Simulation model of the organization of technological transport movement at a mining enterprise

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Abstract. The article presents a simulation model for organizing the movement of technological transport on the road network of a mining enterprise, the study of which will justify the use of technical means of traffic control and avoid emergencies. The simulation model of traffic management on the road network of the mining enterprise is designed to study the effectiveness of the road network and the traffic control system on it, including using automation tools, calculating the control parameters of traffic regulation and verifying the correct choice of their number and location on the ground. The simulation model has a block-modular structure. As the control program, the algorithm of the technical means for organizing traffic at the facility and section of the road is used. The developed simulation model makes it possible to take into account such parameters of the traffic flow as the type, speed of the vehicle, and time intervals between vehicles. During the simulation, situations of standard movement of vehicles along a road section, the occurrence of a traffic accident and accumulation of vehicles on a road section, as well as the maintenance, repair and reconstruction of roads and the functioning of traffic control equipment at the enterprise are set up.

1. Introduction

Modern mining enterprises are the largest organizations, the territory of which sometimes reaches hundreds, and sometimes thousands, square kilometers in area. They have in their staff large parks of various types of main and technological transport, as well as an extensive network of technological automobile internal roads. In such a situation, it is necessary to take additional measures to organize the movement of technological and other vehicles, otherwise it may threaten the occurrence of congestion and traffic jams on the territory of the enterprise. To prevent such situations, it is proposed to organize traffic at the enterprise, the simulation model of which is presented in the article.

The simulation model of traffic management on the road network of a mining enterprise is designed to study the effectiveness of the functioning of the road network and the traffic control system on it, including using automation tools, calculating control parameters of traffic regulation and verifying the correct choice of their number and location on the ground.

In the simulation model of the organization of traffic on the road network of the mining enterprise using an automated system of technical means of traffic control, private simulation models of the work
of technical means for organizing traffic on the object and section of the road, as well as an information model of traffic control are laid [1]. As the control program, the algorithm of the technical means for organizing traffic at the facility and the road section is used [1].

The development of the simulation model is based on the following principles:

- traffic control equipment (TCE) should ensure maximum use of the potential throughput of the road section (object) (intersection, junction, single-track section, single-track bridge, etc.);
- TCE functions as a feedback cybernetic adaptive system. The adaptation of their work consists in the choice of traffic light cycles and the phases that make up these cycles in accordance with the traffic intensity on the road section (object) and the priorities of the traffic participants;
- imitation of the work of the equipment should be based on imitation of traffic flow;
- the basis for the optimal choice of traffic light cycles and phases of traffic control of vehicles (TS) along a road section (object) should be a criterion for ensuring the maximum traffic capacity of the section. At the same time, the limitations are the time and speed of skipping the required traffic volumes, as well as the exclusion of congestion and accumulation of equipment in front of objects with limited bandwidth.

The main assumptions used in simulating the traffic flow and the operation of the TCE:

- when simulating a traffic flow, it was assumed that the traffic intensity during the day is a random variable and is characterized by the normal distribution law. In this case, its minimum and maximum values are considered known;
- when modeling, it is assumed that each vehicle moves with a set permissible speed, which depends on the condition of the road, meteorological conditions, the number of cars in the stream and is also a random variable. According to previous studies, the speed of columns along the road obeys the normal distribution law;
- it is assumed that various types of vehicles may be present in the stream, both with trailers and without them. In this regard, the dynamic dimensions of vehicles are also random variables.

2. Materials and methods

![Figure 1. Structure of the simulation model of the organization of traffic on the road network of a mining enterprise](image-url)
The structure of the simulation model of the organization of vehicle traffic on the road network of the mining enterprise, including several blocks, is shown in Figure 1.

The simulation takes place in a single model time, with the initial time \( T_0 \) being the start time of the enterprise (road network) on the current working day, and the final time \( T_{final} \) is the end time of its operation.

### 3. The results of experimental studies and their discussion

Using block 1, a traffic stream is simulated.

In this block, according to the known initial data, the laws of the distribution of random variables described in modeling the movement of vehicles on the object and the road section, their type and speed, as well as the time interval between their arrival, are calculated.

Simulation of a traffic stream includes the following steps:

- **Modeling time intervals** between vehicles separately in different directions of movement \( \tau_z \) and \( \tau_z \) [1].
- The simulation of time intervals is organized using the inverse function method as:
  \[
  \tau = -\frac{1}{\bar{N}} \ln \xi, \quad (1)
  \]
  where \( \bar{N} \) is average vehicle traffic intensity within the enterprise in the considered period of time, veh./h;
  \( \xi \) is uniformly distributed number in the interval \((0; 1)\).

**Vehicle Type Simulation**

The type of vehicle is determined using the Monte Carlo procedure. An event signifying the appearance of a vehicle (by carrying capacity, dimensions or make) is established on the basis of inequality [2]:

\[
\sum_{i=1}^{\nu} P_i < \xi \leq \sum_{i=1}^{\nu+1} P_i
\]

where \( P_i \) is the probability of occurrence of a vehicle of the \( i \)-th type in the transport stream;
\( \xi \) – is random uniformly distributed number.

**Simulation of vehicle speed** along a road section [2]:

\[
\bar{v}_k = \sigma_{vk} \xi + \bar{v}_k, \quad (3)
\]

where \( \bar{v}_k \) is vehicle speed in the private implementation of the model, km/h;
\( \sigma_{vk} \) is standard deviation of the vehicle speed;
\( \xi \) is random value of normalized normal value \( \in (0; 1) \);
\( \bar{v}_k \) is average vehicle speed, km/h.

**Calculation of the travel time of the vehicle** along a road section/object (intersection, junction, single-track section, etc.).

The travel time of a road section (object) by a vehicle of the \( i \)-th kind in different directions \( (t_{1i}) \) and \( (t_{2i}) \) is determined separately according to the dependence:

\[
t_{ji} = \frac{d_{i+L_{obj}}}{\bar{v}_k}, \quad (4)
\]

where \( v_k \) is the traffic direction;
\( d_i \) is the length of an individual vehicle and the distance between it and the neighboring vehicle (dynamic dimension), km;
\( L_{obj} \) is the length of the road section (object), km.

**Simulation of the column movement permission (prohibition) event** along the road section (object) using the traffic control equipment.
At the same time, passing of an ahead vehicle with a lower priority is carried out on the oncoming lane. Depending on the direction of movement, the time of its passage through a section of the road with a limited throughput is calculated according to:

\[ t_i = \frac{l_{\text{act}} + l_{\text{obj}} + l_i}{v_k}, \]  

where \( l_{\text{act}} \) is the distance from the tactical sensor to the actuator of the traffic control system, km.

\( l_i \) is the length of the \( i \)-th vehicle.

**Blocks 2 and 3** imitate traffic on road sections. Moreover, the number and data of these blocks are equal to the number and data of objects and sections of the road [3].

The result of the work of blocks 2 and 3 are the values of the time of passing vehicles, their number by type, as well as the time of functioning and throughput of objects and sections of roads.

**Block 4** implements the procedure for the occurrence of an accident.

As a result of a random event, taking into account the known probability of an accident at the facility (site), a conclusion is made about the performance of the facility (site).

The modeling mechanism provides for the drawing of a random number and its comparison with the probability of an accident, i.e. [4]

\[ \xi \geq (1 - P_{\text{oper}}). \]  

where \( \xi \) is a uniformly distributed random number in the interval from 0 to 1 (for \( \xi \geq P_{\text{accident}} \) as an accident occurred on a section of the road, where \( P_{\text{accident}} \) is the mathematical expectation of the probability of an accident).

\( P_{\text{oper}} \) is the probability of maintaining the road operation.

**Block 5** simulates the maintenance, repair and reconstruction of enterprise roads [3, 4]. These measures require time for maintenance, repair and reconstruction of the site \( t_{\text{rep}} \), the modeling of which is done by drawing a random number in the interval of the probable time of repair work \([t_{\text{rep, max}}, t_{\text{rep, min}}]\).

In **block 6**, the situation is simulated, characterizing the accumulation of vehicles at one or more objects or sections of the enterprise’s roads [6].

This process can be modeled by the following recurrence relation:

\[
\begin{cases} 
N_j > P_{fj} \\
(M_{\text{in}} - M_{\text{out}}) + \sum_{i=1}^{n} L_{\text{dist},i} \geq L_{\text{sect},j}
\end{cases}
\]

where \( N_j \) is traffic intensity on the \( j \)-th section of the road, veh./h;

\( P_{fj} \) is the actual throughput of the \( j \)-th section of the road, veh./h;

\( M_{\text{in}} \) is the number of vehicles entering the \( j \)-th section of the road;

\( M_{\text{out}} \) is the number of vehicles leaving the \( j \)-th section of the road;

\( d_j \) is the dynamic dimension, km;

\( n \) is the number of vehicles in the \( j \)-th section of the road;

\( L_{\text{dist},i} \) is the distance between the \( i \)-th and \( i+1 \)-th vehicles on the \( j \)-th section of the road, km;

\( L_{\text{sect},j} \) is the length of the \( j \)-th section of the road, km.

In this case, there is a decrease in the speed of the traffic flow and its compaction, which requires response measures to control traffic on the road using technical means.

In **block 7**, the algorithm of the traffic control equipment on the road network is implemented [7–11].

The algorithm mimics the operation of traffic control equipment on the road, affecting the speed, flow density at objects and sections, as well as the distance between vehicles. In addition, it may switch movement from an object or section to a parallel road route [7].

The output of **block 7** is the adjusted values of the speed of the vehicles, as well as the distance between them.
In block 8, data on vehicle traffic is superimposed on the graph of the enterprise’s road network [10, 11, 12].

In this case, data on the intensity and density of the traffic flow are transmitted from one characteristic section of the road to another one after another. Taking into account the throughput capacity of objects and road sections, the occurrence of road accidents and maintenance, repair and reconstruction works will give a picture of the probable places of occurrence of congestion and traffic jams on the road network of the mining enterprise.

**Block 9** interprets the simulation results.

In it, data on traffic intensities at objects, sections, road networks of an enterprise are compared with data on throughput capacities of these objects, sections and the road network as a whole [13, 14]. In addition, data are presented on the vehicle’s movement time and missed traffic volumes on objects, sections and the road network as a whole. In this case, probable areas of occurrence of accumulations of vehicles can be visualized on a map (diagram) of the road network of the mining enterprise.

4. **Conclusion**

A simulation model of the organization of technological transport on the road network of an extractive enterprise using an automated system of technical means of traffic control allows simulating the flow of technological transport at an extractive enterprise, technical means of organizing traffic at facilities, road sections in order to study their impact on the effectiveness of traffic management for various the conditions of its organization, taking into account the occurrence of an accident, as well as difficulties in the movement of vehicles. It allows exploring the patterns of influence of technical means of organization and automation of traffic control on the characteristics of the traffic flow, traffic volumes and its safety, the use of the potential throughput of the road network of the mining enterprise.

The simulation model will allow developing the structure of an automated system of technical means of traffic control, as well as compare the effectiveness of the application of different composition of technical means of traffic management, which has different values of the characteristics of mobility, reliability, maintainability, cost, etc.

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