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METHODS FOR ASSESSING THE RISK OF ACCIDENTS IN THE DRIVER-VEHICLE-ROAD-ENVIRONMENT SYSTEM

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Abstract

High level of accidents and injuries in Ukraine prompts the search for ways to solve this problem. The purpose of this work is the study of modern approaches to assessing the safety of transport systems and the justification of the need to improve the existing or develop new methods of determining the risk of accidents on the country's roads. The article analyses the works related to the study of the functioning of the driver–vehicle–road–environment system, by the theory of performance properties of the motor vehicle, which is the methodological basis for the analysis of traffic accidents. The analysis of modern approaches to the assessment and audit of traffic hazards revealed the widespread use by researchers of the multiplicative form of models, which corresponds to the provisions of the risk theory: in the event of independent factors, the aggregate risk can be estimated on the basis of the product of partial risks. The general procedure for risk assessment is a process that includes the identification, analysis and comparative assessment of risk. The inadequacy of the existing risk assessment methods is manifested in the inability to predict the risk of road accidents based on the data on the state of the environment and the dynamics of its changes. The obtained conclusions indicate the need to develop new methods that will allow assessing the risk of traffic accidents based on a combination of road characteristics and elements of the external environment. At the same time, it should be remembered that risk factors can manifest themselves in complex combinations, and therefore the identification of the critical factor – the real cause of the failure of the driver–vehicle–road–environment system is a task.

Keywords: road safety; traffic management; transport systems; road conditions audit; risks of road traffic accidents

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1. Introduction

High level of accidents on the highways and, consequently, high mortality and injury rate is the problem, inherent not only to Ukraine but practically to all the countries of the world [42]. It is impossible to solve the problem of enhancing the safety level of the road traffic without the in-depth study of cause-effect relations, acting during the occurrence of the road traffic accidents in Driver-Vehicle-Road-Environment system (DVRE). DVRE system is a conceptual model used in transportation studies and traffic safety to analyse and improve interactions within road networks. It focuses on four interconnected components. The component "Driver" is the human operator behind the wheel. This component considers their physical attributes (e.g., vision, reaction time), mental state (e.g., concentration, stress), driving skills, and decision-making abilities. The "Vehicle" component represents the physical and mechanical aspects of the automobile, such as its design, condition, safety technologies, maintenance, and overall capabilities that impact driving and safety. The "Road" component includes all aspects of road infrastructure, such as surface conditions, road markings, signage, intersections, curvature, and layout, which shape traffic flow and driver behaviour. And the component "Environment" encompasses external factors like weather (rain, snow, fog), lighting, time of day, traffic density, and any other situational influences that affect driving conditions. The DVRE system emphasises the importance of understanding how these components interact to ensure traffic safety, efficient road use, and optimal driving experiences.

Important condition for providing high level of road traffic safety is early recognition of the risks of traffic hazards occurrence. Risk assessment in road safety is a systematic process of identifying, analysing, and mitigating potential hazards that could lead to traffic accidents. It involves evaluating the likelihood and severity of risks within the transportation system and implementing measures to minimise their impact on drivers, passengers, pedestrians, and infrastructure. The main factors that create potential hazards are poor road conditions, careless driver behaviour, faulty vehicle components or adverse weather conditions. The key to studying the causes of road accidents is to consider the sociotechnical and anthropogenic nature of road safety factors (the combined influence of human, social, technological, and environmental elements on the overall safety of transportation systems). Special attention should be paid to the circumstances of road traffic accidents with the fatal outcomes and locations of road traffic incidents concentration. Application of the methods of assessing the risk of accidents is a necessary condition for ensuring the audit quality of the road safety and guarantee of street and road network (SRN), road reserve area safety, safety of vehicles operation and safe circulation of the road users.

Research areas in road traffic accident risk assessment focus on understanding, predicting and mitigating the factors that contribute to road traffic accidents. The main aspects are crash risk prediction, social risk modelling, road safety audits, human factor analysis and environmental risk assessment.

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Road accident risk prediction involves the use of mathematical models and data analysis to estimate the probability of road accidents based on driver behaviour, vehicle condition, and road characteristics. For example, the study of [27] describes new specialized technique of forecasting serious injury accidents, connected with the impact of the weather factors, by means of machine learning models: stacking algorithm (random forest) and boosting algorithm (increase of extremal gradient). Results of the assessment of these models' performance by means of the methods of data processing showed that the suggested approach promotes the development of more accurate models of forecasting the accident severity and improvement of road traffic safety strategy. Work of [7] considers evaluation of road traffic accidents risk on bus routes. New approach is suggested to the evaluation of road traffic accident risk on bus route, based on integration of the safety factors in DVRE system, forecasting models and risk methods. Application of the results of investigation enables to evaluate the risk of accidents on the routes, control the efficiency of each route safety and qualify each route according to the latest safety standards.

Social risk modelling involves studying the socio-economic consequences of accidents, such as costs to society, and developing strategies to minimise them. Similar results are presented in dissertation [2] which is concerned with the solution of the problems dealing with the development of the distributed management of the road traffic in urban transport systems. Based on the research findings, measures, aimed at the improvement of social indices of traffic efficiency.

A road safety audit provides an assessment of the road infrastructure to identify hazardous areas and make recommendations for improvements for safer driving. Thus, the study of road safety factors in the DVRE system on highways is dedicated to the work [43]. In particular, the impact of 11 road factors and environmental factors on the accident's severity was studied. Results of the research show that characteristic changes of the object of roadside protection, type of the highway section, median strip, illumination conditions and time of the traffic accident occurrence have a significant impact on road traffic. A similar conclusion was made in the dissertation [2]. The author proposed ways to solve traffic problems in cities using geographic information models.

Human factors analysis is the study of driver behaviour, including stress, fatigue and distraction, and their impact on accident risk. For example, in the work [38] the object of the investigation was the process of assessment and management of ergonomic risks of lorry drivers. Based on study of subsystem driver-vehicle indices of DVRE system the interrelations between loading index, distinctive working postures of the driver and intensity of joints motion were revealed. This enabled to develop the algorithm for the assessment of ergonomic risk of drivers' activity in the process of vehicle operation, its maintenance or repair, taking into account the individual state, experience, length of time worked and factors of the environment. Study of [25] is also dedicated to the analysis of drivers' characteristics who

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manifest various types of risk behaviour in the driver's seat. The impact of such parameters as education level, age, availability of punishments for non-enforcement of traffic laws, gender, alcohol intake, on the probability of high-risk occurrence. Results demonstrate that the policy of preventive measures must be aimed at different groups of drivers, depending on the specific risk behaviour.

Environmental risk assessment focuses on how weather conditions, lighting and other external factors affect road safety and accident rates. For instance, the study [41] is dedicated to the investigation of risk factors in DVRE system. These studies provide valuable information regarding the foreseeable risk of fatal accidents and highlight great impact of anthropogenic factors on the occurrence of fatal road traffic accidents.

As it is seen from the analysis of the recent publications, carried out, factors of risk of road traffic accident occurrence are formed by the aggregate of DVRE system elements, mathematical models of which are closely connected with the theory of operational properties of the motor vehicle –methodological base for the analysis of accidents in automobile transport. Multidirectionality of the studies shows the complexity of the range of issues, existence of wide field for studies and the existence of problems in combining the results of the audit of road accident concentration areas and the use of the results of automotive technical expertise of various road accidents to more fully take into account the effect of the factor space formed on the basis of: vehicle safety audit, establishment of the accidents mechanism, audit of the behaviour of road users.

The purpose of this article is to analyse the existing methods for assessing the risks of accidents as a key basis for finding ways to improve the mechanisms for ensuring safety in road transport.

Research was carried out, using system approach. For achieving the set aim on the base of analysis the studies of the previous researchers, applying the methods of analysis and synthesis, the structure of factors, influencing the road traffic safety was investigated: its separate components were allocated, their interconnections and impact on general road traffic safety were identified, all these factors were visualized by means of structural and graphic methods. Seven methods of risks of road traffic accidents assessment were analysed, in particular: method of conflict situations, method of conflict points, method of linear graphs of the accident rate, method of linear graphs of safety coefficients, expert method, multifactor regression modelling, multiplicative methodology of hazard assessment of the sections of street-road network. Their efficiency, advantages and disadvantages are identified. On the base of analysis and discussion of the results obtained, productive directions of further studies, aimed at improvement of the existing and development of new methods of the risk of road traffic accidents assessment, are determined.

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2. Materials and Methods

In DVRE system the dynamic circulation of closed loop of information flows occurs. Main element of the system is a driver, who perceives the information about the situation on the road, traffic mode, instrument readings, position of the controls, etc., processes the information, makes decisions and influences the controls of the vehicle, optimizing the motion mode according to the situation on the road. Traffic safety depends on the reliability of DVRE system elements and the character of their interaction inside the system. Road traffic accidents are taken as the consequence of not reliable operation of the system.

2.1. Study of the structure of factors, determining the road traffic safety

For the identification of the conditions of the road traffic safety for the vehicle and determination of the reason of the accident it is necessary to study the factors, influencing DVRE system, structure of which is shown in Figure 1. Analysis of the data of the Figure shows that numerous factors influence the traffic safety, both objective (constructive parameters and road condition, intensity of the motor vehicles and pedestrians flow, provision of the roads with traffic control devices and structures, season of the year, time of day), and subjective factors (state of the drivers and pedestrians, violation of the traffic restrictions).

Thus, there exists complex dynamic system on the roads, the system comprises the aggregate of the elements human–vehicle–road, functioning in certain environment. These elements of the unified road–transport system are in certain relations and connections with each other and form the integrity. They form the risk factors, which can cause road traffic accidents. From the point of view of road traffic safety, they are not without interest for system study both as the risk factors and their various combinations in the subsystem: human–vehicle; vehicle–road; road–human.

Statistical data show that road traffic accidents happen in 10–15% of cases due to technical failures of the vehicles, in 20–30% of cases – due to bad road conditions, in 60–70% of cases they depend on the incorrect actions of the drivers [18, 31, 42]. Thus, the cause of the greater part of road traffic accidents is human [1, 11, 16] (Figure 2), that is why, it is expedient to consider human role in general and the driver's place in DVRE system, in particular, from the point of view of his professional activity that enables to outline main ways of reducing accident rate.

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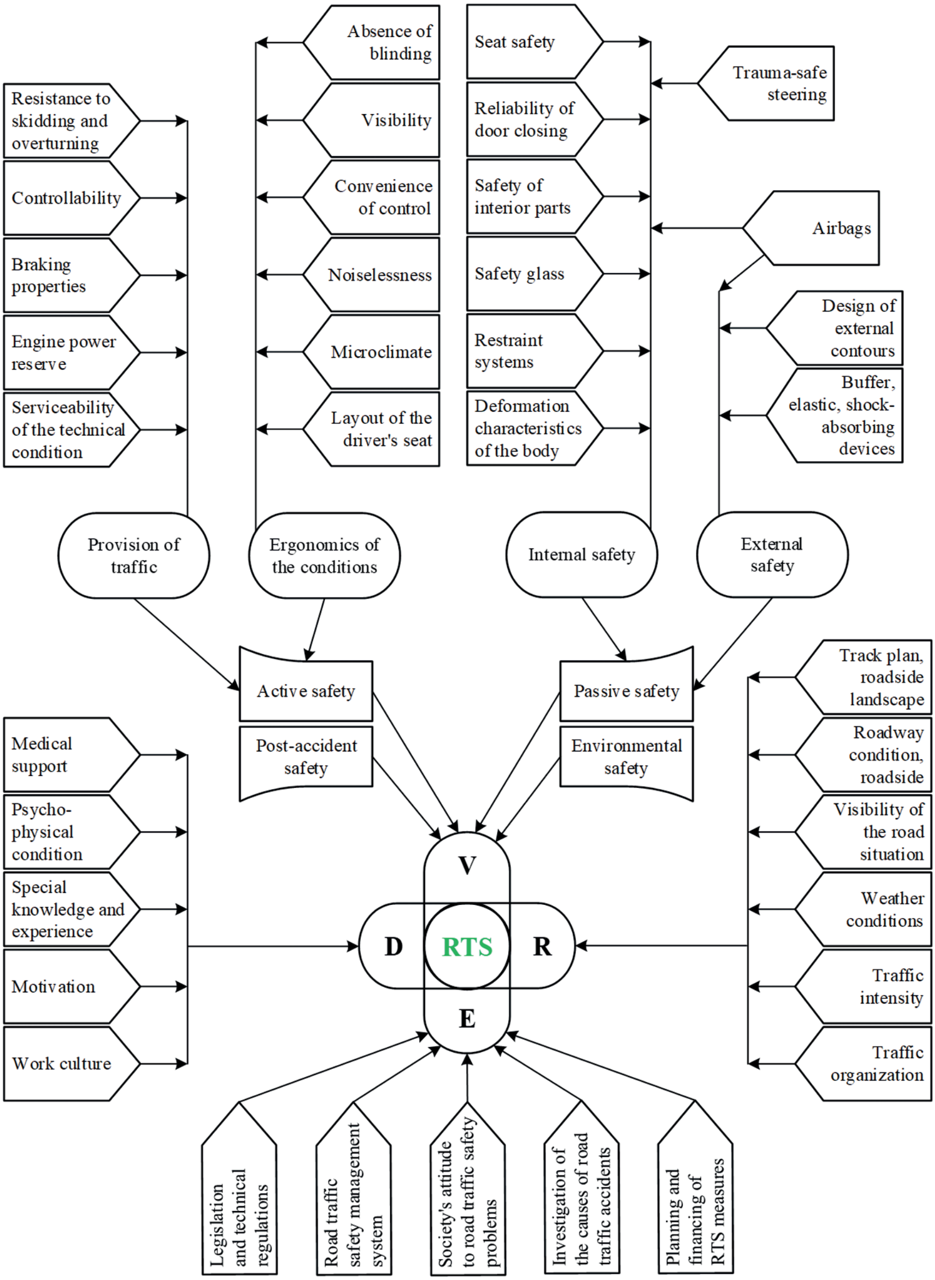

Fig. 1. Structure of factors of DVRE system, identifying road traffic safety: V – vehicle, D – driver, R – road, E – environment, RTS – road traffic safety

Source: composed by the author

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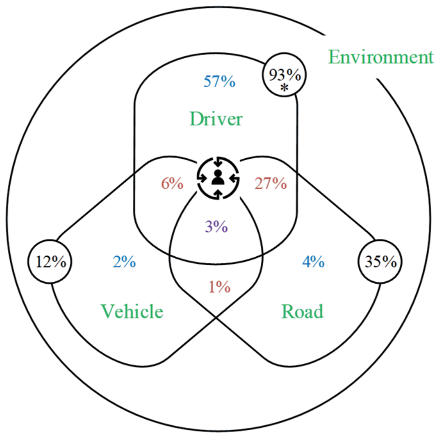

Fig. 2. Risks of road traffic accidents by the elements of DVRE system

*For example, 57% of road accidents are caused by a Driver, the rest are the result of a combination of factors from different components of the DVRE system: 6% – a Driver and a Vehicle, 27% – a Driver and the Road, 3% – a Driver, a Vehicle and the road. The total is 93%.

Source: composed by the author

Selection of the methods and means of road traffic organization is performed on the base of the transport flows, role of which grows with the increase of the traffic intensity. It influences the carrying capacity of the road (street), traffic modes, characteristics of street-road network (SRN) operation failures. Interconnection of the traffic flows intensity with road safety can be evaluated on the base of the following dependence [2]:

$$n_{victims} = N_{vehicle} \cdot k_{accident} \cdot k_{injury} \tag{1}$$

$n_{victims}$ – is the number of victims, injured in road traffic accidents, persons,
$N_{vehicle}$ – is the intensity of the vehicles traffic, vehicle/day,
$k_{accident}$ – is the risk of accidents occurrence, accident/1 million vehicle kilometres,
k_{injury} – is the risk of people injury, persons kilometres day/accidents.

Study of the aspects of transport process safety and conditions of accidents occurrence is based on the analysis of the mechanism of links in DVRE system interaction. Violation of the elements operation, as a rule, leads to a failure of the whole system, that causes the reduction of SRN carrying capacity and road traffic safety. Simultaneous action of several reasons of accidents occurrence complicates greatly the analysis of the circumstances of accidents, main aim of it is revealing of the conditions, provoked the accident, formation and realization of measures, aimed at the elimination of such cases in future.

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2.2. Methods of the road accidents risk assessment

For the assessment of the accident occurrence risk various methods and approaches are applied, among these methods the most widely used are: method of conflict situations [5, 8, 26], method of conflict points [10, 40], method of linear graphs of accident rates [3, 20, 34], method of linear graphs of safety factors [32, 33], expert method [35, 37], multi-factor regression modelling [15, 36], multiplicative methodology of SRN sections hazards assessment [1, 4, 9].

Method of conflict situations is a predictive method for assessing road traffic safety, based on the identification and analysis of situations in which there is a high probability of a traffic accident occurring, but the accident is avoided. It is a proactive approach that allows for risk evaluation based on observed interactions between road users and vehicle dynamics. A study by scientists from Iran and the United States [26] revealed the potential of this method as the first step in conducting an accurate analysis of road conflicts. A positive result of using the experience of Canadian scientists in applying the conflict situation method to analyse traffic conditions on the SR528 highway in Orlando, Florida, USA, is presented in a scientific paper [8]. In this study, the assessment of traffic safety is based on the analysis of real-world traffic data. The interaction of factors such as time to collision in multi-vehicle interactions, manoeuvring space to avoid collisions, and predicted and unpredicted changes in traffic conditions was studied. The method proposed by the authors provides the time necessary for the driver (or the autonomous vehicle control system) to react and adjust actions in accordance with traffic conditions and minimise the risk of a collision in the traffic flow. Study of [5] contains a comprehensive review of the published papers, concerning the usage of the conflict situation technique, based on the analysis of the methodological and empiric grounds.

As a result, it will be fair to state that the method of conflict situations is based on experimental determination of the number of conflict situations by the parameters of motor vehicle manoeuvring: change of path of motion and speed, transversal and longitudinal accelerations. This enables to determine the probability of road accident occurrence by the expression:

$$P_{accident} = \alpha_{TCS} \cdot N_{TCS} \tag{2}$$

$P_{accident}$ – is a forecast level of accident rates, accident/year,
α_{TCS} – is factor leading of conflict situation to road accident,
N_{TCS} – is average annual number of conflict situations.

The given method has the following advantages: enables realistic modelling of driver behaviour, pedestrian actions, and interactions between road users during stressful or high-pressure conditions; facilitates the discovery of potential risks or situations that could lead to accidents, enhancing preventative measures; offers valuable insights into how human behaviour and decision-making processes affect road safety outcomes; this method can also be utilised to train road users to better handle conflict situations, ultimately fostering safer practices.

Disadvantages of this method: certain aspects of conflict situations on roads may be challenging to recreate effectively in a controlled environment; participants might experience stress during simulations, potentially influencing the reliability of the findings; implementing and utilising this method requires substantial investment in terms of time, finances, and expertise; results may not be universally applicable, as the method could produce findings specific to local road conditions or regulations.

Method of conflict points is an analytical approach employed in road safety assessment to identify and analyse areas where potential collisions or incidents might occur. Conflict points are locations (intersections, turn-offs, or roundabouts) where the trajectories of vehicles or pedestrians intersect, creating a risk of collisions or other road accidents. Conflict intensity is analysed based on factors like the likelihood of accidents, participant behaviour, speed, and angles of collision. The main goal is to identify problematic areas and propose solutions to mitigate risks. Stages of applying this method: data collection, situation analysis, risk assessment, recommendation development. The paper [10] proposes a method for detecting and resolving conflicts in the movement of autonomous vehicles by analysing conflict points and the duration of the conflict at unregulated intersections. Studies have shown that the use of spatial and temporal resources in coordinating traffic flows at intersections improves overall road safety. In the USA the given method is used to provide safety for all the participants of the road traffic and creation of the system of common responsibility for road safety indices [39].

The essence of the method is that the danger of the conflict points CP_i may be evaluated as:

$$CP_i = K_i \cdot N_{1i} \cdot N_{2i} \cdot \frac{25}{K_Y} \cdot 10^{-7} \tag{3}$$

K_i – is danger coefficient of the conflict point, it depends on the characteristics of the crossing, direction of motor vehicle motion, turning radius, etc,
N_{1i}, N_{2i} – are intensities of motor vehicle motion in conflict points, vehicle/day,
K_Y – is coefficient of nonuniformity of the traffic.

General danger of the traffic at the crossing is an additive danger of conflict points.

The advantages of the method comprise identifying hazardous locations before actual accidents occur, encouraging a proactive approach to improving road safety, and accounting for the dynamic characteristics of traffic flow. The disadvantages of the method include requiring comprehensive and accurate data for valid analysis, posing challenges in implementation on

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large-scale transport networks, and heavily relying on the correct interpretation of data for effectiveness. Despite these drawbacks, this method serves as a valuable tool in traffic planning and in reducing accident rates.

Method of linear graphs of accident rates is a tool utilised to assess road accident rates by creating graphs that display changes in accident coefficients along the road or specific segments. Accident coefficients calculated based on data such as the number of accidents, their nature, traffic intensity, road conditions, and other relevant factors. Linear graphs which are used to visualise the variation in accident coefficients, highlight problematic sections of the road. Graphical interpretation helps identify high-risk areas and analyse the causes of increased accident rates. The steps for applying this method are as follows: gathering information on accidents, traffic conditions, vehicle types, weather conditions, and more; determining accident rate indicators for each segment of the road; building linear graphs to visually represent changes in accident coefficients along the road; analysing the graphs to identify problematic areas, evaluate reasons for higher accident risks, and propose safety improvements.

Danger is assessed according to aggregate coefficient of the accident rate K_{AR}, determined as a product of partial coefficients K_{Pi}:

$$K_{AR} = \prod_{i=1}^{18} K_{Pi} \tag{4}$$

Linear graph is constructed according to the values of the aggregate coefficient, the graph represents the plat and longitudinal profile of the road.

In the study of [34] it is noted that «among the accident rates the coefficient that takes into consideration the flow rate is missing», impact of which is taken into account by other coefficients indirectly. Among the advantages of the method its specific user-friendliness for the analysis of project documentation, regarding the reconstruction of the existing roads should be mentioned.

Authoring team of the study of [3] underlines that «established list of partial accident rates is not exhaustive and the values are not final. Corresponding organizations, maintaining accounting and audit may establish additional coefficients, taking into consideration the local traffic condition». Similar approach found its application among the scientists of the USA and European Union, they use for accident rate assessment «infrastructure coefficient» that is the analogy of the aggregate accident rate [20].

The advantages of the method include providing a clear visual representation of accident-prone areas, enabling the analysis of accident rate trends over time, and supporting decision-making for engineering improvements in road infrastructure.

The drawbacks of the method are that it requires detailed, high-quality data for accurate analysis, lacks universality as it may be less effective for certain road types or regions, and demands proper analysis of graphs to avoid inaccurate conclusions.

Method of linear graphs of safety factors is based on the calculation of the speed diagrams on the road and identifying the location and value of the velocity step, according to which safety assessment is performed. According to the values of the obtained coefficients K_{saf} the degree of hazard of the road location is determined (locations where safety factor is less than 0.4 – very dangerous for traffic, from 0.4 to 0.6 – dangerous for traffic, from 0.6 to 0.8 – low-risk for traffic, if $K_{saf} \geq 0.8$ the conditions do not influence road safety):

$$K_{saf} = \frac{min\{V_{SM}, V_{RC}\}}{V_{PS}} \tag{5}$$

V_{SM} – is the value of maximum permissible speed of the vehicle, when the stability of movement if the car skids, is provided,
V_{RC} – is the value of maximum permissible (critical) speed of vehicle in rollover crashes,
V_{PS} – is maximum speed vehicle can develop on a previous section of road.

Method enables to assess the road hazard by measuring traffic speed of real flows of vehicles [32]. In author's opinion, the method does not provide quantitative forecast as it operates with qualitative assessments (such as «low safe», «dangerous», etc.) that is why it is expedient to use this method along with the method of linear graphs of the accident rates.

Author of the work [33] considers that each locality inherent its «objective space-time regularity in terms of integrated transport flow traffic modes», it depends on the methods and means of traffic organization, urban planning aspects, plan-economic and social peculiarities. He also arrives at the idea of the necessity to assess vehicles traffic speed on street-road networks of the settlements experimentally.

Method has a number of limitations: account of single vehicle motion, which is a characteristic feature for the roads with low intensity: disregard of the sections with gradual speed reduction, necessary for safe entry into short radius curves and narrow bridges; principle lack of the possibility to take into consideration psychological perception by the driver the road conditions.

Expert method is based on the experience of specialists, who, as a result of long lasting and qualitative accomplishment of their professional functions can independently assess the risk of accident occurrence. Results of this method depend on the competence of experts and generally are used as an initial assessment.

In the work of [37] it is noted that qualitative methods of risk analysis allow to obtain maximum volume of recommendations, regarding road traffic safety and require less volume of infor-

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mation and are less labour consuming. They enable to compare the hazards of different origin during expert analysis of the objects of transport infrastructure. Author comes to the conclusion that there are no conventional techniques regarding risk assessment in transport sphere.

In the study [35], it is proposed to use a fuzzy binary programming model for expert assessment of the optimality of multi-objective personnel allocation to ensure the efficiency and safety of road traffic. Decision-making in the model is based on minimising the risk of accidents and the total operating costs of traffic management. The authors of the paper conclude that it is advisable to improve the applied heuristic algorithms and check the tendencies of solution development by other methods, provided that the range of tasks to be solved is expanded.

Multifactor regression modelling of accidence occurrence risks is based in the analysis of the input variables $x = (x_1,x_2,...,x_n)$ – parameters, characterizing road traffic on separate sections of the street-road network (SRN): daily traffic intensity, seeing distance, curb-to-curb width, etc. Regression equations, as a rule, have the following form:

$$r = q_0 + q_1 \cdot x_1 + q_2 \cdot x_2 + \cdots + q_n \cdot x_n \tag{6}$$

$q_0,\ q_1,\ q_2,\ ...,\ q_n$ – are the coefficients, found on the base of the least-squares method. If considered necessary to take into account pairwise interactions of the parameters, regression equations become more complicated and acquires non-linear character [15].

For the sake of quantitative analysis of the impact of different traffic conditions on the accident risk on the auto road in the work [36] quantitative relationship between different traffic states and accident risk is analysed by means of the model of the Bayesian conditional logistic regression. Results of the research show that different conditions of traffic safety have various accident risk level. Authors recommend to use this method for the improvement of the level of risks management, concentrating the usage of this method on prevention and control of high accident risk conditions.

Basic limitations of the method:

1. Regression analysis allows to solve only the problems, where the output value (solution) and impact factors are determined (quantitative).
2. Value of the output index r, obtained, using the regressive model is sensitive to the conditions of the experiment, by the results of which the coefficients $q_0,\ q_1,\ q_2,\ ...,\ q_n$ were obtained. That is why, regression models, determined for certain conditions (state of the vehicle, state of the road, etc.) are not always used in other conditions.
3. Statistically-valid regression coefficients are obtained on the base of processing large experimental material.

Main advantages of the method are:
Possibility of revealing the interactions between various factors (weather, state of the road, type of the vehicle, motion speed, etc.) and adaptivity of the models to new data. Method provides the possibility to perform the support of decision making by the government organs, companies and other parties involved regarding the improvement of the road safety. The method is most efficient for studying the locations of road accidents concentration.

Multiplicative technology of the assessment of SRN section hazard – Highway Safety Manual (HSM) is based on usage of the methods, intended for determination of SRN sections with high potential for road traffic safety improvement, methods of average accident rate forecasting depending on the parameters of the road and methods of assessment of the level of accident rate change, depending on the implemented measures. Assessment of SRN section hazard – level of average accident rate $N_{predicted,i}$ is carried out by means of multiplicative model:

$$N_{predicted,i} = N_{SPE,i} \cdot (AMF_1 \cdot AMF_2 \cdot \ldots \cdot AMF_n) \cdot C_{0x} \quad (7)$$

$N_{SPE,i}$ – is accident rate at standard (basic) conditions,
AMF – are the accident modification factors due to the difference of the given road section from the standard,
C_{0x} – is correction factor; it depends on the local conditions.

American Association of State Highway and Transportation in its normative documents [1, 4] provides that for the assessment of the accident rate at basic conditions the type of the road is identified (road outside of the settlements with two lanes of traffic; with large number of lanes of traffic; urban and suburban roads) and correspondingly to the chosen type of functional dependence the target value $N_{SPE,i}$ is determined. Accident modification factors AMF are also determined by means of the dependences for each road characteristic that differs from the basic one. Correction factors C_{0x} represent local conditions: traffic intensity change, weather conditions, etc.

Algorithms of HSM method were checked on the accuracy of forecasting of the expected average accidents rate frequency on the section of the road with the pre-set geometric and geographical conditions during certain period for specific annual average daily traffic in the study of [9]. The results showed that the implementation of HSM methods promotes the development of local safety functions and minimizes the cases of road accidents. To improve the predictive quality of the HSM method, the authors proposed the methodology to incorporate multiple calibration factors for different components of the predictive method (safety performance function and accident modification factors). Researchers came to a conclusion that the application of proposed method leads to the improvement of the project's selection procedure and enhancement of road traffic safety at separate sections of SRN.

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Survey of the methods of accident occurrence risk assessment proves that the existing methods help in complex approach to accident occurrence risk assessment. This enables to improve road traffic safety and reduce the accident rate. However, many of the suggested techniques of risk assessment have significant shortcomings in practical application (they are labour intensive, require large volume of quantitative data), that is why, they do not find wide practical application. Great disadvantage of numerous above-mentioned techniques is that they do not take into consideration the duration of the existence of hazardous factors, in its turn, this does not make possible the development of efficient means of accidents prevention.

3. Results of the analysis of road traffic accident risk modelling processes

Modelling of the risks of traffic accidents occurrence is important for road safety improvement and reduction of accident rate. Risk models enable to predict possible locations and situations where the probability of road accident occurrence is the highest. On the base of the model's efficient measures, aimed at road safety enhancement can be developed and implemented. Data and results of the models serve the base for grounded decision-making by the government bodies, transport companies and other parties involved.

Results of the analysis of main approaches to the problem of determination of road accidents risk occurrence are presented in Table 1. The given list is not exhaustive but it represents main scientific directions, mainly discussed by the researchers in the chosen sphere. Risks modelling is based itself on five types. Multiplicative model – it is a model, where the interaction between variables is expressed by their product; additive model – it is a model, where a general result is a sum of effects of different factors or variables; multiple model – it is a kind of multiplicative models, where the impact of one variable depends on the values of other variables, model of expert survey represents structural approach to the collection and analysis of experts' ideas in certain branch for obtaining objective and deep information; mixed model – it is a statistic model, combining both fixed and random effects.

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Tab. 1. Results of the analysis of basic approaches to accident occurrence risks determination

Method	Record factors	Type of the model
Method of conflict situations	Data regarding transverse and longitudinal acceleration	Multiplicative
Method of conflict points	Road intersections characteristics, traffic intensity	Additive
Method of linear graphs of accident rates	Road characteristics	Multiplicative
Method of linear graphs of safety factors	Road characteristics, velocity diagrams	Multiple
Expert method	Optional	Expert survey
Multifactor regression modelling	Road characteristics, traffic intensity and speed	Mixed
Multiplicative methodology of hazard assessment of SRN sections	Road characteristics	Multiplicative

As it is seen from the Table 1, at the present day there exist several approaches, regarding the assessment of road traffic hazards. Many researchers use multiplicative form as the model for calculation, this form corresponds to the provisions of the risk theory: in the event of the factor's independence, aggregate risk can be assessed on the base of the product of partial risks (the probabilities of risk events occurring for each factor separately). Common order of risk assessment is included in State Standard of Ukraine IEC/ISO 31010:2019 [13], it is the process, comprising identification, analysis and comparative assessment of the risk. Selection and substantiation of the factors of the road accident occurrence can be singled out as the first stage of the assessment of the risk of conflict situation occurrence (risk identification), the second stage (stage of risks assessment) provides the determination of hazards occurrence probability and scope of possible consequences, third stage (risk-management) provides the elaboration of measures, aimed at reduction of risks and control of the realization of these measures. Such an approach is provided for by the legislation of Ukraine [28, 29] and International Standard of risk management [14]. Strict adherence to the stages of risks assessment helps to provide situation, when all the possible risks are taken into account and reliably managed.

The necessity of complying with the stages of risk assessment has been confirmed by the research of numerous scientists. In particular, in the study of [21] the importance of adherence to the methodology of risk perception, connected with the processes of new products development is underlined. At the same time in the work of [6] the author comes to conclusion of the need to upgrade the scientific fundamentals of risk assessment and management in order to improve the decision-making processes in the conditions of uncertainty.

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In the process of research, it was revealed, that the scientists refer to the factors, used for accident occurrence risk modelling constant road characteristics, this fact proves the need of their record. At the same time, insufficiency of the developed methods and models for the assessment of accident initiation risk on the sections of SRN in the conditions of the dynamic change of the environment (as a result of combined action of weather conditions, time of the day, etc.), is noted, also there is no possibility to predict and assess the risk of accident initiation on the base of the data, regarding the state of the environment. Meanwhile, many researchers underline the significancy of the environmental impact on the possibility of accident initiation.

In particular, within the frame of the research project SafetyCube, funded by the European Commission under EU program of research and innovations in the sphere of road traffic safety the analysis of 243 works related to the assessment of the risk factors impact and measures, connected with the behaviour, infrastructure or vehicles was carried out. Assessment of the results proved the importance of the account of the external environment impact and enabled to create innovation system of the decision-making support, concerning the analysis of crash risk factors related to the road infrastructure [30].

In recent years, the efforts of many scientists in the field of road accident risk assessment have focused on assessing the impact of socio-economic aspects (the COVID-19 pandemic [19, 23]), factors of driver perception of the situation on the road (mood, fatigue, psychophysiological characteristics) [12, 24], environmental aspects (visibility of road objects in the dark [17]) and analysis of spatio-temporal models to identify high-risk areas [22, 41].

Impact of COVID-19 pandemia on the formation of the factors of accident initiation risk turned out to be significant. Notably, in the work of [19] impact of COVID-19 on driver's behaviour and safety indices is investigated, it is established how the decrease of the traffic volume as a result of lockdown led to increase of transportation flows traffic speed. In the study of [23] it was investigated how after the outbreak of COVID-19, travel-restriction policy, widely accepted by the cities all over the world, played an important role in the change of road traffic patterns. The author underlines the growth of the cycle rides and road traffic accidents with cyclists' participation.

The study [24] analysed factors influencing drivers' perception of road situations, identifying a relationship between mood, fatigue, mental load, drowsiness, and quantitative indicators of street lighting for car drivers. The authors conclude that the regulation of street lighting has the potential to enhance driver alertness, mitigate fatigue and cognitive load, thereby contributing to a reduction in the frequency of night-time road traffic accidents. Regression model of accident risk prediction, based on risky driving behaviour of transport vehicle and traffic flow data was developed in the work of [12]. Sensitivity of the developed model to the conditions of the experiment and the necessity to operate the deterministic (quantitative) data leaves the space for its development and application in the conditions of uncertainty.

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In the study of [17] the improved technique of assessing the visibility of road objects in the light of car headlights in the process of road traffic accident analysis was suggested. Assessing of visibility was performed according to the parameters, which greatly influence the processes of object recognition in darkness and selection of traffic speed by the driver according to the requirements of road traffic safety regulations.

The analysis of spatio-temporal models for identifying high-risk areas, as presented in the study [22], introduces valuable insights into real-time monitoring of the risk situation of both motor vehicles and their drivers. Real-time monitoring ensures instant information exchange and decision-making, which is particularly vital in areas such as road safety, healthcare, information technology, and more. Propose approach offers significant potential for the early detection and mitigation of single-vehicle accidents. The authors conclude, taking into account the mechanism of risk coupling, that further refinement of the proposed method for calculating the risk of accident occurrence is necessary. A number of researchers believe that the prediction of road accident risk occurrence on different sections of the road remains a problem, as it is difficult to take into account accident uncertainty. For example, in the study of [40] the authors suggested new model of driving risk assessment, which includes driving models of the target vehicle, driving models of surrounding vehicles and interaction between the target vehicle and surrounding vehicles to enhance driving safety in such conditions as tailgating the car and convergence of traffic flows. Results of the experiments, carried out by the authors showed that the models of surrounding transport vehicles driving in different positions differ from target transport vehicle driving risk and have rather large degree of uncertainty.

The identified shortcomings of existing methods for assessing road traffic accident risks, particularly the necessity to account for the combined influence of road characteristics and environmental factors, complex combinations of risk factors, and the identification of a critical factor – the true cause of system failures in DVRE systems, highlight the need for further scientific research. New models should focus on enabling optimal decision-making under conditions of uncertainty by utilising artificial intelligence and machine learning for accident prediction, sensors, the Internet of Things (IoT), and intelligent transportation systems for monitoring and risk reduction, while considering socio-economic and environmental aspects.

4. Conclusions

An essential condition for ensuring a high level of road traffic safety is the early recognition of accident risks. This research has analysed modern approaches to assessing the safety of transport systems and identifying the causes of road traffic accidents, emphasising the need to improve existing methods or develop new ones.

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Key Findings:

1. Seven widely used methods for assessing road traffic accident risks were evaluated: the method of conflict situations, the method of conflict points, the method of linear graphs of accident rates, the method of linear graphs of safety factors, the expert method, multi-factor regression modelling, and the multiplicative methodology for assessing SRN section hazards.
2. The analysis revealed that the methodological basis for examining road accidents is rooted in the study of DVRE (Driver-Vehicle-Road-Environment) system functionality and the operational characteristics of vehicles.
3. Road traffic safety significantly depends on the reliability of DVRE system elements and their system-wide interaction. Road accidents are largely interpreted as a result of insufficient system reliability, with human factors identified as the primary cause.

Limitations:

Existing models for assessing accident risks on street-road networks were found to be inadequate in dynamically changing environmental conditions (e.g., weather, time of day) and often failed to account for the mutual influence of risk factors.

Promising Avenues for Further Investigation:

- Developing new methods for accident risk assessment based on an aggregate of road characteristics and external environmental factors.
- Incorporating artificial intelligence, machine learning, sensors, IoT, and intelligent transportation systems to enable real-time risk prediction and evaluation.
- Considering socio-economic and environmental aspects to ensure holistic road traffic safety improvements.

5. Nomenclature

DVRE driver-vehicle-road-environment system
EU European Union
HSM Highway Safety Manual
RTS road traffic safety
SRN street and road network

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