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RESULTS OF STUDYING ROAD CONSTRUCTION PARAMETERS' CONDITION

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Abstract

A system for the accounting of road infrastructure facilities' parameters specified during design and construction of motor roads. A study of parameters' condition was performed. Analysis of road accident rate statistics and identification of parameters to assess the efficiency of the proposed road construction activities aimed at the reduction in the number of road accidents were carried out.

Actual data on condition parameters with the use of modern automated multi-functional diagnostic equipment were obtained. Actions aimed at the improvement of road infrastructure parameters through traffic safety enhancement, as well as actions aimed at the reconstruction of the motor road or project-supported construction of road segments were developed. Efficiency of the proposed actions was assessed.

Keywords

Motor road, construction, reconstruction, road surface, vehicle, parameters, road accidents.

Introduction

Obtaining of studies results is based on the use of the improved system for accounting of parameters during design and construction of motor roads. Non-compliance with construction regulations has adverse effects during operation. In particular, it can lead to premature destruction of the road surface, appearance of rutting, low adhesion characteristics of the road surface, certain condition of the roadway and shoulders (especially in winter), producing accident-prone situations.

Generally, such factors decrease traffic safety decrease and increase the number of road accidents. Troubleshooting reduces to expert study which represents a set of successive systematic theoretical and practical methods or actions aimed at identifying the causes and factors that led to a failure in the Driver–Vehicle–Road–Environment (DVRE) system.

A failure in the system means operating trouble of one of the key components, i.e. Vehicle, Driver, Road or their combinations, including the Environment component, which, in their turn, cease to perform their assigned functions partially or totally, leading to violations in safe operation of the entire system.

Analysis of operating troubles or failure prevention are possible through qualitative expert study. Scientific studies of some parameters of the subsystem "Vehicle–Road" condition, performed by scientists Nemchinov M. V., Vasiliev A. P., and Domke E. R., are aimed at braking performance and characteristics of wheel adhesion with the road surface during operation and reconstruction of the latter (Kurakina, Evtyukov, 2017; Domke, 2012; Evtyukov, Vasiliev, 2012; Kurakina, 2014b; Suvorov et al., 1990). Scientists Suvorov Yu. B., Kikot I. M. and others (Evtyukov, Vasiliev, 2012; Kurakina, Evtyukov, 2015) were engaged in diagnostic studies of elements of operated motor roads at segments where road conditions affected traffic safety.

Kiryukhin G. N. proved the relevance of road surface diagnostics and determination of traffic flow characteristics with the use of a wide range of devices and equipment for testing and diagnostics of motor roads (Kurakina, 2016, 2017, Kurakina, Evtyukov, 2014, 2015).

Expert study is supported by various procedures, algorithms, methods, strategies, techniques and equipment, depending on the purpose of the expert study, its complexity and the number of questions posed. Subjects of various researches are reviewed in works of such scientists as Borovskiy B. E., Ilarionov V. A., Evtyukov S. A., Zamarayev I. V., and Stolyarov V. V. (Ilarionov, 1989; Kurakina, 2014b; Kurakina, Evtyukov, 2015).

However, during construction, the system of accounting for the main parameters of the "Road" subsystem is specified by regulatory documents of the construction industry.

Mutual comprehensive studies of parameters conditions shall be carried out at all stages of construction, operation and reconstruction in order to prevent emergency conditions (Kurakina, 2014a; Kurakina, Evtyukov, 2014; Kurakina, Evtyukov, 2015; Kurakina et al., 2017; ROSDORNII, 2015; Suvorov et al., 1990). Based on such study, actions aimed at the improvement of road infrastructure parameters through traffic safety enhancement, as well as actions aimed at the reconstruction of the motor road or project-supported construction of road segments are developed.

Subject, tasks and methods

The study subject is parameters of above-ground transport and road infrastructure facilities' condition, as well as the number of road accidents as a result of their adverse effect.

The study tasks include the following:

− analysis of road accident rate statistics and identification of parameters to assess the efficiency of the proposed road construction activities aimed at the reduction in the number of road accidents;

− obtaining actual data on condition parameters with the use of modern automated multi-functional diagnostic equipment;

− development of actions aimed at the improvement of road infrastructure parameters through traffic safety enhancement, as well as actions aimed at the reconstruction of the motor road or project-supported construction of road segments;

− assessment of the efficiency of the proposed actions.

Methods for implementing the set tasks include methods of analysis of properties and opportunities for improvement of complex multi-functional systems, such as statical and systematic methods, mathematical methods, computational methods, probability theory, data processing theory with regard to research results, and information technologies.

Results and discussion

The Driver–Vehicle–Road–Environment (DVRE) system operates due to dynamic road infrastructure parameters and environmental conditions, motor vehicles' specifications and processes, psychophysiological state of drivers, and continuous system monitoring of changing processes. The main task of such system monitoring is to prevent road accidents and reduce severity of their consequences. As known, a road accident is a complex mechanism of interaction between "Vehicle–Vehicle", "Vehicle–Road", "Vehicle–Pedestrian", and "Vehicle–Environment" subsystems. Circumstances, causes and factors of road accidents are examined at the global expert level.

Road accident rate statistics are analyzed with an analytical approach including the safety factor method, accident rate factor method, and black spot identification method (Table 1).

Table 1. Methods applied to analyze "Vehicle–Road" subsystem parameters with an analytical approach

No	Method	Characterizing parameters	Analyzed "Vehicle–Road" subsystem parameters
1	Safety factor method	Maximum traffic speed at the analyzed motor road segment — $V_{\max}^{traffic}$ vehicle's initial speed — $V_{initial}$	Traffic intensity. Shoulder-to-shoulder width and width of shoulders. Clear vision distance (plan and profile views). Longitudinal grade. Curve radius in the road cross-section (on long ascending grades)
2	Accident rate factor method	Partial accident rate factors — K_i	Results of road accident statistical analysis. Traffic intensity. Shoulder-to-shoulder width and width of shoulders. Number of traffic lanes. Clear vision distance (plan and profile views). Longitudinal grade. Clear vision (plan and profile views). Vertical curves (plan view). Grade separation. Road surface condition.
3	Black spot identification method	Absolute and relative number of road accidents	Traffic intensity. Results of road accidents with injuries.

In the field of road construction, motor road operation and reconstruction, it is necessary to take into account the system of parametric characteristics of objects and conditions for their existence:

− geometry of road environment facilities (GREF);

− transport and operating conditions (TrOC);

− technical and operating conditions (TechOC);

− characteristics of road infrastructure facilities (CRIF).

Obtaining information about GREF, TrOC, TechOC, and CRIF is possible by means of diagnostic and computational methods of obtaining and processing of parametric characteristics (Kurakina, Evtyukov, 2017; Kurakina, 2014, 2016; Kurakina, Evtyukov, 2015, ROSDORNII, 2015) (Table 2).

Table 2. Methods applied to analyze parameters with diagnostic and computational methods

Diagnostic method			
1	Systematic monitoring	Usability of motor roads. Specified time intervals.	Shoulder-to-shoulder width and width of shoulders. Clear vision distance (plan and profile views). Longitudinal grade. Clear vision (plan and profile views). Vertical curves (plan view). Curve radii. Road surface evenness and strength. Adhesion characteristics.
2	Method for determination of transverse evenness of the road surface	Clearance between the road surface and the bottom surface of the leveling beam; clearance between the road surface and the profilograph wheel.	Road surface evenness. Rutting.
3	Dynamometer method for determining evenness of the road surface	Clearance between the road surface and the PKRS-2U (evenness and adhesion inspection tool with an oscillograph) wheel	Road surface evenness.
4	Method for determining the road/tire adhesion coefficient	Maximum rim pull. Vertical load on the road surface. Registration using PPK, IKSp-m (portable instruments for adhesion coefficient measuring).	Adhesion coefficient
5	Method for determining roughness of the road surface	Average valley depth	Valley depth roughness affecting the adhesion coefficient
6	Georadar sounding of road structure	Georadar profile with road structure density fluctuations	Depth of road structural layers. Landslide curve location.
7	Method for determining strength of the road structure	Elastic deflection value. Area of contact with the road surface. Falling weight characteristics.	Road surface strength and reliability. Elastic deflection of the road structure.
8	Core sampling method	Elastic deflection value. Drilling bit characteristics.	Road surface strength and reliability. Elastic deflection of the road structure.
Computational method			
1	Automated calculation and analysis	Computational software	Transport, technical and operating parameters. Road accident registration and analysis.
2	Method of panoramic video shooting of motor roads	Specifications of digital cameras, performed linear measurements	Shoulder-to-shoulder width and width of shoulders. Availability of cracks, potholes, and other types of damage in the road surface.

Mathematically, the model of expert study implementation with account for parameters can be represented in the following form:

$$\mathrm{Y} = f(\mathrm{X}) \tag{1}$$

where X — parameters applied and obtained during the study.

Taking into account methods of obtaining and processing of parameters during the study, the value X of the sum of all characteristics and conditions can be represented in the following form:

$$\left\{ \begin{aligned} \sum_{i=1}^{n} X^A &= f(x_i^A), \\ \sum_{i=1}^{n} X^D &= f(x_i^D), \\ \sum_{i=1}^{n} X^C &= f(x_i^C) \end{aligned} \right\}, \tag{2}$$

where $f(x_i^A)$ are parameters, their characteristics and conditions determined analytically, i.e. $f(x_i^D)$ are determined diagnostically and $f(x_i^C)$ are determined with computational methods, i is the number of obtained values of the studied parameters.

Taking into account equation 2, we obtain a set of values of parameters, obtained during studies with analytical, diagnostic and computational methods.

Therefore, taking into account equation 1 and parameters to be determined, the accounting during the expert study, involving numerous parameter values,

will be characterized by parameters involved in the study.

Evaluation of parametric characteristics of objects and conditions represents an expert opinion on the results of the study aimed at the following:

− accident rate at the analyzed road section;

− black spot identification on motor roads;

− identification of "weak" motor road segments to determine the qualitative component of the road infrastructure, in particular, the load-bearing capacity of the road structure. Identification of road surface defects, deflections, and moduli of elasticity to determine its remaining life.

− development of an automated road data base (ARDB) on “weak” motor road segments to raise awareness and improve expert study quality;

− compliance of the obtained values of vehicle and road infrastructure condition parameters with the requirements of regulatory documents;

− determination of road accident risks.

The dependence of the study, conducted by a diagnostic method, during which condition parameters were determined, has the following form:

$$\begin{aligned}
&\Upsilon(X^D) = f(N_i, W_{pull.}, W^{sh.}_{marg.}, W^{cent.}_{div.str.},\\
&S^{sh}_{marg}, L_{stop.}, i, i_{trans}, i_r, R_{curve}, S_{cl}, R_{convex}, R_{concave},\\
&Z, h_f, \angle_{slope}, I_{veh}, M_1 \div O_2, V_a, G_{veh}, K^{I-V}_P,\\
&N_{acc}, ACC_{abs}, ACC_{rel}, \phi, t, r, r_h, E,\\
&D_{r.s.}, T_{a.s.}, T_{drain}, T^{signs}_{loc}, T_{light}, \grave{O}_{rail}, MTORT),
\end{aligned} \tag{3}$$

where N_i is the number of lanes;

W_{pull} is the pullover width;

W^{sh}_{marg} is the width of the margin strip of the shoulder, m;

$W^{cent}_{div.str.}$ is the width of the central dividing strip, m;

S^{sh}_{marg} is the margin strip of the shoulder, m;

L_{stop} is the stopping strip, m;

i is the longitudinal grade, per mille;

i_{trans} is the transverse grade, per mille;

i_r is the raised curve grade, per mille;

R_{curve} is the curve radii in plan, m;

S_{cl} is the clear vision distance to the object, m;

R_{convex} is the radii of convex curves in profile, m;

$R_{concave}$ is the radii of convene curves in profile, m;

Z is the structure of the road bed;

h_f is the depth of fill, m;

h_e is the depth of excavations, m;

$\angle_{slope}$ is the slope grade;

I_{veh} is traffic intensity, vehicles/day;

$M_1 \div O_2$ the categories of vehicles from M_1 to O_2;

V_a is the vehicle speed, km/h;

G_{veh} is the vehicle mass, t;

K^{I-V}_P is the coefficient of braking performance of the vehicle;

N_{acc} is the number of road accidents;

ACC_{abs} is the absolute accident rate;

ACC_{rel} is the relative accident rate;

φ is the road/tire adhesion coefficient;

t is the rut depth (road surface rutting (wheel tracking)), cm;

r is the roughness of the road surface, average height of material projection, μm;

r_h is the hydraulic roughness;

E is the modulus of elasticity, MPa;

$D_{r.s.}$ are defects of the road surface;

$T_{a.s.}$ are artificial structures;

T_{drain} is the condition of the drainage system;

T^{signs}_{loc} is presence of driver location signs;

T_{light} is availability of lighting;

T_{rail} is presence of railway crossings;

$MTORT$ is equipping with technical means of road traffic organization.

The algorithm of the study on the analyzed system is presented in Figure 1.

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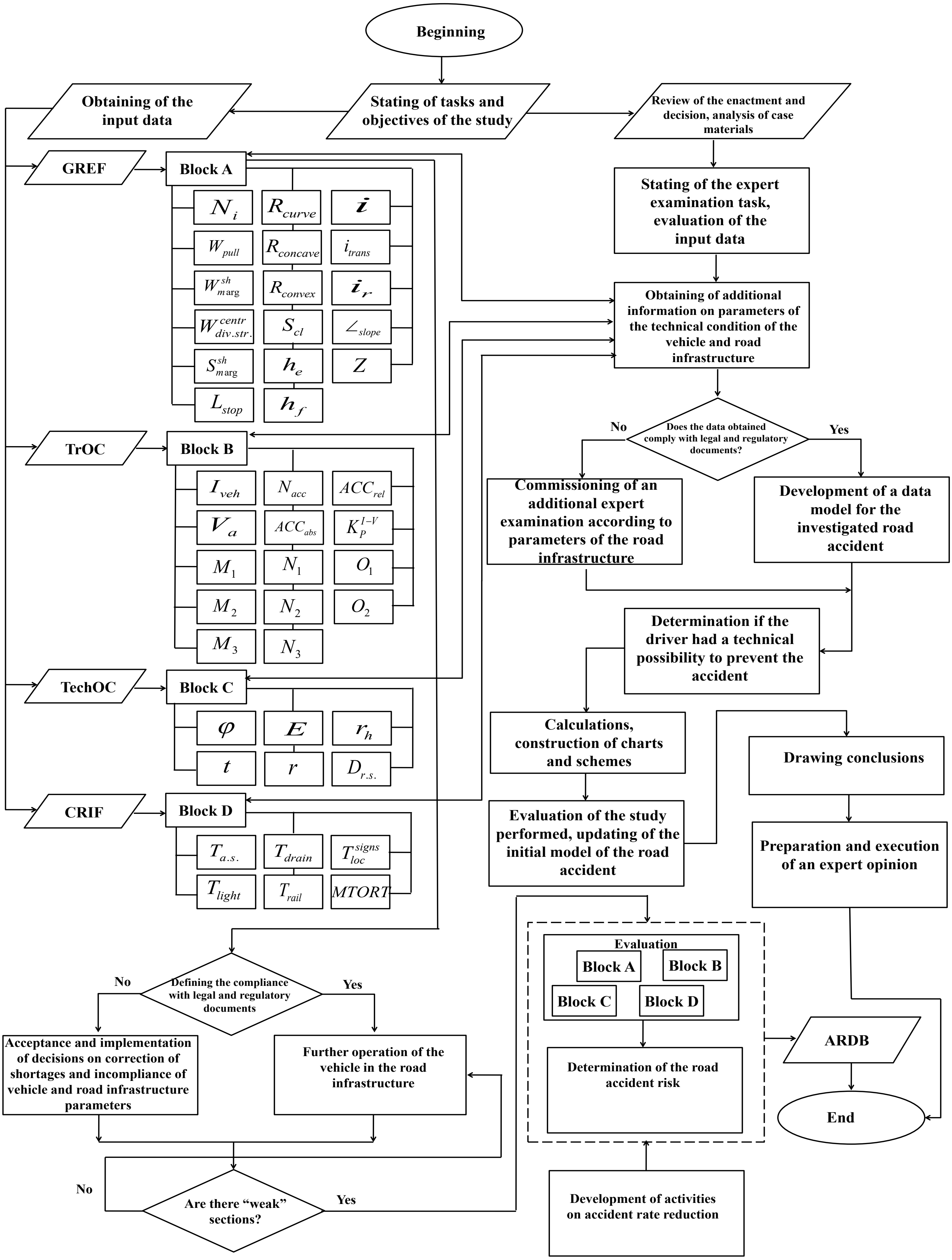

Figure 1. Algorithm of the study on the road infrastructure parameters' condition

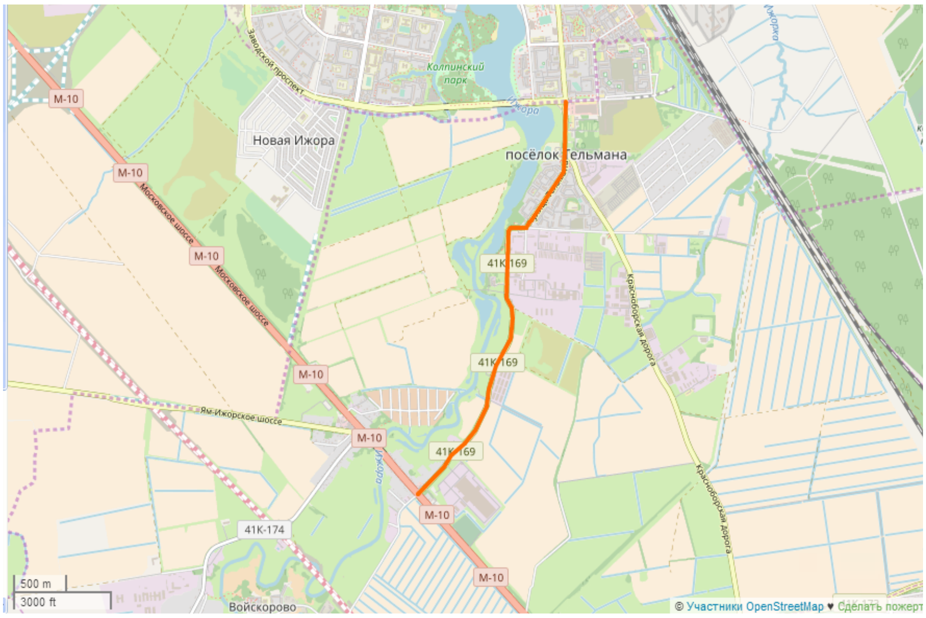

Figure 2. Location of the "Approach to Kolpino" road running in the Tosno District

The development of actions aimed at the improvement of road infrastructure parameters through traffic safety enhancement, as well as actions aimed at the reconstruction of the motor road or project-supported construction of road segments, is illustrated by an example of the "Approach to Kolpino" motor road segment.

The "Approach to Kolpino" regional public road running across the territory of the Tosno District (Figure 2). Length — 4,065 km (road No. 41K-169). An entrance from the Kolpino District of Saint Petersburg to the Russia M-10 federal public road (Moscow–Tver–Veliky Novgorod–SPb)

In 2016, 7 registered road accidents with injuries occurred on the "Approach to Kolpino" road, 1 accident cluster (black spot) was distinguished for analysis.

A list of actions aimed at black spot elimination was developed.

The corresponding actions were classified into three categories: low-cost, medium-cost and high-cost actions.

Table 3 presents general data on black spots where accidents with injuries occurred during the analyzed period.

Table 3. Condition of parameters at the "Approach to Kolpino" road segment

<table>
<tr><td colspan="9">Black spot address</td></tr>
<tr><td colspan="3">Motor road</td><td colspan="2">Start of the segment, km + m</td><td colspan="2">End of the segment, km + m</td><td colspan="2">Length of the segment, m</td></tr>
<tr><td colspan="3">"Approach to Kolpino"</td><td colspan="2">3 + 400</td><td colspan="2">4 + 400</td><td colspan="2">1,000</td></tr>
<tr><td colspan="9">Black spot characteristics</td></tr>
<tr><td rowspan="3">No</td><td rowspan="3">Date</td><td rowspan="3">Time</td><td rowspan="3">Type</td><td rowspan="3">Location, km + m</td><td colspan="3">Injured</td><td rowspan="3">Poor road conditions</td></tr>
<tr><td rowspan="2">Fatalities</td><td colspan="2">Injuries</td></tr>
<tr><td>Total</td><td>incl. children with injuries</td></tr>
<tr><td>1</td><td>10.06.2016</td><td>10:25</td><td>Vehicle/pedestrian accident</td><td>3 + 900</td><td>1</td><td>–</td><td>–</td><td>Absence or poor visibility of horizontal signalization</td></tr>
<tr><td>2</td><td>18.02.2016</td><td>8:00</td><td>Vehicle/pedestrian accident</td><td>3 + 440</td><td>–</td><td>1</td><td>1</td><td>Absence or poor visibility of horizontal signalization</td></tr>
<tr><td>3</td><td>20.10.2016</td><td>18:10</td><td>Collision with a standing vehicle</td><td>3 + 820</td><td>–</td><td>1</td><td>–</td><td>Absence of shortcomings in transport and operating conditions of the roadway</td></tr>
<tr><td>4</td><td>28.08.2016</td><td>18:20</td><td>Vehicle/pedestrian accident</td><td>3 + 400</td><td>–</td><td>1</td><td>1</td><td>Absence or poor visibility of horizontal signalization</td></tr>
<tr><td>5</td><td>23.09.2016</td><td>20:40</td><td>Vehicle/bicycle accident</td><td>4 + 030</td><td>–</td><td>1</td><td>–</td><td>Absence or poor visibility of horizontal signalization</td></tr>
</table>

Table 4. Data on black spots on the "Approach to Kolpino" road 3 + 400 – 4 + 400

"Approach to Kolpino" road 3 + 900 — vehicle/pedestrian accident	
Traffic violation / concurrent traffic violations	Jaywalking with a crosswalk in sight or an underground (ground level) crosswalk in close vicinity
Street and road network facilities	Road section
Road conditions:	
weather conditions	Clear weather
roadway condition	Dry
lighting	Day-time
"Approach to Kolpino" road 3 + 440 — vehicle/pedestrian accident	
Traffic violation / concurrent traffic violations	Jaywalking with a crosswalk in sight or an underground (ground level) crosswalk in close vicinity
Street and road network facilities	Road section
Road conditions:	
weather conditions	Clear weather
roadway condition	Treated with deicing agents
lighting	Day-time
"Approach to Kolpino" road 3 + 820 — collision with a standing vehicle	
Traffic violation / concurrent traffic violations	Failure to keep distance
Street and road network facilities	Road section
Road conditions:	
weather conditions	Clear weather
roadway condition	Dry
lighting	Day-time
"Approach to Kolpino" road 3 + 400 — vehicle/pedestrian accident	
Traffic violation / concurrent traffic violations	Violation of rules for driving across the crosswalk / non-compliance with mandatory vehicle insurance requirements
Street and road network facilities	Unsignalized crosswalk
Road conditions:	
weather conditions	Clear weather
roadway condition	Dry
lighting	Day-time
"Approach to Kolpino" road 4 + 030 — vehicle/bicycle accident	
Traffic violation / concurrent traffic violations	Disregard of priority rules/violation of vehicle arrangement on the roadway/alcohol-impaired driving
Street and road network facilities	Departure from the adjacent territory
Road conditions:	
weather conditions	Clear weather
roadway condition	Dry
lighting	Night-time, lighting is on

Results of full-scale study of the black spot on the "Approach to Kolpino" road 3 + 400 – 4 + 400

1. Low quality of shoulder maintenance, availability of potholes filled with water.
2. Road surface shortcomings and defects, rutting.
3. Absence or poor visibility of horizontal signalization.
4. Traffic signalization is maintained on the road segment.

Actions aimed at elimination of the black spot on the "Approach to Kolpino" road 3 + 400 – 4 + 400 were developed.

For elimination of black spots, the following priority actions were developed with expected accident rate reduction (%) as a result of their implementation:

– installation of priority traffic signs, prohibitory signs and warning signs for speed reduction, informing of approach to a crosswalk, children crossing zone, dangerous corner — 34%;

– marking of horizontal signalization with wear-resistant materials;

– marking of prohibitory and warning signs on the road surface;

– installation of traffic lights T.7 in zones where pedestrians cross the roadway, marked with horizontal signalization 1.14.1 and traffic signs 5.19.1, 5.19.2 "Crosswalk" to increase focus of drivers when approaching a crosswalk and raise their vigilance upon its passage — 10%;

– arrangement of sidewalks to improve pedestrian traffic safety and avoid vehicle/pedestrian accidents — 23%;

– arrangement of guardrails along sidewalks, in pick-up and drop-off areas, in crosswalk areas to avoid vehicle/pedestrian accidents and ensure safe pedestrian traffic — 25%.

Priority forward-looking actions:

– arrangement of lighting along the road and in pedestrian traffic zones to improve visibility and detection of vertical and horizontal signalization — 25%;

– road surface restoration (road paving) — 21% in case of 2 lanes, 59% in case of more than 2 lanes.

Mandatory actions aimed at traffic safety improvement shall comply with the GOST R 50597 requirements to operating conditions acceptable in a safe traffic environment.

Efficiency of the proposed actions is described in Table 4 (with account for low-, medium- and high-cost actions). Changes in condition parameters after implementation of actions at the black spot of the "Approach to Kolpino" road 3 + 400 – 4 + 400 are assessed.

Table 5. Efficiency of the proposed actions

Low-cost actions	Costs: 151,212.44
Approximate assessment of impact, reduction in the number of registered road accidents	-41%
Expected annual effect in case of implementation of actions; reduction by:	0.41 fatalities
	1.64 non-fatal injuries
Annual savings in case of road accident prevention	7.71 mln RUB
Payback period	0.3 months
Medium-cost actions	Costs: 4,617,134.44
Approximate assessment of impact, reduction in the number of registered road accidents	-68%
Expected annual effect in case of implementation of actions; reduction by:	0.68 fatalities
	2.72 non-fatal injuries
Annual savings in case of road accident prevention	12.84 mln RUB
Payback period	4.3 months
High-cost actions	Costs: 14,933,319.84
Approximate assessment of impact, reduction in the number of registered road accidents	-93%
Expected annual effect in case of implementation of actions; reduction by:	0.93 fatalities
	3.72 non-fatal injuries
Annual savings in case of road accident prevention	17.56 mln RUB
Payback period	10 months

Conclusions

During road construction, it is necessary to follow construction regulations and take into account the relief and climate of the district. In the course of further road maintenance, condition of the following road infrastructure facilities' parameters shall be monitored: qualitative and quantitative characteristics of the traffic flow, vehicle braking processes, road structure strength as per the modulus of elasticity, identification of black spots as per the risk of their formation, their impact on accident rate prediction.

Analysis of the data obtained diagnostically and processed with analytical and computational methods allows obtaining actual results regarding traffic safety condition and compliance of parameters with applicable regulations. Obtaining actual results regarding parameters allows developing actions aimed at elimination of black spots and accident rate decrease. Such actions also allow predicting road accident risk formation, improving reliability of conclusions and accuracy of calculations in expert reports.

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