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Algorithm for adjusting cargo delivery routes taking into account the state of the resource allocation system of the road and transport infrastructure

V A Buyvis, E N Yuryeva and A V Novichikhin

Siberian State Industrial University, 42 Kirova str., Novokuznetsk, 654007, Russia

E-mail: Buyvis_va@mail.ru

Abstract. The features of the provision of transport and logistics services by road transport in the conditions of the Russian Federation are determined. The urgency of solving the issue of reducing costs by adjusting routes of cargo delivery by road transport is substantiated. It should be made taking into account the state of the resource allocation system of the road and transport infrastructure. An additional set of indicators is proposed, which allows the process of adjusting the routes of cargo delivery to be divided into three stages and taking it into account the state of the resource allocation system of the road and transport infrastructure. An algorithm is developed for adjusting the routes of cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure. The problem of adjusting the routes of cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure is solved. The proposed algorithm for correcting cargo delivery routes allows it to be used for solving the problem of multi-criteria choice optimization of the route option that best meets all the requirements declared by users of the road and transport infrastructure.

1. Introduction

In the Russian Federation, the share of losses related to transport and logistics services fluctuates at the level of 20% of the gross domestic product, therefore, the issue of reducing them to the level of costs in countries such as the USA, Germany (with costs two times lower) is currently relevant [1]. Automobile transport is the second (after rail transport) in terms of the volume of transport and logistics services provided. The high value of transport and logistics costs in this sector is predetermined by the state of the road complex, which does not fully meet the modern requirements of the economy [2, 3]. The share of roads that meet regulatory requirements for 2020 is 44% [4].

Under the term "tariff distance for the cargo delivery" the legal system understands the shortest distance between the points of departure and destination, determined by the road network. Therefore, transport and logistics companies strive to lay their routes for the cargo transportation along the trajectory that is as close as possible to this distance, without taking into account the state of the resource allocation system of the road and transport infrastructure.

2. Development of an algorithm for adjusting cargo delivery routes, taking into account the state of the resource allocation system of the road and transport infrastructure

Most of the works that determine the route of cargo delivery [5, 6] do not consider the influence of the transportation process organized by a transport and logistics company on the value of the following additional costs:

- additional financial investments in the maintenance of the road infrastructure, ensuring the corresponding state of the infrastructure for the increased volume of traffic;
- an increase in the costs of enterprises due the increase in the time spent by passengers travelling;
- losses from an increase in the number of road accidents, etc.

The following set of indicators is proposed as a toolkit that will allow such costs to be taken into account [7]:

- infrastructure indicator Ind_1, which characterizes the length of the sections of transport communications with restrictions on traffic capacity due to non-compliance with regulatory requirements;
- the indicator of transport work Ind_2, characterizes the volume of traffic following the reserve routes due to the failure of highways, along which the main routes are laid, to meet the regulatory requirements, transport and operational indicators;
- operational indicator Ind_3, characterizing the amount of shipments delivered by road transport in time exceeding the standard (contractual) period;
- social indicator Ind_4, characterizes the amount of additional time spent by the population travelling due to the non-compliance of highways with regulatory requirements;
- economic indicator Ind_5 – characterizes the efficiency of investments directed to the system of the road complex; it is proposed to use net discounted income as an indicator.

The set of indicators presented above makes it possible to divide the process of adjusting cargo delivery routes into three stages and to carry it out taking into account the state of the resource allocation system of the road and transport infrastructure:

- primary selection of routes;
- comprehensive assessment;
- the final stage is the ranking of routes using the method of hierarchies analysis.

The algorithm for adjusting the routes for the cargo delivery taking into account the state of the resource allocation system of the road and transport infrastructure is shown in figure 1.

At the first stage, during the initial selection of routes, road facilities are included that allow transportation to be carried out without additional capital investments (for example, for the reconstruction of road facilities, such as bridges, road surfaces, etc.). Routes, on which technical or technological restrictions do not allow transportation to be organized, are not allowed to the second stage.

At the second stage, the indicators are determined and ranked by the method of expert assessments.

The process of adjusting the routes for the cargo delivery taking into account the state of the resource allocation system of the road and transport infrastructure assumes that the following conditions are met:

$$Ind_1(t+1) \leq Ind_1(t), t \in [0,T] \tag{1}$$
$$Ind_2(t+1) \leq Ind_2(t), t \in [0,T] \tag{2}$$
$$Ind_3(t+1) \leq Ind_3(t), t \in [0,T] \tag{3}$$
$$Ind_4(t+1) \leq Ind_4(t), t \in [0,T] \tag{4}$$
$$Ind_5(t+1) \geq Ind_5(t), t \in [0,T] \tag{5}$$

where t – the settlement period, years;
T – the duration of the project, years.

For routes in which the adjustment process is based on a fuzzy form of presentation of primary and intermediate data, a tool to justify the choice of the assessment of the state of the resource allocation

system of the road and transport infrastructure (at a qualitative level) is proposed [8]; the following condition is proposed for their assessment and selection (6):

$$SSRR(t + 1) \geq \text{SSRR}(t) , t \in [0, T] \tag{6}$$

where SSRR is an assessment of the state of the resource allocation system of the road and transport infrastructure.

The final stage is the ranking of routes using the method of hierarchies analysis [9]. Routes that pass the scoring and selection procedure described above are included in the package and prepared for implementation.
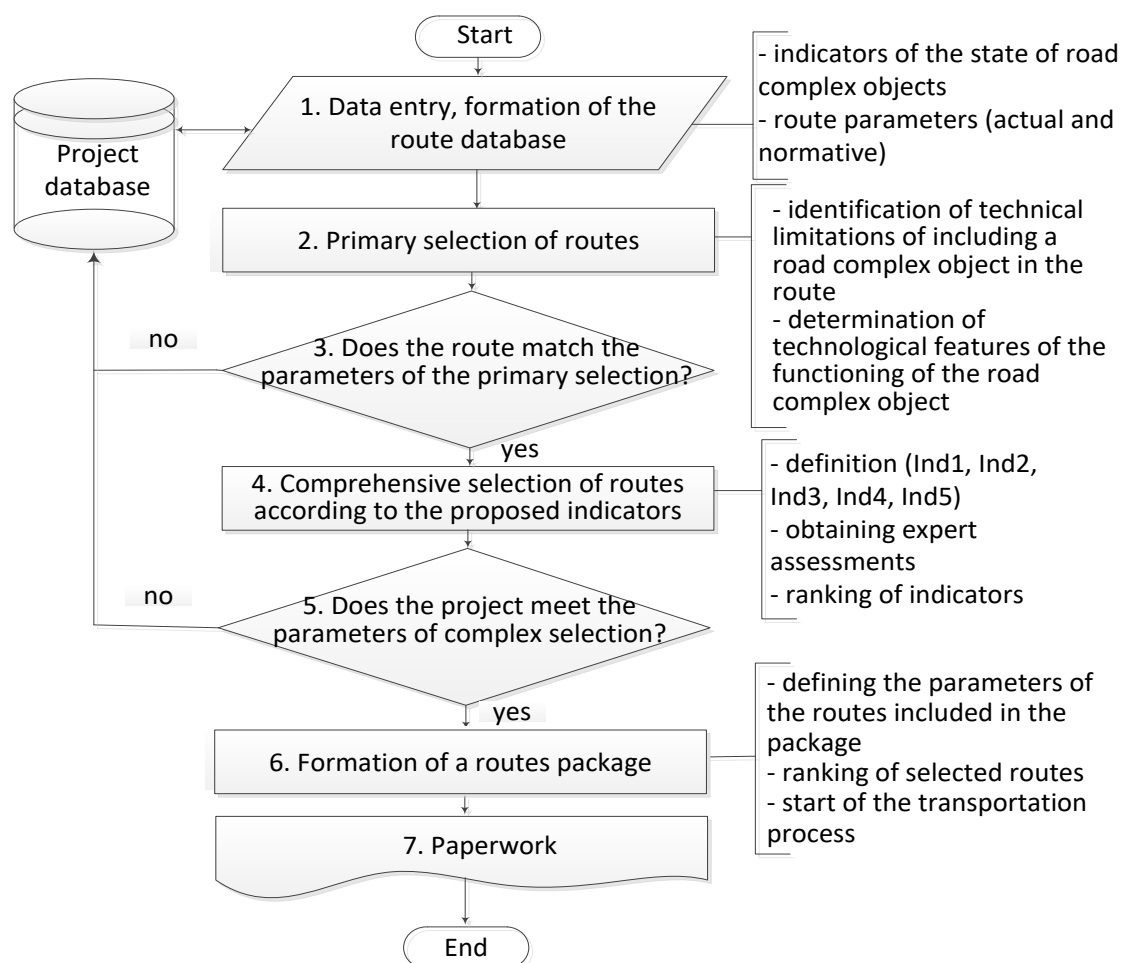
Figure 1. Algorithm for adjusting cargo delivery routes taking into account the state of the resource allocation system of the road and transport infrastructure.

3. Results and discussion

In this work, in the conditions of Myskovsky urban district, the modeling of the process of adjusting the route for the cargo delivery, taking into account the state of the resource allocation system of the

road and transport infrastructure, is carried out on the basis of a software package developed in the SMath Studio. Indicators were identified, ranked and selected for three alternative routes:

- alternative route 1 (R1): transportation runs on a toll road with a length of 28 km. The average technical speed of traffic on the road is 60 km/hour. In the autumn-spring period, the movement of vehicles with a carrying capacity of more than 6.0 tonnes (80% of all trucks) is foreseen. There is a fare of 72.5 rubles/km and a detour of 65 km. According to the design data, the increase in traffic intensity will be approximately 8%.
- alternative route 2 (R2): transportation runs along the road with a length of 38 km. The average technical speed of traffic on the road is 40 km/h. In autumn and spring, cars with a carrying capacity of more than 6.0 tonnes (50% of all trucks) detour approximately 65 km. The detour speed – 25 km/h. The duration of the road closure is 50 days.

According to the design data, the increase in traffic intensity will be approximately 3%.

- alternative route 3 (R3): transportation runs along the detour road with a length of 65 km. The average technical speed of traffic on the road is 25 km/h. According to the design data, the increase in the traffic intensity will be approximately 5%.

It is proposed to solve the problem of adjusting the routes of cargo delivery taking into account the state of the resource allocation system of the road and transport infrastructure by the method of hierarchies analysis. The solution technique considered in [10] lies in the achievement of maximum customer satisfaction by means of ranking and selecting routes for the cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure according to the highest priority of efficiency. The calculation of the priority vectors values is shown in tables 1-2.

Table 1. Initial matrix of pairwise comparisons of alternative projects by indicators.

indicators	Ind 1	Ind 2	Ind 3	Ind 4	Ind 5
Ind 1	1	0.5	1	5	2
Ind 2	2	0.2	0.2	1	5
Ind 3	0.25	0.5	0.5	0.2	1
Ind 4	4.583333	5.2	4.7	11.7	14
Ind 5	1	0.5	1	5	2
Σ	2	0.2	0.2	1	5

Table 2. Matrix for calculating priority vectors of alternative projects by indicators.

indicators	Ind 1	Ind 2	Ind 3	Ind 4	Ind 5	priorities vector
Ind 1	0.218182	0.576923	0.212766	0.042735	0.285714	0.267264
Ind 2	0.072727	0.192308	0.425532	0.42735	0.142857	0.252155
Ind 3	0.218182	0.096154	0.212766	0.42735	0.142857	0.219462
Ind 4	0.436364	0.038462	0.042553	0.08547	0.357143	0.191998
Ind 5	0.054545	0.096154	0.106383	0.017094	0.071429	0.069121

From the point of view of achieving the goal of choosing the most preferable option for the cargo delivery, the most significant is the operational indicator Ind_1 (26.7%), followed by the infrastructure indicator Ind_2 (25.2%), the next indicator of transport work Ind_3 (21.9%). Social indicator Ind_4 and economic indicator Ind_5 have the smallest weight coefficients (19.2% and 6.9%, respectively).

Compilation of matrices of pairwise comparisons for each indicator is performed in tables 4, 6, 8, 10, 12.

Table 3. Initial matrix of pairwise comparisons of infrastructure indicator elements Ind_1.

Ind 1	route 1 (R1)	route 2 (R2)	route 3 (R3)
route 1 (R1)	1	4	0.5
route 2 (R2)	0.25	1	0.2
route 3 (R3)	2	5	1
$\sum$	3.25	10	1.7

Table 4. Matrix of pairwise comparisons of infrastructure indicator elements Ind_1.

Infrastructure indicator Ind 1	route 1 (R1)	route 2 (R2)	route 3 (R3)	priorities vector
route 1 (R1)	0.307692	0.4	0.294118	0.333937
route 2 (R2)	0.076923	0.1	0.117647	0.09819
route 3 (R3)	0.615385	0.5	0.588235	0.567873

Table 5. The initial matrix of pairwise comparisons of the infrastructure indicator elements Ind_2.

Ind 2	route 1 (R1)	route 2 (R2)	route 3 (R3)
route 1 (R1)	1	0.5	3
route 2 (R2)	2	1	4
route 3 (R3)	0.333333	0.25	1
$\sum$	3.333333	1.75	8

Table 6. Matrix of pairwise comparisons of indicator elements of transport activity Ind_2.

Indicator of transport work Ind 2	route 1 (R1)	route 2 (R2)	route 3 (R3)	priorities vector
route 1 (M1)	0.3	0.285714	0.375	0.320238
route 2 (M2)	0.6	0.571429	0.5	0.557143
route 3 (M3)	0.1	0.142857	0.125	0.122619

Table 7. The initial matrix of pairwise comparisons of the infrastructure indicator elements Ind_3.

Ind 3	route 1 (R1)	route 2 (R2)	route 3 (R3)
route 1 (R1)	1	1	2
route 2 (R2)	1	1	3
route 3 (R3)	0.5	0.333333	1
$\sum$	2.5	2.333333	6

Table 8. Matrix of pairwise comparisons of performance indicator elements Ind_3.

Performance indicator Ind$_3$	route 1 (R1)	route 2 (R2)	route 3 (R3)	priorities vector
route 1 (R1)	0.4	0.428571	0.333333	0.387302
route 2 (R2)	0.4	0.428571	0.5	0.442857
route 3 (R3)	0.2	0.142857	0.166667	0.169841

Table 9. The initial matrix of pairwise comparisons of infrastructure indicator elements Ind_4.

Ind 4	route 1 (R1)	route 2 (R2)	route 3 (R3)
route 1 (R1)	1	0.333333	4
route 2 (R2)	3	1	5
route 3 (R3)	0.25	0.2	1
$\sum$	4.25	1.533333	10

Table 10. Matrix of pairwise comparisons of the social indicator elements Ind_4.

Social indicator Ind_4	route 1 (R1)	route 2 (R2)	route 3 (R3)	priorities vector
route 1 (R1)	0.235294	0.217391	0.4	0.284228
route 2 (R2)	0.705882	0.652174	0.5	0.619352
route 3 (R3)	0.058824	0.130435	0.1	0.096419

Table 11. The initial matrix of pairwise comparisons of infrastructure indicator elements Ind_5.

Ind 4	route 1 (R1)	route 2 (R2)	route 3 (R3)
route 1 (R1)	1	2	0.2
route 2 (R2)	0.5	1	0.166667
route 3 (R3)	5	6	1
∑	6.5	9	1.366667

Table 12. Matrix of pairwise comparisons of economic indicator elements Ind_5.

Economic indicator Ind_5	route 1 (R1)	route 2 (R2)	route 3 (R3)	priorities vector
route 1 (R1)	0.153846	0.222222	0.146341	0.174137
route 2 (R2)	0.076923	0.111111	0.121951	0.103328
route 3 (R3)	0.769231	0.666667	0.731707	0.722535

The highest priority of efficiency will be the maximum value of the weighting coefficients obtained as a result of the product of the priorities matrix of particular criteria (columns 5 of tables 4, 6, 8, 10, 12) and the matrix of priority vectors of the alternative projects under consideration (column 7 of table 2).

$$\begin{pmatrix} 0.333937 & 0.320238 & 0.387302 & 0.284228 & 0.174137 \\ 0.098190 & 0.557143 & 0.442857 & 0.619352 & 0.103328 \\ 0.567873 & 0.122619 & 0.169841 & 0.096419 & 0.722535 \end{pmatrix} \times \begin{pmatrix} 0.267264 \\ 0.252155 \\ 0.219462 \\ 0.191998 \\ 0.069121 \end{pmatrix} = \begin{pmatrix} 0.321605 \\ 0.389976 \\ 0.288419 \end{pmatrix}$$

As a result of the calculations, we obtain the highest priority of efficiency for the routes of cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure (table 13).

Table 13. The highest priority of efficiency for routes of cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure.

Route names	Highest priority for efficiency in shares	Highest priority of efficiency in%
route 1 (R1)	0.321605	32.16
route 2 (R2)	0.389976	39.00
route 3 (R3)	0.288419	28.84

Thus, the decision to adjust the routes of cargo delivery, taking into account the state of the resource allocation system of the road and transport infrastructure, is planned through the organization of transportation along route R2, which has the highest priority of efficiency. Transportation along it is carried out by the road with a length of 38 km (deviation from the originally chosen route is 8.4%).

Organization of transportation along route R2 will ensure a decrease in the loss of profit of a transport and logistics company by 8.4% due to: a decrease in the over-mileage of road transport; the number and magnitude of losses from road traffic accidents; reduction in the negative impact of the transport and road complex on the environment; increase in the speed of movement; improving the quality, transportation of cargo and passengers by road.

4. Conclusion

The proposed algorithm for correcting cargo delivery routes, taking into account the state of the resource allocation system of the road and transport infrastructure, containing additional tools in the form of a set of indicators, allows it to be used in solving the problem of multicriteria choice optimization of the route that best meets all the requirements stated by users of the road and transport infrastructure.

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