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MONITORING OF SNOWFILLING ROADS SECTIONS — INFORMATION MODELING

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Statement of the problem. The problems of information modeling for monitoring of skidding road sections in winter season are discussed.
Results. As a skidding section, the road section in a ditch has been considered. The information model substantiation describing the geometrical parameters of a skidding road section is designed. Information resources characterizing the state of an external environment are described. Computational and analytical component of the information model is represented by means of the algorithm of obtaining about skidding road sections and need for snow removal.
Conclusions. It was concluded that information models could be designed that can be used at the maintenance stage of the road life cycle for organizing the operational management of snow removal.

Keywords: winter road maintenance, skidding section, monitoring, information modeling, level of development.

Introduction. According to the decree by the President of the Russian Federation, a list of new national projects up to 2024 has been defined in 12 strategically important directions, one of which is the “Safe and High-Quality Roads”. The national project proposes measures for improving traffic safety, preventing traffic accidents and reducing casualties. This is going to be achieved by means of developing information technology on highways — intelligent transport systems, digitalization of road management.

One of the priority areas for information technologies in the road sector is introducing the concept of information modeling providing an information model of a road object that functions as a common resource for obtaining information about it for making optimal decisions at all stages of its life cycle [12, 13].

The winter season is considered the most challenging in terms of traffic safety. Snow-covered sections of roads are particularly dangerous due to low coupling qualities of a road surface [4]. According to the regulatory documents, excavations are classified as highly prone to skidding [17]. Constant monitoring of such sections, predicting of snow drifts and timely snow removal is an urgent task serving to improve road safety.

The purpose of the study is to analyze and justify the information resources necessary to manage winter maintenance of snow-covered road sections from the point of view of information modeling. The objective of the investigation is a section of a road with a ditch.

1. Theoretical justification of information resources for monitoring snow-covered areas.

Technical monitoring of roads at the maintenance stage is aimed at systematic monitoring of their condition in order to timely detect current changes, preventing negative processes from happening as well as eliminating their consequences. In this case, the state of the object is predicted considered a mutual influence of an object and an environment.

The Russian national standards impose rigid requirements on winter maintenance of roads and regulate the thickness of snow deposits and time of their clearing following snowfalls and blizzards [16]. In order to ensure the best properties of roads in wintertime, it is the duty of road maintenance services to conduct work to combat snow deposits. The necessary material and technical resources such as road special equipment, time of commencement of work and its amount can be calculated using a quantitative assessment of snow deposits on a surface.

The authors previously conducted studies to identify the amount of snow accumulations in road ditches and of snow deposits in a roadway [7]. As during the winter season the amount of snow deposits within a road subgrade is constantly changing, studies were conducted on the dynamics of snow accumulation during this period [10, 20]. The growth of volumes blown during snowstorms and snowfalls, snow removed from the carriageway and roadsides during patrolling snow removal, and a decrease in periods in between blizzards due to weather factors, i.e., compaction and melting of snow, were calculated.

The viability of the models set forth by the authors was tested on snow-covered sections of roads of the Voronezh and Oryol regions through the course of experimental studies [9]. A comparison of the data obtained during snow measurements and the results of numerical modeling employing the models set forth by the authors showed that their convergence is over 85 %.

Thus, it was concluded that these models could be employed in order to investigate the dynamics of snow accumulation on roads during the winter season. However, currently considering the availability of technical tools, communications and computer technology in road maintenance units, it is possible to address practical problems at the stage of road maintenance based on the results of continuous monitoring of the operational status of ditches in wintertime [5].

A viable dynamic mathematical model describing snow accumulation on a snow-covered section of a roadway enables its operational status to be monitored in the winter on the condition that that there is information support, algorithms and models for processing and analyzing the information needed for making decisions.

The information model allows us to identify the operational state of a skidding area, to predict its likelihood in the future as well as to select a snow removal technology. The main objective of managing transport objects at the maintenance stage can be defined as providing the safety and efficiency of a road and road structures and maintaining their transport and operational condition in compliance with the requirements under the conditions of ensuring continuity and road safety in any period of a year. In winter maintenance of roads, due to an impact of an external environment, it is vital to consider management from the perspective of information provision. In this case, a generalized control scheme can be presented in the form that reflects the interaction of a few subsystems [8]: information-measuring, information-reference and telecommunication (communication systems). The scheme of the interaction of the subsystems is given in Fig. 1.

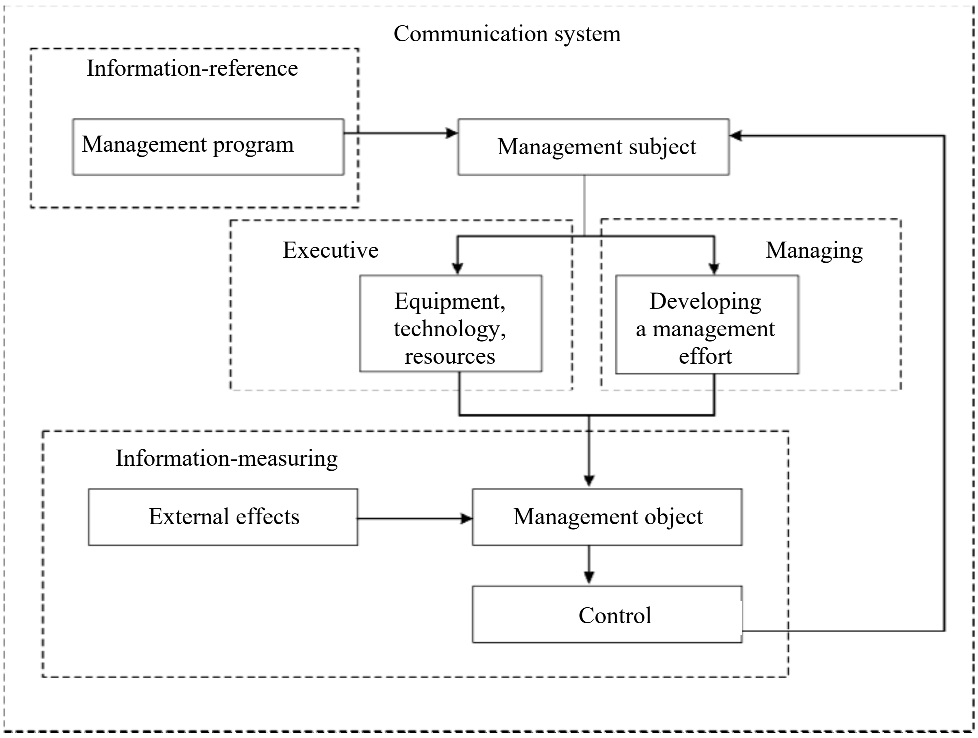

Fig. 1. Major subsystems for managing roads at the maintenance stage (informational aspect)

To obtain the information on the external influences and the actual state of the control object (transport structure), *an information-measuring subsystem* is required. For winter maintenance of roads to run effectively, it is necessary to obtain operational information on weather parameters in the vicinity to the roads and information on the state of the road surface. The measurement of these parameters does not only describe the actual situation in the control object, but under certain conditions it also allows its change to be predicted.

An information and reference subsystem contains information on the regulatory state of the control object as prescribed in the national standards. It was previously assumed that the same subsystem should include digital databases describing the control object, i.e., the road and available resources (not shown in the diagram) [8]. However, at the current stage of development of information technologies, information on the control object should be its information model [12], some of its aspects are discussed in the article.

A control subsystem based on the analysis of the incoming information provides the choice of optimal control actions. Effective organization of work is not possible without reliable *communication*. This subsystem provides transfer of information from measuring devices and sensors to the processing center, allows recommendations on the choice of a particular technology to be transferred, the progress of their implementation to be monitored and the result to be recorded based on feedback.

Let us look at the implementation of the suggested scheme using the example of the organization of maintenance of a snow-covered road section with a ditch.

The dynamics of changes in the amount of snow deposits on slopes and road ditches at any time *t* was generally described by means of a dynamic model [10]:

$$Q_{отл}(t) = f\left[Q_{снп}(t);\ Q_{мет}(t);\ Q_{уб}(t);\ Q_{пот}(t);\ t\right], \qquad (1)$$

where $Q_{снп}$ is the amount of snow during snowfalls, m^3/m; $Q_{мет}$ is the amount of snow during blizzards, m^3/m; $Q_{уб}$ is the amount of snow moved from the roadway and ditches during machine snow clearance, m^3/m; $Q_{пот}$ is the amount of snow loss under the effect of weather conditions, m^3/m; *t* is the time, h.

Each of the components of the model depends on multiple factors and is calculated depending on particular values [10].

A dynamic mathematical model that is sufficiently indicative of snow accumulation in a ditch allows for monitoring of the operational state of the skidding area in the wintertime on the condition that there is information support, algorithms and models for processing and analyzing the information needed for making decisions.

All the factors affecting the operational state of the skidding area can be divided into internal (road) and external ones (describing the state of the environment) [8].

According to the functional purpose for the task of monitoring skidding of *information modeling*, it can consist of the following parts:

— object, which will include a description of a snow-covered road section;

— weather and climate, containing an actual description of and external environment and predictions of its changes;

— computational and analytical including calculations, analysis of results, predicting the condition of an object, selection of recommendations and technologies for prevention or elimination of snow drifts.

2. A geometric model of a snow-covered road section in a ditch. Skidding during snowstorms is determined by physical processes of a snow and wind flow around a transverse profile of the subgrade.

In order to monitor snow accumulation in ditches, geometric models describing a transverse profile of the subgrade can be employed [3, 22]. A design scheme with the geometric parameters of an uncovered ditch is shown in Fig. 2.

Depending on the relationship between the amount of snow and snow capacity of the uncovered ditch, two calculation schemes are employed. The first one is employed for snowfall volumes not exceeding the snow capacity of a ditch, and its upper surface of snow deposits is limited by the line AB with a slope in the direction of the road axis 1 : 8 [3]. The second design scheme is employed when the amount of snowfall exceeds the snow capacity of a ditch according to the first design scheme. In this case, the area of snow deposits on the slope and in the ditch is limited by a shaded polygon.

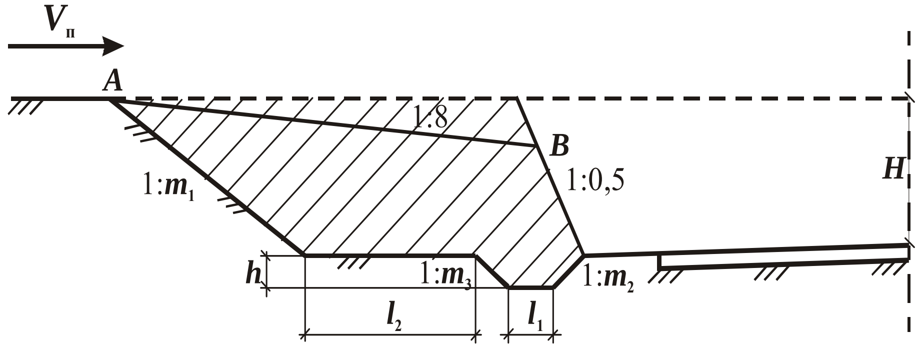

Fig. 2. Calculation scheme for identifying skidding of a road ditch

H is the depth of a ditch, m; m_1, m_2 and m_3 are the coefficients of the ditch slopes;

l_1 is the width of the ditch slope, m; l_2 is the width of the bottom of the ditch, m; h is the depth of the ditch, m

For the first design scheme, the maximum amount of snow on one running meter of leeward slope of the ditch (considering its geometric parameters) is given by the formula:

$$Q_{отк,кюв} = 0.5\left(H^2 \cdot m_1\right) + l_2 \cdot H + 0.5H\left[2l_1 + 2h\left(m_2 + m_3\right) - 0.5H\right] + \\ +0.5h\left[2l_1 + h\left(m_2 + m_3\right)\right] - 0.0625\left(H \cdot m_1 + l_1 + l_2 + h\left(m_2 + m_3\right) - 0.5H\right)^2 . \quad (2)$$

Similarly, based on the geometric calculations, the maximum amount of snow on the leeward slope of the ditch according to the second scheme is given by the formula:

$$Q_{отк,кюв} = 0.5\left(H^2 \cdot m_1\right) + l_2 \cdot H + \\ +0.5H\left[2l_1 + 2h\left(m_2 + m_3\right) - 0.5H\right] + 0.5h\left[2l_1 + h\left(m_2 + m_3\right)\right]. \quad (3)$$

The dependences (2) and (3) describe a maximum snow capacity of a ditch. The suggested models allow one to calculate both the so-called residual snow capacity of slopes and predict one of the following:

1) all the snow blown by a blizzard $W_{пр}$ will be on a slope and bottom of a ditch and no snow is expected on a roadway surfacing;

2) some of the snow blown by a blizzard will be on a roadway surfacing and has to be cleared within a specified period of time.

For the second situation the amount of snow in the soil $Q_{зп}$ is given by the formula:

$$Q_{зп} = W_{пр} - Q_{отк,кюв}, \quad (4)$$

where $W_{пр}$ is the amount of snow blown to the road during a blizzard, m^3/m.

The resources needed for snow removal are calculated for this particular amount.

Let us look at the possibility of designing an information model that describes the geometric parameters of a transverse profile shown in Fig. 2.

According to the existing terminology, an information model (IM) is defined as a combination of graphic and textual data on an object presented digitally which is a single reliable source of information on an object at all or individual stages of its life cycle. If we look at a snow-covered section of a road as an element of a digital information model, then the geometric data includes the one that determines its size, shape and spatial location.

All the parameters in the equations (2) and (3) for each specific skidding area can be represented using the spatial coordinates (*x, y, z*) of all of its characteristic points. The spatial location of the road section makes it possible to determine the amount of snowfall during a particular snowstorm depending on the direction of a blizzard.

Currently three-dimensional digital information models (DIM) of transport structures in the form of a digital project model designed using a digital model of an area are formed during surveys and design by means of computer-automated design systems (CAD) [1, 14, 15]. When transferring them to the next stages of a life cycle — construction and operation — the information model should be supplemented by various attributes.

In order to be able to employ the information model (IM) at various stages of a life cycle, the concept of a level of model development (LOD) is introduced [11, 19] which is a set of requirements that determines the development of a DIM element (a minimum amount of geometric, spatial and attribute data needed to address problems at a specific stage of a life cycle of an object).

The Set of Guidelines (СП) 333.1325800.2017 defines five basic levels of processing: LOD 100, LOD 200, LOD 300, LOD 400, LOD 500. The analysis of the descriptions of the basic levels of processing of CIM elements provided in this regulatory document led us to conclude that the description of the geometric scheme presented in Fig. 2 and the subsequent solution of the tasks of monitoring snow removal and snow clearance is sufficient for the level of development of the information model LOD 300.

For this level, an element of the digital information model is represented as an object with exact fixed dimensions, shape, exact spatial position, orientation and necessary attribute information. In spite of the fact that the application for this level is the design stage, preparation of design and working documentation, it can be employed for a geometric description of a skidding area.

3. Information resources describing the external environment. Winter maintenance is a complex process that is dependent on weather conditions. It is associated with collection, processing and transfer of information that comes from different sources. In order to make a decision to start snow removal, it is necessary to have information available from the units of the Hydrometeorological Centre of Russia and from road networks to automatic weather stations in roads (AWS) [6, 8].

Considering the information resources available at the Hydrometeorological Centre of Russia and practical experience of the operation of road weather monitoring systems, the composition of the information needed for operational management of work to combat snow deposits and drifts can be formulated in the "Concept of Meteorological Support for the Road Economy of the Russian Federation" [6].

The information obtained from the Hydrometeorological Centre of Russia is presented in Table.

It is recommended that information about weather conditions in the vicinity of a road (air temperature, speed and direction of wind, time and type of rainfall) is requested from the AWS network, which successfully operates in the main Russian highways. Equipping AWS with modern contactless optical “intelligent eye” sensors allows real-time data to be additionally obtained on the type and intensity of rainfall, thickness of snow on pavement, on slopes and in soil [18, 21, 22]. Weather information obtained from the AWS network is faster than the one obtained from meteorological stations of the units of the Hydrometeorological Centre of Russia, as the sensors are automatically surveyed within the right of way. The period of the survey may vary depending on the degree of danger of weather conditions for a road surface.

Table

Weather data for monitoring skidding coming from the Hydrometeorological Centre of Russia

Data	Parameters needed for information models
Weather warnings	Time of the beginning and the end of a rainfall event, its type and intensity
Wind information	Direction and speed of wind
Meteorological radiolocator data	Text-decoded intensity and amount of rainfall according to the major road directions in maps and tables
A 12-hour weather forecast (from 9am to 9pm and from 9 pm to 9 am)	Weather forecast for major highways
A specialized 4-hour weather forecast with an hour gap (up to 8 ones a day)	Temperature, wind, rainfall locations and intensities
Storm warnings with mandatory storm cancellations 2 hours in advance	Time of the beginning and the end (regression) of an event

Information about weather events, condition of a road surface and a subgrade can be supplemented by video data obtained in real time from road surveillance cameras set up both in conjunction with AWS and individually [2]. Measurements of the AWS sensors in conjunction with the data from the cameras allow a better understanding of the condition of a road within the right of way in a controlled area.

4. Algorithm for monitoring skidding of a ditch and snow removal warnings. The computational and analytical component of monitoring provides a set of mathematical models that describe both an object of observation and parameters of an external environment.

The main parameter the decision on snow removal measures depends on is the thickness of snow deposits on a surface. In the event of a rainfall or snowstorm, it is necessary:

— to identify a possibility of snow deposition on certain sections of roads;

— to determine the accumulation time of a maximum permissible thickness of snow deposits on a surfacing for each typical site;

— to provide recommendations on the start of snow removal of snow-covered areas.

Snow removal warnings should be issued separately for each snow-covered road section. It is these areas that are primarily recorded by snow and they are in need of special attention.

A step-by-step algorithm for monitoring the condition of road sections in ditches can be represented by 9 subsequent steps. The calculation formulas for individual steps of the algorithm are shown in the previous studies [7, 10].

Step 1. According to the forecast of possible solid rainfall, amount of snow accumulation on slopes and in ditches is recalculated considering snow losses under the effect of weather factors (evaporation and thawing) for the period from the moment of the latest rainfall.

Step 2. If a snowfall is expected without snow transfer, go to *Step 4*.

Step 3. According to the forecast on the speed, direction of wind and duration of a rainfall, amount of snow transfer and amount of snow removal to a road section in an uncovered ditch is calculated. Go to *Step 5*.

Step 4. According to the forecast, a possible amount of snow deposition on a subgrade, on a slope and in an uncovered ditch from a predicted snowfall is identified.

Step 5. The obtained values are summed up with the amount of snow accumulated on the leeward slope and in a ditch at the time of a blizzard or a snowfall.

Step 6. The residual snow removal is estimated considering the calculated amount of snow.

Step 7. The average height of accumulations on the carriageway and roadsides is identified and recommendations are provided on the snow removal in a road. If there is no need for snow removal, go to *Step 9*.

Step 8. For machine snow removal of roadways and roadsides, the amount of snow accumulation on a slope and in an uncovered ditch is recalculated.

Step 9. Design a database with snow accumulation in an uncovered ditch.

Steps 1—9 are repeated multiple times throughout the winter season.

If weather conditions change and forecast updates are obtained, it is necessary that additional calculations are performed and the technological regimes are adjusted for winter maintenance.

Implementation of the calculations according to the suggested algorithm allows all the necessary current and weather information to be obtained considering the dynamics of snow accumulations on a road section in a ditch and recommendations on snow removal to be obtained.

The suggested algorithm accounts for a physical nature of snow accumulation, therefore and can thus be employed in calculations for any road and climatic zone.

Conclusions

1. For the first time, an approach to the organization of monitoring snow on roads from the perspective of information modeling has been proposed. The resources describing a monitoring object and an external environment are substantiated.

2. It is suggested that a 3D-model of a road formed in CAD at the design stage for the geometric description of the snow-bearing section is used. The level of model development (LOD) for monitoring snow cover is accounted for.
3. Information resources that describe an external environment and their sources are substantiated.
4. For the first time, calculation and analytical component of information modeling is represented by means of an algorithm for processing and analyzing information for making decisions on snow removal.

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