

Mathematical models of functioning and allocation indicators of road-transport complex resources in the fuel and raw materials region

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Abstract. A number of features of coal industry functioning was determined for the conditions of Kemerovo region, and the specifics of planning and organization of coal transportation were revealed. The analysis of indicators of motor and railway types of transport in the process of coal transportation was executed. The necessity of improving the tools of coal products transportation in the modern conditions is substantiated. Specific features of functioning of a road-transport complex in the fuel and raw material region (on the example of Kemerovo region) are determined. The modern scientific and applied problems of functioning and allocation of the road-transport complex resources are identified. To justify the management decisions on the development and improvement of road-transport complex a set of indicators are proposed: infrastructural, transportation performance, operating, social and economic. Mathematical models of indicators are recommended for formulation and justification of decisions made during operational and strategic planning of development, evaluation and development of algorithms of functioning and allocation of road-transport sector in Kemerovo region in the future.

1. Introduction

At present, the basic industries of the Russian Federation in accordance with the structure of gross added value are: transport and communications – 7.8% and extraction of minerals – 9.4%, while the share of coal from the total amount of extracted energy products is 13.9% [1].

One of the main centers of coal industry in the Russian Federation is the Kuznetsk coal basin, which is located on the territory of Kemerovo region. Currently, more than 56% of the country coal is mined in the region, as well as about 80% of all coking coal, and total geological coal reserves are estimated at 319 billion tonnes [1, 2].

The coal industry shows positive dynamics of coal production in the Russian Federation and Kemerovo region [3] and according to forecasts in future periods the growth of production will remain [1, 2]. The volumes of coal production in the Russian Federation and Kemerovo region from 1998 to 2020 are shown in figure 1.

More than 85% of coal from Kemerovo region is exported, thus, the transportation distances on average exceeds 4.500 km, and the transport component in the cost of coal for the consumer is more than 45% [4]. Rail transport is mainly used for coal transportation to remote points of destination in Russia, coal in the transportation structure is more than 26% [3]. Motor transport for the coal transportation is used mainly for short distances – the average delivery range is 45 km, but their volumes exceed the railroad volumes [4].





Figure 1. Volumes of coal mining in the Russian Federation and Kemerovo Region [1 - 3].

Table 1 presents the dynamics in the volumes of products transportation by road and rail transport in the Russian Federation for the period 2000-2020. From 2010 there has been a steady growth in indicators, showing the overcoming of the crisis phenomena of 2008.

Table 1. Volumes of products transportation by road and rail transport in the Russian Federation for the period 2000-2020 [4].

Type of transport	Volumes of transportation, million tonnes / year				
	2000	2005	2010	2015	2020 (prediction)
Public railroad	1046.8	1273.3	1312	1380	1558.3
Railway industry	3140.4	3486.6	3272.2	3757.1	4355.5
Motor transport of general use	550	612	498.3	571.8	628.8
Automotive industry	5328	6073	4738.1	6091.5	7140.6

Thus, at the present time there is no doubt that necessity of improving the tools of coal products transportation in the Russian Federation is urgent.

2. Methods of research

With an intensive growth in the share of volumes of motor transportation (table 1), the load on the infrastructure significantly increases, with no significant improvement in the level of its development and technical capabilities [4]. In this regard, we shall consider the problematic aspects of motor transportation process.

At present, almost 27% of the road network is operated with exceedance of the normative load, while the local road network is not enough developed [5]. In Kemerovo region, 26.73% of public roads do not meet the regulatory requirements for transport performance indicators, including 66.36%

of regional or inter-municipal roads and 11.32% of local roads [6, 7]. Acceleration of motorization of the country has not yet led to a corresponding increase in the volume of construction, reconstruction and repair of the road network, and repair of roads in recent years has even somewhat decreased. For example, with the increase in the length of public roads by 15% over the past 10 years, the fleet of vehicles has increased by more than 1.7 times [8]. The axial load of 11.5 tonnes was observed on the sections of federal roads with a total length of 2613 km (5.2% of the total network length), with a requirement of 22 000 km, ten-tonnes load – on 11.9 thousand km (23.8% of the total network length) at a demand of 26 thousand km respectively [8, 9].

To overcome the above-mentioned problem situations it is necessary to solve the following modern scientific and applied problems of functioning and allocation of road-transport complex resources:

- specification and improvement of the best practices in functioning of a road-transport complex in the fuel and raw material region;
- improvement of the system of planning functioning and allocation of the road-transport complex resources taking into account regional and industry-specific features of the fuel and raw material region [10];
- improvement of the tools for allocation of road-transport complex resources based on the development of flexible systems of incentives and change management;
- development of recommendations for improving the regulatory framework of the road-transport complex in the fuel and raw material region.

3. Results and discussion

To solve these scientific and applied problems we propose a set of math models of functioning and allocation indicators of road-transport complex resources as a tool for justifying management decisions and development of projects for future periods:

1. Infrastructure indicator Ind_1 – it is an indicator characterizing the length of transport communication sections, on which there are limitations of traffic and carrying capacities due to noncompliance with regulatory requirements:

$$Ind_1 = \sum_i \sum_j \sum_k (L_{TC}^{ijk} + L_{AL}^{ijk} + L_{OV}^{ijk} + L_{RS}^{ijk} + L_A^{ijk}), \quad (1)$$

where i – organization servicing the road, $i \in [1; I]$; j – type of transportation (transit, technological, local, etc.), $j \in [1; J]$; k – administrative area, $k \in [1; K]$; $L_{TC}^{ijk}, L_{AL}^{ijk}, L_{OV}^{ijk}, L_{RS}^{ijk}, L_A^{ijk}$ – length of motor roads that do not meet the regulatory requirements for traffic capacity, axial loads, spaces for oversized vehicles, the type of road surface, and the absence of a year-round car traffic respectively, km.

2. Indicator of transportation performance Ind_2 – characterizes the volume of traffic on the reserve routes due to noncompliance with regulatory requirements for of motor roads, on which the main routes by transport-operational indicators are laid:

$$Ind_2 = \sum_i \sum_j \sum_k (Q_{ijk}^{TC} \cdot L_{TC}^{AD} + Q_{ijk}^{AL} \cdot L_{AL}^{AD} + Q_{ijk}^{OV} \cdot L_{OV}^{AD} + Q_{ijk}^{RS} \cdot L_{RS}^{AD} + Q_{ijk}^A \cdot L_A^{AD}), \quad (2)$$

where $Q_{ijk}^{TC}, Q_{ijk}^{AL}, Q_{ijk}^{OV}, Q_{ijk}^{RS}, Q_{ijk}^A$ – the volume of traffic on the additional routes due to noncompliance with regulatory requirements for of motor roads, on which the main routes for traffic capacity, axial loads, spaces for oversized vehicles, type of road surface, absence of year-round motor traffic, t; $L_{TC}^{AD}, L_{AL}^{AD}, L_{OV}^{AD}, L_{RS}^{AD}, L_A^{AD}$ – route length on the reserve trajectories due to noncompliance with regulatory requirements for the basic routes: traffic capacity, axial loads, spaces for oversized vehicles, type of road surface, absence of year-round motor communication, km;

3. The operating indicator Ind_3 – is an indicator characterizing the value of shipment delivered by motor transport within a set timeframe exceeding the standard (contractual) period:

$$Ind_3 = \sum_i \sum_j \sum_k (Q_{ijk}^{TC} \cdot t_{TC\,ijk}^{AD} + Q_{ijk}^{AL} \cdot t_{AL\,ijk}^{AD} + Q_{ijk}^{OV} \cdot t_{OV\,ijk}^{AD} + Q_{ijk}^{RS} \cdot t_{RS\,ijk}^{AD} + Q_{ijk}^A \cdot t_A^{AD}), \quad (3)$$

where $Q_{ijk}^{TC}, Q_{ijk}^{AL}, Q_{ijk}^{OV}, Q_{ijk}^{RS}, Q_{ijk}^A$ – volume of transportations delivered by motor transport within a set timeframe exceeding the standard (contractual) period due to noncompliance of motor roads with the normative requirements for traffic capacity, axial loads, type of road surface, absence of a year-round car traffic, $t_{TC\,ijk}^{AD}, t_{AL\,ijk}^{AD}, t_{OV\,ijk}^{AD}, t_{RD\,ijk}^{AD}, t_A^{AD}$ – additional time of traveling on reserve (bypass) roads due noncompliance of motor roads with the normative requirements for traffic capacity, axial loads, type of road surface, absence of a year-round car traffic, day.

4. Social indicator Ind_4 – characterizes the value of additional time people spend travelling by roads due noncompliance of motor roads with the normative requirements:

$$S_4 = \sum_i \sum_j \sum_k \sum_p (S_{ijkp}^{TC} \cdot t_{TC\,ijk}^{ET} + S_{ijkp}^{AL} \cdot t_{AL\,ijk}^{ET} + S_{ijkp}^{OV} \cdot t_{OV\,ijk}^{ET} + S_{ijkp}^{RS} \cdot t_{RS\,ijk}^{ET} + S_{ijkp}^A \cdot t_A^{ET}), \quad (4)$$

where p – category of population, pensioners, employees, workers $p \in [1; P]$; $S_{ijkp}^{TC}, S_{ijkp}^{AL}, S_{ijkp}^{OV}, S_{ijkp}^{RS}, S_{ijkp}^A$ – number of people that have to spend extra time travelling due to noncompliance with regulatory requirements for of motor roads, on which the main routes for traffic capacity, axial loads, spaces for oversized vehicles, type of road surface, absence of year-round motor traffic, pers.; $t_{TC\,ijk}^{ET}, t_{AL\,ijk}^{ET}, t_{OV\,ijk}^{ET}, t_{RS\,ijk}^{ET}, t_A^{ET}$ – time of the enforced travelling due noncompliance with regulatory requirements for of motor roads, on which the main routes for traffic capacity, axial loads, spaces for oversized vehicles, type of road surface, absence of year-round motor traffic, hour;

5. Economic indicator Ind_5 – characterizes the efficiency of investments into the system of the road-transport complex, as an indicator it is proposed to use the net present value (NPV). In the general form NPV is defined [11]:

$$NPV = \sum_{t=1}^T \frac{CF_t}{(1+E)^t} - \sum_{t=1}^T \frac{Inv_t}{(1+E)^t}, \quad (5)$$

where CF_t is the amount of moneys received in the period t , rub.; Inv_t – the amount of investments in the period t , rub.; E – discount rate; T is the calculation period, years.

4. Conclusion

The proposed set of indicators is recommended for justifying the management decisions in the operational and strategic planning of development, effectiveness evaluate and models building of functioning and allocation of the road-transport complex resources in Kemerovo region in the future.

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