LOGISTIC CENTERS IN SUPPLY CHAINS: A DISTRIBUTION SYSTEMS DESIGN PROBLEM

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***Abstract**: Globalization, competitiveness in global markets and products with short life cycles, have significantly increased cargo flows. Facilitation of these flows in an efficient and cost effective way represents one of the biggest challenges for the logistic systems. This primarily implies finding an optimal location of objects that are part of the logistic systems. The location problem considered in this paper concerns the optimal number, type, size, location and allocation of logistic centers in distribution systems. To solve this problem, a mathematical model for the optimization of the distribution systems, based on an expanded capacity-limited fixed cost location allocation model on a network has been developed. Alternatively, genetic algorithm has been developed and recruited to seek for the appropriate solution of the model. The effectiveness of the proposed approach is evaluated with a numerical example of locating international logistic centers in the Republic of Serbia.*

Keywords: *distribution systems, location problems, logistic centers.*

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1. INTRODUCTION

In today's global and competitive business environment, efficiency of logistics operations has become one of the most powerful weapons for winning the leading positions on the market. It is therefore of fundamental importance to optimize the flows of goods among suppliers, distributors, and customers by designing optimal distribution system. Distribution system design problems consider determining the best way to transfer goods from the supply to the demand points while minimizing the overall costs. They involve strategic decisions which influence tactical and operational decisions and affect the cost of the distribution system and the quality of the customer service level. One of the most important strategic decisions at designing a distribution system and optimizing a supply chain is to find an adequate location of objects that are part of the system. Optimal locating of objects in relation to existing or expected material flows represents a prerequisite for the optimization of the overall distribution system and a basis for making appropriate tactical and operational decisions.

In this paper, a location problem of logistic centers in a distribution system was investigated. This type of the problem has been investigated by Taniguchi et al. [10]. Nozick and Turnquist [8] were dealing with locating distribution centers for automotive industry. Klose and Drexl [5] gave a good overview of the developed mathematical models for solving location problems in distribution systems. Melachrinoudis and Min [7] were dealing with the problem of redesigning a network of distribution warehouses. Yang et al. [12] investigated locating of distribution centers using fuzzy logic.

In order to solve the problem, an expanded capacity-limited fixed cost location allocation model on a network has been developed. Capacity-limited models imply solving a facility location problem in which facilities have constraining capacities on the amount of demand they can serve. These types of problem have been investigated by Zhou and Liu [13] and Rodrıguez et al. [9].

The fixed costs approach considers locating facilities on a network while taking into account the capacity of the facility and costs for its locating. The objective of this approach is to minimize total facility and transportation costs, determining the optimal number and locations of facilities, as well as the allocation of demand nodes to a facility. This approach has been investigated by Balinski [1] and Current et al. [2].

In this paper, the problem of distribution system design was to locate one or more logistic centers on the existing transportation network needed to cover the entire demand for logistics services in a defined catchment area. The centers are expected to satisfy high level of logistics service quality criteria. In order to solve the problem, a mathematical model was developed. The model enables determining optimal number, type, size and location of logistic centers, as well as the allocation of customers to the located centers, while seeking to minimize total distribution costs of considered cargo flows. Additionally, the model determines the optimal transport mode for transporting particular cargo flows between each two pairs of origin and destination nodes, taking into account the planned or allowed share of available transport modes on the network. Also, it has a specific approach at determining the optimal capacity of located centers, by considering fixed operating costs of the center in addition to the investment costs related to locating a center at the location.

The developed model was tested in the numerical example of locating logistic centers of international importance in the Republic of Serbia. The location problem of intermodal terminals and logistics centers in Serbia has been previously addressed in the project IMOD-X (Intermodal Solutions for Competitive Transport in Serbia), as well as in Vidovic et al. [11] and Georgijevic et al. [4].

The paper is organized as follows. In Section 2 the defined distribution network design model is introduced. Section 3 provides an overview of the considered numerical example as well as the obtained computational results. Section 4 contains some conclusions and future research directions.

2. MATHEMATICAL MODEL

In order to model the location problem of logistic centers in a distribution system, the following notations for the parameters are introduced:

$i \in \{1, 2, ..., I\}$ is the index for supply nodes on the network;

$j \in \{1, 2, ..., J\}$ is the index for logistic centers potential location nodes;

$k \in \{1, 2, ..., K\}$ is the index for demand nodes (customers) on the network;

$t \in \{1, 2, ..., T\}$ is the index for modes of transport;

$n \in \{1, 2, ..., N\}$ is the index for logistic centers types;

w_{ik} – cargo flows generated in supply node i that have destination in the demand node k;

p – max number of centers to be located in order to cover total demand;

S_j^n – capacity of the logistic center of a type n located in node j;

c_j^n – investment costs related to locating a logistic center of a type n in node j per unit of capacity;

f_j^{fix} – fix costs of the center located in node j per unit of capacity;

f_j^{var} – variable costs of the center located in node j per unit of cargo flows handled;

d_{ij}^t – distance between the nodes i and j by the transport mode t;

d_{jk} – distance between the nodes j and k;

α^t – transport costs per unit of cargo flows and unit of distance between the nodes i and j, in relation to the used mode of transport t;

β – transport costs per unit of cargo flows and unit of distance between the nodes j and k;

M^t – max share of the transport mode t in total realized transport.

Decision variables are defined in the following way:

$$Y_j^n = \begin{cases} 1, & \text{if center of a type } n \text{ is located in node } j \\ 0, & \text{if center of a type } n \text{ is not located in node } j \end{cases}$$

X_{ijk}^t – fraction of flow from the supply node i to the destination node k routed through the logistic center located in the node j by the transport mode t, $0 \le X_{ijk}^t \le 1$

The defined mathematical model of the location problem:

$$\begin{aligned} \min F = & \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\alpha^t d_{ij}^t w_{ik} X_{ijk}^t \\ & + \sum_{j\in J}\sum_{n\in N}\left(c_j^n + f_j^{fix}\right) S_j^n Y_j^n \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{t\in T} f_j^{\text{var}} w_{ik} X_{ijk}^t \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{t\in T}\beta d_{jk} w_{ik} X_{ijk}^t, \end{aligned} \tag{1}$$

subject to:

$$\sum_{j\in J}\sum_{n\in N} Y_j^n \le p \tag{2}$$

$$\sum_{n\in N} Y_j^n \le 1 \quad \forall j \in J \tag{3}$$

$$X_{ijk}^t \le \sum_{n\in N} Y_j^n \quad \forall i \in I, \forall j \in J, \forall k \in K, \forall t \in T \tag{4}$$

$$\sum_{t\in T}\sum_{j\in J} X_{ijk}^t = 1 \quad \forall i \in I, \forall k \in K \tag{5}$$

$$\sum_{i\in I}\sum_{k\in K}\sum_{t\in T} w_{ik} X_{ijk}^{t} \le \sum_{n\in N} S_j^n Y_j^n \quad \forall j \in J \qquad (6)$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} w_{ik} X_{ijk}^{t} \le M^t \sum_{i\in I}\sum_{k\in K} w_{ik} \quad \forall t \in T \qquad (7)$$

The objective function (1) enables determination of optimal number, type, size and location of logistic centers, as well as allocation of customers to the located centers, on the defined geographical area for the projected cargo flows, while seeking to minimize total distribution costs. It contains four parts. The first part of the function includes the cost of shipping goods flow from supply nodes to the located logistic centers, taking into account the mode of transport used. The second part of the function considers fixed costs of the logistic centers, including investment costs, taxes, insurance, salaries, etc. The third part considers variable costs of the logistic centers which are directly related to the volume of commodity flows that pass through the centers. The fourth part includes the costs of shipping the goods from the logistic centers to demand nodes (customers).

Constraint (2) allows locating at most p centers. Constraint (3) ensures that only one center can be located at the node j. With (4) allocation of demand nodes (customers) is allowed only to the located centers. The complete coverage of demand nodes is fullfiled with (5). Constraint (6) is a capacity constraint assuring that total demand at node j and demand of all allocated demand nodes do not exceed the capacity of the distribution center located at the node j. Constraint (7) restricts the maximal share of particular transport modes.

In order to simplify the problem in the model is considered only one type of goods. It is assumed that every supplying node i is connected by at least one mode of transport with every potential distribution center location j, as well as that every potential center location j is connected with every destination node k by road transport. In order to analyze problems in a more realistic way, the maximal share of a particular transport mode is restricted by the parameter M^t. To each arc between the nodes are assigned distances $d_{ij}^{\,t}$ and d_{jk} according to the available transport modes. Transport costs are calculated in dependence of the transport distance between the nodes, quantity of transported cargo and used mode of transport.

The costs of locating a distribution center are defined per capacity unit in dependence of the center type and every particular potential location of the center assuming that different conditions of existing infrastructure at different locations can significantly influence the amount of required investments. Considering that investment costs per unit of capacity decrease with the increase of capacity, it is to assume that the centers of higher capacity will be selected. However, unused capacity of centers can result with unnecessarily higher operational costs of the centers. In order to avoid the over sizing of centers and therewith increasing operational costs of the centers, within the model the operational costs of a located center are broken down into fixed and variable costs. The fixed costs are the one related to the capacity of a center and include labor costs, taxes, depreciation of infrastructure and equipment, while the variable ones are exclusively related to the amount of cargo flows handled. Besides ensuring adequate determination of centers capacity, breaking down the operational costs enables the measurement of savings in fixed costs achieved by the adequate allocation of demand nodes (customers).

3. NUMERICAL EXAMPLE: LOCATION PROBLEM OF DISTRIBUTION CENTERS IN THE REPUBLIC OF SERBIA

The effectiveness of the proposed approach is evaluated in a numerical example of locating logistic centers of international importance in the Republic of Serbia, required to handle distribution of import cargo flows.

Geographically, Serbia represents the shortest road and rail transit route connecting Western Europe with the Middle East. It is crossed by two important European corridors: the road-railway corridor X and the internal waterway corridor VII that are at the same time, the backbone of the Serbian traffic system.

In the example, seven supply nodes, representing the most significant cargo hubs in the region which are handling import flows of Serbia, were analyzed. The nodes are Budapest, Constanta, Istanbul, Thessaloniki, Bar, Rijeka (Koper) and Banjaluka.

The set of customers is defined by 37 demand nodes which represent the most significant economic centers in Serbia: Subotica, Zrenjanin, Kikinda, Vrsac, Pancevo, Sombor, Apatin, Novi Sad, Vrbas, Backa Palanka, Sremska Mitrovica, Ruma, Indjija, Belgrade, Sabac, Loznica, Valjevo, Smederevo, Pozarevac, Kragujevac, Jagodina, Bor, Negotin, Zajecar, Knjazevac, Uzice, Priboj, Cacak, Kraljevo, Novi Pazar, Krusevac, Nis, Prokuplje, Pirot, Dimitrovgrad, Leskovac, and Vranje. These selected 37 nodes are a result of the spatial aggregation of demand that was made with the aim to reduce the size of the location problem. Within the example each demand node is viewed as a potential location of a distribution center.

Distances between the nodes in the model represent the shortest paths between the nodes on the real transport networks. Initially defined maximum share of road, rail and water transport is up to 100%, 15% and 15% respectively. Transportation costs between the supply nodes and centers for rail transport are defined on the basis of current official rate for international transport of the Serbian Railways, 0.05 € / tkm. Transportation costs between the supply nodes and centers for road and inland waterway transport are defined on the basis of the current market rates and as defined in Limbourg and Jourquin [6], 0.07 and 0,015 € / tkm respectively.

Distribution of goods from the centers to the customers is assumed to be realized by road transport. The defined distances between the nodes represent real distances on the existing road network. In this example is allowed the distribution of goods to a customer (allocation of a customer to a center) which are at a distance less than 250 km from the located logistics center. The transportation costs of these distribution flows are set to € 0.11 / tkm, based on the current market rates and on the Limbourg and Jourquin [6].

Import quantities/customer demands are derived values based on the official statistics of the Customs Administration Office of the Republic of Serbia for 2012 [3].

The capacities of the distribution centers are assumed to be ranging from 5 to 100 thousand tons, with a step of increase of 5 thousand tons. The required capacities are defined under the assumption that the average handling and holding of every cargo unit in a center will take approximately a week (52 weeks a year). Within the process of handling and holding a cargo, it is assumed that 20 % of the cargo will require placement in racks while remaining 80% of the goods are expected to require block storing, container storing, or bulk storing.

Three types of logistic centers were considered in relation to the modes of transport they could serve: trimodal (IWT - rail - road), bimodal (rail - road) and unimodal (road). Investment value of these centers was defined based on expert's evaluation of investments in land, terminals, manipulative equipment, office building, warehouse and IT systems (this data can be provided by the authors, to interested parties on request). It is assumed that the necessary investments will be covered by a loan, for the time period of 20 years at an annual interest rate of 5%.

The fixed operational costs are set to 25 €/t of capacity and the variable operational costs to 5 €/t of analyzed cargo flows.

The model was tested for the given example by using the software *LP solve 5.0.0.0.* with the following settings:

- Scale type: Geometric, Equilibrate, Integers
- Pivot rule: Dantzig, Adaptive; Max Pivot - 250
- Branch Bound: BB Floor First, AutoOrder; BB Rule - First; Depth Limit: - 50; Obj bound: 1E30.

Additionally, in order to enable eventual testing of the model for greater number of nodes, a genetic algorithm was developed. In order to evaluate the effectiveness of the approach, the model was also tested on the same example with the application of the algorithm and the results were compared with the ones obtained by the *LP solve* software.

In order to examine the influence of number of distribution centers to the design and total costs of the distribution system, the numerical example was tested for cases of setting the maximal number of centers that should be located to 10 and to 3.

3.1 Simulation results

The first simulations were carried out by the *LP solve* for the case of locating maximally 10 centers. The best results – the lowes total costs of 357.07 million € per year were achieved for locating 7 distribution centers. The selected locations, capacities and types of centers are given in table 1.

Table 1. Simulation results – selected types, capacities and locations of centers

Locations	Capacity in 1.000 t	Type
Subotica	10	Bimodal
Novi Sad	40	Trimodal
Beograd	65	Trimodal
Šabac	15	Unimodal
Užice	10	Unimodal
Kragujevac	30	Bimodal
Niš	15	Bimodal

Allocation of the demand nodes to the selected distribution centers location is shown in figure 1.

The second simulations were carried out by the *LP solve* for the case of locating maximally 3 centers. The lowest total costs, 383.51 million € per year, were achieved for locating 3 logistic centers. The selected locations, capacities and types of centers are given in table 2.

Considering that in this case all demand for logistics services on the defined geographical region has to be carried out by only three distribution centers, the allocation of customers can not be precisely limited, so every of the center partially covers the demand of almost every customer depending on the supply node and the amount of demand.

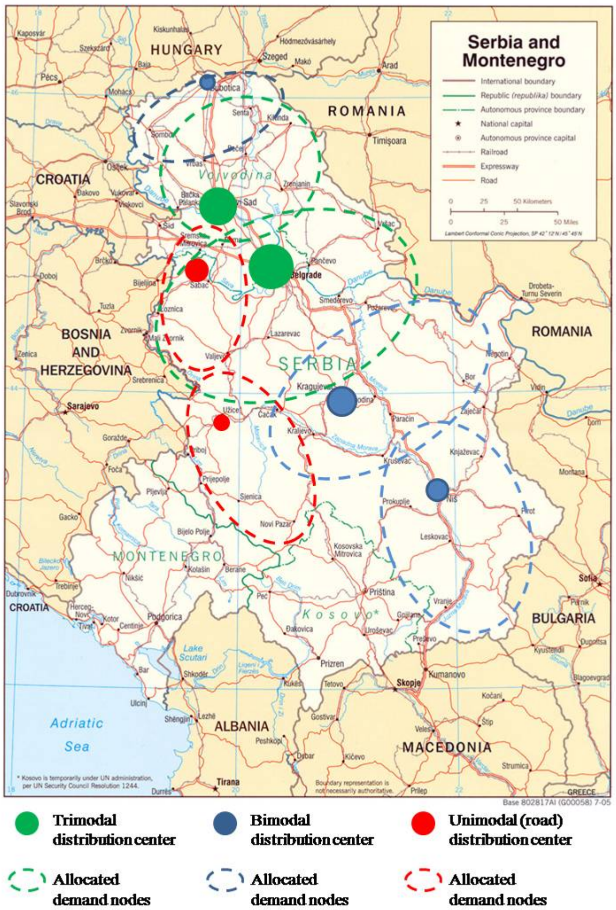

Figure 1. Simulation results, allocation of customers to located centers

Table 2. Simulation results – selected types, capacities and locations of centers

Locations	Capacity in 1.000 t	Type
Novi Sad	60	Trimodal
Beograd	95	Trimodal
Krusevac	30	Unimodal

The significant difference in the total distribution costs in the considered cases points out the dominance of the long distance transport costs over logistic centers investment costs.

The selected capacities of the logistic centers, in all analyzed cases (for the defined amount of cargo flows) have an utilization of over 85 % which justifies the particular consideration of fixed logistic centers operational costs in relation to the centers investment costs.

The simulations for both cases were additionally carried out by the developed genetic algorithm. The algorithm provided results in significantly shorter time period but were approximately 10 - 12 % diverging from the optimal ones.

Comparison of the results obtained by these two tools is given in table 3.

Table 3. Comparison of the results obtained by the *LP solve* and by the genetic algorithm

Considered cases	LP solve		Genetic algorithm	
	Total costs in 10^6 €	Simulation time in s	Total costs in 10^6 €	Simulation time in s
7 located centers	357.07	3397	404.67	14
3 located centers	383.51	2417	426.79	13

In both cases, by both tools, the same locations of logistic centers were selected as optimal ones, however, there were some divagations regarding the capacities of the centers and allocations of customers to the located centers. Due to that divagations, the simulations using genetic algorithm provided results with higher total distribution costs.

Given that the simulations were conducted for a relatively small number of nodes, the *LP solver* provides optimal results within a reasonable period of time. Therefore the application of the genetic algorithm is not necessarily required. However, it is expected that, in the case of considering a larger number of nodes, the duration of the simulation in the LP solver will increase significantly due to which the application of the genetic algorithm to solve the problem can be required. In this case, the resulting solutions, regardless of their deviation from the optimum, would be considered as good enough.

4. CONCLUSIONS

Based on the obtained results it can be concluded that the defined mathematical model represents a tool that can be useful in the process of making strategic decisions related to the distribution system design, particularly to the location problems of logistic centers. However, the decision about a distribution system design and location of logistic centers, in real systems, requires considering additional criterias besides the total costs minimization.

Testing of this model on the example of Serbia, came to the following conclusions:

- Dominant role in the total distribution costs of the import cargo flows have transport costs of cargo flows between the supply nodes and logistic centers;
- Simulation results showed that for the same cargo flows on the defined region (for the given input parameters), in the case of locating three centers, the total distribution

costs increase 26.44 million € (about 7 %) in relation to the total cost of the distribution system in the case of locating seven centers;

- In all considered cases, the trimodal logistic centers in Novi Sad and Belgrade were selected as optimal ones.

Given that in this numerical example, a relatively small number of nodes has been analyzed, the *LP solver* provided the optimal solutions within a reasonable period of time, while the genetic algorithm provided the solutions within a few seconds, but these solutions deviated from the optimal ones for 10 % or more. In the case of using the model to solve a location problem in an environment of much larger number of considered nodes, it is expected that the duration of the simulation using the LP solver would be too long so that the use of genetic algorithm would be needed, and the results obtained by the algorithm would be good enough.

In future research, it would be interesting to investigate the problem by treating some parameters as fuzzy variables, motivated by the uncertainty that often can be associated with parameters such as future customer demands.

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