Modeling and optimization of processes of transportation of heavy cargoes based on the automation of monitoring systems for the motor vehicles movement

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Abstract. This article presents the results of a study of the causes of destruction of the roadway. This allowed one to identify the relationship between the movement of heavy trucks and excessive wear of road structures, as well as to develop management and infrastructure solutions to ensure optimal planning of transportation of heavy goods with a view to reduce the impact on roads.

1. Introduction
Accelerated growth rates in the industrial sector and construction in the Russian Federation have significantly increased the volume of transportation of heavy cargoes in road transport [1]. Transportation of this category of cargo by road is one of the most difficult road transportation types and, at the same time, an integral part of the industrial and mining complexes [2]. A significant factor affecting the efficiency of transportation of heavy cargoes is that there are a number of restrictions on the roads associated with the weight and dimensions of the cargo being transported.

2. Results and Discussion
In the study of the transportation of heavy cargoes by road, three levels of the transportation process were identified: federal, regional and local. Considered all the stages of the organization of the transportation process. At each level, three main types of roads were defined depending on the permitted axle load of vehicles, that affecting the amount of damage, the penalty for which is levied within the permit for the transportation of heavy cargo, and the reasons, that affecting the condition of roads (Fig. 1).

At each level, the transportation process is optimized according to the following criteria [3, 4]:
- the volume of transport work in the n-th period should not contradict the continuing trend of increasing road transport in the next n + 1 period – \( P_{tr}(n+1) > P_{tr}(n) \) \( P_{tr}(n) \neq 0 \);
- the amount of damage to roads from road traffic flows should not be greater than the damage that can be created by vehicles carrying heavy cargoes in excess of the permissible load by axles and by total mass – \( R_d < R_{pd} = f(c_3) \).

There are general restrictions for different levels: \( A_{2i} \in A_3 \) and \( L_{1k} \in L_{2k} \).

The view of the optimization models is described below.

Level 3:
\[ P_3 = \sum f(A_{31}, A_{32}, ..., A_{3n}; W_{31}, W_{32}, ..., W_{3n}); \quad R_3 = \sum f(A_{31}, A_{32}, ..., A_{3n}; r_{31}, r_{32}, ..., r_{3n}) \]  
where \( A_{3i} \) is the car fleet of \( i \)-th vehicles; \( W_{3i} \) and \( r_{3i} \) are respectively the amount of transport work and the amount of damage per unit of \( i \)-th vehicles for the calendar period.

Level 2:
\[ P_2 = L_2 \sum f(q_{21}, q_{22}, ..., q_{2n}; A_{21}, A_{22}, ..., A_{2n}); \quad R_2 = L_2 \sum f(g_{21}, g_{22}, ..., g_{2n}; N_{21}, N_{22}, ..., N_{2n}) \]
where \( q_{2i} \) and \( g_{2i} \) are respectively the transport work and the amount of damage during 1 km run of \( i \)-th vehicles for the \( k \)-th section of length \( L_k; A_2 \) and \( N_2 \) are the number and the intensity of \( i \)-th vehicles.

Level 1:
\[ P_1 = \sum f(\omega_{11}, \omega_{12}, ..., \omega_{1n}; t_{p11}, t_{p12}, ..., t_{p1n}); \quad R_1 = \sum f[L_{2k} g_{1L} + g_{1r}; (t_{p11}, t_{p12}, ..., t_{p1n})] \]
where \( g_{1L} \) and \( g_{1r} \) are respectively the amount of damage of \( i \)-th runs for heavily loaded vehicles under control of \( j \)-th drivers; \( \omega_{1j} \) and \( t_{p1j} \) are respectively hourly performance and operating time of \( i \)-th vehicles under control of \( j \)-th drivers.

**Optimization methodology of heavy cargo transportation planning**

![Diagram of optimization methodology](image)

**Heavy cargo transportation levels**

- **Level 1**: Federal
- **Level 2**: Regional
- **Level 3**: Local

Fig. 1. Optimization levels of modeling the transportation process of heavy cargoes by road

At levels 1, 2, the number and composition of the regional car fleet is optimized. The structure of the region’s car fleet must meet the conditions \((C < C_p)\). Modeling is carried out for car fleets of carriers who have permission to transport on federal, regional roads, as well as transportation licenses.

At level 3, the mode of movement of the individual crew (driver and car) is optimized.

For the practical implementation of the models [5-12] formed an automatic motion monitoring system for the organization of weight control using a matrix QR-code (Fig. 2). This system includes four main nodes that control the object of identification and transfer of the received information: radar sensor, video camera, matrix QR-code reader, broadband channel receiver. All nodes of the identification module are controlled by a microprocessor on three buses: control bus, address bus and data bus.
3. Conclusion
Thus, to ensure the optimization process of heavy cargo transportation planning, an integrated approach is needed based on the construction of mathematical models that differ in different levels of simplification in describing the operation process. A systematic approach to the planning of large-sized and (or) heavy road transport by road consists in a detailed description of the transportation process at all levels (stages) of its implementation. This approach will make it possible to efficiently organize the transportation process at the planning stage. Considering the importance of road safety and control in this area by state bodies, it is necessary to take into account the negative impact of heavy vehicles when planning transportation.

Figure 2. Scheme of the organization of weight control using a matrix QR-code

References
[1] Kozlov L N, Urlichich Yu M, Tsiklis B E 2009 On the Conceptual Approaches to Forming and Development of Intellectual Transport Systems in Russia Transport of The Russian Federation 3-4 (22-23) 30–35
[2] Zubov V P 2017 Status and Directions of Improvement of Development Systems of Coal Seams on Perspective Kuzbass Coal Mines Journal of Mining Institute 225 292–297 DOI: 10.18454/PMI.2017.3.292
[3] Safiullin R N, Afanasiev A S, Reznichenko V V 2019 The Concept of Development of Monitoring Systems and Management of Intelligent Technical Systems Journal of Mining Institute 237 DOI: 10.318915
[4] Safiullin R, Kerimov M, Afanasyev A, Marusin A 2018 A Model for Justification of the Number of Traffic Enforcement Facilities in the Region Transportation Research Procedia 36 493–499

[5] Vishnevskiy V M, Larionov A A, Tselikin Yu V 2012 Research and Analysis of Design Methods of Automated Road Security Systems Using Novel Broadband Wireless and RFID Technologies T-Comm 6 (7) 48–54

[6] Safiullin R N, Kerimov M A 2017 Intelligent On-Board Transport Systems for Road Transport (Moscow-Berlin: Direct-Media) p 354

[7] Safiullin R N, Kerimov M A, Marusin A V 2017 Evaluation of Functional Efficiency of Automated Traffic Enforcement Systems Transportation Research Procedia 288–294

[8] Gaikovich G F 2009 Standardization in the Field of Industrial Networks. Development of Wireless Standards for Process Control Systems Electronic components 1 48–52

[9] Safiullin R N, Afanasyev A S 2018 Integrated assessment of methods for calculating harm caused by vehicles in transport of heavy cargoes IOP Conference Series: Earth and Environmental Science 194(7) 072011

[10] Afanas'ev A S, Egoshin A M, Alekseev S V 2018 Justification of logistical approach application in road safety management IOP Conference Series: Earth and Environmental Science 194(7) 072001

[11] Safiullin R 2011 Patent for PM №174174 RF Automated data control system on the technical condition of the internal combustion engine of the vehicle /. Newton. / Publ.05.10.2011. Bul. No. 28.

[12] Trinity N 2003 A unified transport system: textbook for students of institutions. Professor of education. (M.: publishing center "Academy")