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Navigation Control of Cargo Transportation in the North of Russia



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ABSTRACT

To develop the northern territories and ensure a normal life for people working there, significant quantities of construction materials, fuel, machinery, equipment, food and other goods are needed, a significant part of which must be transported to these territories.

The peculiarity of the processes of transportation of goods to the Northern regions by road is that most of the transportation process is carried out using temporary roads which are called winter (or snow) roads [1, 2]. Unlike permanent paved roads with corresponding infrastructure maintenance elements, winter roads have a traffic track representing a snow-cleared lane without specially prepared layers of pavement. The track has temporary landmarks [3, 4]. However, in bad weather, sudden changes in temperature, the route can be «lost», which negatively affects reliability and safety of the transportation process.

Geoinformatics tools allow to create a virtual spatial model of a temporary road, which can be shown on an electronic map [5–7]. Satellite navigation tools form actual navigation data, which are « linked» to the route by means of geoinformatics. The current location of a vehicle on a winter road track can be displayed using an electronic terrain map on a display screen of an on-board telematic unit [8–10].

The objective of the article is to consider the main tasks that are solved by the supervisory control system when monitoring movement of vehicles on temporary winter roads.

Using mathematical methods and special methods of analysis and planning of road transportation, a methodological basis has been developed to increase the level of automation of basic functions of the dispatch control of road transportation of goods in mixed multimodal traffic based on the use of information generated by GLONASS global navigation system. It is shown that the use of geoinformatics, mobile communications and satellite navigation will significantly improve reliability and safety of the processes of cargo transportation in the North of Russia. According to experts, the use of the proposed methodology allows reducing time for cargo handling by an average of 30 % and decision-making time by 50 %, as well as increasing the efficiency of using vehicles by reducing by 95 % the number of deviations from the planned schedule.

Keywords: transportation, road transport, geoinformatics, satellite navigation, spatial digital model of the route, cargo of the northern delivery, temporary roads.

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Background. Transport is one of the decisive factors for the successful development of productive forces, exploration and mining, and ensuring vital functions in the northern regions of countries, part of which is located beyond the Arctic Circle.

In the Northern regions of Russia, the transport network remains mainly seasonal (waterways, winter roads). The availability of these transport routes is largely dependent on climatic conditions.

At present, more than half of the length of the road network of newly developed northern regions consists of winter roads. Significant labor costs for their seasonal creation and maintenance lead to the fact that the cost of road transport on winter roads is 70 % higher than on roads of III–IV class.

The use of Intelligent Transport Systems (ITS) technologies in the areas of the Far North and areas equated to them will provide an opportunity to predict the state of temporary transport routes, monitor the processes of cargo transportation, monitor the status of the transportation process, integrate transport and logistics information and to provide access to it at any time to all participants to the transportation process. This will improve the efficiency and safety of the process of cargo delivery to the Northern regions.

Crossing frozen rivers and transportation using a winter road require increased attention from all traffic participants. The practical use of winter roads in bad weather increases the level of risk during transportation. To increase traffic safety and to improve technical and operational performance, it is necessary to use ERA-GLONASS system. Vehicles manufactured in Russia after 2017 should be equipped with ERA-GLONASS emergency response system [8], the main purpose of which is automatic generation and transmission of a signal to the 112 [emergency call number] service in case of an accident. For this purpose, a vehicle is equipped with a special mobile navigation communication unit, which in case of an accident determines severity of an accident, position of a vehicle and transmits a distress signal through any mobile operator whose signal in this place will be the strongest. An on-board unit includes a distress signal button, which a driver can press in an emergency to manually call the operator of ERA-GLONASS system.

The enterprises of cargo road transportation should introduce modern satellite communications and navigation technologies as part of an automated navigation system for dispatch control and vehicle traffic control. Each vehicle of an enterprise must be equipped with a set of telematic devices.

Objective. The objective of the article is to consider the main tasks that are solved by the dispatch control system when monitoring cargo transportation by vehicles on temporary winter roads. In this regard, in particular, issues of development of a spatial model of a temporary automobile road (winter road) are considered.

Methods. The authors use mathematical and specific informatics methods.

Results.

Determining the distance traveled by trucks on a route using a digital model

Automatic control of the plan of cargo transportation along the route is carried out on the basis of the use of the « distance function», which for a given point in time determines the distance traveled by the controlled vehicle from the starting point of the route [11, 12].

In general, the distance function is written as follows:

$$S = \int (\phi(t), \psi(t), dt), \qquad (1)$$

where t is point in time at which the value of the distance function is determined;

$(\phi(t), \psi(t))$ – coordinates of the model point to which the current navigation mark is attached at time t.

In practice, the digital route model is implemented using a piecewise-broken function that simulates sections of the route. In this case, the distance function uses a table of route distances with entries of the following structure: «Number of the digital model segment», «Length of the segment, m». The distance from the start point of the route (distance traveled) S is calculated as follows.

1. If the navigation mark is tied to a point that is the end of the n-th segment, then the distance traveled is calculated by the formula:

$$S(t) = \sum_{i=1}^{n} l_i \,, \qquad (2)$$

where l_i – length of the i-th segment of the model, m. If the current navigation mark obtained at time t is tied to a point that is an intermediate point of the n-th segment with coordinates $(\phi(t), \psi(t))$, then the distance traveled is calculated by the formula:

$$S(t)=\sum_{i=1}^{n-1} l_i + S_n(t)\ , \quad (3)$$

where l_i – length of the i-th segment of the model, m;

$S_n(t)$ – Cartesian distance from the beginning of the n-th segment to the model point with coordinates ($\phi(t)$, $\psi(t)$), to which the navigational mark obtained at time t is tied, m.

The value of $S_n(t)$ is determined by the formula

$$S_n(t)=\sqrt{(c_\varphi(\phi_n\text{-}\phi(t))^2+(c_\psi(\psi_n\text{-}\psi(t))^2}\ , \quad (4)$$

where ($\phi(t)$, $\psi(t)$) – coordinates of the model point to which the current navigation mark is attached at time t;

(ϕ_n, ψ_n) – coordinates of the start point of the n-th segment;

C_ϕ – coefficient of conversion of a degree measure of latitude to metric;

C_ψ – coefficient of conversion of a degree measure of longitude to metric.

Substituting the expression (4) in (3) we get:

$$S(t)=\sum_{i=1}^{n-1} l_i+\sqrt{(c_\varphi(\phi_n\text{-}\phi(t))^2+(c_\psi(\psi_n\text{-}\psi(t))^2}\ . \quad (5)$$

Estimation of deviation of the planned time of vehicle movement at an arbitrary point in time and control of deviation by the dispatch system

The deviation of cargo transportation by road transport from the planned traffic time at any moment is estimated automatically based on a comparison of the planned and actual location of the vehicle on the route at a given time. The planned location of the vehicle is determined on the basis of information from control traffic points, as each vehicle should pass each control point at exact scheduled time.

To simplify the calculations, we consider the case when the vehicle is between the control points of the route with numbers i and (i + 1). Moreover, its location according to the plan also corresponds to the distance between the control points with numbers i and (i + 1). Let $t_{p\,(i)}$, $t_{p\,(i+1)}$ be the planned times for passing the control points i and (i + 1). Let l_i, $l_{(i+1)}$ be the distance from the beginning of the route to the control point with numbers i and (i + 1), respectively. Then the value S^p (t) which is the planned distance from the beginning of the route at time t falling into the time interval [$t_{p\,(i)}$, $t_{p\,(i+1)}$], is determined by the formula:

$$S^p(t)=\sum_{i=1}^{n-1} l_i + S_n^p(t)\ , \quad (6)$$

where l_i – length of the i-th segment of the model, m;

$S^p_n(t)$ – Cartesian distance from the beginning of the n-th segment to the model point corresponding to the position at the planned time t, m.

The planned average speed V_{av} on the route section between stops with numbers i and (i + 1) is determined from the expression:

$$V_{av}=\frac{\left[l_{(i+1)}-l_i\right]}{\left[t_{p(i+1)}-t_{p(i)}\right]}\ . \quad (7)$$

Then the value of $S^p_n(t)$ can be calculated by the formula:

$$S_n^p(t)=\frac{\left[l_{(i+1)}-l_i\right]}{\left[t_{p(i+1)}-t_{p(i)}\right]}\bullet\left[t-t_{p(i)}\right]. \quad (8)$$

The first term (fraction) in formula (8) determines the planned average speed of movement between the control points with numbers i and (i + 1). The second term (difference) determines the planned time elapsed from the moment of passing the control point with number i to the current time t. Inserting the expression (8) to (6) we obtain:

$$S^p(t)=\sum_{i=1}^{n-1} l_i+\frac{\left[l_{p(i+1)}-l_{p(i)}\right]}{\left[t_{p(i+1)}-t_{p(i)}\right]}\bullet\left[t-t_{p(i+1)}\right]. \quad (9)$$

Let's consider the case when both the planned and actual location of the vehicle belong to the same segment between the control points with numbers i and (i + 1).

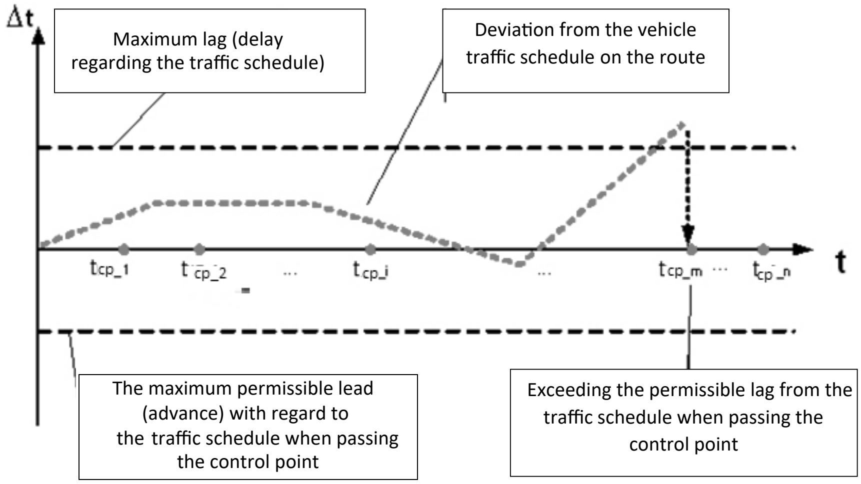
The difference ΔS between the actual and planned distance at time t is determined by the formula:

$$\Delta S = S(t) - S^p(t). \quad (10)$$

The time deviation Δt of movement of cargo vehicle is determined from the expression:

$$\Delta t=\frac{\left|S(t)-S^p(t)\right|}{V_{av}}\ . \quad (11)$$

The time deviation is equal to the absolute value of the difference between the planned and actual distance traveled at time t divided by the average speed. For the purposes of dispatch control, one can consider the value of Δ with a sign. If the actual distance traveled at time t is greater than the planned distance, then there is movement of the vehicle at an average speed higher than planned. In this case, Δt will be positive. If the actual distance traveled at time t is less than the planned distance, then there is a «lag» (delay), i.e. driving at an average speed lower than planned. In this case, Δt will be negative. Substituting S(t), V_{av}, $S^p(t)$ with their expressions



Pic. 1. Scheme of control of vehicle movement on the route.

from formulas (5), (7), (9) and having performed the transformations, we obtain:

$$\Delta t = \frac{\sqrt{(c_{\varphi}(\phi_n - \phi(t))^2 + (c_{\psi}(\psi_n - \psi(t))^2} - \frac{\left[l_{p(i+1)} - l_{p(i)}\right]}{\left[t_{p(i+1)} - t_{p(i)}\right]} \cdot \left[t - t_{p(i+1)}\right]}{\frac{\left[l_{p(i+1)} - l_{p(i)}\right]}{\left[t_{p(i+1)} - t_{p(i)}\right]}}. \quad (12)$$

Pic. 1 schematically shows an automatic system for monitoring the respect of the schedule by a vehicle on a route.

The model described above allows the system to continuously and automatically monitor the Δt value. In this case, the system technologist sets the maximum permissible values of Δt. When they are exceeded, the system generates a signal to the dispatcher about the need for regulatory actions in order to return the transportation process to its planned state or, if this is impossible, in order to reduce the negative consequences of the violation. The picture graphically displays the process of increasing the deviation of the vehicle movement from the schedule, and the point in time at which the fact of reaching the maximum permissible deviation is recorded, which can be unsafe for vehicle driver in the northern conditions.

Estimation of the plan of cargo transportation by road transport between control points

Estimating the plan of cargo transportation by road transport between control points is based on a comparison of the planned and actual time when the vehicle passes the control points of the route, particularly specified by experts in organization of transportation for the reasons of control, safety and reliability of cargo transportation. As control points on the route, the system must indicate the start and end points, as well as one, two or three intermediate control points, depending on the length of the route. In order to automatically estimate the respect of the plan of cargo transportation by road transport for each control point, the maximum permissible amount of deviation (lead) from the planned time ($+\Delta t_{per}$) and lag ($-\Delta t_{per}$) are indicated. If the actual deviation from the schedule allowed during passage of the control point falls within the interval [$-\Delta t_{per}$, $+\Delta t_{per}$], the system automatically takes into account the fact of planned passage of the control point. In this case, the actual time taken to pass the control point is determined as follows. For each control point, a certain spatial area is determined and mathematically described, including the location of the control point, which is called the « zone of influence of the control point». If the navigational marks coming from the vehicle are tied to the zone of the control point, it is considered that the vehicle is located at the corresponding control point. The rules by which the system automatically determines the actual time taken to pass the control point are formulated as follows:

1) if the control point is the starting point of the route, then the actual start time of the route is counted by the system according to the time of formation of the last navigation mark received from the vehicle, located within the zone of the first control point which is the starting point on the route;

2) if the control point is the final point of the route, then the actual time of the end of the route is calculated according to the time of formation of the first mark received from the zone of the last control point which is the final point on the route;

3) if the control point is an intermediate point on the route, then the actual time of passing by the intermediate control point is counted as the time when the navigation mark was formed within the zone of the intermediate control point, which turned out to be as close as possible or coincided with the planned time of passage of this control point on the route.

In order to organize an automatic assessment of the planned cargo transportation, the system technologist indicates how many control points on the route should be passed without failures (i.e., not exceeding the specified limit deviations from the planned travel time) so that the entire route is counted as planned. Usually it is allowed to pass no more than one control point on the route outside fixed time, i.e. with exceeding the maximum permissible deviation when overtaking or when lagging, for the system should consider the travel plan as respected. For example, if five control points are defined for a route, then the technologist can specify the value «four control points» to confirm that the travel plan has been respected. At the same time, it does not matter for the system which point out of five will not be passed within the set schedule. If the vehicle passes no less than the number of control points specified by the technologist on the route within the schedule, travel is automatically considered as conform to the plan in the system. Otherwise, transportation is counted as not conforming to the plan.

Digital model of a winter road

The objects of the *digital* model of the temporary winter road are as follows:

1) Track, includes:

1.1) Digital description of the spatial model of the road.

1.2) Semantic description of specific sections (river crossing, dangerous sections, etc.).

1.2.1) Control points (stops).

1.2.2) Dangerous areas with semantics (dangerous moments arising on the route).

2) Time periods (impact of certain dangers/threats with the possibility of programmed processing of these situations at different periods of the year or at different periods of the day, or in both cases).

3) Location of dangerous points and their extent in the description of the characteristics of traffic.

If the situation on the route worsens, the dispatcher informs the driver on the operational situation. Standard messages are pre-programmed for all possible adverse situations. In this case, the dispatcher selects the desired message from the list and sends it to the driver

with a request to confirm reception of the message. Confirmation of the message is mandatory if the dispatcher sends a « Change Route» command. The dispatcher types a short text of approximately 20 characters, which is transmitted to the on-board navigation terminal and is displayed on the terminal screen. The system time is also shown on the terminal screen [14, 15].

The driver of the vehicle also has preformed messages: calling the police, firefighters, ambulance, and an obstacle on the route, which he can choose from the list and send to the dispatcher instead of voice communication.

4) Semantic and spatial description of control points.

The semantic and spatial description of control points depends on the type of control point.

At the end of the operational day, information about the results of the transportation process appears in the system. Information is available to all legitimate users. It may include balances of cargo volumes in warehouses, forecast of cargo arrival for a day, week, month, time of arrival of forecasted consignments.

A forecast of time of movement of vehicles at control points of the route is formed, time of delivery of goods to the consumer is predicted.

Comparison of traditional and proposed principles for monitoring movement of vehicles on temporary roads (winter roads)

1. Principles of motion control in a traditional control system:

1.1. Management is carried out only at certain points in time (the beginning of the route and the end of the route).

1.2. Control is carried out only at specific points (transshipment points).

2. Control principles when using a digital route model:

The introduction of navigation equipment and of a digital track model allows to:

1) determine the distance and time of travel to the next control point.

2) control deviation from the traffic schedule on each planned stage between control points using a function that describes the planned distance from the starting point of the route as a function of time: F(l) = F (l, t). The function allows to determine the deviation from the traffic schedule which is delay time (Td).

Monitoring the current state of the transshipment point: the key object of the transport infrastructure

The digital model of each transshipment point, including the terminal, can be described in terms of queuing systems. This description includes a parametric description of individual terminal facilities (free areas, loading service posts, vehicle queues in the service areas of various cargo flows (bulk, packaged, tare-piece, container, bulk, oversized and large loads, etc.), queues for service by class and direction). A forecast is formed for occurrence of a denial of service situation due to capacity overload (current acceptance of applications exceeds the volume planned for the operational day). In the future, dynamic information about the state of the terminal should be stored in the system and the possibility of redirecting, redistributing part of the cargo to other terminals should be predicted.

From the point of view of the basic functions of the terminal, planning of processing of the incoming application flow is carried out using the following initial data:

1. Forecast of time of arrival of goods to the terminal by days or hours.

2. Service time forecast (cargo volume, processing time, etc.).

3. Forecast of time spent in the queue for service.

4. Forecast of loading of work areas by specialization (service points by specialization).

Initial data for the forecast:

n – number of posts;

n_1, n_2, ..., N_n – number of posts by specialization;

O – service queues;

$O_1(t)$, $O_2(t)$, ..., $O_n(t)$ – queues for posts by specialization.

Applications flow parameters:

P^1_1, P^1_2, ..., P^1_n – number of applications for the next day by specialized posts;

P^2_1, P^2_2, ..., P^2_n – number of applications for the second day (from the current date) by specialized posts;

P^m_1, P^m_2, ..., P^m_n – number of applications for next days (from the current date) by specialized posts,

where m is forecast horizon in days.

Conclusions. The developed methodological basis for increasing the level of automation of basic functions of dispatch control of cargo transportation by road transport in mixed multimodal traffic based on the use of information generated by GLONASS global navigation system allows, according to experts, to reduce, on average, time for cargo processing by 30 % and decision-making time by 50 %.

The developed new approaches to formation of the transportation system, which increase the efficiency of the use of road transport, which works under control of the navigation systems of the dispatch control, can also reduce deviations of vehicles from the planned travel time by 95 %.

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