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# Scheduling of Vehicle Fleet of Oil Products in Intercity Traffic

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## ABSTRACT

*The objective of the study is to develop a practically applied methodology and a mathematical model that considers the requirements for transportation of dangerous goods, the technical condition of rolling stock, modes of work and rest of drivers on the routes of intercity transportation, customers' requirements, and the interests of the trucking company.*

*The functioning of motor pool while transporting dangerous goods is presented as the relationship between transportation of goods and performance of technical maintenance.*

*A proposed approach to planning takes into account the correspondence of the effective number of technical maintenances to the standard required value for a certain period for vehicle fleet carrying out transportation of oil products; compliance of rolling stock output with the volume of oil products that might be delivered and unloaded in the current month; compliance of time of movement of drivers to a specialised resting place on the intercity route with time established for the modes of work and rest. The mathematical model makes it possible to determine output of the motor pool in each month, considering that transportation of oil products, started last month, ends only in the current one. The mathematical model of operating the vehicle fleet during transportation of oil products includes assumptions related to fulfilment of the requirements for motor pool and the driver, which are specified in the Agreement concerning the International Carriage of Dangerous Goods by Road, Decision of the Customs Union Commission dated 09.12.2011 No. 877 (revised on 21.06.2019).*

*Special attention was paid to planning of vehicle operations when volumes of oil products transported are growing during the construction and renewal of roads. The algorithm of the methodology was used to plan operation of motor pool when transporting BND 90/130 bitumen from the city of Omsk in intercity traffic and was the basis for making management decisions on the implementation of the suggested indicators in a motor transport enterprise practice.*

*Keywords: road vehicles, vehicle fleet, intercity transportation, oil products, mathematical model, technique.*

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***Текст статьи на на русском языке публикуется в первой части данного выпуска.***

## INTRODUCTION

The issues referring to planning and organisation of intercity transportation of oil products for construction of roads are relevant in many countries because of widely developed road construction, remoteness of sites of production of road materials from the construction sites, special features characteristic of transportation of such goods.

For instance, in Russia under a currently implemented Development of the transport system Federal program approved by the Government Decree of December 20, 2017, No. 1596, 100 billion roubles have been allocated for construction and reconstruction of roads in the regions of the Russian Federation by the end 2021.

In modern conditions, construction and reconstruction of roads provides for the use of viscous road bitumen (hereinafter bitumen) derived from residual oil products: petroleum bitumen and tar. Bitumen is produced at oil refineries in accordance with GOST [Russian state standard] 22245-90[1]. Nine grades of bitumen are used in road construction, each of which belongs to the category of dangerous goods.

Dangerous goods are goods that have such properties that, when performing transportation operations, it is possible to cause harm to the environment, industrial and civil objects, life, and health of people. When transporting dangerous goods, requirements are imposed on availability of specialised vehicles, which should be in a technically sound condition, on packaging and labelling, and loading and unloading operations performed by qualified personnel. When planning operation of vehicle fleet, it is necessary to consider the hazard class of the cargo, operating conditions [1], which lead to accelerated wear of individual units and parts. The economic damage from car accidents with dangerous goods significantly exceeds the amount of damage caused by accidents with other types of transport [2].

To carry out the operations of the transportation process, it is necessary to comply with the requirements of national legislation and of international agreements (Agreement concerning the International Carriage of Dangerous Goods by Road) (ADR) and to get a certificate of admission to the carriage of dangerous goods. The transportation of oil products in intercity traffic imposes additional constraints on scheduling of vehicle fleet's operation.

The authors of the paper have studied the practices of transporting oil products, as a result, it was established that, according to the requirements of the customers, each time of parking on the intercity route exceeding five minutes must be agreed upon in advance. Parking lots can only be located within the «road network». When driving, it is forbidden to deviate from the established route, stop outside the timetable, and exceed the speed.

For road transport enterprises (RTE), carrying out transportation of oil products for construction and reconstruction of roads, it is obligatory to strictly comply with the terms of contracts. In case of a violation in terms of transportation, including due to a technical malfunction of motor pool, penalties are provided.

The results of studies of domestic and foreign scientists, practitioners have shown that when transporting oil products by road, tasks of increasing safety of the transport process prevail [3]. J. Flodén, J. Woxenius [4] suggested recommendations on development of a route for transportation of dangerous goods to improve safety of transportation and its coordination with suppliers and customers.

S. V. Kondratov, A. N. Novikov [5] developed methodological aspects of risk analysis in transportation of dangerous goods by road, within the system «man–machine–environment–cargo». The work [6] presents the ranking of risk assessment criteria according to the degree of importance for transportation of oil products by road.

Several scientific research results are devoted to identification of factors affecting performance of vehicle fleet. S. Niu, S. V. Ukkusuri [7] found that road and climatic conditions, traffic flow power and average speed affect the mileage of motor pool.

V. N. Fedotov [8] carried out research to determine output of vehicles when transporting oil products, depending on the distance of transportation, time of loading and unloading operations, the parameters of the traffic flow of the street and road network of the city of Volgograd. In work [9], it is concluded that it

[1] GOST [State standard] 22245-90. Viscous oil road bitumen. [Electronic resource]: https://docs.cntd.ru/document/1200003410. Last accessed 25.05.2021.

is necessary to consider seasonal irregularities in transportation of oil products. The studies of S. M. Mochalin, V. A. Radionova [10] are devoted to accounting for probabilistic factors.

Special attention in scientific research is paid to the characteristics of the routes along which dangerous goods are transported. In [11], a plan for transportation of oil products was developed due to grouping of routes, the choice of motor pool.

I. M. Tsarenkova [12] suggested to select vehicle fleet considering its performance and choosing a transportation scheme based on the criterion of minimum costs for transportation of goods during road construction.

N. Holeczek [13] provides a detailed classification of routes to ensure safety. A. Kishore, B. Niels, A. R. Zuidwijk [14] used operations research models to develop rolling stock schedules for specific cargo transportation routes.

Z. Lukai, F. Xuesong [15] proposed an integrated approach to planning, considering risk indicators regarding transportation of dangerous goods in tank trucks and the characteristics of intercity routes. The developed planning algorithm has been practically implemented in some areas of East China.

The work [16] presents a route for transportation of goods using the graphic-analytical method. In [17], it is proposed to pay special attention to assessment of quality of transportation.

In articles [18–20], assessment of the risk for safety of transportation of goods was carried out, based on failures in operation of vehicle fleet, which is studied as a system of interconnected units and assemblies. It is concluded that it is necessary to timely perform technical maintenance of vehicles carrying oil products.

However, modern scientific concepts do not allow a comprehensive approach to solving the planning problem aimed to consider current requirements for transportation of dangerous goods, the technical condition of vehicles, the requirements of customers and the interests linked to RTE activity.

In modern conditions, the solution to the problem of planning the work of vehicle fleet when transporting oil products in intercity traffic is relevant with regard to above requirements.

The *objective* of the study is to develop an algorithm for a methodology for that can be practically implemented and a mathematical model that takes into account the requirements for transportation of dangerous goods, the technical condition of vehicle fleet, the modes of work and rest of drivers on the routes of intercity transportation, the requirements of customers and the interests of the trucking company.

To achieve this goal, the following tasks are solved:

- To develop a mathematical model that reflects functioning of vehicle fleet during transportation of oil products considering several constraints justified by the current legislative documents and the practices of RTE, and that will allow to use profit indicator to select the best value when determining the target indicators.
- To propose an algorithm of the methodology for practical implementation of the mathematical model, which allows making managerial decisions on the use of the planned performance indicators of motor pool when transporting oil products.

The research supposed to approve the developed technique through practical implementation.

The scientific novelty of the study consists in development, based on the study of legislative documents, research of scientists and practitioners, practices of transporting dangerous goods, the concept of current planning of the RTE work, of a mathematical model and methodology that allow planning operation of rolling stock when transporting oil products in intercity transportation.

## MATERIALS AND METHODS

The work [21] presents a theoretical and practical toolkit that reflects functioning of specialised vehicle fleet of certain dimensions and types owned by an RTE for fulfilling the terms of contracts for carriage of goods in intercity traffic. The developed concept of the current planning of RTE operations synthesises the methods of the theory of cargo road transportation, the theory of maintenance and repair of motor vehicles. The implementation of the presented methods in the practice of RTE allows the selection of vehicle fleet of RTE, subject to the conditions aimed at meeting the needs of customers and at performing scheduled maintenance.

**Table 1**

**Features of the requirements used as assumptions in the mathematical model (compiled by the authors)**

| Name of the document | Characteristics |
|---|---|
| Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) | Requirements to vehicle fleet in terms of the number of trailers (or semi-trailers), the presence of a certificate of admission to the carriage of dangerous substances and its validity period, the presence of special markings and a flashing light, satellite navigation GLONASS or GPS, certain equipment. Requirements for a driver to possess a certificate (ADR) and other documents, driving experience, work experience, etc. |
| Decision of the Customs Union Commission dated 09.12.2011 No. 877 (as amended on 21.06.2019) «On adoption of the technical regulations of the Customs Union «On safety of wheeled vehicles» (together with «TR CU 018/2011. Technical regulations of the Customs Union. On safety of wheeled vehicles») | Requirements for tanks, road tankers, trailers (semi-trailers). Prohibition of installation of additional fuel tanks not provided by the vehicle manufacturer, heaters in the driver's cab and cargo compartments. Special requirements for the service braking system, protection of electrical circuits, the presence of elements of protection against accidental operation, as well as the designation of the switch for disconnecting the battery from the electrical equipment of vehicle, etc. |

The work [22] presents a mathematical formula that considers the number of maintenance services for vehicles used in intercity traffic; in studies [23], characteristics of motor pool and requirements for transportation of dangerous goods are described.

In this study, we have developed a mathematical model of functioning of vehicle fleet transporting oil products. The use of the model makes it possible to consider constraints and apply profit indicator to select the best value with regard to the following constraints:

• Correspondence of the number of technical maintenance services of vehicle fleet carrying out transportation of oil products to the standard required value during a certain period.

• Compliance of vehicle fleet's output with the volume of oil products that may be delivered and unloaded during the current month.

• Correspondence of time of movement of drivers when transporting oil products to a specialised resting place on the intercity route with time established for the modes of work and rest.

To construct a mathematical model of functioning of vehicle fleet during transportation of oil products, certain assumptions were introduced related to implementation of the provisions specified in the documents currently in force (Table 1).

## THEORY

In the mathematical model, the number of vehicles varies from 1 to $X$, and work planning is performed for each unit of vehicle fleet when transporting oil products. As a result of conclusion of an agreement with the customer, a service is provided for transportation along the $i$-th route of intercity traffic, which has characteristics that determine the possibilities of stopping and parking of vehicles during the driver's rest. Each route corresponds to a specific contract. If several routes are served under a single contract, then the mathematical model provides for summation of indicators (traffic volume, labour intensity of technical maintenance, costs, income and profit) for each route.

To carry out transportation of oil products, it is necessary to ensure the technically sound condition of vehicle fleet, therefore, the mathematical model provides for planning of maintenance services, taking into account the mileage and frequency of these services (formulas (1)–(3)).

The mathematical model allows considering the existing requirements for frequency of scheduled maintenance (formula (1)), the volume of maintenance and repair work (formula (3)), their number (formula (2)) for vehicle fleet carrying oil products.

This study takes into account the peculiarities of formation of the output of vehicle fleet during each month (formulas (4)–(7)). It is possible to increase production in the current month if transportation of oil products, started last month, ends only in the current month (formula (5)).

Formulas (8)–(10) presented in the mathematical model ensure compliance of time of movement of drivers when transporting oil products to a specialised resting place on the intercity route with the time established for the modes of work and rest. Requirements according to the terms stipulated by customers regarding volume of transported oil products in intercity traffic are presented in the constraint (formula (11)). According to formulas (12)–(14), the profit is calculated to select the best value within the established constraints.

$$N_{\mathrm{TM\text{-}1i,x}} = \frac{L_{\mathrm{i,x}}}{W_{\mathrm{TM\,i,x}}};\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}, \tag{1}$$

$$N_{\mathrm{TM\,i,x}} \geq 2;\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}, \tag{2}$$

$$n_{\mathrm{i,x}} = \begin{cases} 1,\text{if} \begin{cases} \left(N_{\mathrm{TM-1i,x}} \cdot u_{\mathrm{TM-1x}}\right) \geq y_{\mathrm{TM-1i,x}}; \\ \left(N_{\mathrm{TM-2i,x}} \cdot u_{\mathrm{TM-2,CRx}}\right) \geq y_{\mathrm{TM-2,CRi,x}}; \end{cases} \\ 0 \text{ otherwise}, \end{cases}$$

$$\mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}, \tag{3}$$

where $L_{i,x}$ is mileage of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, km;

$W_{TMi,x}$ is standard mileage before scheduled technical maintenance of the $x$-th vehicle, considering operating conditions and natural and climatic conditions when transporting oil products along the $i$-th route of intercity communication, km;

$N_{TM\text{-}1i,x}$, $N_{TM\text{-}2i,x}$ are numbers of impacts for the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, units;

$N_{TM\text{-}1i,x} = \mathrm{int}(N_{TM\text{-}1i,x})$, $N_{TM\text{-}2i,x} = \mathrm{int}(N_{TM\text{-}2i,x})$; $u_{TM\text{-}1x}$, $u_{TM\text{-}2,CRx}$ – labour intensity of one impact, respectively, for *TM*-1, *TM*-2 and current repair (*CR*) for the $x$-th rolling stock when transporting oil products, considering the coefficients for adjusting labour intensity standards, persons·*h*;

$y_{TM\text{-}1i,x}$, $y_{TM\text{-}2,CRi,x}$ – required labour intensity, respectively, for *TM*-1, *TM*-2 and *CR* for the *x-th* vehicle when transporting oil products along the $i$-th route of intercity communication, persons·h.

$$t_{\mathrm{Ri,x}} = \begin{cases} \left(t_{\mathrm{ci,x}} + t_{\mathrm{wli,x}}\right) - t_{\mathrm{Pi,x}}, \\ \text{if}\ \mathrm{WT} - \left[\dfrac{\mathrm{WT} - d_x}{t_{\mathrm{ci,x}} + t_{\mathrm{wli,x}}}\right] \cdot \left(t_{\mathrm{ci,x}} + t_{\mathrm{wli,x}}\right) \geq t_{\mathrm{li,x}}; \\ 0,\text{if}\ \mathrm{WT} - \left[\dfrac{\mathrm{WT}}{t_{\mathrm{ci,x}} + t_{\mathrm{wli,x}}}\right] \cdot \left(t_{\mathrm{ci,x}} + t_{\mathrm{wli,x}}\right) < t_{\mathrm{li,x}}, \end{cases} \tag{4}$$

where $t_{Ri,x}$ is time required to complete the ride with a load in the current month of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity traffic, h;

$t_{ci,x}$ is time of movement with cargo of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, h;

$t_{wl,x}$ is time of movement without load of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, $h$;

$t_{Pi,x}$ is travel time in the previous month for the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, $h$;

*WT* is total working time fund, h;

$d_x$, is duration of downtime during maintenance for the $x$-th vehicle, h;

$t_{li,x}$ is time for loading the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, $h$.

$Q_{i,x} = \mathrm{Z}_{i,x} \bullet \mathrm{M}_{oi,x} \bullet n_{Di,x}$;

$$i=\overline{1,I};\ x=\overline{1,X}; \tag{5}$$

$$n_{Di,x} = \begin{cases} 1, if\ t_{Di,x} \geq t_{pi,x}; \\ 0, if\ t_{Di,x} < t_{pi,x}, \end{cases}\quad i=\overline{1,I};\ x=\overline{1,X}; \tag{6}$$

$$Z_{i,x} = \left[\frac{\mathrm{WT} - \mathrm{d_x} - \mathrm{t_{Di,x}}}{2\mathrm{t_{ge\,i,x}}}\right];\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}, \tag{7}$$

where $Q_{i,x}$ – monthly output of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, t;

$\mathrm{Z}_{i,x}$ – number of rides of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, units;

$Z_{Mi,x} = \mathrm{int}(\mathrm{Z}_{\mathrm{Mi},x})$; $M_{oi,x}$ – mass of dispatch of oil products for the $x$-th vehicle on the $i$-th route of intercity communication, t;

$n_{Di,x}$ – a Boolean variable of the increase in the output of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, $n_{Di,x} = \overline{0,1}$, $n_{Di,x} = \mathrm{int}(n_{Di,x})$.

$$t_{\mathrm{ci,x}} = t_{cdi,x} + t_{spi,x} + t_{gpsi,x} + t_{gpni,x} + t_{goi,x};\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}; \tag{8}$$

$$t_{cdi,x} \leq \frac{l_{cdi,x}}{V_{Tм}};\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}; \tag{9}$$

$$t_{spi,x} \leq \frac{l_{spi,x}}{V_{Tм}};\ \mathrm{i}=\overline{1,\mathrm{I}};\ \mathrm{x}=\overline{1,\mathrm{X}}, \tag{10}$$

where $t_{cdi,x}$, $t_{spi,x}$, $t_{gspi,x}$, $t_{gpn\,i,x}$, $t_{goi,x}$ – respectively, time of continuous driving from the beginning of the driver's work, time for movement between special breaks, time of special breaks per shift, time for feeding, the time for the driver's rest for changing the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, $h$;

$l_{cd\ i,\ x}$ – mileage to the place of stopping (parking) after continuous driving from the start of work of the driver of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, km;

$l_{spi,\ x}$ – mileage to the place of stopping (parking) after a special break of the $x$-th vehicle when transporting oil products along the $i$-th route of intercity communication, km.

$$\sum_{x=1}^{X}(Q_{i,x} \bullet n_{i,x}) \bullet D_i \geq Q_{rqi}, \ i=\overline{1,I}; \quad (11)$$

$$R_i = \sum_{x=1}^{X}(Q_{i,x} \bullet n_{i,x}) \bullet D_i \cdot T_i, \ i=\overline{1,I}; \quad (12)$$

$$P_i = R_i - C_i, \ i=\overline{1,I}; \quad (13)$$

$$E = \sum_{i=1}^{I} P_i \to \max, \quad (14)$$

where $D_i$ is planned number of months of work on the $i$-th route of intercity communication, units;

$D_i = \text{int}(D_i)$; $Q_{rqi}$ – amount of cargo required by the customer for transportation along the $i$-th route of intercity traffic, t;

$T_i$ – tariff for carriage of goods along the $i$-th route of intercity traffic, rub./t;

$R_i$ – result from the carriage of goods along the $i$-th route of intercity communication, roubles;

$C_i$ – costs of cargo transportation along the $i$-th route of intercity communication, roubles;

$P_i$ – profit from the carriage of goods along the $i$-th route of intercity communication, roubles;

$E$ – effect of operation of rolling stock (vehicles) during transportation of oil products in intercity traffic, roubles.

The following conditions are comprehensively implemented in the mathematical model:

• Meeting the requirements for the number of technical maintenance services during a specific time for rolling stock carrying oil products.

• Meeting the requirements for determining the planned volume of cargo transportation in intercity traffic since it can increase in the current month since the loading of oil products was performed in the previous month, and unloading was made in the current month.

• Ensuring the requirements for the work and rest modes of drivers by matching time required to get to a special stopping place and (or) parking of rolling stock on the intercity transportation route within the established time.

## RESULTS AND DISCUSSION

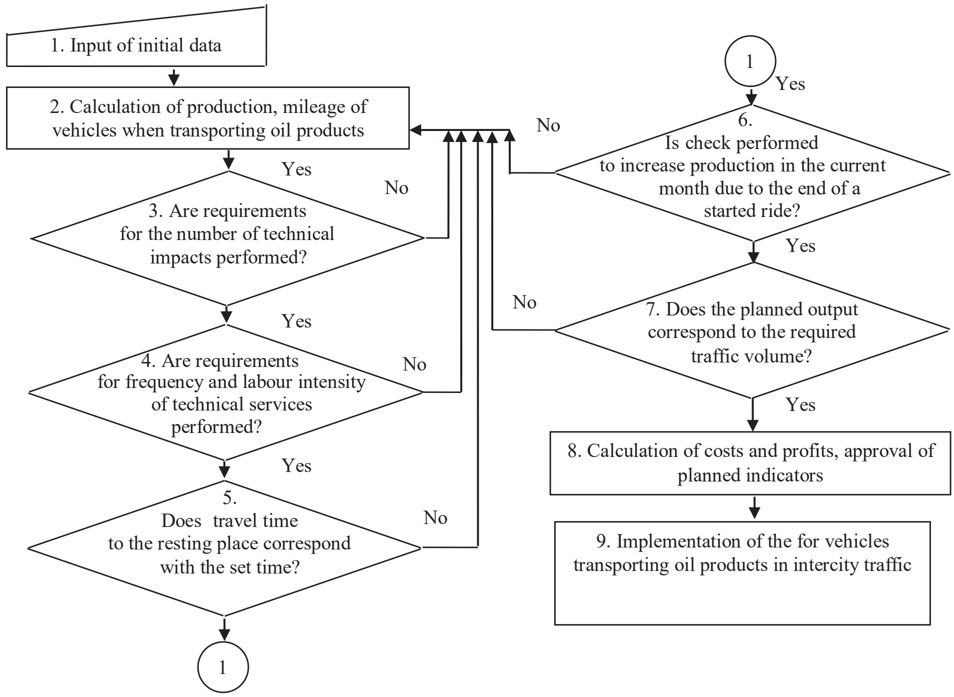
An algorithm of the methodology has been developed for practical implementation of the mathematical model, which includes the main stages for determining the planned indicators (Pic. 1).

The initial data include information about rolling stock, the requirements of the customers regarding the volume of cargo transportation and tariffs per month, the requirements for the work and rest modes of drivers when transporting cargo in intercity traffic. The initial data contain the values of the distances to the parking lots within the framework of the «road network», which are agreed upon in advance. Time for loading and unloading, average technical speed, the mass of dispatch of oil products along a specific route are the characteristics of the technology for transportation of goods and constitute an obligatory element for calculating the planned indicators.

The practical implementation of the methodology is carried out during intercity transportation of BND 90/130 bitumen from the city of Omsk. The length of the ride with a load is from 820 km to 870 km. Transportation is carried out by Volvo FH12 440 truck tractors with a SESPEL-SF3B25 semitrailer. The application of the methodology made it possible to determine the planned indicators per months, considering the need for cargo during this period. In the first working month (March) and the last working month (November), a trip is planned for each unit of rolling stock on intercity routes, considering all the requirements for transportation of dangerous goods. It has been established that 11 units of rolling stock will be required to fulfil the planned volume of transportation (4400 tons). The amount of profit amounted to 10004455 roubles, which is 8,3 % more than the profit obtained when calculating the indicators without taking complex account of the impact of the established requirements for transportation of oil products in intercity traffic.

## CONCLUSIONS

This paper presents studies on planning the operation of vehicle fleet within the transport system, characterised by an increase in the volume of transportation of oil products for construction and reconstruction of roads.




***Pic. 1. Algorithm of the methodology for scheduling the work of rolling stock when transporting oil products in intercity traffic (compiled by the authors).***

A mathematical model of functioning of motor pool transporting oil products has been developed, which makes it possible to determine the planned indicators considering the requirements of the legislation on transportation of dangerous goods, according to the modes of work and rest of drivers on intercity routes, the technical condition of vehicles, as well as the requirements of customers and the results of operation of RTE.

A methodological algorithm for practical implementation of a mathematical model is proposed, which makes it possible to make managerial decisions on the use of planned performance indicators for vehicle fleet when transporting oil products.

The performed studies were transferred for practical implementation to a RTE of the city of Omsk, which carries out intercity transportation of bitumen. Further research will be devoted to development of theoretical provisions for planning the work of vehicle fleet.

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