Risk of road-traffic accidents in the city of Kazan, Russia

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Abstract. According to the records of the World Health Organization for the year 2018, mortality rate due to road traffic accidents (RTAs) in Russia is equal to 18 RTAs per 100,000 citizens. It ranks Russia the 72th among all the other countries in the world. Statistics of the road traffic accidents occurring between 2013 and 2019 was analyzed in order to reveal the major reasons thereof. The method of levelling of longstanding tendencies by analytical dependencies was used for the evaluation of dynamics and predictions of RTA number. As a result, predicted number of RTAs in 2020 in case of linear dependency was equal to 2118 cases and 1816 cases in case of tendency line. Common RTAs include collisions, hitting of pedestrians and falling of passengers. Most RTAs occur near apartment buildings with death toll rise by 23 % (27 deaths 2018/2017) and 218 % rise (2018/2017) in the number of RTAs near nonresidential buildings.

Keywords: road-traffic accidents, statistics, road safety, city, development analysis, forecast.

1 Introduction
The quality and effectiveness of road-traffic safety management decisions depend directly on the completeness of analysis of the road traffic accidents data and the objective evidence of the causes and conditions of their occurrence [1-4]. Basically, analysis and management are the parts of an inseparable single process with different content depending on the features of the object of management. People are the main objects of management in social systems, which include the road-traffic safety system. Therefore, such systems are characterized by a high degree of responsibility for decisions made and a high degree of uncertainty in the conditions in which such decision are made [5-8].
Practices of philosophy, logic, mathematics, psychology, economics, sociology, and other fields of knowledge are used while taking decisions. They allow deeper analysis, more reliable forecasting, and more effective influence on technical, economic, and social processes [9-12]. Due to the results of scientific research in the field of social systems management it was possible to identify a number of conditions to be met to get realisable and affective management practices. Accidence analysis is an integral part of the general road-traffic safety management process [2, 13-15]. Therefore, the decision to evaluate the effectiveness of both analytical activities and the general work on RTA prevention based on the final results achievement is understandable. However, this approach is even more difficult to implement than the evaluation of the effectiveness of single activities. Consequently, it is more advantageous to determine not the analysis effectiveness, but its quality while evaluating it according to both objective and subjective factors.

In the last decade the problem of accidence related to motor vehicles has become particularly acute in the light of suboptimal road-traffic safety system and poor discipline of road users [11, 16, 17].

Within seven years (from January 01, 2013 to December 31, 2019) of realisation of the Federal Target Program "Improving road-traffic safety in 2013-2020" 13,721 road-traffic accidents (RTA) took place in the city of Kazan with 435 people killed and 15,875 people suffered wounds of varying severity [7].

In 2012, 1421 road-traffic accidents (87.3 percent) were caused by drivers and 190 (11.7 percent) – by pedestrians. A total 1631 road-traffic accidents were registered on the territory of Kazan in 2012, causing death of 78 people and injury of 1,880 people.

Measures taken by the executive authorities and other civil services to reduce accident rate have led to the improvement of the most important effectiveness indicator of policy measures in Kazan: reducing the number of road fatalities, including children deaths. Comparing figures of 2019 with those of the reference year of 2012, we see that the number of deaths in RTA decreased by 23.1 percent, while the number of accidents increased by 17 percent and the number of injuries – by 17.7 percent.

A total 1909 road-traffic accidents were registered in the territory of Kazan in 2019, with 60 people killed and 2,213 people suffered wounds of varying severity. Against the same period in 2018, the number of people killed in RTA increased by 22.4 percent with the number of RTA decreased by 6 percent, and the number of injured people – by 5.9 percent.

Kazan has experienced a constant increase in the number of vehicles in recent years. For example, in 2012 there were 307,663 vehicles in Kazan,
while in January 2020 there were 445,028. The number of vehicles increased by 44.6 percent in seven years.

The population in Kazan as of January 1, 2012 was 1,161,308 people, and in 2019 – 1,251,969 people. So, it increased by 7.8 percent in seven years.

The increased number of motor vehicles and the wholesale inclusion of new drivers have led to a significant change in the characteristics of road conditions and their complexity. It resulted in increased traffic density and traffic load, which has a negative impact on the rate of the accident reduction [18].

Quarter-century international practices of safety audit have shown that effective safety management programs shall be adopted on the basis of balance between reactive and proactive strategies with respect to local conditions [19-21].

Countries, which succeeded in road traffic safety, applied their national strategies acknowledging the necessity of close cooperation and coordination between all the interested parties. In other words, these countries understood that the road traffic safety increased most effectively when traffic regulation observance authorities, traffic control authorities, legislation authorities, public healthcare and education authorities and all the other interested parties worked in close cooperation and followed national road safety strategies. They acknowledged that the road itself could also cause RTAs and that the road authorities could eliminate dangerous sectors by means of detailed analysis of RTAs and affordable corrective measures. Moreover, in course of the construction of the new roads, they managed to implement the process of road safety audit in order to minimize the chance of newly-built road sectors being dangerous. The success of these countries was due to most of their efforts being directed to the road itself [10, 18, 22, 23].

2 Methods

Studying and comparing the development of the accident rates is the most common method of analysis of absolute and any specific and relative indicators. There are several basic methods of studying and comparing the development of the accident state, their practicability confirmed in practice not only within accident analysis, but in many other fields of knowledge:

1. Development analysis in relation to the similar previous period. This method is the most common in real-time control and response to accident changes. Its ever-growing use is principally attributed to the goal of the road-traffic safety system: to reduce absolute indicators. The comparison of indicators of two similar periods gives a straightforward criterion for the goal meeting, where the decline of absolute indicators shows that the goal was achieved. So, the main reason for its wide application is the ease of
connection this method with the ultimate goal of the entire system functioning. However, the same ease leads to the main drawback of the method, i.e. the ambiguity of the analysis conclusions.

2. Development analysis in relation to the "reference" year. According to this method, accident rates for several years are recalculated as a percentage in regard to one "reference" year. The results obtained are easily represented in the form of graphs and are used to compare indicators with stable trend.

3. Development analysis in relation to the average indicators. Development analysis in relation to the average indicators helps to smooth over fluctuations in the analyzed indicators. Three or five years are usually taken as the averaging period, i.e., for example, the average accident rates for the two subsequent quinquennium are calculated and compared with each other. If the analyzed period is long enough, this method can be combined with the previous one, with the "reference" five-year or three-year period taken instead of one "reference" year.

4. Development analysis based on the "point-to-average" principle. This method combines the first one and last one of the above methods, where data for one last period is compared with the average value for several (usually three) previous periods. This method can be recommended both for dynamic response and for evaluating road-traffic safety activities over a specific period of time.

5. Smoothing long-term trends by analytical dependencies. According to the actual data, we can assume that the general trend is towards a steady increase in the number of RTA and that the jogged line can be "smoothed" by a right line. Therefore, in this case, a linearly increasing dependence of the number of RTA on time can be used as the model of development of the number of RTA in the region.

The possibilities of smoothing long-term data are considered on the specific example of the accident in Kazan (See Fig. 1).
The model built, we will get the average value of the analyzed indicator for some period, as well as the average rate of the indicator growth (or decline).

The formula for the average rate of indicators development within a linear model is well known and is as follows:

\[ k = \frac{\sum_{i=1}^{n}(I_i - I_{av})(t_i - t_{av})}{\sum_{i=1}^{n}(t_i - t_{av})^2}, \]

where \( I_i \) is the value of the analyzed indicator at \( t_i \) points of time;

\( I_{av} \) is the average value of the \( I_i \) indicator for the analyzed period;

\( t_i \) are points of time with relevant values of \( t_{av} \);

\( t_{av} \) is the midpoint of the analyzed time period;

\( n \) is the number of points of time with relevant values of \( I_i \);

\[ I_{av} = \frac{\sum_{i=1}^{n} I_i}{n}, \]  

\[ t_{av} = \frac{\sum_{i=1}^{n} t_i}{n}, \]  

Another advantage of the calculated indicators is that they enable to estimate the expected number of RTA for any given time, provided that existing trends persist.

Expected number of RTA is:
\[ I(t_i) = I_{av} + k(t_i - t_{av}), \quad (4) \]

where \( t_i \) is the point of time for which the accident rate is calculated.

3 Results

The examples of smoothing long-term data and usage of the calculated values are given in Table 1.

Table 1. Building a linear model for changing the number of RTA in 2012-2019.

| Years \((t_i)\) | Number of RTA (I) | \( I_i - I_{av} \) | \( t_i' - t_{av} \) | \( (I_i - I_{av}) \cdot (t_i' - t_{av}) \) | \( (t_i' - t_{av})^2 \) |
|--------------|-------------------|--------------------|-------------------|-----------------------------|---------------------|
| 2012         | 1631              | -288               | 4                 | 5                           | 6                   |
| 2013         | 1819              | -100               | 2                 | -2.5                        | 250                 |
| 2014         | 1851              | -68                | 3                 | -1.5                        | 102                 |
| 2015         | 1970              | 51                 | 4                 | -0.5                        | -25.5               |
| 2016         | 2092              | 173                | 5                 | 0.5                         | 86.5                |
| 2017         | 2050              | 131                | 6                 | 1.5                         | 196.5               |
| 2018         | 2030              | 111                | 7                 | 2.5                         | 277.5               |
| 2019         | 1909              | -10                | 8                 | 3.5                         | -35                 |
| Total        | 15,352            | 36                 | 36                | 1860                        | 42                  |
| Average number| 1919              | 4.5                |                   |                             |                     |

Table 1 provides data on changing number of RTA in 2012-2019. The first column represents data on the analyzed period from 2012 to 2019. The second column shows the number of RTA over the same years. Columns 3-7 give the intermediate calculations and information necessary for calculating \( k \). The third column shows the difference between \( I_i \) and \( I_{av} \) (the value of which is given in the last row of the Table).

To avoid multiplication of too large figures, the "offset time" was introduced, i.e. 2012 became No. 1, 2013 – No. 2, so forth. This "offset time" is indicated by \( t_i' \) and is given in Column 4.

The fifth column is similar to Column 3, except that it indicates time instead of accident rate. The content of Columns 6 and 7 is clear from their labeling.

Substituting the values shown in Column 5 into the formula for calculation \( k \), we get:

\[ k = 1860:42 = 44.3. \]
Thus, we calculated two characters of the process of the number of RTA development in the city over eight years: the average level (1919 RTA per year) and the average rate of growth (44.3 RTA per year).

Using Formula 4 and information given in Table 1, we estimate the expected number of RTA in 2020. Since we introduce the offset time in our calculations, we shall also take \( t_i' = 2020 - 2011 = 9 \) instead of \( t_i = 2020 \). Substituting all the necessary number values in Formula (4), we will get:

\[
I(2020) = 1919 + 44.3(9 - 4.5) = 2118
\]

Thus, 2118 road-traffic accidents are expected to occur in 2020.

Let us note again, that this forecast is grounded on the fact that the current trend will persist. Since the number of RTA is expected to increase, it is obvious that the management object is to ensure this trend not to persist, i.e. that the number of RTA decreases.

However, the same jogged line (See Fig. 1) can be smoothed over by various lines drawn slightly higher or lower, steeper or flatter. Which of these direct dependencies shall be chosen? To answer this question we will use methods of mathematical statistics, which enable us to select the model with minimal error (See Fig. 2).

![Fig. 2. Development of the number of RTA: actual data; average curve of the number of RTA.](image-url)
On the presented trend line (See Fig. 2) the forecast number of RTA for 2020 is 1,816.

In 2016, there were 2092 road-traffic accidents in which 19 drivers and passengers, 31 pedestrians, and 1 cyclist were killed and 1432 – 893 – 42 people respectively were injured. In 2017, there were 2050 road-traffic accidents in which 12 drivers and passengers, 31 pedestrians, and 1 cyclist were killed and 1477 – 832 – 41 people respectively were injured. In 2018, there were 20,940 road-traffic accidents in which 17 drivers and passengers, 30 pedestrians, and 2 cyclists were killed and 1577 – 775 – 61 people respectively were injured.

Development of accident rates in 2016-2018 in relation to type of RTA is presented in Table 2.

| Type of RTA                        | 2016 | 2017 | 2018 |
|-----------------------------------|------|------|------|
| Crash                             | 878  | 859  | 925  |
| Automobile-pedestrian accident    | 875  | 823  | 771  |
| Passenger falling                 | 182  | 224  | 195  |
| Head-on crash                     | 71   | 71   | 83   |
| Automobile-cyclist accident       | 43   | 39   | 63   |
| Hitting of a standing vehicle     | 19   | 15   | 23   |
| Overturn                          | 17   | 9    | 20   |
| Other                             | 7    | 10   | 14   |

Development of accident rates in 2016-2018 in relation to violations is presented in Table 3.

As evidenced in practice, the places of RTA are unevenly distributed on highways, roads and city streets. When studying the map showing the RTA areas, some places where RTAs occur more often, that is, concentrated places, stand out. These areas are termed variously – dangerous areas, black spots, accident hotbeds, etc. But they define the same notion: these are places where RTAs take place more often than totally on the street and road network.

Challenges related to the detection of the most dangerous road sections and the development of measures to eliminate the causes of their occurrence have been widely developing since 1960s. Currently, there are a lot of various criteria and methods for detecting and identifying such sections.

All accident hotbeds are primarily divided into two types. The first type includes RTA hotbeds at street crossings, intersections, road junctions, railway crossings, and complex engineering structures such as bridges, tunnels, high
banks, etc. It is in little doubt that these units of the street and road network belong to the sources of increased danger and no special proof is required to identify them as accident hotbeds. In this case different elements are simply compared to each other in terms of the danger degree.

All other areas of RTA concentration are classified as accident hotbeds of type 2, and their identification needs application of formal statistical criteria. Statistics in relation to the place next to RTA is presented in Table 4.

**Table 3.** Development of the number of RTA in 2016-2018 in relation to violations.

| Violations                                                                 | 2016 | 2017 | 2018 |
|----------------------------------------------------------------------------|------|------|------|
| Wrong spacing                                                              | 299  | 369  | 402  |
| Violation of pedestrian crossing rules                                     | 287  | 298  | 310  |
| Other traffic violations made by the driver                                | 146  | 297  | 298  |
| Violation of the priority rules at roundabouts                             | 296  | 259  | 255  |
| Violation of traffic light                                                 | 135  | 123  | 154  |
| Non-compliance with the lateral interval                                   | 83   | 77   | 113  |
| Crossing the roadway outside the pedestrian crossing in sight of it or within easy reach to an underground (above-ground) pedestrian crossing | 133  | 132  | 110  |
| Violation of the lane-change rules                                         | 118  | 85   | 95   |
| Non-compliance with the conditions of back run                             | 95   | 77   | 85   |
| Violation of the regulations on the use of public transport                | 47   | 72   | 71   |
| Speed mismatch to specific driving conditions                              | 203  | 57   | 65   |
| Wrong-way driving                                                          | 90   | 58   | 62   |
| Crossing the roadway in undesigned areas (with an intersection in sight)   | 77   | 53   | 54   |
| Other violations                                                            | 49   | 47   | 41   |
| Non-compliance with highway traffic regulations                            | 31   | 37   | 31   |
| Nonconformity with traffic signs                                           | 26   | 21   | 25   |
| Violation of the rules for the vehicle location on the roadway             | 35   | 30   | 20   |
| Speed enforcement                                                          | 14   | 29   | 19   |
| Violation of stopping and parking rules                                     | 7    | 7    | 14   |
| Crossing the roadway in a prohibited area (equipped with pedestrian barriers) | 4    | -    | 9    |
| Violation of road marking                                                   | 1    | 5    | 7    |
| Motion along the roadway granting the sidewalk in satisfactory condition    | 5    | 4    | 7    |
| Standing on the roadway without the purpose of crossing it                  | 4    | 10   | 4    |
| Crossing into oncoming traffic with a U-turn, turn to the left or obstacle avoidance | 4    | 2    | 4    |
| Unexpected emerge from the vehicle                                         | 4    | 3    | 4    |
| Crossing of the roadway by a cyclist at a pedestrian crossing              | 3    | 2    | 4    |
| Place nearby                                                                 | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10 |
|------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|
| Apartment blocks                                                            | 1128  | 1255  | 24    | 1348  | 1535  | 22    | 1389  | 1572  | 27    |    |
| Controlled intersection                                                     | 778   | 924   | 16    | 737   | 881   | 11    | 794   | 948   | 16    |    |
| Public transport stop                                                        | 600   | 666   | 16    | 557   | 599   | 14    | 713   | 801   | 19    |    |
| Signalised crossing                                                          | 271   | 291   | 5     | 494   | 578   | 7     | 598   | 686   | 12    |    |
| Large retail facility                                                        | 203   | 237   | 4     | 261   | 292   | 8     | 379   | 433   | 6     |    |
| Zebra crosswalk                                                              | 320   | 327   | 8     | 344   | 357   | 10    | 311   | 333   | 8     |    |
| Administrative buildings                                                     | 66    | 76    | 1     | 84    | 97    | 2     | 267   | 312   | 5     |    |
| Emerge from the surrounding area                                            | 133   | 150   | 1     | 160   | 177   | 1     | 232   | 257   | 7     |    |
| Residential individual buildings                                             | 147   | 172   | 2     | 154   | 189   | 5     | 199   | 244   | 7     |    |
| Uncontrolled intersection of non-equipotential streets (roads)               | 158   | 191   | 6     | 128   | 158   | 3     | 164   | 192   | 1     |    |
| Single retail facility                                                       | 43    | 46    | 2     | 65    | 67    | -     | 136   | 149   | 4     |    |
| Overhead road, overpass                                                      | 96    | 119   | 1     | 101   | 142   | 5     | 135   | 172   | 3     |    |
| Fuel filling station                                                         | 87    | 107   | 5     | 84    | 112   | 1     | 124   | 150   | 1     |    |
| Courtyard territory                                                          | 146   | 147   | 1     | 130   | 129   | 3     | 103   | 104   | -     |    |
| Sports and entertainment facilities                                          | 38    | 44    | 4     | 45    | 57    | -     | 74    | 105   | -     |    |
| Parking space (separated from the roadway)                                  | 48    | 52    | -     | 50    | 55    | -     | 73    | 78    | -     |    |
| Underground pedestrian crossing                                              | 34    | 40    | 2     | 47    | 57    | 5     | 58    | 76    | -     |    |
| Streetcar stop                                                               | 25    | 26    | 1     | 25    | 33    | -     | 57    | 65    | 1     |    |
| Overground pedestrian crossing                                               | 28    | 30    | 2     | 36    | 42    | -     | 53    | 58    | 2     |    |
| Place nearby                                               | 2016 | 2017 | 2018 |
|-----------------------------------------------------------|------|------|------|
| Medical treatment facilities                              | -    | -    | 30   |
| Manufacturing facilities                                  | 31   | 36   | 1    |
| Bridge                                                    | 36   | 41   | 1    |
| Uncontrolled intersection                                 | 75   | 85   | 2    |
| Object of religious faith                                 | 5    | 5    | -    |
| Approach to the bridge, overhead road, and overpass       | 21   | 25   | -    |
| Sidewalk, pedestrian precinct                            | 35   | 40   | 31   |
| Other educational establishment                          | -    | -    | 12   |
| School or other children's organization                  | 13   | 13   | -    |
| Uncontrolled intersection of equipotential streets (roads)| 16   | 21   | -    |
| Recreational area                                         | 14   | 15   | -    |

Note: Columns 2, 5, 8 indicate the number of RTA; Columns 3, 6, 9 – the number of injured people; Columns 4, 7, 10 – the number of fatalities.

It worth noting that any conclusion about the presence of an accident hotbed, made on the basis of statistical data, will be probabilistic, and one can speak only about the degree of confidence in the conclusions obtained.

### 4 Discussion

Mathematical research methods of complex systems and processes and their operation are becoming more significant in various branches of science and technology. It is generally recognized that the most complex managed processes studied on the basis of statistics run in economical and social systems, which include the road-traffic safety system.

Until recently, the analysis of the road-traffic safety activities was limited mainly to the study of the incidence dynamics and structure by selected indicators. However, nowadays, with the problem of road-traffic safety sharply aggravated, the requirements for the quality of analysis and
preparation of management decisions proposals have increased. It has proved impossible to keep to traditional research methods mainly because of the inability to process, understand and correctly interpret a huge amount of source data.

The following conclusions can be made based on Table 4:
- the largest number of RTA occur near apartment blocks, with the dynamics of increasing number of deaths;
- against 2016, in 2017 the number of RTA at regulated intersections and public transport stops declined, and in 2018 – increased;
- the number of RTA at regulated pedestrian crossings increased;
- the number of RTA near major shopping centers increased by 30 % (2018/2017);
- the number of RTA near administrative buildings increased by 218 % (2018/2017);
- the number of RTA when emerging from the surrounding area increased by 45 % (2018/2017);
- the number of RTA near residential individual buildings increased by 29 % (2018/2017);
- the number of RTA at uncontrolled intersections of non-equipotential streets (roads) increased of 28 % (2018/2017);
- the number of RTA near single retail facilities increased by 109 % (2018/2017);
- the number of RTA near overhead roads and overpasses increased by 34 % (2018/2017);
- the number of RTA near fuel filling stations increased by 48 % (2018/2017);
- the number of RTA near sports and entertainment facilities increased by 64 % (2018/2017);
- the number of RTA near school or other children's organization increased by 175 % (2018/2017);
- the number of RTA at courtyard territories reduced by 21 % (2018/2017);
- the number of RTA at uncontrolled intersections reduced by 29 % (2018/2017);
- the number of RTA at sidewalks and pedestrian precincts reduced by 26 % (2018/2017);

One section of applied mathematics called mathematical statistics considers the processing of statistical information and corresponding model-building. Due to the variety of models used in mathematical statistics it is
impossible to describe the methods of their construction even in special publications.

One of the first and main issues discussed in mathematical statistics is the regularity and incidental correlation in the source data. In fact, the accidence features obtained for a sufficiently large group of RTA are governed by statistic patterns. The existence of statistic patterns is confirmed by the fact that although each specific RTA is a result of a combination of many factors and, therefore, may be random in nature, with sufficiently large sets of RTA these results become sustainable.

However, despite the size of RTA group used to calculate an accident rate, it remains finite, and the accident rates for this group will have some random fluctuations relative to stable trends.

It worth noting that incidental does not mean the absence of cause. There shall be objectively existing reasons for even the smallest differences and changes. The point is that no matter how detailed the source accidence data is there is always the possibility of an error in the results and conclusions obtained where this data is solely used. To receive more accurate results, new data should be obtained. This process is infinite, and it is important to set the "limit" so that to minimize the probability of improper conclusions. Causation in statistical studies is a separate and neglected issue.

5 Conclusions

Many tasks of accident rate analysis require the degree of dependency between various indices to be determined and estimated. The matter of data analysis is mainly in determining the interrelations between various variables. However, it is certainly not always about determining interrelation in the form of some math correlation. Analysis is often performed without building any formal model, but in any case, though unintentionally or intuitively, one has to make conclusions on the nature of interdependency of the indices under analysis in order to receive a final evaluation.

As a result of RTA statistics analysis by levelling longstanding tendencies with analytical dependencies, predicted number of RTAs in 2020 in case of linear dependency was equal to 2118 cases and 1816 cases in case of tendency line.

Common RTAs include collisions, hitting pedestrians and falling passengers. Most of RTAs occur near apartment buildings with death toll rise: 218 % rise (2018/2017) in the number of RTAs near nonresidential buildings, 45 % rise (2018/2017) in the number of RTAs attributed to exiting from the adjacent areas, 109 % rise (2018/2017) in the number of RTAs near individual commercial objects, 64 % rise (2018/2017) in the number of RTAs near sports
and entertainment objects, 175% rise (2018/2017) in the number of RTAs near schools or other children organizations.

The task of establishing causation is complicated by the fact that the relation between accident rate indices and factors influencing them is rarely simple and obvious in the Road Safety System. Difficult problems hardly ever have simple solutions, i.e. solutions related to only one variable or cause. Accident rate is influenced by many factors and impact of the one of them may be replaced and deformed by the other ones. Such dependency is not easy to understand and hard to determine. However, even insignificant or partial progress in understanding the occurrences may lead (though a long way it may take) to effective solution of highly complicated problems.

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