Periodica Polytechnica Transportation Engineering, 51(4), pp. 386–393, 2023

Automated System for Freight Transportation Optimization on the Transport Network

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Received: 08 November 2022, Accepted: 21 June 2023, Published online: 20 July 2023

Abstract
An automated system for freight traffic optimization on a transport network has been developed, which is realized in the form of a complex computer program with application of the visual design environment of Embarcadero RAD Studio. The program complex consists of the main form from which two subprograms are loaded. The search of optimum routes performed by the routing optimization subprogram is used at transportations of freight on the set transport network based on different schemes (from one vertex (the supplier) to all other vertices (consumers), serially – from each vertex to all other vertices, and from two (or several) set of vertices to all other vertices). Freight delivery between the supply and consumption points was optimized by means of the freight transportation optimization subprogram, taking into account the restrictions on the volume of freight at the points of departure and destination.

Keywords
transport task, routing optimization algorithms, automated system, computer software complex, freight delivery

1 Introduction

Transport is one of the most important sectors of the state's production. The main task of transport is timely, high-quality and full satisfaction of the needs of the national economy and the population in transportation. The most important element in developing freight technology is the choice of transport and technological systems. Each transport and technological system can be represented as a set of standard operations, the main elements of which are: cargo; transport network; rolling stock; freight concentration points; loading and unloading means; participants in logistics processes; packaging materials (Christopher, 2016).

The main factors determining the choice of transport and technological systems are local technological processes in all parts of the transport logistics system, which have a number of features and depend on the type of freight, mode of transport and its structure, industry characteristics, and state of logistics process elements (Boldizsár et al., 2022; Mirotin et al., 2019).

Reserves for improving the transport and logistics processes are in the rational organization of the interaction of participants in the supply chain, in the coordination of their interests and the search for mutually beneficial and suitable solutions (Elovoy and Lebedev, 2018).

1.1 Background and literature review

Considerable attention in scientific publications is paid to the theory and practice of the development of freight transportation organization. Thus, Escobar et al. (2020), Heidari et al. (2018), Khorshidian et al. (2019), and Kumar et al. (2016), present the results of the study of routing optimization by the criterion of minimum delivery time. In Lai and Bierlaire (2015), Nasiri et al. (2018) and Soeanu et al. (2020) methods of route selection are considered, based on alternative sampling. Luisa De Maio and Vitetta (2015) and Sun (2020) and use routing modeling methods in transport systems based on fuzzy logic. Manley et al. (2015) and Tokgöz et al. (2015) have described a heuristic model of route selection. Havelock et al. (2018), Hu et al. (2018), Rodado et al. (2017) and Xu et al. (2020) consider the statistical model of a routing choice in transport systems. The method of freight transportation using genetic algorithms is described by Chiappone et al. (2016), Mohammed et al. (2017), Lu et al. (2017), Tintu and Amudha (2020) and Yang et al. (2016). Hess et al. (2015) and Nyrkov et al. (2015) suggest modeling the results of the route choice using data from the Global Positioning System (GPS).

Analysis of the results of those studies shows that these works use various analytical methods for organizing cargo

Cite this article as: Dekhtyaruk, M. (2023) "Automated System for Freight Transportation Optimization on the Transport Network", Periodica Polytechnica Transportation Engineering, 51(4), pp. 386–393. https://doi.org/10.3311/PPtr.21485

flows and modes of operation of individual elements and parts of logistics systems.

At the same time, progress in the field of information technology makes it possible to significantly increase the efficiency of transport logistics, information and computer support, having a proper place among the key logistics functions (Sergeev, 2019; Židová and Zitrický, 2023).

1.2 Methodology

Using new information technologies and systems contributes to the increased efficiency of freight transportation. Information systems for logistic automation processes enable the automation of all information and technological activities of the transport enterprises participating in the processes of the freight transportation organization. Automation of transport logistics is necessary to increase the efficiency and optimization of transport. Due to computer data processing, introduction of information systems for routing, accounting and planning at the transport enterprises, transport logistics has reached a totally new level (Shcherbakov et al., 2016).

The effective automation of transport logistics systems depends significantly on the set of hardware and software tools that make it possible to develop programs, which are efficient in terms of the amount of software code and the speed of program execution (Cleary, 2019, Williams, 2019).

To create automated systems for the optimal organization of freight transportation, it is effective to use object-oriented programming systems, namely: Microsoft Visual Studio, Embarcadero RAD Studio, and others (Embarcadero RAD; Poliakov, 2019; Sharp, 2020). All these systems provide means of automatic management of the sequence of changes (events) in the computer model, dynamic distribution of data in memory, necessary for building complex mathematical models, standard programs for statistical processing of modeling results (accumulation and output of histograms, average values of random variables, etc.).

Therefore, it is relevant to develop an automated system for optimizing freight transportation by means of object-oriented programming in order to analyze and select the optimal routes and volumes of freight delivery (de Jonge and Scarf, 2020).

1.3 Objectives

The purpose of this work is to use modern computer information technologies for modeling and optimizing the operation modes of transport logistics systems. Using the Embarcadero RAD Studio object-oriented programming system (Embarcadero RAD), it is necessary to develop an automated system for optimizing freight transportation on the transport network. This system contributes to searching for the shortest distances and determining the optimal volumes of freight transportation on a given transport network.

2 Mathematical model of transport task

In order to find the most economical plan for the transportation of goods in transport logistics, specialized methods are used, which are more effective than methods designed for solving general problems in linear programming. Among these methods, the key place is occupied by transportation routing (the transport problem), which belongs to the class of linear programming problems (Shortle et al., 2018; Trivedi, 2016).

The classical formulation of the transport task (TT) looks like this: at m points of departure (production or extraction) (PP) (A_1, A_2, …, A_m) there are, respectively, a_1, a_2, …, a_m units of homogeneous (or interchangeable) freight (resource), which needs to be delivered to n points of destination (consumption) (PD) (B_1, B_2, …, B_n) in the required number of b_1, b_2, …, b_n units. Let us denote by a_i: freight stocks at the i-th point of departure of the freight transport A_i; by b_j: cargo needs at the j-th destination point of the PD B_j; by x_{ij}: the number of units of freight transported from the point A_i to the point B_j; and by c_{ij} tariffs (cost) of transporting a unit of freight from the i-th point of departure to the j-th destination. The mathematical model of the transport task is as follows (Shortle et al., 2018).

It is necessary to determine the value of the objective function:

$$Z = \sum_{j=1}^{n} \sum_{i=1}^{m} c_{ij} x_{ij} \to \min . \quad (1)$$

Subject to restrictions:

$$\begin{cases} \sum_{j=1}^{n} x_{ij} = a_i & \left(i = \overline{1,\ m}\right) \\ \sum_{i=1}^{m} x_{ij} = b_j & \left(j = \overline{1,\ n}\right) \end{cases} . \quad (2)$$

At the same time, it is necessary for the transportation to be positive:

$$x_{ij} \geq 0 \quad \left(i = \overline{1,\ m};\ j = \overline{1,\ n}\right). \quad (3)$$

The objective function Z in Eq. (1) is the total cost of all transportation tasks. It is recorded as a double amount. The internal sum corresponds to points of production, with the external sum corresponding to points of consumption.

It is necessary to transport the freight in such a way as to satisfy all orders, with the minimum cost or the minimum time of its delivery as the criterion of optimality.

TTs can be of two types:

1. Closed-type TT (when the total volume of freight in all PPs is equal to the total volume of consumption in all PDs):

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j . \tag{4}$$

2. Open-type TT (when the total volume of freight in all PPs is not equal to the total volume of consumption in all PDs):

$$\sum_{i=1}^{m} a_i \triangleright \sum_{j=1}^{n} b_j \quad \text{or} \quad \sum_{i=1}^{m} a_i \triangleleft \sum_{j=1}^{n} b_j . \tag{5}$$

When solving a TT, as a rule, open-type tasks are reduced to TTs of closed type. There are two well-known methods of reducing an open TT to a balanced form:

- introduction of additional (fictitious) PP or PD freight;
- reduction of the volume of demand (supply) by the amount of discrepancy in one of the PDs (PPs).

Further, the problems are solved by methods developed for closed transport tasks.

Practically, as a rule, real transport and logistics structures are formed according to territorial and production principles and are limited to several adjacent districts or regions, on the territory of which producers and consumers of certain products or resources are located. As a rule, there are several dozen objects. Therefore, the automated system for optimization of cargo transportation on the transport network is designed to solve such transport problems of medium complexity.

2.1 Optimization of transport routing

Special attention should be paid to such transport tasks, in which it is necessary to minimize the execution time of the specified work volumes. Time can be a criterion for solving such TTs, since, in certain life situations, while planning transportation, it is necessary to minimize the total time of transportation, but not the transport costs. This criterion is often used during agricultural operations (harvesting), transportation of raw materials and perishable products, etc.

The optimal plan for such TTs will be a plan according to which all cargo from PPs to PDs will be delivered as soon as possible. Thus, it is necessary to distribute deliveries (transportation) in such a way that the longest transportation time is minimal. Provided transportation starts at the same time (with a small margin of error), the transportation plan will be completed within the time equal to the longest transportation.

The problems of finding the shortest paths belong to the fundamental problems of combinatorial optimization, as many of them can be reduced to finding the shortest path on the network (Trivedi, 2016). There are different types of tasks with regard to the shortest path:

1. between two given vertices;
2. between one vertex and all others;
3. between each pair of vertices in the network;
4. between two specified vertices for paths passing through one or more specified vertices;
5. the first, second, third, etc. shortest paths in the network.

Today, there are quite a few algorithms for finding the optimal TT solution, but practically, only a few of them deserve attention, in particular, the well-known algorithms of Dijkstra and Floyd (Shortle et al., 2018).

Dijkstra's method searches for the shortest path from a given vertex (source) to all other vertices in the graph. Floyd's method searches for the shortest path in turn from each vertex to all others, and this is how it differs from Dijkstra's one. The matrix method is very similar to Floyd's method, it enables you to find the matrix $\boldsymbol{D}$, with the elements of which being equal to the minimum values of the routes, as well as the distance from each vertex to itself.

The transport task is significantly complicated in production and transport economic systems, which produce a wide range of products and raw materials at several independent industrial facilities, with different types of transport used for their transportation. It should be noted that in practice, transportation can be performed directly from suppliers to consumers, as well as through several intermediate points, creating complex transport communications.

Transport tasks, in this interpretation, belong to the class of network tasks. The interpretation of TTs in network form makes it possible to take into account the capacity of individual sections of the transport network. In network form, it is easier to take into account loading and discharging at intermediate stations, with each considered a hub.

It should also be noted that the solution of network TTs directly on the topology of the transport network does not allow for algorithm development or further automation of the search for the optimal transportation plan based on modern computer technology.

At the same time, it is more expedient to submit the network TTs in matrix form, which enables algorithm development for the optimal solution search. The paper proposes a method for minimizing the matrix form of network TTs, which greatly simplifies the procedure for solving large network TTs and reduces the number of necessary computational operations.

To solve this problem, the algorithms considered cannot be applied because Dijkstra's algorithm is insufficient (by applying it, we find only one line from the matrix of shortest distances), and Floyd's algorithm is redundant (it generates a matrix of the shortest distances between any PP_i and PD_j).

A more economical and effective method of solving network TTs of large dimensions is proposed, which combines the methods of solving the classical TTs in matrix form with a modification of the well-known Dijkstra method for finding the shortest distances in the network of connections between PP_i and PD_j, given in the form of a graph. It is this combination that makes it possible to carry out a well-defined algorithm development for network TTs and to apply modern computer technologies for its solution.

The modification of Dijkstra's algorithm lies in including an ordered system of sorting supplier vertices (m) in it, on the one hand, and user vertices (n), on the other. Thus, we add two nested loops, iterating over all suppliers as a vertex of V_m and all users as a vertex of V_n. Thanks to this, it is possible to find the shortest paths from each supplier to each user and determine the cost characteristics of transportation directly from PP_i to PD_j, taking into account intermediate hosts.

2.2 Optimization of freight transportation

Optimization of cargo transportation begins with the construction of a reference (base) plan, which is further improved in order to obtain an optimal transportation scheme using one of the standard methods of finding optimal transportation schemes.

Among many methods of building reference schemes, three of them deserve attention, namely: the methods of the northwest corner (due to its simplicity), the smallest element in the entire transport table (due to its efficiency), and Fogel's approximation (due to its effectiveness) (Shortle et al., 2018; Trivedi, 2016).

The construction of the reference plan by the method of the northwest corner begins by filling in the upper left cell of the table (x_n), with the smaller of the two numbers a_1 and b_1. Then the next cell in a row or column is filled, etc. The filling of the table is finished in the lower right cell.

The idea of the minimum cost method is that at each step, the cell of the table with the lowest cost of transportation of a product unit is filled. Such actions are repeated until all products are distributed between suppliers and consumers.

According to Fogel's approximation method, the difference between the two smallest values in each row and column of the transport table is determined at each step. These differences are recorded in specially designated places in the table. Among all the differences, the largest one is chosen and filled in the cell with the lowest value in the corresponding row or column. If there are several identical largest differences, any corresponding row or column is chosen. When only one row or column remains unfilled, the calculation of differences is stopped, and the table continues to be filled using the method of minimum cost.

The obtained reference scheme of the transportation task must be brought to the optimal transportation scheme. There are several methods of TT optimization, and more precisely, bringing the previously prepared reference scheme to the optimal transportation one. They all give the same results. By applying one of the standard methods of finding optimal transportation schemes (simplex, distributive, potential and differential rent method) to the received reference scheme, it is possible to obtain an optimal transportation scheme (Shortle et al., 2018).

The work process of most methods of TT optimization is based on the construction of closed circuits for the redistribution of cargo flows. The most common method for optimally solving TTs is the method of potentials, since it does not require the compilation of an increased number of additional tables with cell estimates, with the error in the previous calculations corrected in the next steps. The method of potentials enables, based on some reference scheme, building an optimal transportation plan for a finite number of iterations.

The number of iterations required to solve the TT using the potential method depends significantly on the initial scheme. A successful choice of the building method of a reference scheme can significantly reduce the number of iterations and thus speed up the process of solving the problem. Therefore, it is very important to have a fairly simple method, which often enables you to build a scheme that is close to optimal.

3 Development of a software complex and conducting experimental research

The algorithms considered for optimizing routing and freight transportation on the transport network are implemented in the form of a computer software complex, which makes it possible to automate the procedure of finding the shortest distances between given sets of vertices in the network and determining the optimal volumes of transportation on a given transport network.

The complex has been developed using the visual design environment Embarcadero RAD Studio. This system includes a complete set of visual tools for rapid application development (RAD is rapid application development), which supports user interface development and connection to corporate databases (Embarcadero RAD).

The program complex consists of the main form, from which two subprograms are loaded.

3.1 Subprogram of routing optimization

Fig. 1 shows a directed graph of the transport network, with the search for optimal routes performed for the freight transportation, according to different schemes (from one vertex (supplier) to all other vertices (consumers), in turn from each vertex to all other vertices, from two (or several) given vertices to all other vertices).

At the same time, freight transportation can be carried out both directly from suppliers to consumers and through one or more intermediate points.

The vertices on the column indicate the points of departure and destination. The connected arches of the vertices correspond to the points that have a transport connection. The numbers located near each arc correspond to the distances between these points (conditional units (c. u.)).

Fig. 2 shows the subroutine window for determining the optimal routes during the freight transportation according to different schemes. Optimization of transportation routing is as follows.

Initially, the number of available vertices in the graph is introduced. Then, the Distance Table includes initial data that are, distances, in the form of a matrix, between points having interconnections with each other. It should be noted that the entry of initial data is possible directly into the matrix, or in the software, by pre-entering the

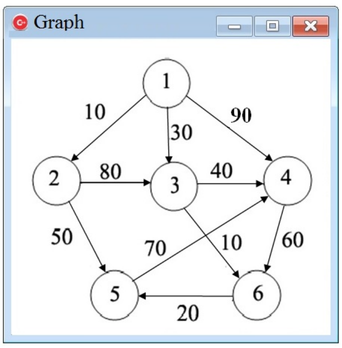

Fig. 1 Graph of the transport network for determining optimal routes

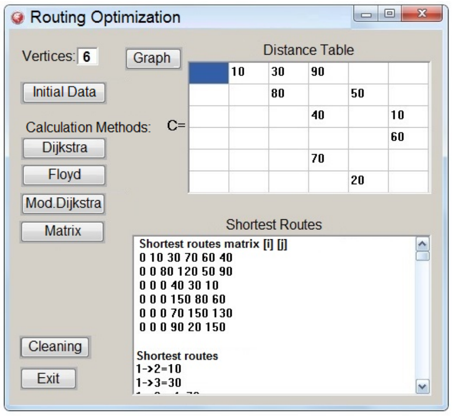

Fig. 2 Window of subprogram for determining the optimal routes

data into the program and entering them into the matrix of transportation when pressing on the Initial Data button.

The search for the shortest routes, according to the corresponding algorithms (Trivedi, 2016), occurs when clicking on the buttons 'Dijkstra', 'Floyd', 'Mod. Dijkstra', 'Matrix'. At the same time, when calculating the method 'Mod. Dijkstra', points 1, 2 are accepted as departure points, and points 3, 4, 5, 6, as destinations. The output of the final results of the calculations is shown in the table 'Shortest Routes'.

Clicking on the 'Clearing' button clears the data entered in the Shortest Routes table. The form with the traffic routes of transportation (Fig. 1) is displayed when clicking on the 'Graph' button. The 'Exit' button completes the work of this subroutine.

Table 1 shows that the results of the shortest routes which were calculated between the corresponding vertices, obtained by different methods, coincide. Thus, the calculation of optimal routes between vertex 1 and all other vertices, obtained by different methods, gives the same results. The results of the shortest route calculation between vertices 1, 2 and all other vertices obtained by the Floyd method and of the modified method Dijkstra also coincide.

3.2 Subprogram of optimizing freight transportation

Fig. 3 shows a non-oriented transport network graph, which optimizes the transportation of freight between departure and destination points, taking into account restrictions on the volume of freights at departure and destination.

The graph in Fig. 3 reflects the ways of connecting departure and destination points. The entire set of its vertices is divided into two subsets. The first subset of vertices includes the points of departure (A_i), with the second subset including the destinations (B_j). The vertices connected by the edges correspond to the points with the

Table 1 Methods for calculating the shortest routes

Calculating methods			
Dijkstra	Floyd		Mod. Dijkstra
1→2 = 10	1→2 = 10	4→1 = 460	1→3 = 30
1→3 = 30	1→3 = 30	4→2 = 460	1→3→4 = 70
1→3→4 = 70	1→3→4 = 70	4→3 = 460	1→2→5 = 60
1→3→6→5 = 60	1→2→5 = 60	4→6→5 = 80	1→3→6 = 40
1→3→6 = 40	1→3→6 = 40	4→6 = 60	
			2→3 = 80
	2→1 = 460	5→1 = 460	2→3→4 = 120
	2→3 = 80	5→2 = 460	2→5 = 50
	2→3→4 = 120	5→3 = 460	2→3→6 = 90
	2→5 = 50	5→4 = 70	
	2→3→6 = 90	5→4→6 = 130	
	3→1 = 460	6→1 = 460	
	3→2 = 460	6→2 = 460	
	3→4 = 40	6→3 = 460	
	3→6→5 = 30	6→5→4 = 90	
	3→6 = 10	6→5 = 20	

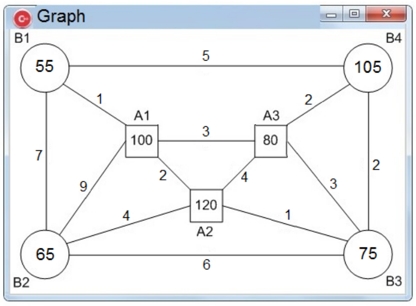

Fig. 3 The transport network graph on which freight transportation is optimized

routes between them. The cost of transportation between the relevant points are marked near each edge (conditional cost units (c. c. u.)). Supply volumes are affixed at the vertices of the departure points, with consumption volumes at the top of the destination (also expressed in c. u.).

It is necessary to find the shortest transport routes between departure and destination, including traffic through intermediate points (which can be both departure and destination points). The calculations are made using a mathematical model of transport tasks Eqs. (1)–(4). The optimality criterion is the minimum cost of transportation.

Fig. 4 shows the calculation results of freight transportation optimization between departure points and destinations on the transport network shown in Fig. 3.

Freight transport is optimized as follows. When clicking on the Initial Data button, the tables 'Transportation Cost' are filled, that is, the cost of transportation between points having connections with each other, data on suppliers 'Suppliers' – volumes of freight at supply points and consumers 'Consumers' – the needs of freights at consumption points. It is also possible to enter the initial data directly into the matrix, or in the software, by pre-entering the data into the program and entering them in the transportation matrix when clicking on the Initial Data button.

Then, by clicking the 'Shortest Routes' button the determination of the shortest routes between supply and consumption points is performed according to the modified Dijkstra method and entered in the Transportation Table.

The reference scheme is built by the method of the smallest (minimum) element of the table when clicking on the Reference Plan button. At the same time, the data is displayed in the Transportation Freight Table, with the shortest routes obtained by the modified Dijkstra method displayed in the field of the Shortest Routes table.

The received reference transport scheme is optimized using potentials, when clicking on the Optimization button. The optimization results are displayed in the Transportation Freight Table.

Label components are used to output the objective function at each iteration and inform the user of the optimal transportation scheme accordingly.

The 'Clear', 'Graph' and 'Exit' buttons placed on this form have a similar purpose.

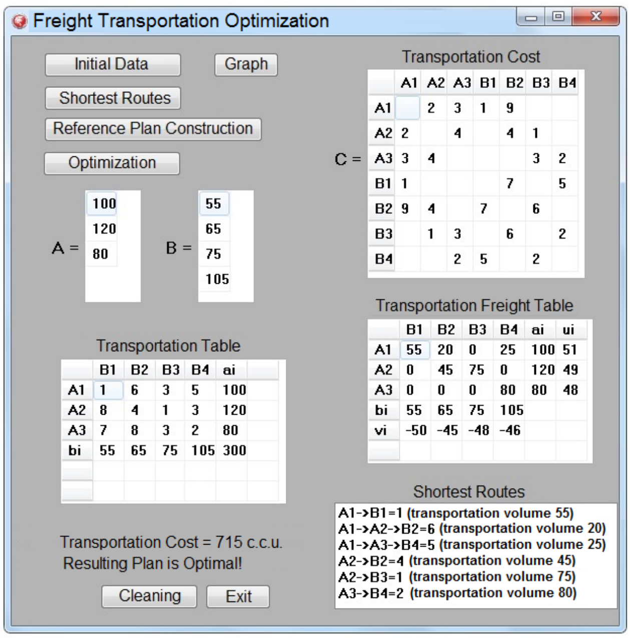

Fig. 4 Window of a subprogram for optimizing freight transportation

4 Conclusion

The work has developed an automated system for optimizing freight transportation on the transport network in the form of a complex computer software using the visual design environment Embarcadero RAD Studio. The program complex consists of the main form, from which two subprograms are loaded.

1. Using the routing optimization subprogram, optimal freight transportation routes along the transport network are sought, according to various schemes (from one vertex (supplier) to all other vertices (consumers), in turn from each vertex to all other vertices, from two (or more) given vertices to all other vertices). At the same time, freight transportation can be carried out both directly from suppliers to consumers and through one or more intermediate points.
2. With the help of the freight transportation optimization subprogram, transportation of freight between supply and consumption points is optimized, taking into account restrictions on the volume of freight at the points of departure and destination. The optimum criterion is the minimum cost of transportation.

References

Boldizsár, A., Meszaros, F., Torok, E. (2022) "Social and Economic Analysis of the EU Road Freight Transport Fleet", Cognitive Sustainability, 1(2). https://doi.org/10.55343/CogSust.16

Chiappone, S., Giuffrè, O., Granà, A., Mauro, R., Sferlazza, A. (2016) "Traffic simulation models calibration using speed-density relationship: an automated procedure based on genetic algorithm", Expert Systems with Applications, 44, pp. 147–155. https://doi.org/10.1016/j.eswa.2015.09.024

Christopher, M. (2016) "Logistics & supply chain management", Pearson FT Press. ISBN 978-1-292-08382-7

Cleary, S. (2019) "Concurrency in C# Cookbook", O'Reilly Media, Inc. ISBN 978-1492054504

de Jonge, B., Scarf, P. A. (2020) "A review on maintenance optimization", European Journal of Operational Research, 285(3), pp. 805–824. https://doi.org/10.1016/j.ejor.2019.09.047

Elovoy, I. A., Lebedev, I. A. (2018) "Интегрированные логистические системы доставки ресурсов: (теория, методология, организация)" (Integrated logistics systems of resource delivery: (theory, methodology, organization)), Pravo i Ekonomika. ISBN 978-985-442-992-2 (in Russian)

Escobar, J. W., Marin, A. A., Lince, J. D. (2020) "Multi-objective mathematical model for the redesign of supply chains considering financial criteria optimisation and scenarios", International Journal of Mathematics in Operational Research, 16(2), pp. 238–256. https://doi.org/10.1504/IJMOR.2020.105903

Havelock, J., Ommen, B. J., Granmo, O.-C. (2018) "Novel distance estimation methods using "stochastic learning on the line" strategies", IEEE Access, 6, pp. 48438–48454. https://doi.org/10.1109/ACCESS.2018.2868233

Heidari, F., Zegordi, S. H., Tavakkoli-Moghaddam, R. (2018) "Modeling truck scheduling problem at a cross-dock facility through a bi-objective bi-level optimization approach", Journal of Intelligent Manufacturing, 29(5), pp. 1155–1170. https://doi.org/10.1007/s10845-015-1160-3

Hess, S., Quddus, M., Rieser-Schüssler, N. (2015) "Developing advanced route choice models for heavy goods vehicles using GPS data", Transportation Research Part E: Logistics and Transportation Review, 77, pp. 29–44. https://doi.org/10.1016/j.tre.2015.01.010

Hu, C., Lu, J., Liu, X., Zhang, G. (2018) "Robust vehicle routing problem with hard time windows under demand and travel time uncertainty", Computers & Operations Research, 94, pp. 139–153. https://doi.org/10.1016/j.cor.2018.02.006

Khorshidian, H., Akbarpour Shirazi, M., Fatemi Ghomi, S. M. T. (2019) "An intelligent truck scheduling and transportation planning optimization model for product portfolio in a cross-dock", Journal of Intelligent Manufacturing, 30(1), pp. 163–184. https://doi.org/10.1007/s10845-016-1229-7

Kumar, R. S., Kondapaneni, K., Dixit, V., Goswami, A., Thakur, L. S., Tiwari, M. K. (2016) "Multi-objective modeling of production and pollution routing problem with time window: a self-learning particle swarm optimization approach", Computers & Industrial Engineering, 99, pp. 29–40. https://doi.org/10.1016/j.cie.2015.07.003

Lai, X., Bierlaire, M. (2015) "Specification of the cross-nested logit model with sampling of alternatives for route choice models", Transportation Research Part B: Methodological, 80, pp. 220–234. https://doi.org/10.1016/j.trb.2015.07.005

Lu, F., Bi, H., Huang, L., Bo, W. (2017) "Improved genetic algorithm based on delivery time control for Fourth Party Logistics", In: 2017 13th IEEE Conference on Automation Science and Engineering (CASE), Xi'an, China, pp. 390–393. ISBN 978-1-5090-6782-4 https://doi.org/10.1109/COASE.2017.8256134

Luisa De Maio, M., Vitetta, A. (2015) "Route choice on road transport system: a fuzzy approach", Journal of Intelligent & Fuzzy Systems, 28(5), pp. 2015–2027. https://doi.org/10.3233/IFS-141375

Manley, E. J., Orr, S. W., Cheng, T. (2015) "A heuristic model of bounded route choice in urban areas", Transportation Research Part C: Emerging Technologies, 56, pp. 195–209. https://doi.org/10.1016/j.trc.2015.03.020

Mirotin, L. B., Gudkov, V. A., Zyryanov, Z. Z. (2019) "Управление грузопотоками в транспортно-логистических системах" (Management of freight flows in transport and logistics systems), Telecom. ISBN 978-5-9912-0133-9 (in Russian)

Mohammed, M. A., Abd Ghani, M. K., Hamed, R. I., Mostafa, S. A., Ahmad, M. S., Ibrahim, D. A. (2017) "Solving vehicle routing problem by using improved genetic algorithm for optimal solution", Journal of Computational Science, 21, pp. 255–262. https://doi.org/10.1016/j.jocs.2017.04.003

Nasiri, M. M., Rahbari, A., Werner, F., Karimi, R. (2018) "Incorporating supplier selection and order allocation into the vehicle routing and multi-cross-dock scheduling problem", International Journal of Production Research, 56(19), pp. 6527–6552.
https://doi.org/10.1080/00207543.2018.1471241

Nyrkov, A., Belousov, A., Sokolov, S. (2015) "Algorithmic support of optimization of multicast data transmission in networks with dynamic routing", Modern Applied Science, 9(5), pp. 162–176.
https://doi.org/10.5539/mas.v9n5p162

Poliakov, K. J. (2019) "Программирование. Python. C++" (Programming. Python. C++), BINOM. ISBN 978-5-9963-4137-5 (in Russian)

Embarcadero RAD "RAD Studio 11 Product Reviewer"s Guide", [online] Available at: http://docwiki.embarcadero.com/RADStudio/11 [Accessed: 01 November 2022]

Rodado, D. N., Escobar, J. W., García-Cáceres, R. G., Atencio, F. A. N. (2017) "A mathematical model for the product mixing and lot-sizing problem by considering stochastic demand", International Journal of Industrial Engineering Computations, 8, pp. 237–250.
https://doi.org/10.5267/j.ijiec.2016.9.003

Sergeev, V. I. (2019) "Управление цепями поставок" (Supply chain management), Jurait. ISBN 978-5-534-01356-6 (in Russian)

Sharp, J. (2020) "Microsoft Visual C# Step by Step", Pearson Education, Inc. ISBN 978-0-13-761983-2

Shcherbakov, V. V., Merzliak, A. V., Kostur-Ogly, E. O. (2016) "Автоматизация бизнес-процессов в логистике" (Automation of business processes in logistics), Moscow: Piter. ISBN 978-5-49-601409-0 (in Russian)

Shortle, J. F., Thompson, J. M., Gross, D., Harris, C. M. (2018) "Fundamentals of queueing theory", John Wiley & Sons, Inc. ISBN 9781118943526
https://doi.org/10.1002/9781119453765

Soeanu, A., Ray, S., Berger, J., Boukhtouta, A., Debbabi, M. (2020) "Multi-depot vehicle routing problem with risk mitigation: model and solution algorithm", Expert Systems with Applications, 145, 113099.
https://doi.org/10.1016/j.eswa.2019.113099

Sun, Y. (2020) "Green and reliable freight routing problem in the road-rail intermodal transportation network with uncertain parameters: a fuzzy goal programming approach", Journal of Advanced Transportation, 2020, 7570686.
https://doi.org/10.1155/2020/7570686

Tintu, G., Amudha, T. (2020) "Genetic algorithm based multi-objective optimization framework to solve traveling salesman problem", In: Sharma, H., Govindan, K., Poonia, R. C., Kumar, S., El-Medany, W. M. (eds.) Advances in Computing and Intelligent Systems: Proceedings of ICACM 2019, Springer, pp. 141–151. ISBN 978-981-15-0221-7
https://doi.org/10.1007/978-981-15-0222-4_12

Tokgöz, E., Alwazzi, S., Trafalis, T. B. (2015) "A heuristic algorithm to solve the single-facility location routing problem on Riemannian surfaces", Computational Management Science, 12(3), pp. 397–415.
https://doi.org/10.1007/s10287-014-0226-6

Trivedi, K. S. (2016) "Probability and Statistics with Reliability, Queueing, and Computer Science Applications", Wiley. ISBN 978-0471333418

Xu, Y., Zhou, J., Xu, W. (2020) "Regret-based multi-objective route choice models and stochastic user equilibrium: a noncompensatory approach", Transportmetrica A: Transport Science, 16(3), pp. 473–500.
https://doi.org/10.1080/23249935.2020.1719550

Williams, E. (2019) "C++ Concurrency in Action", Manning Publications. ISBN 9781617294693

Yang, Y., Dong, H., Qin, Y., Zhang, Q. (2016) "Parameter calibration method of microscopic traffic flow simulation models based on orthogonal genetic algorithm", In: Proceedings of the 22nd International Conference on Distributed Multimedia Systems, Salerno, Italy, pp. 55–60. ISBN 9781510841284
https://doi.org/10.18293/DMS2016-047

Židová, Z., Zitrický, V. (2023) "The Impact of the Use of Technology in International Rail Freight Transport on Transport Processes", Promet - Traffic & Transportation, 35(2), pp. 243–254.
https://doi.org/10.7307/ptt.v35i2.123