facilities	**Maximal distance between two nodes**	**Covering distance**	**Maximal distance hub - node**	**Average weighted distance**	**Covered demands**
3	463 km	180 km	157 km	51.39 km	100 %

4.2. Uncapacitated fixed charge location model

By application of uncapacitated fixed charge location model we found out that the minimum costs for given input values are achieved when locating three facilities at nodes representing the covering regions of cities Galanta, Martin and Prešov. The establishment of high-level nodes in these locations ensures the covering of all demands of the entire Slovak territory while minimizing the building and transport costs. The assignment of demand nodes to individual located facilities corresponding to the final solution are presented below (**Figure 3** and **Table 2**).

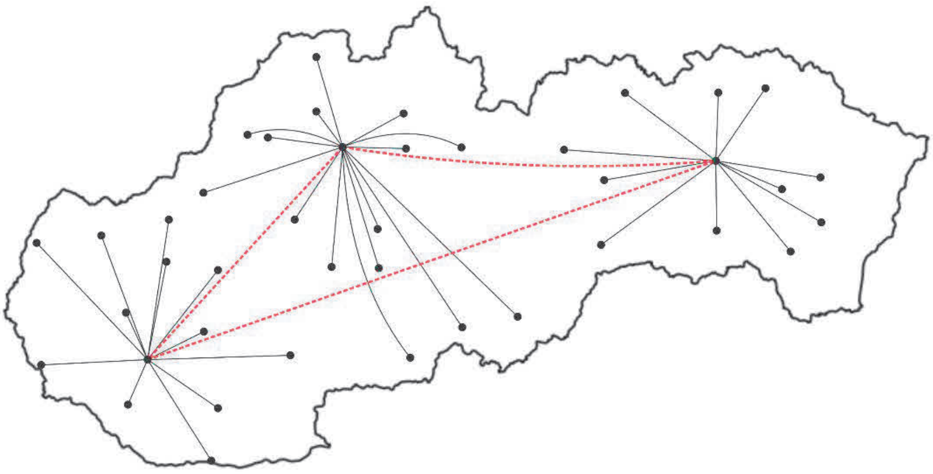

Figure 3 Results of uncapacitated fixed charge location model [12]

Table 2 Obtained solution for uncapacitated fixed charge location model

Final results of model					
Number of facilities	**Total fixed costs**	**Total demand weighted transport costs**	**Total costs**	**Average weighted distance**	**Covered demands**
3	2 740 200 €	6 609 581.26 €	9 349 781.26 €	47.057 km	100 %

5. CONCLUSION

Based on above mentioned characteristics and parameters of both models, we can observe their similarities and differences. Both models were applicable on the same network, which is represented by complete weighted graph G = (V, H, c, w) to simplify the calculations. Both had the same set of nodes and edges as well as evaluation (weight) of nodes and edges. Input variables include a set of nodes with demands to be served, set of candidate nodes for facility location, the demand value of individual nodes and the distance between each pair of nodes.

The input variable of p-median location model was also the number of facilities to be located on network. Algorithms solving this model were looking for mathematically optimal solution for given number of facilities and finish after finding it. This model did not count with the cost of building up the facilities; it tried to find the solution with minimal transport costs.

The uncapacitated fixed charge location problem did not have a specified number of facilities on input, which increased the variability of solution. The input variables included costs per distance unit per demand unit, which were relatively difficult to determine. Also the costs of building up facilities may differ in each node. However, in addition to mathematically optimal solution, this model brings significant degree of economical optimality compared to the p-median location model. Such optimality is required when strategic decisions are made, similar to locating the postal processing and distribution centers. Therefore, for the solution of decision problem addressed in this article we will use both models the uncapacitated fixed charge location model and p-median location model. Since the current layout of middle-level covering regions is obsolete, it would be necessary to deal with the issue of changing the covering area and reducing their number. After such optimization the presented model can bring even better results. Application of p-median and uncapacitated fixed charge facility location model on selected infrastructure resulted in finding the location of three hubs. They are Trnava, Martin and Prešov (for p-median model) and Galanta, Martin and Prešov (for uncapacitated fixed charge facility location model)

The obtained optimal results and used calculations can serve as a cornerstone for further search of optimal solution by allocation models in the field of postal logistic networks.

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