Optimization of transportation routing of high-tech transport companies is an important factor in the development of the country's regions

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Abstract. This article examines the issues of optimizing the routing of transportation of high-tech transport companies as one of the important factors in the development of the country's regions. The authors studied the methods of optimization of logistics flows, studied the experience of modern domestic companies providing logistics services. In addition, it is proved that high-tech transport companies, optimizing their activities based on the use of innovative technological solutions, contribute to the economic and social development of the country's regions. The calculations were carried out by the authors using simulation modeling in the AnyLogistix environment. Practical results were obtained that make it possible to determine the optimal location of distribution centers relative to the time spent on delivery and the cost of delivery. The authors have proved that economic and mathematical methods and digital technologies are the basis for optimizing the routing of high-tech transport companies, whose activities in turn serve as the basis for the competitiveness of regions in the unified economic complex of the country.

1 Introduction

The sanctions pressure that has recently been felt on the activities of all sectors and spheres of the economy of the Russian Federation has been reflected in the functioning of high-tech companies in the transport sector. As practice shows, foreign logistics companies have left the Russian market, which has set the task of developing Russian analogues. In this regard, conducting research in this area is relevant and timely. Modernization of domestic transport production, optimization of logistics processes is currently an important task of domestic high-tech companies in the field of cargo delivery to consumers based on the use of modern digital technological solutions (Dybskaya (2002)).

In the course of the study, the authors revealed that such high-tech express cargo delivery companies as SDEK, DPD, Boxberry, IML, Pickpoint, etc. show good development trends in the Russian market. The study showed that the development of e-commerce has led to the

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emergence of such points of targeted delivery of final goods to the end user as the consumer's home, pick-up point, postamat, online store warehouse, "dark store". As a result, during the delivery of goods to customers, the number of operations for loading, unloading, storage, preservation, consolidation, reloading, sorting, labeling, packaging and repacking, preparation and release of documents and other work on handling products has increased dramatically. To increase the efficiency of logistics operations and reduce losses, operations are structured and acquire the character of full-fledged technological processes. Like any technological process, they need an appropriate infrastructure, the main element of which are logistics or distribution centers. A distribution center is a spatial and functional object in which logistics services related to the reception, storage, distribution and delivery of goods, the provision of related services are provided.

Choosing the optimal location of a distribution center is important for the efficiency of logistics activities of a high-tech company, since most companies have approximately the same access to modern equipment for intra-warehouse logistics and cargo handling, and only the location is a unique attribute of each warehouse and cannot be repeated and/or reproduced for objective reasons. The correct location of the distribution center has a decisive influence on the value of such indicators as the time of delivery of products to and from the warehouse, the cost of resources for delivery.

Taking into account the relevance of this topic, in this paper the authors demonstrate the possibility of determining the optimal location of distribution centers using simulation modeling technologies, which can be used in the modern period by high-tech companies in the logistics sector.

2 Materials and methods of research

Logistics processes are currently studied by many foreign and domestic scientists. Among the leading foreign scientists, it is necessary to note the works of such authors as Ballou (1998), in whose works the essence of cargo transportation from the point of view of economics is revealed and it is proved that during the formation and management of logistics systems, the share of transportation costs can be up to 2/3 of the total logistics costs, Christopher (1992), Copacino (1997), Johnson (2002), Bowersox (2002), whose works show that as the degree of globalization increases, the costs associated with stocks, materials and production tend to decrease, while the costs of, the importance associated with transportation is increasing, Linders (2002), Waters (2003), Shapiro (2001) and others.

In the works of scientists such as Kowalski (2012), Lukinsky, Shulzhenko (2013), Sergeev (2011) it is shown that modern logistics is based on intelligent technologies, which allows minimizing the operating costs of goods and reducing customer service time. Today, the smart distribution network consists of several logistics platforms, warehouses and centralized services, which, thanks to modern transport systems, allow delivering goods to the end consumer in the shortest possible time. However, as before, the issue of optimizing the location of storage facilities in the functioning of high-tech companies in the field of transport and logistics remains not fully resolved in modern science. In this regard, the authors conducted an independent study, the results of which are described in the following paragraphs of this work.

The optimal location of the distribution center network in the operation of high-tech companies makes it possible to provide services at affordable reasonable prices. Table 1 shows the factors affecting the location of the distribution center.
Table 1. Factors and their impact on the location of the distribution center.

<table>
<thead>
<tr>
<th>Factor</th>
<th>The nature of the influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>The volume of transported goods, demand</td>
<td>A correct assessment of the volume of demand and the volume of transported goods will increase the efficiency of working with consumers of the product and suppliers</td>
</tr>
<tr>
<td>Proximity to customers, transport accessibility of the area.</td>
<td>The assessment of proximity to consumers and suppliers, the quality of roads leading to the distribution center, proximity to the main highways, etc. is important, since a large share of the costs of a logistics project are transportation costs</td>
</tr>
<tr>
<td>Geographical accessibility, characteristics of the site</td>
<td>A significant amount of transport is involved in the work of the distribution center, which needs space for parking, maneuvering, etc.</td>
</tr>
<tr>
<td>Plans of local authorities, compliance with legislation</td>
<td>The distribution center has a developing structure, therefore it is necessary to familiarize yourself with the plans of local authorities for the use of adjacent territories that hinder development: take into account construction standards, safety restrictions, proximity to communications and other factors</td>
</tr>
<tr>
<td>Social factors</td>
<td>During the construction of a distribution center, it is necessary to take into account the availability of labor resources.</td>
</tr>
</tbody>
</table>

Finding the optimal geographical location for the distribution center is a rather complex economic and mathematical problem. The complexity is explained by the large number of placement options to be analyzed, the number of which is estimated by the product of the number of types of logistics centers, the number of possible locations for their placement and the number of strategies for using each center. To carry out such an analysis, detailed information on a variety of technical and economic indicators is needed. Choosing the best alternatives based on such an abundance of data requires appropriate sophisticated analysis and modeling techniques.

Depending on the initial data, several methods are currently used to solve the problems of placing a warehouse network. With a small number of consumers, a direct calculation of the reduced costs for each option is applied. With a large number of consumers, the multivariance of the placement of elements of the warehouse network increases significantly. At the same time, analytical methods, optimization methods based on linear programming and simulation modeling methods, as well as expert methods are usually used (Akhmadinurov (2016)).

To solve it, the following analytical methods are currently used (Brodetsky (2016)):

- The full search method. The problem is solved by a complete search of all possible options for the placement of distribution centers and their evaluation. Usually, the solution is performed using software products based on mathematical programming. At the same time, this method cannot be applied if the number of transport communications increases, which entails an increase in the options for placing distribution centers;
- The method for determining the center of gravity of cargo flows. The method is similar to determining the center of gravity of a physical body. Its essence consists in the fact that coordinate axes are plotted on the geographical map of the service area, then the distance from the origin of the coordinate axes to the point indicating the location of the consumer (coordinates of each point) is determined along the axes. It is believed that if the distribution center is placed at the center of gravity of the model, then the transportation costs for the distribution of goods will be minimal. The disadvantage is that the distance from the consumer’s point to the location of the distribution center is taken into account
in a straight line, so the region where the distribution center is planned to be located must have a developed road network, otherwise the model will not correspond to the object being modeled;

- Heuristic method. The method is based on the experience and intuition of a specialist who selects acceptable options for placing a distribution center. All acceptable options are analyzed from a technical, technological and economic point of view;

- The trial point method. It is based on a sequential check of each segment of highways of the serviced section. However, this method does not allow determining the optimal location of the distribution warehouse in the case of a non-rectangular configuration of the highway network on the serviced site;

- Won Thunen's model is based on cost analysis. Distance and costs are taken into account as the main factors. The strategy of logistics capacity placement is based on cost minimization;

- The Hoover model, when choosing a location, takes into account both the costs of the distribution center and the territorial consumer demand.

To determine the optimal location, we will choose gravity analysis, which is a modification of the method for determining the center of gravity of cargo flows and allows us to take into account the topology of real transport routes when calculating the distance between objects. This method is used at the early stages of planning and assumes a high level of abstraction, so it requires a minimum amount of initial data, namely the estimated locations and the volume of demand for each client. As a tool, consider AnyLogistix, a software product developed by XJ Technologies (St. Petersburg, Russia) to solve a wide range of supply chain management tasks (Ivanov (2021)).

Simulation modeling in the AnyLogistix environment based on gravity analysis will allow you to find the "point of attraction" of the main traffic flows, taking into account the population of nearby settlements and the shortest distance to the intended point of delivery of goods from the logistics center. The result of the analysis in the AnyLogistix environment is an approximate, optimal location of the warehouse, in which the cost of all incoming and outgoing shipments is minimized.

The simulation model of the transport system, which includes distribution centers, will allow to evaluate the parameters and adjust the operation of the distribution center taking into account the necessary technological features, to dynamically assess the outcomes of possible situations of functioning.

To solve this problem in the AnyLogistix environment, using gravity analysis, it is possible to determine the number of distribution centers and the optimal location of distribution centers, taking into account such initial data as the location and supply volume needs of each potential customer. To implement this mathematical model, AnyLogistix uses the cplex "solver", designed to solve mathematical programming problems, including integer programming. The optimal location of a warehouse facility is determined by finding the point at which the sum of the distances from all customers to the warehouse, weighted by the volume of product flow between each customer and a potential warehouse, will be minimal (Akhmadinurov (2016), Zhukovskaya (2022)). The result of the analysis is an approximate, optimal location of the production or warehouse, in which the cost of all incoming and outgoing shipments is minimized.

Let's define the location of a potential customer as an ordered pair of coordinates \((x_i, y_i)\), where \(i\) can take values from 1 to \(n\), specifying the number of customers. These data are the input parameters of the task. The coordinates of the new distribution center \((p_x, p_y)\) will be the solution to the problem. The total transportation costs will depend on the distance to the intended location of the distribution center, set by coordinates \((p_x, p_y)\). It is assumed that the transportation costs from the distribution center \((p_x, p_y)\) to the customer's location \((x_i, y_i)\) are directly proportional to the distance and volume of cargo transported, equal to the demand.
Thus, to calculate transport costs, it is necessary to determine the distance \( d((p_x, p_y); (x_i, y_i)) \) between the location of the i-buter and the warehouse. To minimize transportation costs, we will change both \( p_x \) and \( p_y \) until the value of the total cost function for servicing all customer requirements \( Z(p_x, p_y) \) becomes minimal.

Therefore, the objective function can be denoted by the formula (1):

\[
Z(p_x, p_y) = \sum_{i=1}^{N} d\left((p_x, p_y), (x_i, y_i)\right) \rightarrow \text{min}
\]

The function \( Z \) is continuous and differentiable, therefore, differential calculus methods can be used to determine the optimal value of \( Z \). Calculate the partial derivatives of the function \( Z \) and equate them to zero.

\[
\frac{dZ}{dp_x} = \frac{NP_x}{\sqrt{(x_i-p_x)^2+(y_i-p_y)^2}} - \sum_{i=1}^{N} \frac{x_i}{\sqrt{(x_i-p_x)^2+(y_i-p_y)^2}}
\]

\[
\frac{dZ}{dp_y} = \frac{NP_y}{\sqrt{(x_i-p_x)^2+(y_i-p_y)^2}} - \sum_{i=1}^{N} \frac{y_i}{\sqrt{(x_i-p_x)^2+(y_i-p_y)^2}}
\]

Model (1) is called a model for determining the center of gravity of cargo flows. Using demand data, formulas (4) and (5) are used to calculate the optimal coordinates of the spatial location of the distribution center \((p_x, p_y)\).

\[
p_x = \frac{\sum_{i=1}^{N} \frac{D(x_i, y_i) \cdot x_i}{\sqrt{(p_x-x_i)^2+(p_y-y_i)^2}}}{\sum_{i=1}^{N} \frac{D(x_i, y_i)}{\sqrt{(p_x-x_i)^2+(p_y-y_i)^2}}}
\]

\[
p_y = \frac{\sum_{i=1}^{N} \frac{D(x_i, y_i) \cdot y_i}{\sqrt{(p_x-x_i)^2+(p_y-y_i)^2}}}{\sum_{i=1}^{N} \frac{D(x_i, y_i)}{\sqrt{(p_x-x_i)^2+(p_y-y_i)^2}}}
\]
Formulas from (1) to (5) allow us to determine the optimal location of a separate distribution center.

Based on the functionality, accessibility, simplicity and ease of use, the degree of adequacy of the models to the conditions of reality, AnyLogistix software was chosen as a software tool implementing the simulation modeling method. AnyLogistix implements the possibility of finding the optimal location for several distribution centers, as well as the required number of distribution cents, taking into account the maximum service radius. This possibility allows to compare the costs of several supply chains (Zhuravlev (2015)).

3 Research results

Let's consider the solution of the problem of choosing the optimal location of the company's distribution centers on the example of the high-tech company "Alliance", which faced the question of choosing the optimal location of the logistics complex. In 2003, the company launched work in the field of full-scale housing construction. To date, the company is one of the three leading developers in Volgograd with more than 300,000 m2 of real estate [16]. One of the actively developing areas of activity is the construction and/or purchase with subsequent leasing of warehouse commercial real estate located in the central Federal District. The main task of the company's employees is to analyze the liquidity, profitability and commercial attractiveness of real estate. The current task is to select multi-temperature and standard warehouse complexes for purchase and rental.

The collection of data for the evaluation of objects and their processing require a significant amount of time and the participation of specialists. Considering that the period of preparation and implementation of such transactions takes from three months to a year, it is absolutely necessary to reduce the time for evaluating the object and making a decision on concluding a transaction. Currently, preparatory work is underway in the company and a technical task is being formed to create its own object evaluation model using existing methods and software tools available on the market.

To implement the first stage of simulation modeling in anyLogistix by the method of gravity analysis, the following data are required:

- Geographical location of clients;
- Expected demand.

To solve the problem, 100 clients were created, evenly distributed on the serviced area in the redistribution of the M3-M7-A107 motorways. We will set the volume and frequency of orders based on the projected demand for the company's products, and indicate the stochastic nature of the appearance of orders. Let a new order appear every 5 days and have an average volume of 20 to 50 m³.

When operating a model with one distribution center, a recommendation was received to choose a location near the city of Zhukovsky. At the same time, the cost of transportation will be 3,894,007 conventional units. The total service distance of all customers is 4,268 km.

The results of the experiment for two distribution centers are shown in Figure 1:
The recommended location of the RC near the cities of Podolsk and Zhukovsky is calculated. At the same time, the cost of transportation is 2,540,019 conventional units. The total service distance of all customers is 2,552 km.

Simulation experiments (SIM) were carried out on the basis of gravity analysis data. These simulation experiments make it possible to test the efficiency developed by gravity analysis of supply chains. To make calculations, anyLogistix collects statistics on 200 key performance indicators, which by default are divided into several groups, including information about revenue and expenses, the distance traveled by vehicles, the volume of goods in stock, processed and unclosed orders, etc.

To implement a simulation experiment for the proposed distribution centers, we will set fixed storage costs at the level of 500 and 450 conventional units per day, the cost of preparing an order for shipment from the warehouse (processing, consolidation, loading) is 2 conventional units per m³. We will indicate the transportation costs. 1 km of road for the selected type of transport costs an average of 25-35 rubles. Calculations will be carried out in conventional units. Let's select a group of routes from all locations to all locations. We will enter data on the type of vehicles used, their capacity and speed: we will indicate a truck with a capacity of 20 m³, the maximum speed of movement of which is 60 km/h. We will enter information about the rules of shipment: transportation will be carried out with a full load (FTL), the minimum loading rate is 0.9. The priority in processing cargo handling is FIFO (first in first out). In addition, we will establish a rule that each distribution center can serve all customers.

To visualize the results of the experiment, we will set up a dashboard with which you can see how the supply chain will work and analyze the selected indicators (Figure 2).
Fig. 2. Visualization of simulation experiment results.

A third experiment was also conducted with the requirement to locate three distribution centers on the specified territory.

4 Discussion of the results of the study

Analysis of the results of simulation modeling of the optimal location of the distribution center of the Alliance company, taking into account the topology of real roads, provided the following cost data (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>Flow, m³</th>
<th>Distance, km</th>
<th>Flow cost estimation, m³·km</th>
</tr>
</thead>
<tbody>
<tr>
<td>One distribution center</td>
<td>108 157,50</td>
<td>4 268.45</td>
<td>3 894 007.12</td>
</tr>
<tr>
<td>Two distribution centers</td>
<td>108 157,50</td>
<td>2 552.39</td>
<td>2 540 019.75</td>
</tr>
<tr>
<td>Three distribution centers</td>
<td>108 157,50</td>
<td>2 651.83</td>
<td>2 558 478.65</td>
</tr>
</tbody>
</table>

The experiment with three warehouses showed a clear redundancy in the number of distribution centers. It is optimal to use two distribution centers, as this reduces transportation costs.

The consolidated results of simulation experiments in AnyLogistix are shown in Table 3.

<table>
<thead>
<tr>
<th>Statistics name</th>
<th>One distribution center</th>
<th>Two distribution centers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Received (Orders)</td>
<td>1 899</td>
<td>1 896</td>
</tr>
<tr>
<td>Demand Received (Products), m³</td>
<td>108 385</td>
<td>108 042</td>
</tr>
<tr>
<td>Lead Time, days</td>
<td>3.335</td>
<td>1.772</td>
</tr>
<tr>
<td>Other Cost, ye</td>
<td>45 000</td>
<td>85 500</td>
</tr>
<tr>
<td>Outbound Processing Cost, ye</td>
<td>215 459</td>
<td>215 271</td>
</tr>
<tr>
<td>Shipped Vehicles, vehicle</td>
<td>5 388</td>
<td>5 383</td>
</tr>
<tr>
<td>Total Cost, ye</td>
<td>454 379</td>
<td>426 926</td>
</tr>
<tr>
<td>Transportation Cost, ye</td>
<td>193 920</td>
<td>126 154</td>
</tr>
<tr>
<td>Traveled Distance, km</td>
<td>193 920</td>
<td>126 154</td>
</tr>
</tbody>
</table>

The simulation experiment showed that the supply chain with two distribution centers is more flexible and operational. It took 1.7 days to wait for the order from the moment of
placement to delivery. The longest waiting time for delivery when using one distribution center is 3.33 days.

A comparison of the results of the operation of the two models demonstrates that in the case of one distribution center, the amount of other expenses is less (45,000 cu vs. 85,500 cu when two distribution centers are operating), but at the same time transportation costs are increasing (193,920 cu vs. 126,154 cu), which leads to an increase in total costs to 454,379 cu (for comparison, in the case of two distribution centers 3 426,926 units).

Thus, based on the results of simulation experiments, it can be concluded that the optimal use is the use of two distribution centers located in the cities of Podolsk and Zhukovsky.

5 Conclusion

In the course of the study, the authors studied the main methods used in the management of transportation in supply chains. From which it was concluded that the set of the ass can be combined into two large groups. The first group consists of the tasks of selection and decision-making, and the second group solves the problems of optimizing the parameters of transport business processes.

In addition, conducting their own research on the functioning of high-tech companies in the field of transport and logistics, the authors state the following results: the location of distribution centers is a factor that cannot be changed within the economically justified costs of modernization and reconstruction. A well-chosen location reduces the transportation costs of the logistics process and, to a lesser extent, the costs of its operation throughout the life cycle of the distribution center. The selection and/or evaluation of the optimal location of the distribution center is the first step of any project, both in development and in the acquisition of ready-made facilities. The location of the distribution center is a determining factor in the economic model, the logistics component of business projects in the field of Internet commerce and network retail. In the practical activities of industry companies, the question of the speed and correctness of the assessment of the location of both the existing and planned distribution center is of great importance. The ability to evaluate quickly and correctly, with the possibility of varying placement scenarios and determining economic parameters for each scenario gives a tangible competitive advantage. The correctly chosen methodology makes the selection process faster and more convenient, which in the case of the construction of a new distribution center reduces the time before commissioning, and in the case of purchase 3 reduces the time for evaluating the object and closing the transaction.

As a result of the conducted research, practical results were obtained that make it possible to determine the optimal location of distribution centers relative to the time spent on delivery and the cost of delivery, which contributes to the efficiency of the functioning of high-tech companies and is one of the important factors in the development of regions.

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