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On the optimal placement of logistics centers

A.M. Talibov[1,2*], E.G. Hashimov[2,3], E.N. Sabziev[1,2], A.B. Pashayev[1,2]

[1]*Institute of Control Systems, Baku, Azerbaijan*
[2]*National Defense University, Baku, Azerbaijan*
[3]*Azerbaijan Technical University, Baku, Azerbaijan*

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ABSTRACT

The article addresses the problem of determining the optimal location of prospective logistics centers in the territory of the Republic of Azerbaijan. A mathematical model is given for cost-effective placement of logistics centers based on notional information about the coordinates of cargo terminals and customs posts, drivers' work and rest time standards, economic areas where cargo is collected and distributed, as well as centers that provide maintenance and repair services for motor vehicles. A solution method is proposed.

1. Introduction

Our country's advances in socio-economic development, the new emerging promising areas, economic, social, scientific, technical and financial potential made a long-term economic development strategy an objective necessity. As a result, the decree “On Approval of Strategic Roadmaps for the National Economy and Key Sectors of the Economy”, signed by the President of the Republic of Azerbaijan Ilham Aliyev in December 2016, set new goals for the key priority areas [1, 2].

The Strategic Roadmap requires a systemic and comprehensive analysis and assessment of the current state of our country's socio-economic development, and a fundamental upgrade of implementation mechanisms. The new priority areas once again confirm that the Strategic Roadmap reveals a new approach to economic development and makes it possible to diversify the economy and eliminate reliance on oil revenues.

"The Strategic Roadmap for Logistics and Trade Development in the Republic of Azerbaijan," drafted as a component of the initiatives to build a sustainable economy within the Strategic Roadmap, outlines short-, medium-, and long-term prospects for the development of Azerbaijan's logistics, trade economy through 2020-2025 and beyond 2025 [1, 2].

Experts believe that the critical infrastructure projects being implemented in Azerbaijan will turn our country into one of the largest logistics centers in the world. Efforts are already underway to

*Corresponding author.
E-mail addresses: talibovaziz65@gmail.com (A.M. Talibov), hasimovel@gmail.com (E.G. Hashimov), elkhan.sabziev@gmail.com (E.N. Sabziev), adalat.pashayev@gmail.com (A.B. Pashayev).

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create industrial parks and zones in our country with the purpose of developing the industry. All this gives reason to say that a new stage of development, fundamentally new in content and form, has begun in all sectors of the national economy [2].

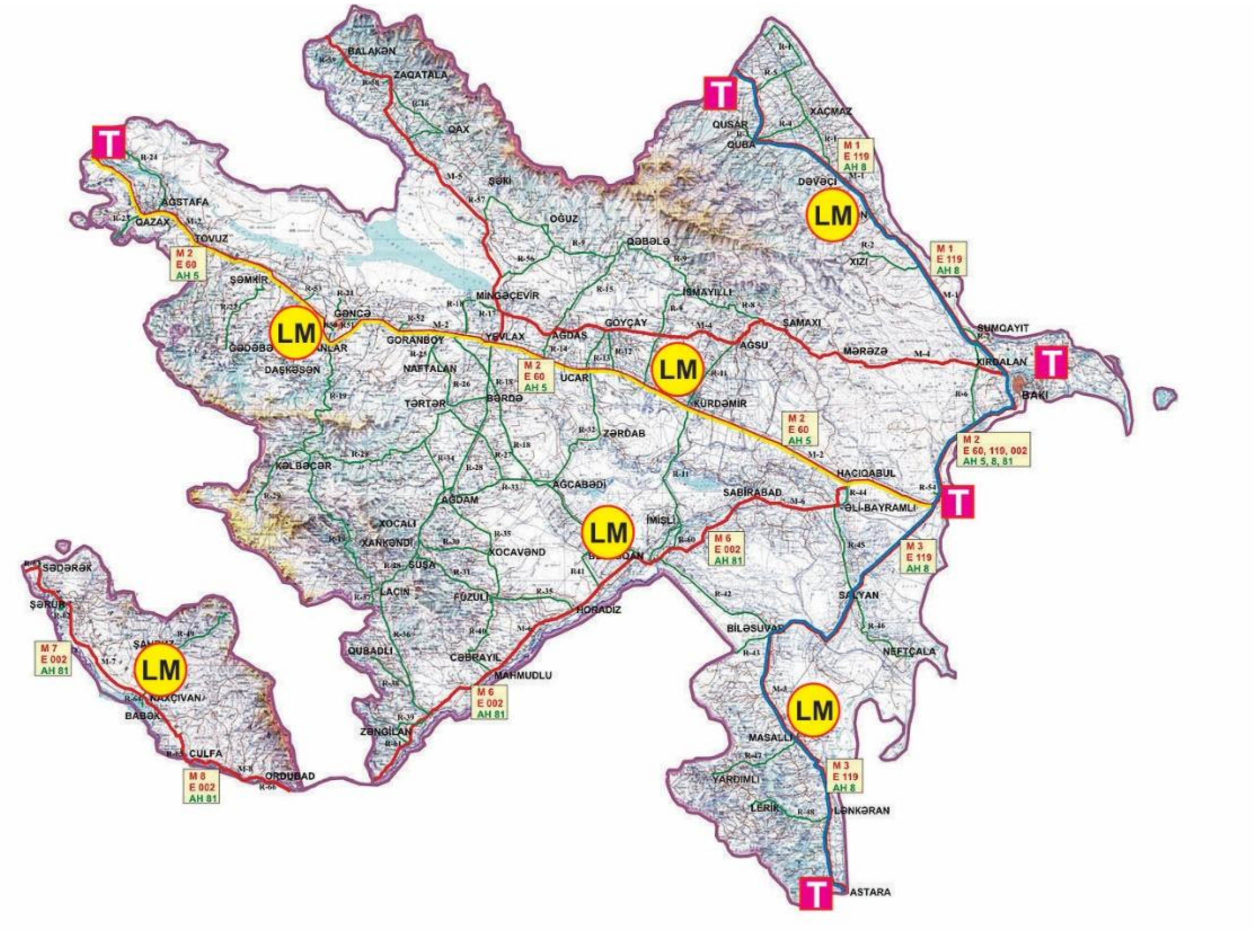

Fig. 1. Roads of the Republic of Azerbaijan

The global political and economic changes that have taken place in the world in recent years, as well as the military conflicts that caused these changes, have also brought about improvements in cross-border transportation, including the selection of optimal corridors. The favorable geographical location of the territory of the Republic of Azerbaijan makes its effective use in the process of global transportation inevitable. The geographical position of our country allows this territory to be used by international transport corridors in all directions and by different transport modes. Multimodal transportation through the territory of our country is being practiced at present and this process is evolving.

The expansion of the logistics market and the range of logistics services in Azerbaijan, the establishment and growth of a network of regional (pillar) logistics centers in the country, the activities of large companies, as well as the logistics infrastructure of international transport corridors, the rapid increase in the number of companies with logistics management divisions, require a rapid development of warehouse logistics in country's industries, especially in agriculture.

The experience of developing countries following the path of market economy shows that the factor of logistics, a new branch of economics, plays a great role in overcoming many economic problems in the development process. Currently, the complexity of the system of market relations, high requirements for the process and quality of product distribution, creation of a flexible production system, transportation and storage of products and organization of necessary reserves, the mechanism of supply process planning and service make it necessary to use logistics as a branch of science in the global economy.

Thus, the rapid development of the country's economy and the widespread introduction of the science of logistics into this process has necessitated the implementation of logistics in the transport sector of Azerbaijan, much like in other areas. With the application of the theoretical and methodological principles of logistics it is possible to bring the performance measures of the system of logistics centers up to modern standards.

The article examines the problem of optimal placement of logistics centers in the territory of the Republic of Azerbaijan (Fig.1), proposing the placement of the logistics center in the nodal points of transport corridors or near them, building a mathematical model of cost-effective placement of a logistics center, with an algorithm for its numerical solution.

The aim of the article is to substantiate the relevance of the problem of optimal placement of logistics centers in the territory of the Azerbaijan Republic, to develop a mathematical model of cost-effective placement of a logistics center on the basis of appropriate data and a calculation algorithm.

2. Background for solving the problem of setting up a logistics center

Analysis of the current dynamics of Azerbaijan's economy shows an increase in storage, loading and unloading, distribution and terminal facilities and offers of services for storage, processing, packaging, distribution and management of products of wide demand in the near future, which necessitates the creation and development of a network of supporting logistics centers in Azerbaijan.

The following are considered to be the main objectives of the logistics centers to be established in the territory of the Republic of Azerbaijan:

- Performing the logistical function of collecting, transporting and exporting products produced in nearby regions.
- Performing the logistic function of unloading and distribution of imported products.
- Maintenance and repair of vehicles engaged in international transportation, as well as vehicles of carriers operating in the country.
- Ensuring compliance with the work and rest schedule of drivers engaged in international transportation, and guaranteed protection of vehicles during their rest period.
- On-site technical assistance to vehicles that break down on the road, or their evacuation to the logistics center. Replacement of broken-down tractors with other tractors, minimization of interruptions in cargo delivery.
- Providing vehicles engaged in international transportation with the necessary spare parts, equipment and materials.
- Diagnostics, repair and sealing of tachographs.
- Providing training for responsible persons of carriers and drivers operating in the country, improving their professional competence.
- As a branch of the Azerbaijan Ground Transport Agency, carrying out its functions in the regions, etc.

The efficiency of a logistics center in comparison with other production and service facilities is determined by its geographical location. For this reason, when building a logistics center, special focus is on its location in a convenient geographical area and its proximity to the localities it will service. In general, the location of the facility in favorable coordinates is considered a classic optimization theory problem. The solution of such problems in the convex set is based on the calculation of the unconditional extremum of the function, which expresses a certain optimality criterion. An example of this is the "Weber problem" (a method of choosing the location for a warehouse that will service production facilities in a particular area) [3]. In this problem, it is necessary to find a point indicating the location of the warehouse such that the cost of transporting goods to a finite number of objects located on that plane and services provided to them is minimal. According to the Weber problem, when determining the location of the warehouse, it should be taken into account that the cost of transporting a single load over the same distance is different for each consumer enterprise. From this viewpoint, to solve the Weber problem, the location of the warehouse is parameterized (the rectangular coordinates entered in relation to the area are taken as a parameter). The objective function is constructed, which represents the sum (depending on the coordinates) of the costs of transportation to individual points (enterprises). The solution of the problem is calculated as the minimum of the objective function.

As the set (zone, area) in which the problem is investigated becomes more complex, new approaches are needed. For instance, the investigated set of the Weber problem in [4] consists of an area obtained by subtracting rectangular zones from the convex set. This type of research is often theoretical. Real placement problems are linked to a specific geographical location. Both the warehouse and the consumer outlets are located at discrete points of the appropriate infrastructure. Therefore, the issue of discrete placement is considered on the graph [5]. Distance between stations and transportation costs are given in tabular form. When solving the discrete placement problem, one of the following approaches is traditionally used:

- Determining the optimal location of the warehouse by calculating all possible options. In this case, the objective function of the total cost of transportation from the proposed location is constructed for the purpose of locating the warehouse. By calculating the values of this function for a finite number of different places, the most suitable of them is selected. This approach is used when the number of considered discrete placement locations is small and the objective function is simple.
- Applying a heuristic approach to finding the optimal warehouse location when the objective function is complex. The essence of this approach is that, based on other logical considerations, a complete survey is implemented for a small number of points, excluding inappropriate (unacceptable) options from the set of possible solutions.
- Solving the problem of determining the optimal warehouse location by the application of mathematical methods, if the characteristics of the objective function allow. In the simplest case, the "center of gravity method" is applied to solve the Weber problem, depending on the consumer needs and their distribution in the graph [6-8].

At present, various location problems are studied in the scientific and technical literature depending on the structure of the set of solutions considered, the specifics of the transportation organization and other factors. A brief summary of a number of articles on the location of logistics facilities is offered in [9].

Unlike enterprises engaged in a wide range of activities, the circulation points of the logistics center being considered and the area it services are known in advance and do not change over the years. This can solve the problem of optimal choice of location in the geographical area by ensuring the efficiency of its operation.

In the process of solving the problem, the following factors can be taken as a basis:

- taking the average speed of vehicles engaged in international transportation as 50 kph, logistics centers must be placed every 3.5-4.5 hours of the road (approximately every 200 km);
- the functions of the logistics center must also be performed by terminals;
- a logistics center must be located in the immediate vicinity of the transport corridor;

- a logistics center must be as close as possible to railway stations and airports;
- it must be located as close as possible to the carriers operating in the country and the economic areas, as well as to the major cities.

Ensuring the optimal performance of these factors and the efficiency of the fulfillment of tasks should be taken into account when determining the optimal location of the logistics center.

We will assume that the logistics center to be set up is fairly close to the infrastructure of the area, its access to the infrastructure is ensured by building a new road if necessary, and the distances between the points are also known. Based on these factors, an approach is proposed in the following paragraphs for a mathematical statement of the problem of determining the optimal location of a logistics center.

3. Mathematical statement of the problem of determining the location of a logistics center

As a rule, the effective organization of a logistics center depends on its location in the existing transport infrastructure. As mentioned above, if necessary, access to the existing infrastructure of the logistics center being built can be provided by the construction of a new road. However, the road implementing this access must be many times shorter than the total length of the route covered during transportation. In this regard, the length of the access road to the infrastructure may not be taken into account when determining the optimal location of the logistics center. In other words, the location of the logistics center can be considered practically in the existing infrastructure.

It should also be noted that restrictions related to security and protection, as well as to the geography of the area (dense forests, rivers, lakes, valleys, mountain ranges, etc.), may be imposed when determining the location of a logistics center [10]. Taking into account these restrictions, possible areas (sets) for the location of the logistics center are identified. However, practice shows that such territorial restrictions do not play a significant role in terms of requirements for the proximity of the logistics center to other infrastructure.

Logistics centers are supposed to cover the country's main road network with a complex topology. To simplify the task in terms of optimal placement of the centers, it is proposed that the trunk roads may intersect. However, it is assumed that these roads do not have a common part.

The formal ranking of each road is established. The problem of optimal placement will be solved first for higher-priority roads, and then, successively, for lower-priority ones.

To simplify the problem, we consider the optimal placement of logistics centers separately for each road. If, as a result of the calculation, logistics centers belonging to different trunk roads turn out to be in close proximity to each other, then the decision to put a new logistics center in their place will be made by the decision-making expert.

Let us number the trunk roads as $i = 1, 2, \ldots$ according to their priority. Their total number and length are determined by the existing road network of the country and are assumed to be known. Denote the length of the i-th trunk road as $s^{(i)}$. Each trunk road has two end points (start-end). One of these points can be considered as a starting point. We will determine the locations of infrastructure points on the considered trunk as distances from this starting point.

If at least one end point of a trunk road has an exit from the country, we denote the set of the roads as K. If both ends of the road are inside the country, we denote the set of such roads as V.

It is assumed that there are different types of infrastructure facilities on the roads. Infrastructure facilities of different types are distinguished by the role they play in the activities of the logistics centers under consideration. In order to distinguish the different types of infrastructure facilities, the data relating to them will use the index $j = 1, 2, \ldots, m$, as shown below, where m is the total number of infrastructure facilities of different types.

1 – terminals,
2 – operating carriers,
3 – railway stations,
4 – airports,
5 – point of intersection of roads, etc.

The degree of importance or significance of the infrastructure facility of the j-th type will be determined by the weighting coefficients $w_j > 0$, identified on the basis of expert opinion. These coefficients are assumed to be determined and known.

We denote the distance from the starting point of the infrastructure facility of the j-th type, located along the i-th trunk road, as $R_{j,k}^{(i)}$, where k_j is the total number of infrastructure facilities of this type.

The distance from the starting point of the estimated location of logistics centers number k on the i-th trunk road in question is denoted by $x_k^{(i)}$, $k = 1, 2, ...$.

The average speed of vehicles traveling on the i-th trunk road is denoted by $v^{(i)}$.

In accordance with international standards on working and rest time, drivers must rest regularly. Taking into account the implementation of this rest in the logistics centers, restrictions on the distance between them are introduced. Regulation of the distance between logistics centers in accordance with these requirements can be described by the inequality

$$3.5 \cdot v^{(i)} \leq \left| x_k^{(i)} - x_{k+1}^{(i)} \right| \leq 4.5 \cdot v^{(i)}. \tag{1}$$

Different models are used to calculate the optimal value of $x_k^{(i)}$ depending on whether the trunk road in question belongs to the set K or V.

It is considered that there must be a logistics center within the greatest distance S from the points of entry and exit to the country, where S is the number determined by expert opinion.

Suppose that the trunk road belongs to the set K. We can see whether either of its endpoints is a border point. Suppose that the starting point of the trunk road is a border point. Then to determine the location of the first logistics center on this trunk road the following conditions can be put forward:

$$0 \leq x_1^{(i)} \leq S, \tag{2}$$

$$\sum_{j=1}^{m} \left(w_j \sum_k \left| x_1^{(i)} - R_{j,k}^{(i)} \right| \right) \to min. \tag{3}$$

Minimum (3) is calculated only for those infrastructure facilities for which $R_{j,k}^{(i)} \leq D^{(i)}$. Here, taking into account the fact that a vehicle moving between points $x_k^{(i)}$ and $x_{k+1}^{(i)}$, in case of technical necessity in the first half of the route will head to the infrastructure facilities close to the point $x_k^{(i)}$, and in the second half of the route to the infrastructure facilities close to the point $x_{k+1}^{(i)}$, we take that $D^{(i)} = 2 \cdot v^{(i)}$.

The form of functional (3) is based on determining the sum of distances to the nearest infrastructure facilities of each type on the considered section of the trunk road as a weighted sum according to the specifications of the problem.

As mentioned above, if the end point of the trunk road is a cross-border checkpoint, condition (2) is replaced by the following inequality to determine the location of the last logistic node on this trunk road:

$$0 \le s^{(i)} - x_{k_0}^{(i)} \le S. \tag{4}$$

The analogue of condition (3) is written as follows:

$$\sum_{j=1}^{m}\left(w_j \sum_{k}\left|x_{k_0}^{(i)} - R_{j,k}^{(i)}\right|\right) \to min. \tag{5}$$

In this case, only those infrastructure facilities are considered for which the inequality $\left(s^{(i)} - R_{j,k}^{(i)}\right) \le 2 \cdot v^{(i)}$ is fulfilled.

Effectively, conditions (1)-(4) allow calculating the number of logistics centers to be placed on the trunk road in question, this number is denoted above as k_0.

If the trunk road belongs to the set V, and after locating the logistics centers near the endpoints of the trunk road belonging to the set K, it may be necessary for the following function to be minimal in the conditions (1) in order to calculate the location of the others:

$$\sum_{j=1}^{m}\left(w_j \sum_{k}\left|x_{k}^{(i)} - R_{j,k}^{(i)}\right|\right) \to min. \tag{6}$$

4. Solution algorithm

The problem is considered as a decision support system. The algorithm for solving the problem can be given as follows.

If the road belongs to the group K, then from problems (2)-(5) the coordinates of logistics centers near the endpoints are determined. The distance between these centers can be easily calculated.

If the considered road belongs to the group V, based on the known length of the road, the other logistics centers are placed on the considered road section regularly at a distance of $4 \cdot v^{(i)}$ from each other. The resulting placement variant is considered the initial iteration for the subsequent steps.

In the next iteration problem (1)-(6) is solved for a given k. Thus, starting from the first logistics center determined on the road, the optimal location of the subsequent logistics centers is calculated.

Note that as a result of iterations the number of centers may differ from the initially calculated number k_0. In this case, the number of logistics centers can be changed by expert decision.

5. Conclusion

- Due to the fact that the road system has a complex topology, to solve the problem of optimal placement of logistics centers on highways of the country, it has been proposed to consider the intersecting roads separately;
- A mathematical model of the problem of determining the optimal location of the logistics center has been built for each road, and an algorithm for its iterative solution has been given;
- If, as a result of the calculation, logistics centers belonging to different trunk roads are in close proximity to each other, then the matter of assigning a new logistics center to replace them rests with the decision-making expert.

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