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Comprehensive Application of Logistics Cost Optimization Models for the Delivery of Goods by Road

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Abstract: The current society's development is the intensive growth of human needs. That leads to an increase in production volumes. That requires an appropriate level of product transportation. Currently, there are various kinds, including automobile, railway, water, and air transport. According to the International Maritime Organization, maritime transport is the undisputed leader in international transportation; however, on land, road freight transportation surpasses other types in demand. That is due to the mobility of cars and the availability of a well-developed road infrastructure, which allows cargo to be delivered directly from the seller to the customer. In this regard, there is a need to plan routes for vehicles, solve transport tasks, and ensure the rational use of the carrying capacity of means of transport. When organizing cargo transportation, tasks include building optimal routes, minimizing transportation costs, and avoiding the underutilization of the truck. Continuous improvement of cargo delivery is a serious strategic objective of competing transport companies. It is necessary to regulate the costs of the services provided. Cost management and optimization are serious tools in organizing a transport company, which contribute to increasing its efficiency. That is due to the relevance of the research topic. The article discusses the theoretical and methodological aspects of cost optimization in transport companies, presents some optimization models, and justifies their application. Practice shows that these models can be applied to the activities of cargo carriers to significantly reduce unproductive costs and ensure the achievement of strategic goals, such as achieving market leadership positions and increasing competitiveness.

Index Terms: Logistics costs, Cost management, Optimization, Cargo delivery, Road transport

1. Introduction

The delivery of various goods is currently in high demand, which exacerbates competition between shipping companies. In the face of increasing competition, only those companies that ensure the timely delivery of goods at attractive prices for customers are developing. The establishment of competitive prices is possible only if the cost of transportation services is low. Optimization models, the development and application of which in transport companies is a competitive advantage, are a good means of finding cost reduction opportunities. A key assumption of the study is that the integrated application of optimization models to the specifics of a particular transport company will enable it to generate sufficient profits for development and remain competitive.

The article aims to explore the possibility of reducing logistical costs with the application of optimization models.

The object is the costs of transport companies; the subject is methods and models for optimizing logistics costs.

1.1. The Structure of the Study and Its Practical Significance

The introduction provides an overview of modern methods and means of managing logistics costs, clarifies the popularity of logistics systems, and the intensity and difficulties of their application. The second part of the article contains the theoretical aspects of logistics cost management based on the postulates of operations research and optimization theory. In the third part, the article presents the main optimization models and shows the results of their application in a transport company. An accurate methodology is to verify the operation of these models and the possibilities of generalizing the results. They are in similar transport companies. The conclusion includes new ideas regarding the expansion of optimization models and their further use not only in the activities of transport companies, but also in the educational process.

1.2. Modern Methods and Means of Logistics Cost Management

Logistical costs are transportation of goods, storage, packaging, inventory management, information processing, and other processes. Logistical costs can be classified according to various criteria, for example, as shown in Figure 1. The figure is compiled by the author based on sources [1,2,3,4,5].

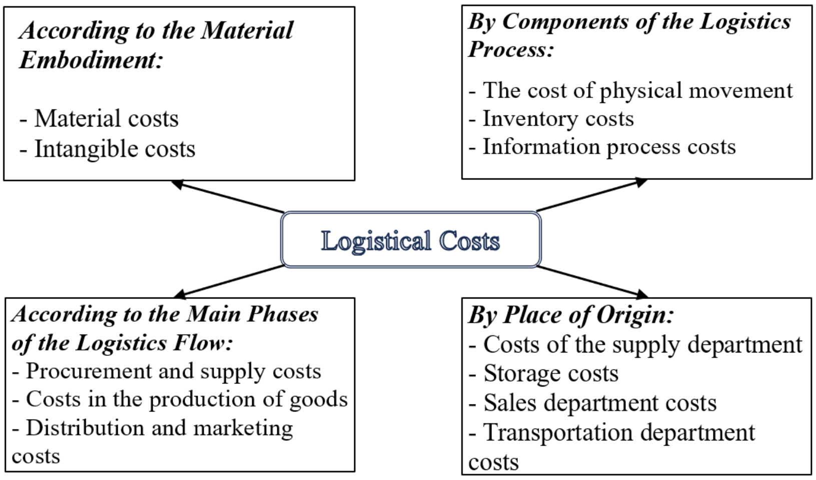

Fig. 1. Classifications of logistical costs.

Logistics costs are tangible (depreciation costs, consumption of materials, fuel, energy) and intangible (labor costs, intangible services, attraction of third-party capital, cash payments in the form of taxes, etc.). According to the main components of logistics processes, the following cost groups are distinguished: for the physical movement of products and materials, for stocks, and information processes. The cost of physical movement is associated with the material flow in the internal and external environment of the enterprise. These include the costs of using vehicles and loading mechanisms, employee salaries, fuel and lubricants, third-party transportation services, and transportation process management. Inventory costs include the receipt, storage, preparation, and dispatch of products, as well as general accounting, and product shortages during storage, product losses in transit, and natural product loss. The costs of information processes are the transfer of data on orders, stocks, and deliveries.

Cost management is a continuous process of planning, organizing, accounting, monitoring, analyzing, and making managerial decisions aimed at optimizing costs (Fig. 2). In connection with the specifics of logistics costs, we can propose a more specific definition of logistics cost management. That is the implementation of full management functions aimed at the efficiency of the logistics system. The basic principles of logistics cost management are: a systematic approach; the unity of methods practiced at different levels of cost management; cost management at all stages of the logistics service process; organic combination of cost optimization with high quality logistics services; avoidance of unnecessary costs; implementation of effective cost optimization methods; improvement of information support; increasing the interest of logistics departments in reducing costs [3,6].

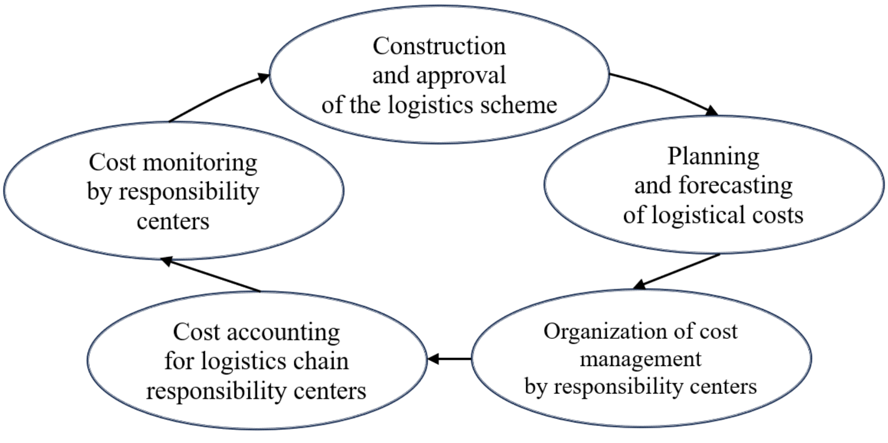

Fig. 2. Logistics cost management scheme.

The choice of approach to logistics cost management and the methods of its implementation depends on management objectives and responsibility centers. Three main approaches are in the literature. Each of them has its characteristics and limitations in application (Table 1).

Table 1. Basic Approaches to Logistics Cost Management

Approach	Features of the approach	Limitations in the application
The traditional approach	It is on the distribution of costs by their places of origin. Focuses on cost accounting and cost calculation.	It was popular in the twentieth century, when labor and materials were the dominant factors of production, and companies divided their activities into production and maintenance. They considered costs as a function of output volume and ignored non-production costs. The approach does not allow for a clear structuring of costs to determine the level and degree of their relationship.
Cost analysis by responsibility centers	The approach is to identify functional areas of the business in which the highest costs are concentrated. Reducing these costs can provide added value to the company. The key feature is the detection of the person responsible for optimizing logistics costs.	Lack of precise criteria for the allocation of responsibility centers; difficulties in identification, since the same resource can be in several responsibility centers. The problem of reconciling assessments and opinions.
The process approach	The approach allows the synthesis of cost data for each logistics process, including planning, procurement, production, storage, transportation, and distribution. It is you who builds a system of relationships between logistical elements.	Limitations of models include local optimization, dependence on the number of transport units and carriers, and the difficulty of accounting for the specific characteristics of the transported products.

The analysis of many studies shows that the effectiveness of logistics cost management can be assessed by the effectiveness of the weakest link in the logistics system. Identifying the weak link allows us to formulate an optimization problem and build a model for its solution, as demonstrated in the third section of this article.

1.3. Modern Logistics Systems and the Difficulties of Their Application in Transport Companies

Specialized software products are to support the approaches to logistics cost management described in Table 1. For example, ERP systems, WMS modules, and TMS programs are to implement the process approach (Table 2).

Table 2. Basic Approaches to Logistics Cost Management

Software category	Description	Difficulties of implementation in companies
ERP (Enterprise Resource Planning)	It is an enterprise resource management system. It unites all business processes, including finance, logistics, sales, and HR. ERP provides all visibility of the supply chain, automates routine tasks, and helps you make informed decisions [7,8].	The installation of an ERP system requires significant investments. The main items of expenditure include: the license, the cost of integration with other systems, and the cost of additional equipment. Technical difficulties may arise related to system integration, data migration, and the system's incongruity with the needs of a particular company. The implementation of an ERP system assumes the use of new technologies, which may cause resistance from employees who are accustomed to the existing systems in the company.
WMS (Warehouse Management System)	That is a warehouse management system. It optimizes warehouse processes, including acceptance, storage, shipment, and inventory. WMS helps to reduce costs and speed up order processing [9].	The disadvantages of WMS systems include: inconsistency with current business requirements, limited functionality, and difficulties with scalability. Often, system downtime or technical problems can disrupt warehouse operations. Companies should have backup plans in place to mitigate potential risks. The use of such systems is limited to the company’s warehouse complex.
CRM (Customer Relationship Management)	The system manages customer interaction, from order processing to tracking delivery. The main functions are: order management, routing and planning, and transport management. CRM helps to improve the service and increase customer loyalty [10].	The implementation of CRM systems is complicated due to technical and human factors that are similar in composition to the factors involved in ERP systems. It is necessary to develop a clear implementation strategy, evaluate resources, and get employees interested in the process so that using CRM becomes a truly effective tool rather than an additional burden.
TMS (Transportation Management System)	That is a transport management system. It helps to plan, control, and optimize transportation. It is to build routes, select carriers, track cargo, and reduce transportation costs [11,12].	The difficulties of implementing these systems are associated with high implementation costs, the need to integrate with existing systems, high expenses for staff training, and dependence on a stable Internet connection.
FMS (Fleet Management System)	That is a fleet management system. It allows you to track the location of vehicles, monitor fuel consumption, vehicle technical condition, and driving quality [13].	The main disadvantages of these systems include high initial costs, a significant amount of time to develop system specifications tailored to future needs, the need for specialized technicians to launch, monitor, and maintain FMS, and limited adaptability when product lines or product ranges change.

There are also other integrated systems for solving logistical problems, described, for example, in the works [14,15,16]. However, all of them are associated with high cost and implementation difficulties due to technical and human factors. In most cases, these programs are not necessary for small companies. Solving logistical problems in small companies is possible by developing optimization models to meet the company’s needs.

It is possible to develop models for reducing transportation costs in any available software environment with optimization and mathematical programming tools. For example, such an environment is MS Excel and the "Solver" tool built into it [11].

2. The Possibilities of Applying Optimization Theory and Operations Research to Reduce Logistical Costs

2.1. A Brief Overview

Operations research is a methodology for applying mathematical quantitative methods to substantiate solutions to problems in various fields of purposeful human activity. The subject of operations research in logistics is making optimal decisions in a logistics system, with management based on evaluating the effectiveness of its functioning. The key postulate of operations research is that the optimal solution (management) is a set of variable values in which the optimal (maximum or minimum) value of the efficiency criterion (objective function) of the operation is achieved with the observance of specified constraints [17]. Mathematical tools of operations research include mathematical programming, network modeling (theory of graphs), and other methods [18].

The number of studies using optimization theory and operations research methods is increasing. That indicates the high popularity of the optimization approach to solving complex practical problems [19].

Typical tasks of operations research in logistics are:

- Resource allocation. They arise when the available resources are not sufficient to carry out each of the planned works in an efficient manner.
- Repair and replacement of equipment allow you to determine the terms of repair and replacement of facilities, which minimizes the cost of repair and replacement over time.
- Inventory management. These tasks are uninterrupted supply of production and trading processes, while minimizing the expense of inventory, its storage, purchase, and transportation.
- Network planning of complex projects. That is a method of graphically displaying project processes in the form of a network. Where nodes indicate events (the beginning or completion of tasks), and arcs indicate the work itself, their duration, and dependencies.
- Route selection and others.

This study examines tasks of lowering logistical costs, such as:

- The transport task involves taking into account the delivery time.
- The task of optimally allocating drivers to routes.
- The task of finding the shortest route.

All these tasks are on linear optimization methods. This approach to solving optimization problems has gained well-deserved popularity since the mid-20th century and is in the works of L.V. Kantorovich [20,21,22] and D.B. Danzig [23,24,25].

The methods and algorithms proposed by these scientists are still actively used in operations research. As examples, I can suggest the works of [18,26,27,28] and others.

2.2. Transportation Task Based on Delivery Time

The mathematical formulation of the classical transport problem is as follows [18,23].

Some homogeneous products, concentrated at n suppliers A_i in the amount of a_i, $(i = 1, \dots, n)$ units, must be delivered to m consumers B_j in the amount of b_j, $(j = 1, \dots, m)$ units. The cost c_{ij} of transporting a unit of weight from supplier i to consumer j is known. It is necessary to draw up a transportation plan that allows managers to take out all the goods with minimal cost and fully satisfy consumers.

If we use x_{ij} to indicate the number of cargo units scheduled for transportation from supplier i to consumer j, then the mathematical model of the problem will take the form:

$$F(\vec{X}) = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} \cdot x_{ij} \rightarrow min \qquad (1)$$

$$\sum_{j=1}^{m} x_{ij} = a_i, i = 1, \dots, n \qquad (2)$$

$$\sum_{i=1}^{n} x_{ij} = b_j, j = 1, \dots, m \qquad (3)$$

$$x_{ij} \geq 0 \qquad (4)$$

Equality (1) is the objective function of the model, constraint (2) indicates that all weight is transport, equality (3) means that all customers gain him, and condition (4) is the condition for non–negativity of variables.

In the considered model, it is that the total reserves are equal to the total needs, i.e.:

$$\sum_{i=1}^{n} a_i = \sum_{j=1}^{m} b_j \tag{5}$$

If equality (5) is not satisfied, then the model is open. The open model is by reducing it to a closed model [18].

When the total reserves exceed the total needs, a fictitious consumer is, whose need is described by the formula:

$$b_{m+1} = \sum_{i=1}^{n} a_i - \sum_{j=1}^{m} b_j \tag{6}$$

If the total needs exceed the total reserves, a fictitious supplier is, whose reserves are described by the formula:

$$a_{n+1} = \sum_{j=1}^{m} b_j - \sum_{i=1}^{n} a_i \tag{7}$$

The cost of transporting a unit of cargo to a fictitious consumer and the expense of transporting cargo from a fictitious supplier are assumed to be zero since the cargo is not in both cases.

Since, in live conditions, the total cost of transport companies is affected by the level of fulfillment of obligations to customers on time and technological limitations, as a result of which the transport company cannot deliver cargo from the supplier to the customer faster than the set time, it is advisable to introduce additional restrictions into the classic transport task of the type (1)– (4). Each of the m customers set the maximum possible delivery dates, which form a vector of delivery dates $S = (s_1, \dots, s_m)$. The maximum possible time here is the time of waits cargo. Exceeding this value is not allowed. The transport company, analyzing the distances from the supplier to the customer, as well as several other factors (for example, weather and road conditions, the likelihood of transport breakdowns, etc.), sets the delivery time from supplier i to customer j, which form the delivery time matrix $T = \begin{bmatrix} t_{11} & \dots & t_{1m} \\ \dots & \dots & \dots \\ t_{n1} & \dots & t_{nm} \end{bmatrix}$. The element of the supply matrix t_{ij} is the delivery time of the cargo. For the company to deliver cargo in the amount of x_{ij} from supplier i to customer j in no more than s_j units of time, additional delivery time limits are required:

$$t_{ij} \cdot x_{ij} \leq s_j \cdot x_{ij} \tag{8}$$

Condition (8) is a condition for the solvability of the transport problem, considering the delivery time. The condition for the solvability of the classical transport problem is condition (5). Thus, the formulated transport problem, taking into account the delivery time, clarifies the classical transport problem and is formulated as follows: it is required to find the minimum of the objective function (1) with constraints (2)– (4), (8).

2.3. The Task of Optimal Allocation of Drivers to Routes

The objective function of this model will be to maximize the efficiency of drivers and forwarders in the delivery of goods. The concept of “work efficiency” includes such components as timely delivery, high quality of transportation, absence (or minimum number) of unproductive stops, detours (for example, due to ignorance of the route), etc. The conditions are: providing each route with one driver and one forwarder (or it can be two drivers replacing each other on long-distance trips. If the delivery is within the city and the cargo is small, then one driver is a route. All at the discretion of the company’s management, but taking into account the need to comply with the work and rest regime of drivers [29]) and ensure that each employee of the company works on one specific route (delivery of goods to recipients located on the route).

Some n employees can perform n flights, and these cargo deliveries can be different efficiencies p_{ij}, $(i, j = \overrightarrow{1, n})$. That is required to distribute all flights among employees in such a way as to maximize overall efficiency. If employee i is assigned flight j, then $y_{ij} = 1$, and if not assigned $y_{ij} = 0$, then the optimization model will take the form:

$$F(\vec{Y}) = \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij} \cdot y_{ij} \to max \tag{9}$$

$$\sum_{j=1}^{n} y_{ij} = 1, i = 1, \dots, n \tag{10}$$

$$\sum_{i=1}^{n} y_{ij} = 1, j = 1, \dots, n \tag{11}$$

$$y_{ij} = 0 \vee 1, \ i, j = 1, \dots, n \tag{12}$$

The value p_{ij} can be interpreted as the experience of driver i on route j and expressed in points from 0 to 100. As practice shows, the higher the driver's experience, the lower the cost. The effect of a driver's best knowledge of the itinerary on reducing transportation costs can use statistical observations and subsequent cost savings analysis, as shown in Table 3.

Table 3. A scale for assessing the dependence of the cost of delivery on the experience of drivers (compiled by the author based on an analysis of the costs of a transport company)

Interval number	**Interval (driver experience levels), points**		**Savings, in % of the average cost per item**		
	The lower limit	**The upper limit**	**Fuels and lubricants**	**Maintenance and repair**	**Guarded parking lots, toll roads, fines**
1	0	20	0.0	0.0	0.0
2	21	40	1.5	1.8	1.7
3	41	60	2.5	3.5	3.2
4	61	80	3.8	4.3	3.5
5	81	100	4.9	5.2	4.0

Knowing the cost values for the items shown in Table 3 on each route and having obtained the optimal distribution of drivers along these routes as a result of solving task (9)–(12), it is not difficult to calculate the amount of savings from each route and the total amount of money saved.

2.4. The Task of Finding the Shortest Route

The essence of the model boils down to finding the best route, the shortest, and therefore less costly in time and economy. The deliveryman departs from some initial locality, where the transport company's office is located, and travels around other localities in the number $n-1$, where n is the total number of destinations. The distance matrix between points is $\{l_{ij}\}$, where $i, j = 1, \dots, n$. The following restrictions are:

- The deliverer enters any point only once and leaves each point only once.
- The route is closed without loops.

Thus, the task of finding the shortest path will look like this:

$$F(\vec{X}) = \sum_{i=1}^{n} \sum_{j=1}^{n} l_{ij} \cdot x_{ij} \to min \quad (13)$$

$$\sum_{j=1}^{n} x_{ij} = 1, i = 1, \dots, n \quad (14)$$

$$\sum_{i=1}^{n} x_{ij} = 1, j = 1, \dots, n \quad (15)$$

$$x_{ij} = 0 \vee 1,\ i, j = 1, \dots, n,\ i \neq j \quad (16)$$

$$u_i - u_j + (n-1) \cdot x_{ij} \leq n-2,\ i, j = 2, \dots, n,\ i \neq j \quad (17)$$

Condition (17) prevents the division of a single route into several unrelated (partial) routes and also eliminates the formation of cycles, meaning the movement of vehicles along a closed partial route. This restriction allows you to determine the sequence in which the deliverer should visit the destinations.

3. Application of Cost Optimization Models in a Transport Company

3.1. Optimization of Cargo Delivery Routes

The optimization models proposed in the second section of the article were in a small Russian transport company specializing in road transportation across the regions of the Russian Federation.

As an example of route optimization, we consider the situation is when an industrial company with four production facilities in different cities of Russia (C1, C2, C3, C4) applied to a transport company with a proposal to deliver their products to seven customers located at destinations R1, R2, ..., R7.

Figure 3's upper part includes the transport company's costs for delivering 1 kg of cargo from each production facility to each customer, calculated based on an analysis of distances between locations, fuel consumption, loading and unloading costs, maintenance, and other factors.

	A	B	C	D	E	F	G	H	I	J
1	*Cost of transportation of 1 kg of cargo, monetary units*									
2			**Final destinations**							**Cargo reserves, kg**
3			**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	
4	**Suppliers**	**C1**	37,21	29,44	31,31	31,57	44,96	35,97	34,50	230
5		**C2**	31,76	24,72	27,30	28,15	37,25	32,53	35,45	180
6		**C3**	31,42	24,81	26,44	28,33	40,69	31,59	34,76	210
7		**C4**	32,36	24,46	25,15	22,49	37,68	29,79	36,14	180
8	**Needs, kg**		100	120	115	155	125	90	95	800
10	*The company's capabilities in terms of cargo delivery speed, days*									
11			**Final destinations**							**Cargo reserves, kg**
12			**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	
13	**Suppliers**	**C1**	1	2	3	2	7	4	5	230
14		**C2**	3	3	5	3	10	4	4	180
15		**C3**	2	4	4	3	7	3	5	210
16		**C4**	3	6	3	2	9	6	8	180
17	**Needs, kg**		100	120	115	155	125	90	95	800
18	*Customer requirements for the speed of cargo delivery (maximum waiting time, days)*		2	4	4	3	8	4	5	

Fig. 3. The initial data for the transport model, taking into account the delivery time.

The tables in Figure 3 show the stocks of products (column "J") available in production warehouses and the volumes of products required by customers (rows 8 and 17).

The second table in Figure 3 shows the company's capabilities in terms of product delivery speed. The last part of Figure 3 shows the customer's requirements for waiting time for deliveries.

The company needs to arrange the delivery of products from an industrial company's warehouses to its customers in a way that minimizes the total cost of delivery.

This task boils down to solving (1) – (4) and (8). In this case, equality (5) is fulfilled, i.e., the model is a closed transport model taking into account the delivery time.

After preparing and entering all the necessary data and formulas on the MS Excel sheet, the MS Excel add-in "Solver" was applied. Figure 4 shows the results of solving the problem.

	A	B	C	D	E	F	G	H	I	J	K
19											
20			0	0	0	0	875	40	475	$t_{ij} \cdot x_{ij}$	
21			0	360	0	0	0	240	0		
22			200	0	360	0	0	60	0		
23			0	0	75	310	0	0	0		
25			0	0	0	0	1000	40	475	$s_j \cdot x_{ij}$	
26			0	480	0	0	0	240	0		
27			200	0	360	0	0	80	0		
28			0	0	100	465	0	0	0		
30	*Verification of compliance between the distribution of shipments and the delivery time*										
31			**Final destinations**							**Cargo reserves, kg**	*Verify*
32			**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**		
33	**Suppliers**	**C1**	0	0	0	0	125	10	95	230	0
34		**C2**	0	120	0	0	0	60	0	180	0
35		**C3**	100	0	90	0	0	20	0	210	0
36		**C4**	0	0	25	155	0	0	0	180	0
37	**Needs, kg**		100	120	115	155	125	90	95	800	0
38		*Verify*	0	0	0	0	0	0	0	0	
39	**Target function**	24 442,76 ₽									

Fig. 4. Optimal route allocation.

Thus, it is most expedient in these conditions to transport 125 kg of products from C1 to R5, 10 kg to R6, 95 kg to R7; from C2 120 kg of products to R2 and 60 kg to R6; from C3 100 kg of cargo to R1, 90 kg in R3 and 20 kg in R6; from C4 25 kg in R3 and 155 kg in R4. With such a distribution, all needs will be satisfied, and the industrial company will fulfill its commitments. The total cost of the transport company will amount to 24442.76 rubles. A different distribution, if it ensures that all the specified conditions are met, will result in a higher value of the target function.

Before the introduction of optimization models, the company's managers, who relied on their own experience, were engaged in solving the tasks listed above.

The model from paragraph 2.2 was applied to assess the efficiency of past cargo delivery situations in the transport company. The managers calculated the cost of these deliveries based on their expert experience (Table 4). The transport model for these situations, considering the delivery time, allows you to get optimal route distributions. The cost of deliveries decreases. If the company had used (1)– (4) and (8), the total savings would amount to 19685 monetary units.

Table 4. Comparison of the cost of cargo delivery in a transport company

Experiment number	**Cost of delivery, monetary units**		**Absolute deviation, monetary units**	**Relative deviation, %**
	With expert calculation	**For automated calculation**		
1	27 586	24 443	-3 143	-11.4
2	35 781	33 717	-2 064	-5.8
3	28 550	25 432	-3 118	-10.9
4	20 518	19 411	-1 107	-5.4
5	37 540	34 726	-2 814	-7.5
6	33 728	29 467	-4 261	-12.6
7	38 893	35 715	-3 178	-8.2
Sum	222 596	202 911	-19 685	–
Average	31 799	28 987	-2 812	-8.8

The average reduction in logistics costs would be 8.8%. Thus, the implementation of this model in the activities of a transport company is advisable.

3.2. Optimizing the Allocation of Drivers to Routes

We used the model of optimal allocation of drivers to routes for the same completed flights. The company's guide decided on two drivers for each flight for safety and security reasons. The experience levels of the fourteen drivers (p_{ij}) on the respective routes are expressed in points (on a scale from 0 to 100 points). They are expert estimates based on the completed flights of each driver along the specified routes and according to the drivers' estimates, all other things being equal (Figure 5). For example, the task is solved based on the assumption that there are no conflicts between drivers.

Figure 5 shows the distribution of drivers on routes, based on the transport company manager's intuition, manually (the selection is in red italics).

		Routes (final destinations)							**Number of Routes for each Driver**
		R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	
Drivers (departure point - Moscow)	**D1**	*90*	70	60	90	85	68	60	1
	D2	85	75	67	76	58	*88*	55	1
	D3	50	*85*	64	70	54	85	50	1
	D4	55	80	58	70	*89*	55	74	1
	D5	78	76	52	72	*85*	45	58	1
	D6	65	42	66	*67*	21	46	15	1
	D7	*85*	46	79	68	20	40	70	1
	D8	80	43	85	66	37	25	*95*	1
	D9	90	75	40	*95*	35	15	90	1
	D10	90	70	31	28	48	*85*	70	1
	D11	64	80	25	18	42	70	*88*	1
	D12	88	*65*	18	55	60	96	80	1
	D13	85	45	*55*	14	80	70	75	1
	D14	75	37	*38*	95	95	85	74	1
Number of Drivers per Route		2	2	2	2	2	2	2	14

Fig. 5. Assigning drivers to routes without using an optimization model.

Based on the estimates presented in Table 3, the values that reduce the cost of cargo delivery are. They depend on the driver's experience (Figure 6). The total savings amounted to 22731.6 monetary units.

Drivers (departure point - Moscow)	Routes (final destinations)						
	R1	R2	R3	R4	R5	R6	R7
D1	2147,87	1163,69	2044,71	2024,75	10014,53	3474,31	1757,44
D2	2147,87	1163,69	2044,71	1641,53	6045,63	4290,18	1338,64
D3	1328,30	1432,65	1657,82	2024,75	6045,63	4290,18	1338,64
D4	1328,30	1432,65	1264,03	1641,53	10014,53	2640,55	1757,44
D5	1741,63	1163,69	1264,03	1641,53	10014,53	2640,55	1338,64
D6	1741,63	891,66	1657,82	1641,53	3333,89	2640,55	0,00
D7	2147,87	891,66	1657,82	1641,53	3333,89	2640,55	2168,39
D8	2147,87	891,66	2044,71	1641,53	3333,89	1451,97	2168,39
D9	2147,87	1432,65	1264,03	2024,75	3333,89	0,00	2168,39
D10	2147,87	1163,69	694,61	687,69	6045,63	4290,18	2168,39
D11	1741,63	1432,65	694,61	0,00	6045,63	4290,18	2168,39
D12	2147,87	1163,69	0,00	1251,39	10014,53	4290,18	2168,39
D13	2147,87	891,66	1264,03	0,00	10014,53	4290,18	1757,44
D14	2147,87	489,50	694,61	2024,75	10014,53	4290,18	1757,44

Fig. 6. Matching savings values to driver experience levels, monetary units.

However, applying the model described in 2.3, a more optimal allocation of drivers to routes was found (Figure 7), with a total savings of 23601.7 monetary units.

Drivers (departure point - Moscow)	Routes (final destinations)							Number of Routes for each Driver
	R1	R2	R3	R4	R5	R6	R7	
D1	0	0	0	1	0	0	0	1
D2	0	0	0	0	0	1	0	1
D3	0	1	0	0	0	0	0	1
D4	0	0	0	0	1	0	0	1
D5	0	1	0	0	0	0	0	1
D6	0	0	1	0	0	0	0	1
D7	0	0	1	0	0	0	0	1
D8	0	0	0	0	0	0	1	1
D9	0	0	0	1	0	0	0	1
D10	1	0	0	0	0	0	0	1
D11	0	0	0	0	0	0	1	1
D12	0	0	0	0	0	1	0	1
D13	1	0	0	0	0	0	0	1
D14	0	0	0	0	1	0	0	1
Number of Drivers per Route	2	2	2	2	2	2	2	14

Fig. 7. Optimizing the allocation of drivers to routes.

The number "1" in Figure 7 indicates that the driver is on the route, and the number "0" shows that there is no destination. That is a more optimal distribution of drivers than in Figure 5. For example, the first driver is assigned to the fourth route, but not to the first, as was earlier. Thus, the model is for use in transportation companies.

3.3. Optimizing the Cost of Cargo Transportation Using the Shortest Path Search Model

We demonstrate the work of the shortest path search model by the example of transportation carried out by a transport company in the Vladimir region (Russia). One of the company's major offices is in Vladimir. The company received orders for the transportation of goods to settlements in the Vladimir region (Table 5). This table also shows the distances between settlements (l_{ij}).

Table 5. Distance matrix, in km

Destinations	Vladimir	Andreevo	Gorokhovets	Gus-Khrustalny	Kovrov	Kurlovo	Melenki	Murom
Vladimir	10 000	57	152	69	81	91	136	130
Andreevo	57	10 000	128	69	68	90	89	79
Gorokhovets	151	127	10 000	192	110	215	137	97
Gus-Khrustalny	69	69	190	10 000	124	22	111	107
Kovrov	81	68	111	125	10 000	147	170	130
Kurlovo	92	89	213	22	146	10 000	111	129
Melenki	137	90	136	113	171	111	10 000	42
Murom	130	79	95	107	130	130	42	10 000

The cost of cargo transportation in the Vladimir region is 98 rubles per kilometer. The task is for the driver to deliver all orders, entering and leaving each destination only once, and returning to the company's parking lot in Vladimir along the shortest route. Values of 10000 are randomly assigned diagonally to exclude zero-distance crossings from the solution. Figure 8 shows the tabular model of the task (13)–(17).

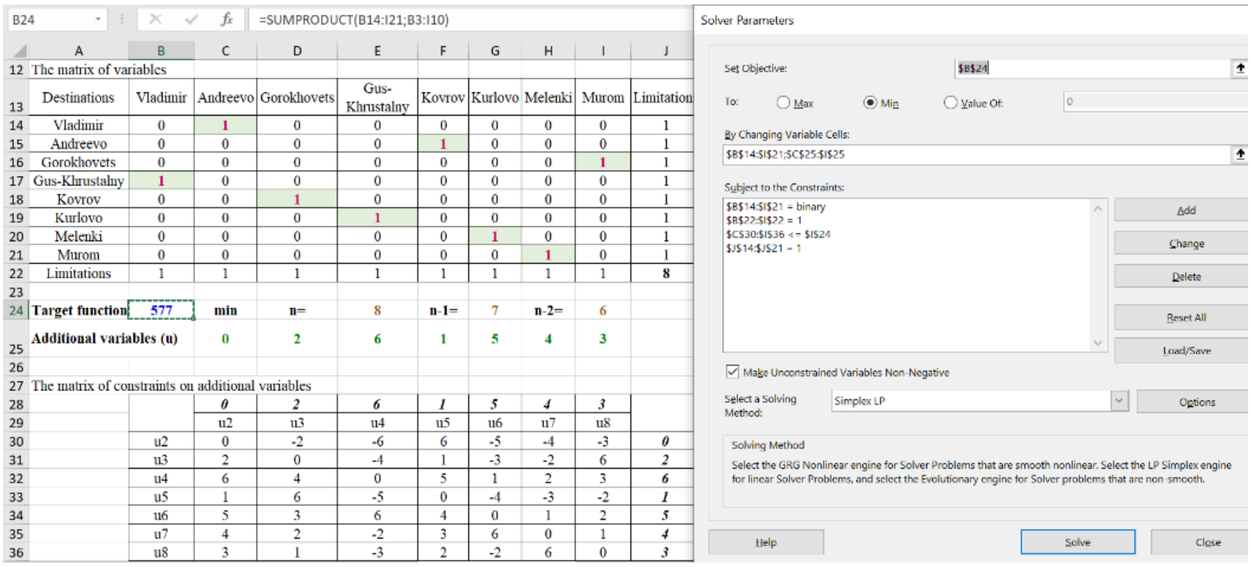

Fig. 8. The tabular model of shortest path search.

Thus, the shortest route will be Vladimir (1) → Andreevo (2) → Kovrov (3) → Gorokhovets (4) → Murom (5) → Melenki (6) → Kurlovo (7) → Gus-Khrustalny (8) → Vladimir (1). The route will be 577 km.

Table 6 also shows two alternative routes that were before optimization.

Table 6. The cost of cargo transportation on routes in the Vladimir region

Route number	Routes									Distance, km	Cost of transportation, rubles
1	(1)	(3)	(2)	(4)	(5)	(6)	(7)	(8)	(1)	618	60 564
2	(1)	(2)	(8)	(7)	(6)	(5)	(4)	(3)	(1)	587	57 526
3	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	577	56 546

The third route is the most optimal.

3.4. Methodology for Verifying the Operation of Models and Identifying the Confidence Level

The methodology for verifying the operability of models and determining the confidence level includes verification and validation processes. These concepts are related to computer modeling and are used to ensure the reliability and accuracy of the results.

The purpose of verification is to verify that the computational model accurately represents the underlying mathematical model and its solution. In this case, the verification results are positive. All models showed the expected results. To verify the correctness of their implementation, we performed testing using the example of a current transport company and compared it with analytical solutions.

The purpose of validation is to establish the extent to which the model is an accurate representation of the physical system in question within its intended use area. The service "Solver" provides a report of the results of the solution, which indicates the characteristics of the solution search module and the results themselves. In this case, for all models, the validation results showed that all the constraints and optimality conditions were met. Cost optimization models can be applied to similar transportation companies.

4. Conclusion

The article discusses the features and basic methods of managing cargo delivery costs in modern transport companies and suggests models for optimizing logistics costs.

We demonstrate the operability of these models in a transport company engaged in road freight transportation in Russia and neighboring countries. A significant economic effect is a drop in unproductive costs. The following conclusions are from the results of the study:

- The development of logistics infrastructure, traffic networks, and increased demand for delivery, which is associated with the positive dynamics of the e-commerce market, contributes to the popularity of road transport in cargo delivery. Therefore, the relevance of developing, adapting, and applying optimization models to reduce logistical costs is beyond doubt.
- The managers of a transport company calculate the cost of delivering goods without using models. They are planning based on expert experience. However, the advantage of the models considered lies in their precise formalization. It is advisable to use them when we are planning the activities of transport companies. To use expert experience better to solve poorly formalized or non-formalized tasks. Mistakes are inevitable with non-automated planning. It is impossible to account for all the factors and choose the best option.
- The models discussed in this paper are only a slight part of the optimization system recommended for implementation in transport companies. The integrated use of optimization models can significantly reduce unproductive freight costs and ensure profit growth. These are the plans for future research.
- We use the results of this and future research in the training of managers in logistics.

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