Optimization Method of the Multimodal Transportation on the Base of Dijkstra’s Algorithm

S N Kornilov¹, E A Deev¹, J I Lukyanov¹

¹Nosov Magnitogorsk State Technical University, Lenina St., 38, Magnitogorsk 455000, Russia

E-mail: kornilov_sn@mail.ru

Abstract. The issues and main problems of the organization of multimodal transportation in Russia are considered in this article. A new method of the optimization of the described cargo transportation is proposed. The advantage of this method is the development of the mathematical model on the base of Dijkstra’s algorithm that could select the most rational variant of the container cargo transportation. The target function of the mathematical model is represented – costs saving of the cargo delivery. Algorithms of the modal operation and software product. The approbation of the method for the certain case of the final products shipping to a consumer is implemented.

1. Introduction
In the present conditions the necessity for multipurpose development of the transport infrastructure of Russian Federation has emerged. The most significant document is “Transport strategy of development of Russia till 2030”, according with it one needs to plan further development of the transport complex of our country. One of the key tasks of this document is increasing of the container transportation scope [1]. This is connected with that the container transportation is supposed to be economically profitable and a convenient method of cargo delivery, especially over long distances with considerable quantity of transshipment points. Rapidity of loading and unloading works significantly reduces down time of the transport what substantially reduces traffic handling cost. Container shipping enables to create the conditions for multimodal transportation arrangement, which are in high demand at the present time in connection with the world economic globalization [2-4].

2. Topicality of creation of the multimodal transportation optimization method
One of the factors, exerting an adverse impact on the multimodal transport volume grow in Russia, is excessive workload of railway public tracks, due to the annual growth of the carriage rolling stock [5-7] ‘figure 1’. This, in its turn, leads to increasing average time of the wagon turnover [6-8] ‘figure 1’.

Dimensions of container shipping of trailing loads in Russia are growing annually, but according to experts, this growth is not sufficient [5-7] and is due to a number of issues. Namely: inequality in directions and region of destination, tarification with multiplying factor, lack of container overload rating on the railway, deficit of logistic centers, which coordinate warehouse and transportation services [9].

According to the Ministry of Transport of Russian Federation, transport costs rate in cost of goods in Russia is almost twice higher than the equivalent figures in developed market economies [10].
Figure 1. Dimensional change of the carriage rolling stock and wagon turnaround of Russian Federation.

This problem hasn’t been solved yet. Existing ways of multimodal transportation are namely aimed at application of additional technical means and demand considerable capital investment [11]. Therefore the method development is topical. This method helps to consider different scheme options in container cargo delivery and choose the most rational ones without raising additional funds for the development of the network of rails.

3. The economic and mathematical model

The economic and mathematical model is developed for the multimodal transportation optimization. The loss function of the model is represented below - lowering costs of the delivering cargo in the container [12].

\[ F = f(t_{\text{deliv.}}, 3_{\text{sh.}}, K_{\text{ex. expen.}}, L_{\text{trans.}}) \rightarrow \min, \]  

where:  
\( t_{\text{deliv.}} \) - term of cargo delivery, days;  
\( 3_{\text{sh.}} \) - shifting of cargo expenses, rub.;  
\( K_{\text{ex. expen.}} \) - extra expenditures, connected with the transportation optimization, rub.;  
\( L_{\text{trans.}} \) - haulage distance of cargo, km.

The following limiting conditions are imposed on the loss function:

\[ \begin{cases} 
  t_{\text{deliv.}} \leq t_{\text{plan.}}; \\
  3_{\text{sh.}} \leq 3_{\text{plan.}}; \\
  K_{\text{ex. expen.}} \leq K_{\text{plan.}}; \\
  L_{\text{trans.}} \leq L_{\text{plan.}} 
\end{cases} \]  

where:  
\( t_{\text{plan.}} \) – planned term of delivery, days;  
\( 3_{\text{plan.}} \) - planned delivering cargo expenses, rub.;  
\( K_{\text{plan.}} \) – planned extra expenditures, rub.;  
\( L_{\text{plan.}} \) - maximal possible planned carrier route amount of length.

The economic and mathematical model is developed in Visual Studio 2015. Dijkstra’s algorithm was used in the calculations [13].
With the help of this model one can find the most optimal, from the customer’s viewpoint, option of cargo delivery from the state of cargo flow beginning to the cargo station destination. The model while running sorts out all available vertexes in the data base of the city. The weight is attributed to each vertex, it is the distance from the first vertex till the current one [14]. Each vertex can also be marked. Sorting out all cities, the algorithm calculates the route for each vertex, and if it turns out to be the shortest, it marks out the vertex. The weight of the route becomes the weight of the current vertex. For the all nearest vertexes the model also calculates the weight, with this in no circumstances without marking them out. The model finishes its work, after reaching the final vertex, and the weight of the final vertex becomes the weight of the shortest way [15].

The same integrations are made for value and temporary transportation indexes. In the result of the work of the algorithm the information collection is formed, which includes three groups of indexes, according to the loss function [16]. Accordingly, interests of the sides of transportation in the developed model are considered on a number of indexes: financial expenses, time of delivery, the length of route.

The algorithm of the work of the optimization model is represented in the ‘figure 2’. The algorithm, laid down in the program code of the calculations, is represented in the ‘figure 3’.

The program product has been developed by the authors for automated calculations of possible ways of container cargo delivery, the program helps the user to get the information about the shortest unimodal and combined ways of transportation.

The algorithm of the program product consists of five basic blocks, each of which performs a certain functionality and can not be excluded.

The first block is basic. On this stage the data are loaded, which are necessary for calculation and comparison with further option of delivery. The database is a dynamic object. Therefore changing of distances between points, addition of new routes and transshipment points are possible. To start calculations, after data downloading, it is necessary to input the starting and finishing points of the cargo transportation. After required data obtained, the program passes to the next block.

The second block is necessary for forming the minimal assortment of cargo carrier routes. On this stage identification of the nearest available locations for the cargo delivery is made [17]. The nearest point to the sender of freight, through which the cargo can be sent to the receiver, is rencorded in the database. After the necessary analysis, the program passes to routes searching.

The third block – the search for the shortest carrier routes. Map with cities and roads between them is a measured directed graph. Therefore Dijkstra’s algorithm is used for the search for the shortest way to the final destination. Search is made on the charts of railroads and roads. Obtained routes are recorded in the shortest unimodal ways database, which makes combined routes after forming.

The fourth block is for making combined routes of delivery. Using data from the third block, the analysis of the shortest ways at availability of transshipment points is made [18]. When the first trasshipment point is found, the shortest route determination is made while transshipping on another kind of transport. When the program gets a new route, a record is made in the combined ways database. The route is also sent again to search for further transshipment points.

After forming unimodal and combined ways, the program passes to the fifth block. Indicators of time and transportation financial expenses are calculated on this stage. In the result of implementation of the last block the chart is displayed on the user’s screen. The chart consists of the shortest unimodal and combined routes of delivery and also their corresponding indicators of time and financial expenses.
Figure 2. The algorithm of the work of the optimization model.
Figure 3. The algorithm, laid down in the program code of the model calculations.
4. Approbation of the multimodal transportation optimization method

After making a verification of the created model using an example of delivery of cold-rolled galvanized steel in ten 20-pounds containers, from Magnitogorsk to Moscow, the following results were obtained (table).

| Route № | Distance of carriage, km. | Delivery time, days | Financial expenses, rub. |
|---------|---------------------------|---------------------|-------------------------|
| 1       | 2545                      | 14,3                | 94889                   |
| 2       | 2418                      | 10,29               | 757840                  |
| 3       | 2416                      | 6,16                | 1449600                 |
| 4       | 2196                      | 12,3                | 85378                   |
| 5       | 2008                      | 5,2                 | 1081474                 |
| 6       | 2008                      | 5,12                | 1204800                 |
| 7       | 2525                      | 14,1                | 94889                   |
| 8       | 1972                      | 7,9                 | 940184                  |
| 9       | 1700                      | 4,33                | 1020000                 |

Then it is necessary to input criteria, in which the customer is interested. In the example above one can compare options of delivery on all three indicators.

If a specific criterion will be the distance, the most optimal option will be the route number 9, because it is the shortest one, its length is 1700 km. Comparing by the time of delivery, the route number 9 again will be a priority.

If the determining factor is the cost of delivery, it is necessary to choose the route number 4.

The developed model of multimodal transportation optimization enables to organize both unimodal and multimodal types of container shipment.

Customer’s preference can be different, but for any customer the main criterion - is the effectiveness of production, transporting and the flow of money [19]. In order to exclude subjectivity of choice of this or that delivery route, the authors offer to implement the universal criterion of effectiveness evaluation, by which the customer will choose the most optimal option of delivery. The idea of this criterion is that one from three parameters (delivery time, distance, the cost of transportation) will be constant, or in other words, a limiting factor.

As a criterion of effectiveness of multimodal transportation we accept multiplication of money expenses and time of delivery, where financial expenses or time of delivery will be constant.

5. Conclusion

Applying the method in the carriers’ practical work will help to reduce time in choosing rational option of delivery, take into account customer’s concerns and get maximal profit.

This method of the multimodal transportation organization should create extra competitive advantages for participants of transportation process, what has the primary significance in open market [20]. This method will also be useful for the company JSC Russian Railways because it will help to lower arrangement of tracks workload through reducing required carriage rolling stock, without reducing the volume of transport.

6. References

[1] Transport strategy of development of Russia till 2030 Official site of The Russian Government - URL: http://government.ru/docs/13190/ (date of the request 25.12.17)

[2] Rakhmanulov A, Sladkowskii A and Osintsev N 2016 Design of an ITS for industrial enterprises Intelligent transportation systems - problems and perspectives. Studies in Systems Decision and Control vol 32 Cham: Springer International Publishing pp 161-215

[3] Konings R, Van Der Horst M, Hutson N and Kruse J 2010 Comparative strategies for
developing hinterland transport by container barge analysis for Rotterdam and U.S. ports

Transportation research record vol 2166 pp 82-89

[4] Beuthe M, Jourquin B and Geerts J-F 2001 Freight transportation demand elasticities: a geographic multimodal transportation network analysis Transportation research vol 4 p 253

[5] Annual report of JSC Russian Railways for 2013 Official site of JSC Russian Railways - URL: ar2013.rzd.ru/ru/performance-overview/freight-transportation (date of the request 23.09.2017)

[6] Annual report of JSC Russian Railways for 2014 Official site of JSC Russian Railways - URL: ar2014.rzd.ru/ru/performance-overview/freight-transportation (date of the request 19.01.2017)

[7] Annual report of JSC Russian Railways for 2015 Official site of JSC Russian Railways - URL: ar2015.rzd.ru/ru/performance-overview/freight-transportation (date of the request 13.05.2017)

[8] Shenfeld K P 2008 About value of the indicator “Wagon turnover” in modern conditions Vestnik RRIRT vol 6 pp 10-12

[9] Kornilov S N, Rahmangulov A N, Akmanova Z S and Fridriksson O V 2012 Mechanism of optimization of time movement of the container flow Vestnik USURT vol 2 pp 67-74

[10] Main outcomes of the implementation of the Federal Target Programme “Modernization of the transport system in Russia (2002-2010)” Official site of the Ministry of transport in Russia - URL: http://www.mintrans.ru/upload/iblock/001/itogi_fzp_2002_2009.doc (date of the request 21.01.2018)

[11] Deev Е А and Kornilov S N 2016 The method of the multimodal container transportation optimization Modern problems of transport complex of Russia vol 1 (6) pp 17-20

[12] Deev Е А and Kornilov S N 2016 The way of improvement of the multimodal transportation organization Role of science in the development of society vol 3 pp 25-31

[13] Alberts D, Cattaneo G and Italiano G 1992 An empirical study of dynamic graph algorithms. In Proc. Seventh ACM-SIAM Symp. Discrete Algorithms (SODA) pp 192–201

[14] Aleksandrov L, Djidjev H, Guo H and Maheshwari A 2004 Partitioning planar graphs with costs and weights. In Algorithm Engineering and Experiments: 4th International Workshop ALENEX 2002

[15] Bronnimann H, Iacono J, Katajainen J, Morin P, Morrison J and Toussaint G 2004 Space-efficient planar convex hull algorithms Theoretical Computer Science 321: pp 25-40

[16] Thulasiraman K, Nishiziki T and Xue G 2008 The Handbook of Graph Algorithms and Applications vol 1 Theory and Optimization. ChapmanHall/CRC

[17] Current status and forecast of container transportation market in Russia Portal for specialists in transport industry - URL: http://rostransport.com/transportrf/pdf/48/46-51.pdf (date of the request 10.09.2017)

[18] Nikiforov V S 1999 Multimodal transportation and transportation logistics (Novosibirsk: “SSUST”) p 103

[19] Fridriksson O V 2012 Justification of the cost-effectiveness of accelerating of rolled metal products container transportation Ural Transport vol 1 pp 26-38

[20] Kornilov S N and Fridriksson O V 2012 The method of the container cargo delivery Modern problems of the transport complex of Russia vol 2 pp 85-92