Analyzing and forecasting road traffic accidents and their consequences: a case study of the Udmurt republic

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Abstract. The article addresses the issue of road traffic accidents and their impact on population mortality and socio-economic processes in the region. Attention is given to the tasks of accident prediction and the assessment of the severity of their consequences. The dynamics of road accidents and their consequences in Udmurt Republic are analyzed using time series. The research reveals variations in the number of accidents over different time periods and seasonal fluctuations. Econometric models are constructed to predict the number of accidents and the severity of their consequences. These models take into account seasonal components, trends, and autoregressive processes. The forecasts for the number of accidents and their severity enable the development of measures for traffic management and road safety.

1 Introduction

Road traffic accidents (RTAs) represent a significant problem, accompanied by high mortality rates and serious socio-economic consequences [1]. Therefore, the analysis and prediction of RTAs, as well as their impact on society, are priority tasks for improving road safety.

Let's consider several scientific articles dedicated to this topic to assess current methods and achievements in this field. Predicting RTAs and assessing the factors influencing them receive significant attention in both domestic and foreign research. In the work [2], a high-precision LSTM neural network is applied to predict the probability of RTAs using data from sensors and information about the condition of specific vehicles. The application of these models in Udmurt Republic is challenging. This is primarily due to the lack of technical equipment with the necessary sensors on road segments.

In the study [3], various ensemble machine learning methods are used to assess mortality in RTAs. However, these models use data on past accidents and do not provide forecasts of potential future events.

In the work [4], the impact of various factors on the severity of RTA consequences is investigated using probit models. It was found that the absence of road lighting plays a key role in the severity of RTAs and contributes to a 10%-14% increase in mortality.

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In the work [5], time series analysis is used to study patterns and trends in mortality in RTAs and was able to detect seasonal peaks of RTAs. The results of this article allow us to develop more effective road safety plans taking into account these seasonal events. In [6-7], the application of the ARIMA model for predicting deaths in RTAs in India is investigated and the growth of RTAs is predicted, which emphasizes the relevance of these studies. In the article [8], the authors considered the time series of RTAs in Serbia (Belgrade) using the SARIMA model and as a result found that the time series has a pronounced seasonal character. The article [9] is devoted to the application of deep learning to predict the severity of an accident using recurrent neural networks (RNN), and the article [10] is devoted to the application of LSTM and GRU models. The authors have shown that deep learning can be an effective method for predicting accidents, especially when there is a large amount of data.

The scientific articles, discussed in this review, demonstrate a variety of methods for predicting road accidents and their severity using time series modeling. To develop effective strategies for managing road safety in the region, it is necessary to conduct a systematic analysis of the dynamics of accidents, assess the severity of their consequences and make accurate forecasts of the development of accidents in the transport system. This will make it possible to develop targeted measures to reduce road accidents and their negative impacts on socio-economic processes in the region.

### 2 Analysis of the dynamics of road accidents and the severity of consequences

Figure 1 shows the dynamics of RTAs and the severity of their consequences (the number of wounded and dead) in Udmurt Republic for the period from August 2012 to August 2023.

![Dynamics of RTAs and severity of consequences in Udmurt Republic.](image)

**Fig. 1.** Dynamics of RTAs and severity of their consequences in Udmurt Republic.
From the graphs shown in Figure 1, it can be seen that the number of accidents has an unstable trend. Until the end of 2015, the number of accidents remained virtually unchanged and there were an average 120 accidents per month (about 1,437 per year). Over the period between 2016 and 2020 there has been an increase in the number of accidents, there were an average of 164 per month or 1971 per year. After that, starting in 2021, the accident rate dropped sharply to the level of 2015.

There is also an uneven distribution of the number of accidents during the year: the maximum number of accidents occurs in August (an average of 173 accidents), and the minimum – in April (an average of 92 accidents).

The graph of the number of deaths in road accidents shows that there is a steady trend towards a decrease in the number of accidents. Which suggests that the policy of reducing deaths in road accidents, carried out in recent years, is effective.

3 Modeling the dynamics of road accidents

Figure 2 shows the autocorrelation (ACF) and private autocorrelation (PACF) function for the time series \( Y_t \) – the number of accidents.

![ACF and PACF](image)

Fig. 2. Autocorrelation and private autocorrelation function of the number of accidents.

Figure 2 shows that the time series \( Y_t \) contains a trend component (the first-order autocorrelation coefficient is significant), a seasonal component with a seasonality period of 12 months (there is a peak of autocorrelation coefficients for lag 12) and an autoregressive process of the 1st order [11] (the first-order partial autocorrelation coefficient is significant).

The model describing the dynamics of the number of accidents was obtained using the maximum likelihood estimate (MLE):

\[
\hat{Y}_t(t) = 40.5 + 0.8Y_{t-1} - 37S_1 - 29.2S_2 - 21.7S_3 - 23.7S_4 + 26.9S_5 + 14.1S_7 - 27S_{11}. \tag{1}
\]

where \( \hat{Y}_t(t) \) is the model value of the number of accidents in month \( t \); \( Y_{t-1} \) is the actual value of the number of accidents in the previous month; \( S_1, S_2, ..., S_{11} \) are dummy variables.
corresponding to time periods (months, for example $S_1$ - January). Time $t$, as well as the months June, September, and October were not included in the model, since the parameters for these variables are not statistically significant.

Model (1) as a whole is statistically significant and has a determination coefficient of 0.79, which indicates that this model describes 79% of the variation in the dynamics of the number of accidents.

For the residues obtained during the use of model (1), the ACF and PACF functions were also constructed (see Figure 3), from which it can be seen that a number of residues are stationary and do not contain autocorrelation, which confirms the possibility of using model (1) to predict accidents.

Fig. 3. Autocorrelation and partial autocorrelation function of residuals in the model (1).

4 Modeling the dynamics of the severity of the consequences of road accidents

The severity of the consequences of RTAs is the number of both injured and killed in the accident. Models for predicting the number of dead $Y_2$ and injured $Y_3$ in an accident are constructed similarly to the model for predicting an accident (1) with the preliminary construction of the ACF and PACF.

As a result of applying the maximum likelihood method to the time series data $Y_2$, the following model for predicting the number of fatalities in an accident was obtained:

$$
\tilde{Y}_2(t) = 22.7 + 0.4Y_2(t-1) - 3.7S_1 - 5.7S_2 - 6.3S_3 - 7.1S_4 - 0.9S_5 - 1.9S_6 + 1.1S_7 + 4.9S_8 + 6.9S_9 + 2.3S_{10}.
$$

(2)

Predictive model for the number of injured in an accident:

$$
\tilde{Y}_3(t) = 187.1 + 0.9Y_3(t-1) - 22.2S_1 - 59.9S_2 - 73.0S_3 - 81.5S_4 - 28.8S_5 + 26.6S_7 + 23.5S_8 + 13.1S_9 - 27.0S_{11}.
$$

(3)
The parameters of models (2) and (3) are statistically significant according to the Student's criterion, and the models as a whole are also significant according to the Fisher criterion.

5 Forecasting of road accidents and the severity of their consequences in Udmurt Republic

Using models (1)-(3), monthly forecasting of the number of accidents and the severity of the consequences until December 2024 was carried out, the results are shown in Figures 4-6.

Figures 4-5 show that the increase in the number of road accidents observed in recent years will continue seasonally adjusted, and in general, an average of 1,676 road accidents are expected in 2024, in which about 2,043 will suffer, and the human mortality rate will be about 185 people.

Fig. 4. Forecasting the number of RTAs Y1 in Udmurt Republic based on the model (1).
6 Conclusion

This research underscores the critical impact of road traffic accidents on population mortality and their adverse effects on the socio-economic development of the region.

To formulate effective management policies in the region, a comprehensive understanding of road accident dynamics and their consequences is essential. Our analysis of the dynamics of road accidents and severity over the past decade reveals an unstable trend,
with notable shifts in accident rates and seasonal variations. Importantly, the decline in the number of fatalities during road accidents reflects the effectiveness of recent safety measures.

The modeling of road accident dynamics has allowed us to construct a statistically significant model that describes 79% of the variation in accident dynamics. The model accounts for trends, seasonality, and autoregressive processes, providing valuable insights for predicting accidents. Similarly, models for predicting the severity of accident consequences have been established, demonstrating statistical significance. Using these models, we have conducted monthly forecasts for the number of accidents and their severity until December 2024.

These findings provide a foundation for policymakers, researchers, and stakeholders to develop and implement targeted strategies aimed at enhancing road safety and reducing the impact of accidents in the Udmurt Republic. The insights gained from this study contribute to the ongoing efforts to mitigate the social and economic consequences of road traffic accidents in the region.

References