Improving traffic safety and accident prediction at pedestrian crossings

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Abstract. The development of roads, a sharp increase in motorization, as well as non-compliance with the traffic rules, leads to an increase in the number of traffic accidents at pedestrian crossings. This article discusses an unregulated pedestrian crossing with a high accident rate outside the city, analyzes the committed traffic accidents and makes a forecast of the number of dead and injured pedestrians for the next year. The methods are considered, the measures to improve the road safety are proposed, and a comparative analysis of the traffic accidents occurrence in some countries is performed.

Introduction
Accident rate on the roads of Russia is an urgent problem. Russia ranks high in the number of road traffic accidents (RTA) among other countries. Every day, people driving motor vehicles die and get injured. The most vulnerable road users are the pedestrians. Accident reduction is possible due to propaganda for both drivers and pedestrians.

In our country, annually about 70 thousand pedestrian accidents happen, and every fourth accident (with injured persons) is a pedestrian accident. Every third accident in the city occurs at a pedestrian crossing, including 86% of cases caused by the drivers. So, over the past month, according to official figures, in the city of Belgorod, 18 pedestrian accidents happened, 17 pedestrians were injured, 1 was killed.

Main part
On average, about 47 pedestrians die on the roads of the Belgorod Region annually, so 54 deaths occurred in 2017. In 2018, a slight decrease was observed, the traffic police services recorded 51 dead people. In 2019, there was a significant decline in road accidents involving the pedestrians, according to the official figures, 35 were killed [1]. As it can be seen, the number of deaths is decreasing every year, but the statistics remain sad.

Statistical data was collected at one busy unregulated pedestrian crossing in the Belgorod region.
This pedestrian crossing is located on a horizontal section of the road, without lighting, does not have a clear marking, part of the road sign is close to the tree, which significantly reduces visibility for drivers. After examining the survey results, we can say that one of the accidents’ causes with pedestrians is the cyclic process of pedestrians arriving at unregulated intersections. This indicates the presence of a temporary and seasonal factor.

Determining the possible number of accidents involving pedestrians for a forecast period of time outside the study period, the condition \( n_t > n_t \) is accepted. According to the inertia property of large technical systems, it seems possible to make the assumption: the regularities of the change in the number of accidents determined at the stage of analysis will remain for a certain time interval \( [2] \).

The analytical approximation of the accident probability occurrence trend is used to point out the values of the number of pedestrians in an accident. The found values are presented in Table 1.

| Time, month   | Number of accidents involving pedestrians | Point forecast | Trend values \( m_3(t) \) | Standard deviations \( \sigma[m_3(t)] \) | Confidence Interval Boundary \( z_1(t) \) | Confidence Interval Boundary \( z_2(t) \) |
|--------------|------------------------------------------|----------------|---------------------------|--------------------------------------------|------------------------------------------|------------------------------------------|
| January      | 2                                        | 3.493527       | 4.429144                  | 1.569                                      | 1.06                                      | 7.36                                      |
| February     | 3                                        | 3.608472       | 4.380369                  | 1.574                                      | 1.0589                                    | 7.389                                     |
| March        | 5                                        | 3.767394       | 4.324171                  | 1.656                                      | 0.9168                                    | 7.574                                     |
| April        | 7                                        | 3.95639        | 4.262807                  | 1.402                                      | 1.4556                                    | 7.0919                                   |
| May          | 2                                        | 4.160137       | 4.198695                  | 1.509                                      | 1.273                                     | 7.341                                     |
| June         | 2                                        | 4.363425       | 4.134387                  | 1.154                                      | 2.01                                      | 6.664                                     |
| July         | 4                                        | 4.552601       | 4.072412                  | 1.063                                      | 2.243                                     | 6.517                                     |
| August       | 6                                        | 4.716798       | 4.015021                  | 1.789                                      | 0.8173                                    | 8.012                                     |
| September    | 2                                        | 4.848817       | 3.964161                  | 1.789                                      | 0.8173                                    | 8.012                                     |
| October      | 3                                        | 4.945594       | 3.921375                  | 1.588                                      | 1.275                                     | 7.63                                     |
| November     | 5                                        | 5.008202       | 3.88763                   | 1.641                                      | 1.184                                     | 7.783                                     |
| December     | 4                                        | 5.041416       | 3.863355                  | 1.586                                      | 1.298                                     | 7.677                                     |

Having built a confidence interval for the trend in question \( m_3(t) \), it is possible to verify the forecast values’ reliability, using the confidence probability values. The confidence interval includes the forecast values within the upper and lower limits.

\( z_1(t) \), \( z_2(t) \) boundaries of symmetric confidence interval:
\[ z_1(t) \leq m_y(t) \leq z_2(t) \]  

In accordance with the probability theory, the mathematical statistics provisions \([2, 3]\) are determined by the expressions:

\[ z_k = m_y(t) \mp \sigma[m_y(t)] \cdot t_{1+q/(n-2p-1)}, (k = 1, 2) \]  

where \( p \) – is the sum of the number of terms in the expression; 
\( q \) – defines the confidence interval probability; 
\( t_{\gamma(n-2p-1)} \) – is the Student’s t-distribution with degrees of freedom \( \gamma \) and \( n - 2p - 1 \)[3].

The predicted trend values taking into account the standard deviations \( \sigma[m_y(t)] \) at the points \( t=60\div71 \) for Monday and the borders of 95% symmetric confidence intervals for the indicators in the number of accidents involving pedestrians for the next month are shown in Table 1.

The values characterizing the number of vehicles at some points go beyond the confidence intervals (Fig. 2). When using the smoothing operation, the revealed pattern is preserved and manifests itself at other points. The observed process is manifested as a result of the fixed values’ scatter and takes into account a possible increase in the number of accidents involving pedestrians.

The likelihood of accidents involving pedestrians is similarly predicted for the subsequent months and years [4].

**Figure 2.** Forecast of the number of vehicles

This forecast makes it possible to increase safety on a certain section of the road, and, therefore, to minimize the likelihood of an accident. Thanks to the forecast calculation, we are able to develop and implement the right measures to improve safety at unregulated pedestrian crossings outside the city.

On the studied pedestrian crossing, an average of about 4 cases of traffic accidents occur to pedestrians on a monthly basis, especially in the dark; in order to reduce the accident rate, it is necessary to strengthen the measures to improve traffic safety, namely, organize:

- the speed limit on this road section;
- to equip the crosswalk with LED strip to attract drivers;
- to apply bright markings 1.14.1 and 1.14.2;
- to apply specialized lights with bulbs in which a motion sensor is built-in. When a pedestrian approaches a pedestrian crossing, a sensor is triggered, and this road section is illuminated with bright light [5].
So, for example, in Japan, to ensure safety at pedestrian crossings, special traffic lights with LED reflection are installed. As soon as the pedestrian is about to cross the roadway, information is transmitted to the traffic light object, which in turn reflects the LED wall on the edges of the pedestrian crossing with stop signs, to attract the drivers’ attention. This method can significantly improve the safety of such crosswalks, and, therefore, to reduce the accident rate to a minimum [6].

European roads, as practice shows, remain the safest in the world. For example, in 2016 there were only 50 accidents per million inhabitants, and every year these indicators are reduced. The countries with the lowest mortality rate from road accidents were: Sweden, where 27 people per million people died, the United Kingdom with 28 deaths and the Netherlands - 33 cases. About 3,000 people die on Hungarian roads annually. Among the countries of the European Union, this is one of the highest rates. The graph (Fig. 3) has been built for the clearer perception of the scale of the number of accidents involving pedestrians for one year:

![Figure 3. Annual statistics of accidents involving pedestrians in countries](image)

Quite often, the pedestrians who cross the street to a red traffic light, or in the wrong place, are guilty of an accident. It is also difficult for the driver to react to a pedestrian crossing the roadway in dark clothes without any reflective elements. Some pedestrians forget to look around when crossing the street at an unregulated pedestrian crossing, which also leads to dire consequences. As an example, the number of accidents involving pedestrians by the region for the year will be given below:

1. In Moscow, more than 2.5 thousand traffic accidents occurred due to the pedestrians. 220 people died.
2. In the Rostov region more than 1000 accidents are recorded, 133 people died.
3. In the Magadan region there were 50 accidents caused by a pedestrian with three fatalities [7].

To reduce deaths, both drivers and pedestrians should comply with the rules by which it is possible to reduce the number of accidents:

1. Pedestrians need to move strictly along the sidewalks or footpaths, if they are absent - along the curbs towards traffic;
2. When driving along the roadsides or the edge of the roadway at night or in conditions of insufficient visibility, pedestrians are advised to wear the objects with retroreflective elements, thereby providing visibility to vehicle drivers;
3. Pedestrians should cross the carriageway only at pedestrian crossings, and if they are absent, at the intersections along the sidewalks or curbs;
4. At unregulated pedestrian crossings, pedestrians can enter the roadway after they have estimated the distance to the approaching vehicles, their speed and make sure that the crossing is safe for them [8].

The measures proposed above are essential to improve safety and reduce the death toll. General data on the number of dead pedestrians are presented in Table 2.
Table 2. The Share of dead pedestrians, [%].

| The population of the city, million people | In the settlements | Percentage of total deaths on roads between the settlements |
|-------------------------------------------|-------------------|-----------------------------------------------------------|
| less 2                                    | 20.1              | 28.6                                                      |
| 2 - 5                                     | 13.3              | 32.4                                                      |
| more 5                                    | 66.4              | 34.5                                                      |

To reduce the accident rate, an important indicator with the participation of pedestrians is the consideration of pedestrian crossings and the identification of the safest paths for movement.

Methodologies

Foreign countries with a high level of motorization have fewer accidents than in Russia. Over the past 20 years, the Europeans have managed to reduce the road deaths by more than 2 times. At this time, the roads in Europe are considered the safest in the world. [9].

Figure 4. Traffic Island in Amsterdam

In Amsterdam, for the safe passage by pedestrians, the carriageway is most often used, traffic islands. Since they are considered one of the most effective ways to make a certain section of the road safer, as a result, the drivers are forced to slow down due to the narrowing of the road.

In Stockholm, the problem of road accidents with pedestrians is solved by connecting several pedestrian crossings, which are combined with the subway exits and are used specifically as underground passages. All crossings are equipped with escalators and elevators and are located under busy city intersections [10].

Today, Warsaw is the champion in the number of underpasses among the Polish cities. As a rule, in addition to the subway stations and large squares, the crossings are located near the tram stops that run along the central part of the street. It is not possible to cross the road at a pedestrian crossing; the carriageway is fenced off from the sidewalks.
Figure 5. Road conditions in America

In America, off-street pedestrian crossings are not used in the central parts of the cities. In the same way as in Europe, underground pedestrian crossings through the subway are duplicated with the ground crossings. With a wide busy highway passing through the city center, the highway either goes down or becomes an overpass, but the pedestrian remains at the junction at the ground and building level [11].

Summary
Based on the analysis, we can conclude that the methods for improving traffic safety at unregulated pedestrian crossings in different countries do not differ significantly. In some countries, underground and elevated pedestrian crossings are considered safe and mass construction is carried out, while in some they are abandoned and use other methods of dealing with accidents at pedestrian crossings.

To improve the pedestrian crossings’ safety, pedestrians are required to know and comply with the requirements of the Road Traffic Rules (traffic rules), signals of traffic lights, road signs and markings, as well as follow the instructions of traffic controllers and really assess the situation.

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