System Approach to Ensuring the Safety of Modern Vehicles

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Abstract: Improving road safety is a priority worldwide. A systematic approach can reduce accidents and injuries, since various resources and methods of solving the problem are involved. The purpose of the article was to establish a relationship between violations and road accidents. To identify the factors affecting the probability of accidents and the severity of their consequences, an analysis of real statistics on violations and road accidents was used. It was found that the city planning decision and its size affect the specifics of traffic control. A developed events to improve road safety is presented, systematized in a modified Haddon matrix, in which, in addition to traditional groups of factors (human, vehicle, environmental factors), a new factor is added - information technology or artificial intelligence. It was noted that feedback was needed to ensure the effectiveness of the recommended events. That is re-analysis of next period statistics, assessment of changes and adjustment of Haddon matrix, by eliminating ineffective measures and replacing them with others.

1 INTRODUCTION

The acceleration of urbanization, causing the growth of megacities and, as a result, the need for mobility and motorization of the megacities' population. At the same time, the level of population's motorization, as well as the number of commercial vehicle parks, is increasing, which, in turn, with insufficient infrastructure development, leads to an increase in the number of road accidents, as well as the severity of their consequences. This reduces the stability and safety of the transport system as a whole. Events related to COVID-19 have changed the parameters of the transport system's functioning. Due to local bans on travel by private automobile transport, the level of drivers' professional skill, determined, among other things, by the regularity of driving, has decreased. After the ban on movement for both pedestrians and drivers was lifted, the risk of accidents increased significantly. To create an effective traffic control system, it is necessary to have a tool with which it would be possible to identify the most significant factors from the actual data, to play various scenarios of the events' development, to make corrective decisions, and subsequently, to analyse their effectiveness.

2 METHOLOGY OF THE SYSTEM APPROACH IN THE ROAD SAFETY MANAGEMENT

The effectiveness of a management strategy based on a systematic approach to the greatest extent affects traffic safety, since thanks to a combination of technical and

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organizational measures, it is possible to predict and prevent most accidents, as well as reduce the severity of the consequences. The effectiveness of this approach is confirmed by the example of many European countries (Zero mortality; Jurecki, 2020; Buehler, 2021; ITF, 2020), which manage to approach zero deaths on the roads, despite the high level of motorization. Public policies in many countries are also focused on the application of a systemic strategy in the issue of road safety. For example, in the document (Road safety strategy, 2018) Intelligent Transport System (ITS) is designated as the basis for improving road safety, which means “a control system that integrates modern information and telematic technologies and is designed for automated search and adoption of the most effective scenarios for managing the region transport and road complex, a specific vehicle or vehicles’ group in order to ensure a given mobility of the population, maximize the use of the road network, improve the transport process safety and efficiency, for drivers’ and transport users’ comfort”. The creation of ITS to improve safety is accompanied by the introduction of communication, data collection, processing, management and control, originally embedded in vehicles and infrastructure (Shepelev, Nikolskaya, 2020; Khazukov, 2020). Then, based on the information received in real time (Makarova, 2016; Shepelev, 2020), effective management decisions are formed.

2.1 Accident Prevention

To reduce the likelihood of an accident, it is necessary to develop active safety - a set of measures aimed at preventing their occurrence. This should include the structural characteristics of vehicles, roadways and infrastructure, as well as drivers’ sufficient experience, driving culture and organizational factors.

The properties of vehicle active safety are characterized by braking qualities, controllability and stability in emergency modes; visibility from the driver's seat, the vehicle’s external information content - the number, color, location of external lighting devices, the level of noise in the passenger compartment. Cruise control systems, blind spot detection, automatic wipers also help the driver to avoid a traffic accident (Gimignani, 2013). Active safety systems should include Advanced driver-assistance systems, which, among other things, solve the problems of recognizing and displaying information about infrastructure objects, road users, weather conditions, and navigation and routing. At the same time, there are systems that allow the driver to make adjustments to the control of the vehicle, depending on the type of prompts that appear, and those that have built-in response tools without involving the driver (Trager, 2021). The researchers in (Makarova, 2017) decline that the vehicles’ intellectualization will increase the stability of transport systems.

The problem of the most vulnerable road users’ safety is also relevant. Therefore, in the study (Makarova, 2018) the authors considered a method of preventing a collision with a pedestrian by installing a push-button traffic light. It is proposed to use a fuzzy logic mechanism to control traffic light phase switching. Despite a range of technical measures and efforts to ensure safety in transport systems, the number of accidents remains high. It is worth noting that the person in the management system is the most important and at the same time the least reliable element, and therefore he cannot perform work accurately for a long time "- says the author of the article (Nikolaeva, 2016). That is why research offering methods and algorithms for the development of driver fatigue control systems is becoming especially relevant (Nadai, 2015).

A significant part of road traffic accidents are related to traffic violations. The study (Martinussen, 2017) focuses on identifying risk groups of drivers and indicators of safe and unsafe driving. The use of virtual reality technologies and mobile applications to improve the education level of driving vehicles seems to be effective. So, the authors of (Hsu, 2018) presented a simulator that expands the trainee's experience in typical and atypical scenarios when riding a motorcycle.

The authors of (Jin, 2021) investigated the use of telephones by drivers during a stop at a red traffic light, as well as while driving. A high correlation was found between the waiting time and the probability that the driver will use his phone (with an increase in the waiting time from 20 to 120-150 seconds, the proportion of using the phone increases from 27.4% to 46.0%).

It is necessary to reduce traffic intensity, optimize traffic flows and reduce travel time for certain road network sites. In (Gorodokin, 2017), the authors propose a new method for expert calculating the working cycle of traffic lights with saving the possibility of entering the intersection of all vehicles arriving from each of the conflicting directions (including the busiest) in one cycle. The probability of an accident generally decreases with a reduce in the traffic flow intensity. One of the current trends (including due to COVID-19), contributing to this, is the widespread introduction of remote workplaces (Crowley, 2020) and distance learning technologies (Shaytura, 2020).

Finally, in view of the intellectualization both of vehicles and infrastructure objects of traffic control, measures are needed to ensure the information security. Because vulnerabilities in ITS can be exploited for terrorist attacks, the research community has begun to investigate and address potential security issues in sensing, positioning, recognition and networking technologies in driverless vehicles (Torre, 2020).

2.2 Reduction of Accident Consequences Severity

Reduction of injuries received during road accidents is ensured by measures to increase passive safety.

The elements of the vehicles' passive safety system include seat belts and sensors that signal the unfastened seat belts, ABS, EBS, triplex glass, steering assembly and dashboards structures that soften the impact on passengers, doors designed to remain closed in case of accidents, protected fuel tanks and battery emergency disconnect switches, vehicle maximum speed limits, front and rear energy absorbing elements that crumple on impact. The vehicle interior frame must have maximum rigidity and strength. Child restraints reduce the likelihood of child death. However, as shown in the article (Posuniak, 2018) the improper use of seat belts can lead to greater danger to the child. Also, choosing a method for installing the child restraint system, child weight, and height must be considered. Wearing good quality protective helmets can reduce the risk of death in a traffic accident by 42%, and the risk of serious hand injuries by 69%. Although 167 countries have passed laws on the mandatory wearing of helmets, only 82 countries have laws requiring helmets to be fastened and 93 refer to helmet standards in their laws (World Health Organization, 2018). To reduce pedestrian injuries, an elastic impact absorbing element is used on the vehicle front bumper. It allows reaching a certain deformation zone of the front part of the vehicle body upon hit. A further development of passive safety systems for pedestrians is the airbag and hood rising when hitting. They provide a significant reduction in injuries when a pedestrian collides with a vehicle.

Passive road safety means measures aimed at reducing the severity of the accident consequences. They include such elements as fences with a structure that ensures the gradual "consumption" of impact energy, emergency deadlocks on mountain roads, fences prevented the vehicle from falling off the road that are installed on dangerous roads sections with roundings, steep and high slopes. Exceeding the maximum permissible speed is the cause of at least 30% of deaths. An increase in speed by 1 km/h causes an increase in the risk of an accident, the participants of which will receive bodily injuries, by 3% and the risk of a fatal accident by 5%. The probability of pedestrian death is eight times higher when in contact with a vehicle moving at a speed of 50 km/h than 30 km/h. 9 (Goniewicz , 2016). In connection with the above, it is necessary to install photo-video recording cameras, to construct artificial road bumps as preventive measures to ensure that drivers comply with speed limits. In addition, cameras are used to monitor violations of safety belts and child restraints.

2.3 Elimination of Accident Consequences

The efficiency and speed of emergency services involved in the aftermath of the accident, the resources availability and the personnel qualification affect the amount of damage from accidents that have occurred, as well as the timeliness of providing medical assistance to victims.

The authors of the work (Lyapin, 2020) propose to solve this problem on the basis of the developed conceptual model of the subsystem of response to accidents, which unites services and organizations involved in the aftermath of the accident, which, in order to minimize damage caused by road accidents to road users, transport infrastructure and the environment, should unite everything resources and integrate with an intelligent transport and logistics system. So, if an accident scene is often cut off from the nearest peak by a "traffic jam" it is necessary to solve the problem of laying a route along rough terrain by correctly choosing a vehicle for driving. It is proposed to control travel time using methods of finding the optimal route based on the graph's theory with variable weight of ribs, depending on the flow speed, road and weather conditions on the route, driver qualification and condition, taking into account vehicle technical characteristics, quality of traffic control, random components.

To reduce the incident duration, secondary accidents and improve the reliability of motorway traffic, a patrol vehicles' fleet is often used to detect traffic accidents and failures, assist stranded motorists, and provide short-term traffic control. In (Abrisqueta, 2019), a model is proposed using a genetic algorithm to optimize the positioning route of security patrols to minimize the average time they respond to an incident. To automatically notify emergency services about a traffic accident and provide timely medical care to vehicle passengers, in vehicles emergency call systems, as well as computer vision technologies are provided. They allow to recognize a traffic accident and respond accordingly.

Periodic analysis of traffic violations statistics reveals a group of potentially dangerous drivers, and accidents analysis systematizes factors affecting their probability and severity. Simulation can be used to assess possible changes in infrastructure or roadway at accident concentration sites. The evaluation of the effectiveness of decisions made and events implemented should be carried out on the basis of feedback: it is necessary to analyze how the adoption of certain laws and other measures affects accident statistics.

3 RESULTS: IDENTIFICATION OF TYPICAL SITUATIONS LEADING TO REDUCED ROAD SEFETY

3.1 In the Russian Federation

Solving the safety problems of transport systems is a priority area outlined in (Road safety strategy, 2018). Although, the main accident rates in recent years tend to decrease, but they are still lagging behind European ones. If on average in the EU countries the established indicator - the social risk index - does not exceed 5.5 people per 100 thousand population, then on January 1, 2019 in Russia is 12.4 people per 100 thousand population (Federal target program, 2018). According to the Pulitzer Center, the real mortality rate on the roads of the Russian Federation is 1.28 times higher than the declared number, since those who died as a result of an accident after 1 month are not taken into account (Pulitzer Center, 2021). In 2019, in Russia 164 thousand accidents occurred in which 211 thousand people were injured and about 17 thousand died (Information about the indicators, 2021). As can be seen from the statistics (figure 1 a), the measures taken are effective, but systemic developments in the area of improving security are needed. The low level of road safety is due to reasons such as the low discipline of road users, due to the insufficient implementation of the principle of punishment inevitability, the low efficiency of the driver training system, the monitoring of the vehicles' technical and the road network condition, as well as traffic organization. In addition, the accidents rate is negatively affected by the lack of control and supervisory mechanisms, including for entities engaged in the transportation of passengers and goods by road transport, as well as shortcomings in the road safety management system. It has been established that more than 85 per cent of road accidents, which account for more than 80 per cent of fatalities and more than 90 per cent of injuries, are caused by traffic violations (Road safety strategy, 2018). That makes it possible to divide the offences into two categories: (1) violations that increase the probability of an accident (driving the vehicle while intoxicated, driving into the oncoming lane, using a mobile phone while driving, speeding); (2) violations that increase the severity of the accident consequences (violation of the rules for transporting children, ignoring seat belts).

Initial data for analysis were obtained from the official website of the Russian Federation traffic police (Information about the indicators, 2021). Figure 1b, showing the violations' dynamics over the past three years, shows an annual increase (by about 20%) in violations that increase the accidents' probability, while the level of violations that increase the severity of their consequences remains stable. This dynamics is due to the growing number of automatic photo-video recording of violations, as well as the expansion of their capabilities: the ability to notice violations of several types at once.

Analysis of violations' types for the three-year period 2017-2019, showed that the most frequent are speeding, non-compliance with signs and markings, driving a red traffic light, violation of parking and overtaking rules, violation of the rules for using seat belts and motorcycle helmets (Figure 2). According to a recent traffic police study, almost half of drivers in Russia (49%) are distracted from the road when driving a car, and 5% do it constantly.

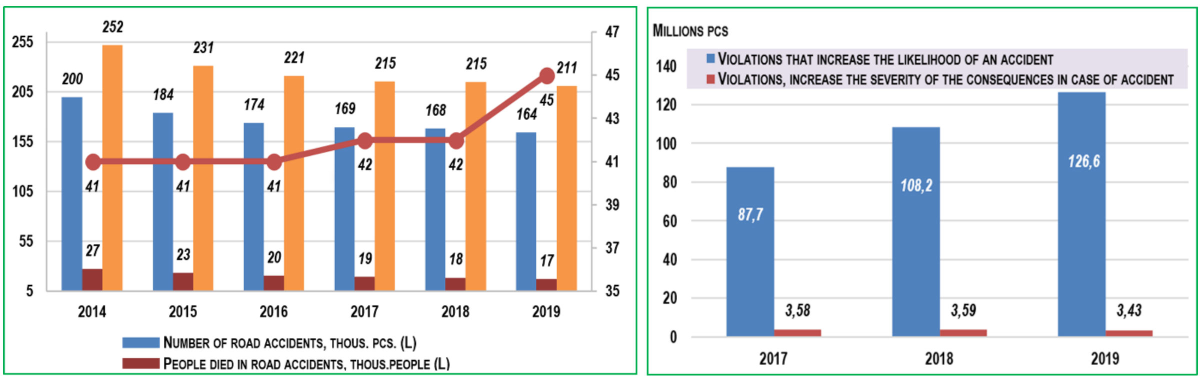

Figure 1: a) Dynamics of motorization and accidents rate, b) Dynamics of violations in the Russian Federation for 2017-2019.

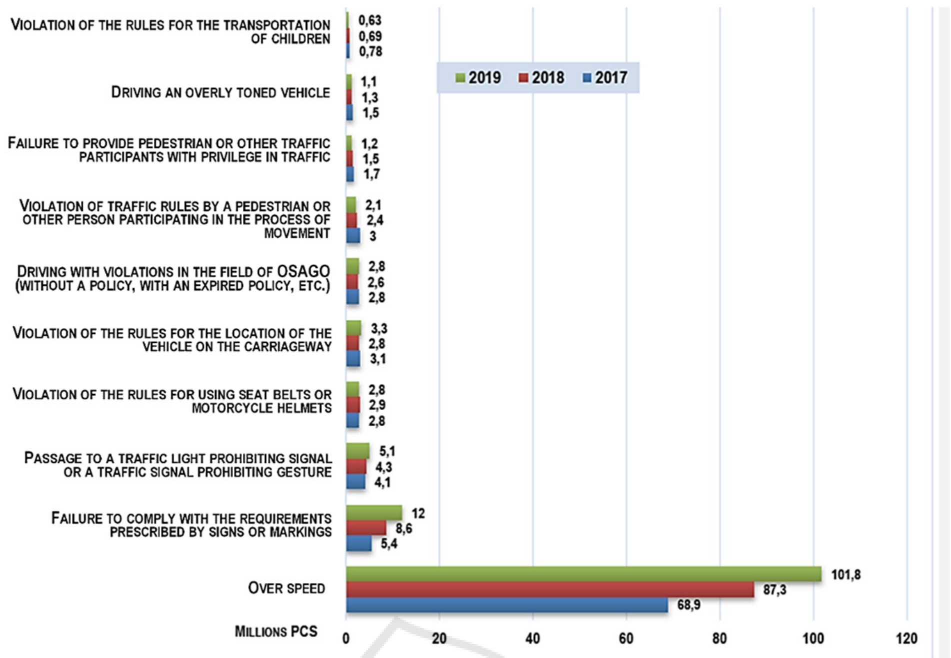

Figure 2: Common types of traffic violations in the Russian Federation for 2017-2019.

The main part of the attention is taken away by gadgets, which explains in most cases the passage to the red traffic light or the driver's late reaction to the changing traffic light. According to statistics, 19% of drivers use phone with slow traffic, and during a stop at a traffic light - almost 42%. According to the traffic police, 40% of drivers died in road accidents did not use seat belts in 2017, and although in 2019 this figure decreased by more than half (to 19%), 1330 people died without being fastened.

3.2 In Yelabuga Town

The specifics of traffic control depend on city's planning solution and size. For example, the Yelabuga city, located in the Tatarstan Republic, was taken. It has a population of 73,913 people, which, according to the classification, gives reason to attribute it to medium-sized cities, but having a high level of motorization. The total length of roads is 166.33 km. All roads have a solid surface: 125.546 km - asphalt, 15.27 km - gravel, 25.514 km - ground. The density of the road network is 3.99 km/km^2, which indicates a high branching of road network, and meets the urban planning standards of the Tatarstan Republic. The support network of Yelabuga consists of roads passing through the city and main streets of citywide and district significance. The support network includes 10 main streets of regulated traffic of citywide significance and 7 transport and pedestrian main streets of district significance. 35% of them are four-lane, 65% are two-lane. 65% of streets have a lane width of 3.5 meters, 30% of streets - 3.0-3.25 meters, 5% - 5.0 meters, which indicates the relative uniformity of support network's roads. The parameters of some main streets of Yelabuga do not correspond to the accepted categories in the number of lanes (less than 4), the width of the carriageway is less than 3.5 m, there are no sidewalks, or the width of sidewalks' pedestrian part is less than normal. On some streets, the minimum distance between pedestrian crossings does not meet the standard. The estimated speed on 65% of the streets is 80 km/h, and on 35% of the streets - 70 km/h. The specifics of the traffic organization is one-way traffic, which contributes to increasing throughput, and also eliminates the conflict of oncoming traffic flows with insufficient width of the carriageway.

An analysis of the initial information received by the Road Safety State Inspectorate in the Yelabuga city for 2017-2019 in terms of accident rate showed that the number of accidents is growing annually, and, as a result, the number of victims and deaths is growing (Figure 3a). The severity of the consequences, calculated as the share of those died in accidents out of the total number of victims (dead and wounded), for 2019 year amounted to 8.7%. At the same time, in almost 100% of cases there was a violation of traffic rules by traffic accidents participants, in 9% of cases the vehicle driver was intoxicated, in 23% of cases unsatisfactory conditions of detention and arrangement of the road network were recorded. At the same time, the dynamics of accidents correlates with the averages in Russia.

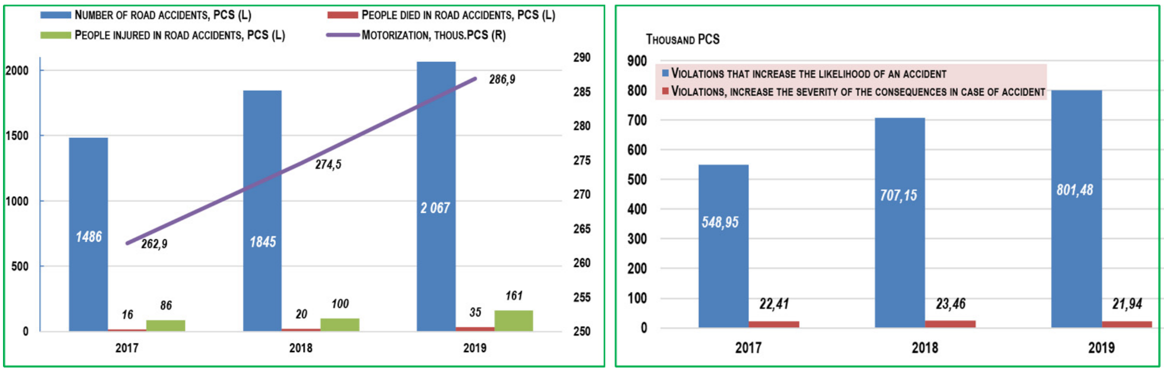

Figure 3: a) Dynamics of motorization and accident rates in Yelabuga for 2017-2019, b) Dynamics of violations in Yelabuga for 2017-2019.

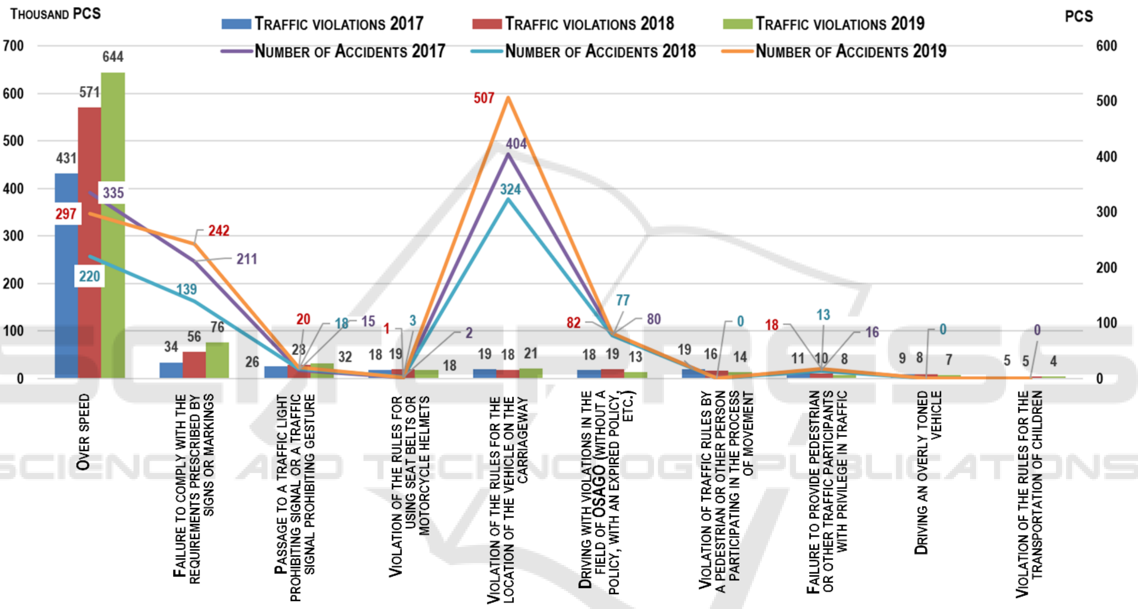

Figure 4: Relationship of traffic violations and the number of accidents in Yelabuga for 2017-2019.

Having analyzed the violations increasing the occurrence probability and severity of the accident consequences, it was found that the dynamics are approximately the same as throughout Russia as a whole (Figure 3b).

To determine the risk of accidents in various types of traffic violations, the data on the revealed facts of traffic violations and accidents were compared (Figure 4). In recent years, the decrease in the number of the most common type of violations (speeding, or non-compliance with the chosen speed with specific road conditions) is primarily due to the active introduction of photo and video recording cameras. At the same time, a significant number of accidents are associated with a violation of the rules for the vehicles' location on the roadway. This situation is explained by the peculiarities of the city's infrastructure, characterized by a small territory, where with the growth of motorization there is a shortage of parking spaces, both for the vehicles' permanent storage (10342 places), and for its temporary stop (5474 places). The maximum load is observed at the intersection of Tugarov and Moskovskaya streets, which is 58% of the throughput. There are other lively unregulated and adjustable intersections. The absence of traffic lights or suboptimal parameters of their operation lead to the accumulation of a large number of vehicles that cause congestion at such intersections, thereby increasing the accident's likelihood. In this regard, there is a need to optimize traffic and the quality of setting the parameters of traffic lights operation. One can test the effectiveness of possible solutions to this problem using simulation of specific situations, as we demonstrated in article (Buivol, 2020).

PHASES →	BEFORE CRASH	IN CRASH	AFTER CRASH
HUMAN BEHAVIOUR (DRIVERS, CYCLISTS, PEDESTRIANS ETC)	❑ WORK WITH VIOLATORS ❑ TAKING INTO ACCOUNT PREVIOUS EXPERIENCE ❑ TOUGHER PENALTIES ❑ CONTROL AND PREVENTION OF OFFENSES	❑ USE OF PASSIVE SAFETY EQUIPMENT (BELTS, CHILD RESTRAINTS)	❑ EMERGENCY RESPONSE ❑ CONTROL OF PERSON BEHAVIOR , RESPONSIBLE FOR THE ACCIDENT ❑ IDENTIFICATION OF 'MALICIOUS' VOILATORS AND WORK WITH THEM
VEHICLE & EQUIPMENT	❑ DRIVER FATIGUE MONITORING SYSTEM ❑ ADAS ❑ CONTROL OF VEHICLE'S TECHNICAL CONDITION	❑ IMPACT PROTECTION (AIRBAGS, LIMITERS, ETC.)	❑ FIRST AID EQUIPMENT ❑ ALERT BUTTON "ERA-GLONASS" ❑ *OPTIMIZING TRAFFIC ROUTING USING SIMULATION*
ROAD ENVIRONMENT	❑ THE ROAD GEOMETRY, THE ROADWAY CONDITION ❑ PROVIDING VISIBILITY ❑ PEDESTRIAN INFRASTRUCTURE	❑ ROADSIDE SAFETY EQUIPMENT (BUFFER ZONES, SAFETY BARRIERS, ETC.)	❑ ACCIDENT RECONSTRUCTION ❑ ALERT TRAFFIC PARTICIPANTS ABOUT THE ACCIDENTS ❑ DENTIFICATION OF ACCIDENT CONCENTRATION PLACES ❑ *INFRASTRUCTURE PARAMETER OPTIMIZATION USING SIMULATION*
IT & COMMUNICATION	❑ IDENTIFY TYPES OF IT THREATS ❑ IMPROVING INFORMATION POLICY ❑ SECURITY ENHANCEMENT	❑ RISK IDENTIFICATION ❑ BLOCKING THREATS ❑ REFLECTION OF CYBER ATTACKS	❑ DAMAGE LOCALIZATION OF VIRUS TREATMENT ❑ REASON'S CONSIDERATION
FACTORS ↑	PRIMARY SAFETY	SECONDARY SAFETY	TERTIARY SAFETY

Figure 5: Modified Haddon matrix.

The problems identified by the analysis require specific measures to improve road safety, which can be consolidated into a Haddon matrix. In particular, at this stage, transport routes' and infrastructure parameters' optimization is appropriate for the initial implementation (Figure 5). This methodology, (Haddon, 1980), is an example of a systematic approach that allows to identify risk factors and develop events to implement a planned and effective management system to prevent and reduce the harmful effects of road traffic injuries. In the studies of William Haddon, factors are subdivided into human, automobile, environmental factors. They are considered in the context of three time phases - before the accident, during the accident and after the accident. In our opinion, due to the fact that the processes of intellectualization affected both vehicles and infrastructure, a new factor has appeared in the traffic control system, which can be indicated by IT or artificial intelligence (AI). So, we modified the Haddon matrix. In any case, after the implementation of the events, re-gathering of statistics and analysis is necessary to understand the effectiveness of the decisions taken. You may then need to adjust the events in the Haddon matrix.

4 CONCLUSIONS

To reduce the likelihood of accidents it is necessary measures aimed at improving management and improving road infrastructure may be implemented. Since most of the accidents are caused by the incorrect vehicles' location on the roadway, it can be concluded that the installation of photo-video recording cameras did not have a significant effect. Alternative low-cost events to expand the parking space should be recommended.

Since the budgets of small and medium-sized cities are small, it is necessary, first of all, to envisage management events, fixed in the Haddon matrix, to optimize the parameters of existing infrastructure facilities, for example, the phases of traffic lights. At the same time, simulation is an effective tool for testing decisions. It should be noted that the necessary conditions for the successful application of the Haddon matrix are the collection and systematization of information on the events carried out, and subsequently on the parameters of infrastructure, traffic flow and environment, road users and road accidents. Only then is it possible to evaluate the effectiveness of the tools from the Haddon Matrix and to provide feedback in transport system management.

In this and previous articles (Makarova, 2020; Yakupova, 2019) we have provided examples of the identification of factors affecting the accidents' probability and the severity of their consequences, as well as the development of events for their minimizing. To verify the effectiveness of these events, the re-collection of accident statistics, analysis and adjustment of events in the Haddon matrix for the management of the road safety in the next period are required. The Haddon Matrix allows to systematize recommended events and track their effectiveness through feedback. This will be the subject of subsequent scientific and practical research by the author's team.

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