Justification of the system parameters for alerting drivers about the emergency situation occurrence

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Abstract. The article analyzes the road traffic accident rate in Russia and the Krasnoyarsk territory. As a way to reduce traffic accident rate on road sections outside built-up areas, a system for alerting drivers in conditions of a lack of visual information about a possible emergency situation is proposed. The results of mathematical modeling and physical experiments are presented, which allow us to justify the values of the system parameters and algorithms for its functioning.

1. Introduction

In the Krasnoyarsk Territory (KT), as in the Russian Federation (RF), over the past 5 years, there has been a decrease in the number of road traffic accidents (RTA) (with a slight increase in 2019), injured and killed in them (Fig. 1) [1,2].

![Fig. 1. Number of road traffic accidents, deaths and injuries in the Krasnoyarsk Territory](image)

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The percentage of injured and dead in road traffic accidents in the Krasnoyarsk Territory from the total number in the Russian Federation practically does not change from year to year and ranges from 2 to 2.5% (Fig. 2).

![Fig. 2. Percentage of road traffic accidents, deaths and injuries in them in the Krasnoyarsk Territory from the total number in the Russian Federation](image)

The Krasnoyarsk Territory is among the 10 regions of the Russian Federation with the largest number and the highest percentage of road traffic accidents and injuries.

Analysis of the number of accidents, injuries and deaths per 1000 km of roads in the Krasnoyarsk Territory (Fig. 3) shows a significant risk of getting into an accident, which is 110 accidents for every 1000 km of roads. At the same time, the number of injured and dead for every 1000 km is 132 and 12 people, respectively, which is also a significant negative indicator. The value of the number of accidents and fatalities per 1000 km in the Krasnoyarsk Territory corresponds to the average value of these indicators for the country.

![Fig. 3. Dynamics of the number of road traffic accidents, injured and killed persons in accidents per 1000 km of roads in the Krasnoyarsk Territory](image)

The analysis of the number of injured and dead persons per 100 accidents and the number of dead per 100 injured persons (Fig. 4) also indicates a high severity of the consequences of accidents, despite the positive dynamics of their decline. In the Krasnoyarsk Territory, 123 and 11 people are injured and killed in 100 road traffic accidents, respectively, and 9 people are killed per 100 casualties.
The accident rate analysis in the Krasnoyarsk Territory shows an annual decrease in both absolute and relative indicators against the background of a decrease in similar indicators in the Russian Federation as a whole. In addition to the above, the share of accidents, persons injured and killed in them in the Krasnoyarsk Territory remains at a high level year on year, and in recent years it has been increasing, despite the fact that by the number of cars the Krasnoyarsk Territory is not among the 10 regions with the largest vehicle fleet.

The Krasnoyarsk Territory ranks 10th in the number of people killed in collisions (2.17% of the total in the country) and 11th in the number of people killed in collisions with a pedestrian (2.25% of the total in the country).

The most serious types of road accidents in the Krasnoyarsk Territory are collisions, rollovers, hitting a stationary vehicle, an obstacle and a pedestrian, and over the past 5 years, there has been no trend towards a decrease in the severity of consequences in the region (Fig. 5).

The absolute indicators of accidents by type of road accidents show that significant highest values are achieved with such types of road accidents as collisions and collisions with pedestrians. These accidents are usually caused by reduced visibility for various reasons: insufficient (due to changes in weather events) and limited visibility (due to the complexity of the terrain). Such road sections are potentially dangerous.

Collisions with high severity of consequences are typical for roads outside built-up areas, where high vehicle speeds contribute to an increase in the number of victims [3].
Despite the fact that highways and their elements are designed to provide the necessary visibility to enable road users to prevent accidents, in practice these conditions are not always met. One of the ways to reduce traffic accident rate on roads outside of built-up areas on emergency-dangerous sections can be a system for alerting drivers in conditions of a lack of visual information. The effective result of the system operation is guaranteed and timely notification of vehicle drivers about a possible collision under the following conditions: adverse weather conditions, complex road geometry, steep ascents, descents, dangerous turns, etc. [4, 5, 6].

Fig. 6. A system for alerting drivers in conditions of a lack of visual information about a possible emergency situation

2. Methods and Equipment
To provide the mathematical apparatus for the functioning of the algorithms of the designed system, it is necessary to determine its basic parameters. Dangerous situations are those situations that, if no response measures are taken, will lead to an accident in the form of a collision. In fact, the response measures aimed at preventing road accidents are reduced either to a decreasing vehicle speed up to a complete stop, or to a changing the direction of the vehicle movement, or to a combination of these actions [7, 8, 9].

According to regulatory documents, the visibility distance along the entire length of the road must be at least the stopping distance of the vehicle to the obstacle:

\[ S_v \geq S_o \]  

where \( S_v \) – the visibility distance;  
\( S_o \) – stopping distance.

Stopping distance – the distance taken by the vehicle from the time the danger was detected to its complete stop, plus the remaining distance to the object [10]:

\[ S_o = S_p + S_{cp} + S_n + S_r + l_0 \]  

where \( S_p \) – the distance traversed by the car during the reaction time of the driver;  
\( S_{cp} \) – the distance traversed by the car during the operation of the brake drive;  
\( S_n \) – the distance traversed by the car during the deceleration increase;  
\( S_r \) – braking distance;  
\( l_0 \) – margin of distance equal to 5-10 m.

In expanded form, formula (2) can be written as follows, m:

\[ S_o = t_p \times V_a + t_{cp} \times V_a + 0,5t_n \times V_a + \frac{V_a^2}{2g \varphi} + l_0 \]  

where \( t_p \) – driver reaction time, s;  
\( t_{cp} \) – brake drive reaction time, s;  
\( t_n \) – deceleration reaction time, s;  
\( V_a \) – vehicle speed, m/s;
g – acceleration of gravity, m/S^2;
φ – the road adhesion coefficient.

When assigning geometric parameters of roads on sections of ascents and descents, the distance of visibility of an oncoming car is used [11], which is calculated, m:

\[ S_v = \frac{V_{85\%}}{3.6} t_p + \frac{K_o V_{85\%}}{254 (\phi \pm 1)} + l_0 \]  \hspace{1cm} (4)

where \( V_{85\%} \) – the speed of the traffic flow, provided 85% km/h;
\( K_o \) – the coefficient of braking efficiency, assumed to be 1.2 when the road surface is dry;
\( i \) – road inclination.

Taking into account the above, we will determine the minimum visibility parameters based on normative documents regulating the geometric parameters of highways for the following typical road traffic situations:

- there is a car moving in the same direction ahead;
- there is a car moving in the opposite direction ahead;

**Situation 1.** In this situation, the car meets an obstacle in the same lane and requires a complete stop at a safe distance from the obstacle.

The visibility distance without taking into account the road inclination is:

\[ S_v = t_p \times V_{a} + \frac{V_{a}^2}{2 \varphi} + l_0 \]  \hspace{1cm} (5)

In accordance with the recommendations on road safety, the driver reaction time \( t_r \) is assumed to be 2.5 s. The values of the adhesion coefficient \( \varphi \) for asphalt concrete pavement are set by the methodological manuals [10, 11] and range from 0.8 (dry, clean) to 0.2 (icy).

**Situation 2.** In this situation, the cars must stop before reaching each other.

The visibility distance is the sum of the distances that cars travel during the reaction time of the drivers \( S_{p1} \) and \( S_{p2} \), the braking distances of the cars \( S_{t1} \) and \( S_{t2} \), as well as the distance margin:

\[ S_v = S_{p1} + S_{t1} + S_{p2} + S_{t2} + l_0 \]  \hspace{1cm} (6)

or

\[ S_v = \left( t_{p1} \times V_{a1} + \frac{V_{a1}^2}{2 \varphi} \right) + \left( t_{p2} \times V_{a2} + \frac{V_{a2}^2}{2 \varphi} \right) + l_0 \]  \hspace{1cm} (7)

In the case of the system being developed, as a criterion for deciding on the alarm to a vehicle driver of a possible "obstacle" on the road in the direction of its movement, it is proposed to use the minimum safe distance between road users \( S_{общ} \), which is determined by calculation. The condition for sending an alert signal is written as follows:

\[ S_{деьь} \leq S_{общ} \]  \hspace{1cm} (8)

where \( S_{деьь} \) – the actual distance between road users, m;
\( S_{общ} \) – minimum safe distance between road users, m.

To determine the distance taken by the i-th car, the formula of the stopping distance, m, is used:

\[ S_{iобщ} = S_p + S_{cp} + S_t + S_{отк} + l_0 \]  \hspace{1cm} (9)

where \( S_{отк} \) – the distance traversed by the vehicle during the system response time, m.

We express \( S_{iобщ} \) from (9), assuming that the braking process corresponds to an equidistant movement to a complete stop with the maximum possible deceleration for specific road conditions, m:

\[ S_{iобщ} = \vartheta_i * t_p + \vartheta_i * t_{cp} + \vartheta_i * t_{t1} - \frac{j * t_{t1}^2}{2} + \vartheta_i * t_{отк} + l_0 \]  \hspace{1cm} (10)

where \( \vartheta_i \) – the initial speed of the i-th car, m/s;
In order to account for weather conditions, \( j \) from the equation for determining the braking force of the car, we define \( N \):

\[
P_t = m_a \cdot g \cdot \varphi = m_a \cdot j
\]

hence

\[
j = g \cdot \varphi
\]

where \( m_a \) – the vehicle weight, kg.

It should also be noted that the car deceleration during emergency braking can be assumed to be \( j = 7.84 \text{ m/s}^2 \) for dry surfaces, \( 3.92 \text{ m/s}^2 \) for wet surfaces, and \( 1.96 \text{ m/s}^2 \) for icy surfaces. During service braking, the car deceleration is assumed to be 3 times less than during emergency braking, and not exceeding \( 2.6 \text{ m/s}^2 \) for dry surfaces, \( 1.3 \text{ m/s}^2 \) for wet surfaces, and \( 0.65 \text{ m/s}^2 \) for icy surfaces.

The braking time of the \( i \)-th car under the condition of equally slow movement to a complete stop can be found:

\[
t_{\text{T1}} = \frac{\vartheta_i}{j}
\]

Consider the situation 1, when the cars are moving in the same direction, then \( S_{\text{общ}} \) is determined by the formula (10) as a difference of the ways, passed by cars for the time required to complete stop of the catching-up car (with index 2) taking into account the rest of the way between the objects, m:

\[
S_{\text{общ}} = S_{2\text{общ}} - S_{1\text{общ}}
\]

then

\[
S_{\text{общ}} = (\vartheta_2 - \vartheta_1) \cdot (t_p + t_{\text{ср}} + t_{\text{T2}} + t_{\text{откл2}}) - \frac{j \cdot t_{\text{T2}}^2}{2} + l_0
\]

or

\[
S_{\text{общ}} = (\vartheta_2 - \vartheta_1) \cdot (t_p + t_{\text{ср}} + t_{\text{откл2}}) + \frac{(\vartheta_2 - \vartheta_1)^2}{2j} + l_0
\] (11)

For situation 2, when cars are moving in the opposite direction, \( S_{\text{общ}} \) is defined as the sum of the ways, passed by cars to a complete stop, taking into account the rest of the way between the objects, m:

\[
S_{\text{общ}} = S_{1\text{общ}} + S_{2\text{общ}}
\]

then

\[
S_{\text{общ}} = (\vartheta_1 + \vartheta_2) \cdot (t_p + t_{\text{ср}} + t_{\text{откл2}}) + \frac{\vartheta_1^2 + \vartheta_2^2}{2j} + l_0
\] (12)

3. The research results

Based on the previously proposed mathematical models, we constructed graphs that reflect the effects of the response time of the projected system (Fig. 6), the coupling coefficient (Fig. 7) and the braking mode (Fig. 8) on the stopping way or the minimum safe distance at different vehicle speeds in comparison with the standard values. At the same time, the stopping distance was calculated without taking into account the reserve of the remaining way \( l_0 \). The speed range of the vehicle (30-240 km/h) is conditioned by the following data: the minimum value at which in the event of an accident there may be serious consequences for the driver and passengers; the maximum value in the conditions of the speed limit on road sections outside the locality (90 km/h), taking into account the speedometer error (+20 km/h) and oncoming traffic (multiply by 2).
Fig. 7. Dependence of the minimum safe distance on the vehicle speed during emergency braking and the coefficient of adhesion of 0.8.

Fig. 8. Dependence of the minimum safe distance on the vehicle speed under different road surface conditions and emergency braking.

Fig. 9. Dependence of the minimum safe distance on the vehicle speed under different braking modes.
Analyzing the obtained dependencies, we can draw the following conclusions: - the proposed mathematical model for determining the minimum safe distance between vehicles does not contradict regulatory documents in the field of road design and safety; - for the correct operation of the system, it is necessary and sufficient that the response time constitutes no more than 1 s; - road conditions significantly affect the minimum safe distance between vehicles, so the projected system must determine and operate in the calculation algorithms with the current values of the tire coupling coefficient with the road surface; - the braking mode (deceleration) also significantly affects the minimum safe distance, especially at high vehicle speeds, so in the projected system it is advisable to use a two-stage notification of drivers, corresponding to service and emergency braking.

To check the technical capabilities of the system, an application for mobile phones has been developed. This application provides transmission of vehicle location coordinates to the server and confirmation of their correct fixation on the server while registering the time of sending and receiving data.

The time of sending service data and receiving confirmation allowed us to determine the response time of the system taking into account various factors, such as the quality of communication in places with different terrain and distance from Krasnoyarsk, as well as to check the accuracy of vehicle positioning. The results of the processed experimental data are presented in table 1.

Table 1. Results of processed experimental data

| Place of measurement, factors of influence | Positioning accuracy, m | Average response time, ms | Quality of communication |
|-------------------------------------------|-------------------------|---------------------------|--------------------------|
| Rain, urban environment, large number of houses and buildings | 7-12 | 135 | 4G |
| Rain, urban environment, forest plantations, small dwellings | 5-10 | 165 | 3G |
| Rain, urban environment, forest plantations, small dwellings | 5-10 | 513 | 2G |
| Rain, track outside the city, flat terrain, buildings | 3-4 | 121 | 4G |
| Rain, track outside the city, flat terrain, buildings | 3-4 | 444 | 3G |
| Rain, track outside the city, flat terrain, buildings | 3-4 | 503 | 2G |
| Rain, track outside the city, flat terrain, forest, developed road infrastructure | 4-6 | 161 | 4G |
| Rain, track outside the city, flat terrain, forest, developed road infrastructure | 4-6 | 150 | 3G |
| Rain, track outside the city, flat terrain, forest, developed road infrastructure | 4-6 | 419 | 2G |
| Rain, country road, mountainous terrain, forested area | 5-7 | 218 | 4G |
| Rain, country road, mountainous terrain, forested area | 5-7 | 202 | 3G |
| Rain, country road, mountainous terrain, forested area | 5-7 | 653 | 2G |

According to the experimental data obtained, the response time of the system satisfies the conditions of the mathematical model, even if poor GSM communication quality and unfavorable meteorological conditions are taken into account.

The maximum values of the vehicle positioning accuracy can be used as a justification for the remaining path margin $l_0$ in the mathematical model of the designed system.
4. Conclusions

Analysis of accidents on road transport in the Russian Federation and the Krasnoyarsk territory shows that, despite the positive dynamics over the last 5 years of reducing the number of accidents, injuries and deaths, the severity of the consequences of accidents remains high.

One of the ways to reduce accidents, especially on road sections outside localities that are characterized by high vehicle speeds, can be a system for notifying drivers in conditions of a lack of visual information about the possible occurrence of an emergency situation.

The results of mathematical modeling and physical experiments allowed us to identify the most significant parameters of the system and justify their numerical values, as well as algorithms for its functioning.

Collectively, the results of the research showed the possibility of technical implementation of the designed system.

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