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Improving the Risk Assessment Process of Road Accidents Involving Trucks

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ABSTRACT: The safety of road freight transport is an important component of the safety management system. The safety basis of freight transport is risk assessment. However, existing models for their assessment operate with static dangerous factors that increase the probability of a dangerous event and the severity of its consequences. The transportation process is characterized by dynamic changes in dangerous factors, which requires appropriate improvement of existing approaches. For this, the relationship between the risk of a hazardous event (road accident) and the negative impact of dangerous factors was determined. This made it possible to develop a model for assessing the risk of road accidents, as a cumulative effect of risks from all dangerous external and internal factors, taking into account dangerous actions and without actions of drivers during cargo transportation. To propose a process of occupational risk management taking into account the change in the influence of dangerous factors on the probability of the occurrence of a hazardous event and the degree of severity of injuries from it, based on the matrix for determining the risk of changing dangerous factors over time. To introduce the division of all dangerous factors into static, which do not change (almost do not change) over time during the year, and dynamic ones – which are changed in a period from one hour to a year, which will allow to determine the overall level of risk from the cumulative impact of dangerous factors, considering all combinations of their manifestation.

KEYWORDS: Occupational risk; Road accident; Dynamic model; Management decisions

1. INTRODUCTION

The safety of transportation by trucks is an important component of the general road safety management system of the motor vehicle company, aimed at protecting the health and life of drivers and the effective use of vehicles for carrying out transport activities. It should be noted that the number of road accidents (hereinafter referred to as RA) involving truck drivers is increasing. This is due to the special working conditions of the drivers, the tension of the transport process, the physical and psycho-physiological state of a driver, etc. factors (Official website of the National Police of Ukraine, 2023; Official website Auto24, 2023). The basis of this security system is risk assessment, which is an important component of management decision-making (Karunathilake et al., 2020). At the same time, risk assessment involves the identification of threats and dangers arising in the process of transport activities, determining who will be harmed and what will be harmed, calculating risks, justifying preventive measures with control to minimize risk (Heggum, 2024). To carry out such a procedure, the methods of structural decomposition-rejection trees (Tsopa et al., 2022; Cheng et al., 2019), decision trees, probability trees and methods of expert evaluations (Kizito & Semwanga, 2020; Goh et al.2012), mainly the brainstorming method (Bazaluk et al.2022), the Delphi method (Zhanbirov et al., 2023) are most often used. All these methods make it possible to analyze the risks fairly qualitatively, but do not take into account the influence of dangerous factors that change over time, thereby increasing, at a certain moment, the probability of a hazardous event occurrence and the severity of the consequences. For example, a change in the psycho-physiological state of the driver (Burlakova & Ganzheev, 2022), the accumulation of fatigue (Zhang et al., 2023), a change in climatic conditions (Ruiz et al., 2020), a change in the condition of the road surface, and others. Each of the mentioned factors by itself may not lead to a critical risk of a road accident, but their combination, in a certain period of time, will significantly increase the probability of a hazardous event - a road accident and its severity of consequences. In addition, the manifestation of interdependent extreme states of the driver in frequently changing traffic conditions increases the uncertainty of risk calculations using well-known qualitative approaches (Adedokun et al., 2013), which are the most widespread in organizations, as they do not require special knowledge (Huang et al., 2024). From this, a rather urgent task of developing or improving the appropriate process of managing the risks of road accidents in freight transportation, which allows to reduce uncertainty in decision-making by drivers is formed.

2. LITERATURE REVIEW

The topic of safety of road freight transportation is quite relevant. This is confirmed by a significant number of different scientific publications that consider this issue from various angles. Thus, according to the authors of the work (Cheberiachko et, 2023; Ferdman, 2020), Ukraine has to pay close attention to the issues of transport safety and to create the best conditions for the functioning of the single European market through the formation of the multimodal Trans-European Transport Network (TEN-T). The vision of the author of the article focuses on the need for domestic transport security to enter the European system, which requires the introduction of a number of requirements. One of these is the improvement of the safety management system, supervision and control in transport in accordance

with international standards based on risk assessment. This requires the appropriate model's construction that will allow predicting the dynamics of the development of the transportation system. Various approaches are used for this, including binary logistic regression (Dubois et al., 2018), multinomial logistic regression (Yang et al., 2019), a fault tree-based model (Wang & Kim, 2019), and a Bayesian network (Zong et al., 2019). At the same time, the application of these approaches requires special training of relevant specialists who will support the ability of the management system to adequately respond to various challenges and threats (Wang et al, 2020b). At the same time, based on the requirements of international standards in the field of occupational safety and health protection of workers (ISO 45001:2018) and road traffic (ISO39001:2023), it is necessary to involve all employees in ensuring the risk management process, only in this case, it is considered that it is possible to achieve a reduction in injuries (incidents) (Mmari & Thinyane, 2019; Mubita et al., 2023). Therefore, there is a need to introduce simple risk assessment models, however, they lead to significant uncertainty and errors, for example due to cognitive biases of experts (Emmons et al, 2018). Hence, there is a need to conduct additional surveys, to identify the level of preparation of drivers and their reactions to unpredictable circumstances (Wang et al., 2020a). Experts recognize that the problem of a driver risk assessment primarily lies in the dynamic traffic environment (Wang et al.2023), which does not allow for the widespread use of simple risk assessment methods. For example, the use of intelligent systems is proposed (Moreau et al., 2017). At the same time, all the described and revised approaches are quite complex and require appropriate preparation, and most importantly, time for their analysis for calculations, identification of relationships. On the other hand, these models do not allow taking into account the dynamics of changes in various threats when driving a car, which requires finding ways to improve such methods.

3. MATERIALS AND METHODS

To build a model for assessing the risks of road accidents with trucks, we will use the basic principles of system dynamics (Yao et al., 2010). This will make it possible to establish cause-and-effect relationships between the hazard (in this particular case, it is a moving car), dangerous factors acting on the driver, and the occurrence of a hazardous event (road accident), with the severity of the consequences, which are associated with economic, ecological losses and losses of life and health of people. Note that all dangerous factors affecting the safety of road freight transportation are divided into external and internal (Hanggraeni et al., 2019) (Fig. 1).

The external factors depend on the state of the environment, the road, and the internal ones on the technical condition of the truck, the physical and psychological state of the driver. Hence, to determine them, it is best to use the general well-known system "driver-car-road-environment" (hereinafter - the "DCRE" system), which connects many different elements that interact with each other and form a certain integrity, unity (Bin et al., 2013; Tajnik & Luin, 2022). This allows us to propose a hypothesis regarding the variability of dangerous factors that affect the level of road accidents risk. To determine them, the "DCRE" system was analyzed, which made it possible to determine the following groups of dangerous factors for assessing the risk of road accidents: aspects of work organization, social factors, working environment, equipment, the state of health of employees, psycho-social, military, domestic aspects (Kulbashna et al., 2019; Basu & Saha, 2022). The identified dangerous factors from each of the specified groups are characterized by a certain frequency of manifestation for a certain period of time, which will contribute to an increase in the probability of the occurrence of a hazardous event due to their combined influence and the impossibility of timely response (Ali et al.,2022). According to the frequency of occurrence, all dangerous factors can be divided into static factors, which do not change (almost do not change) over time during the year, and dynamic factors - which are changed in a period from one hour to a year (Fig. 2).

To assess the risk of road accidents, we suggest using the well-known "bow tie" model (Fig. 3), which is successfully used at all stages of risk assessment and management, from the identification of hazards and dangerous factors to the justification of protective and preventive measures (reference to the IEC 31010:2018 standard). In addition, the mentioned model allows, on the basis of the identified feedback mechanisms (Jahnke et al., 2021), to take into account the influence of variable dangerous factors that can change after certain intervals of time (by hours of a day; by days of a week; by a season of a year).

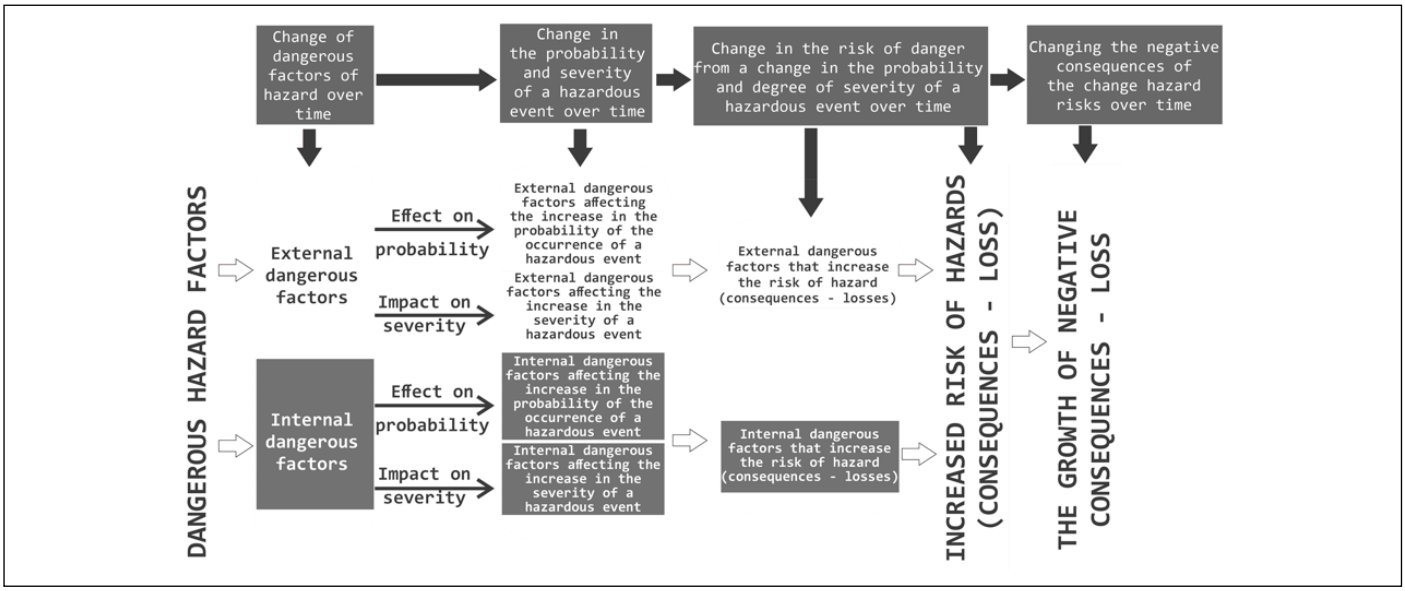

Figure 1. The model of the connection of the factors of the organization environment related to their influence over time and as a result of the change of occupational risks over time

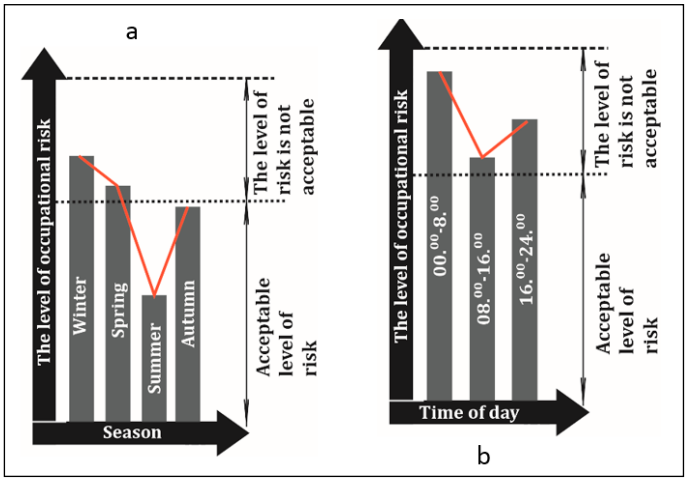

Figure 2. The example of a change in the risk of a road accident due to the influence of a dangerous factor: the frequency of changes in weather conditions by season (a) and the psycho-physiological state of a driver due to the accumulation of fatigue (b)

Based on the given model, an improved risk management process is proposed, which differs from the well-known, five-step one (Batarliene, 2008) by the presence of additional stages that will allow identification of not only hazard, hazardous event and negative consequences, but also all external and internal dangerous factors, dangerous actions and without a driver action (Fig. 4).

For this purpose, it is suggested to use observation of a driver activities, their interviews, analysis of incidents, establishment of their level of health, psycho-social state, character, behavior in extreme conditions, for example, through simulation of dangerous situations during training. In addition, at the third step, the risk assessment is based on the summation of risks from all dangerous external and internal factors at the workplace, taking into account dangerous actions and without actions of drivers during cargo transportation according to the formula 1 (Bazaluk et al., 2024):

$$(1) \quad R_j = \sum (B_{ji} \cdot T_{ji})$$

where R_j is the risk of danger j taking into account dangerous factors – i,

B_{ji} is the probability of the occurrence of a hazardous event (incident, accident, road accident etc.) from danger – j under the influence of a dangerous factor – i, which affects the probability of the occurrence of a hazardous event,

T_{ji} is the degree of severity of the consequences of a hazardous event (incident, accident, road accident, etc.) from danger – j under the influence of a dangerous factor – i, which affects the degree of severity of the injured person health state by the hazardous event.

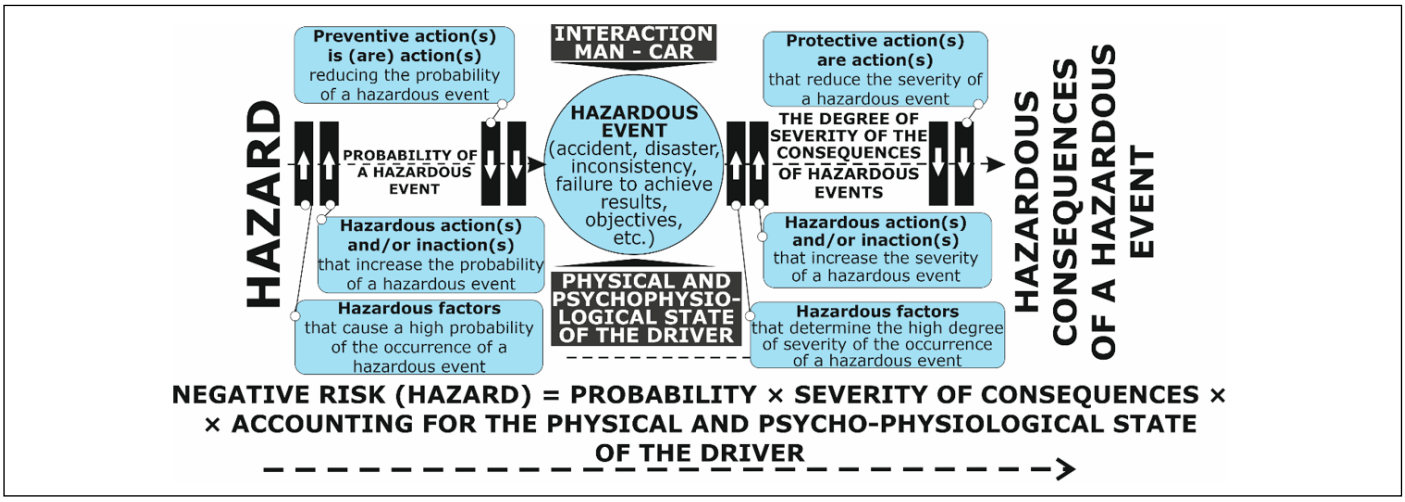

Figure 3. DF management model when the factors of the external and internal environment change over time

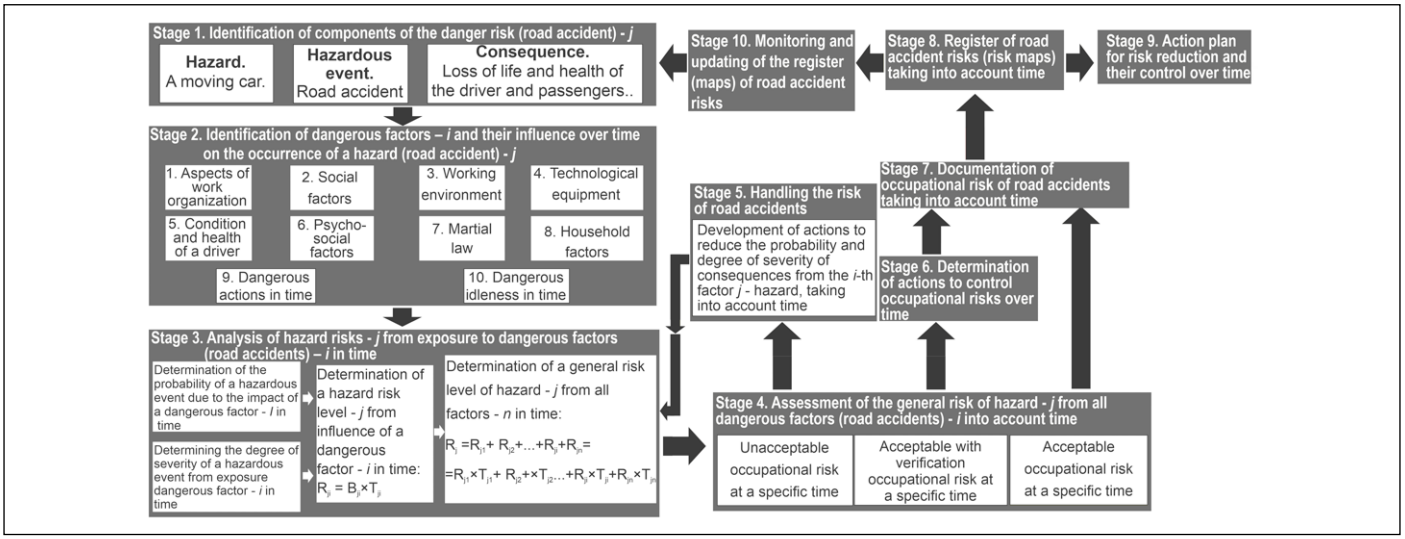

Figure 4. The process of managing occupational risks taking into account the change in the influence of dangerous factors on the probability of the occurrence of a hazardous event and the degree of severity of injuries from it, taking into account time

The differences in the proposed process include the stage of determining preventive actions to control risks that change over time, which involves their early detection or predicting of their manifestation with an increase in the overall level of risk. This can be done by building a special matrix (Table 1), in which we describe the identified dangerous factors horizontally (for example, let us take nine of them), and vertically we set the time of their manifestation (for example, a day, a month, a quarter, six months). Further, on the basis of the manifestation of certain dangerous factors, in a certain period of time, we determine the total risk, which allows us to find their most significant combination.

Also, there is a need to develop a new form of dynamic risk assessment map (Table 2), the difference of which is the determination of the amount of total risk from the manifestation of certain dangerous factors in certain time intervals. This will allow to establish the most significant combinations that have an unacceptable level of risk.

There is also a need to develop (create) a register of dangerous factors with their division into static and dynamic. For this, you can create any suitable tables that will allow you to quickly analyze the impact of certain dangerous factors on a specific route. As for determining the level of risk, two categories are offered: acceptable and unacceptable. The level of acceptability is determined based on the principle "As low as reasonably practicable" (ALARP), which is based on the understanding that the level of risk should be reduced as much as it is practically possible (Oakley & Harrison, 2020). For-

Exposure time DF_i	Dangerous factors (DF)									Determination of the level of occupational risk over time - t
	DF_1	DF_2	DF_3	DF_4	DF_5	DF_6	DF_7	DF_8	DF_9	
t_1	no	no	no	no	no	yes	no	no	no	$R_{t1} = R_{j6}$
t_2	yes	no	yes	no	no	yes	no	yes	no	$R_{t2} = R_{j1} + R_{j3} + R_{j6} + R_{j8}$
t_3	no	yes	no	yes	no	no	no	no	no	$R_{t3} = R_{j2} + R_{j4}$
t_4	no	no	yes	no	no	no	yes	no	no	$R_{t4} = R_{j3} + R_{j7}$
t_5	no	yes	no	yes	no	no	no	no	no	$R_{t5} = R_{j2} + R_{j4}$
t_6	no	no	no	no	no	yes	no	no	no	$R_{t6} = R_{j6}$
t_7	no	no	yes	yes	no	no	no	no	yes	$R_{t7} = R_{j3} + R_{j4} + R_{j9}$
t_8	no	no	no	no	no	no	no	yes	no	$R_{t8} = R_{j8}$
t_9	no	no	no	no	no	no	yes	yes	no	$R_{t9} = R_{j7} + R_{j8}$

Table 1. Matrix for determining the risk of exposure to dangerous factors over time.

Hazard number	Identification				Determination of the risk level of hazard *j* from dangerous factor - *i* in time - t_m				The first assessment of the level of OR from the corresponding dangerous factor
	Hazard	A hazardous event	Negative consequences	A dangerous factor	Time - t of exposure to a dangerous factor	Determination of the influence of a dangerous factor		The amount of risk from a dangerous factor	
						The probability of occurrence of a hazardous event	The degree of severity of the consequences of a hazardous event		
j	H_j	HE_j	NC_j	DF_{j1}	t_1	B_{j1}	T_{j1}	R_{j1}	Acceptable/ Not acceptable
				DF_{j2}	t_2	B_{j2}	T_{j2}	R_{j2}	Acceptable/ Not acceptable
				DF_{j3}	t_3	B_{j3}	T_{j3}	R_{j3}	Acceptable/ Not acceptable
				...	....	...	...	...	Acceptable/ Not acceptable
				DF_{jn}	t_n	B_{jn}	T_{jn}	R_{jn}	Acceptable/ Not acceptable
	Assessment of the total risk from hazard – *j* taking into account all dangerous factors – *i* in time – t_{ji}				$t_1 = t_n$		$R_j = R_{j1} + R_{jn}$		Acceptable/ Not acceptable
					$t_2 = t_4$		$R_j = R_{j2} + R_{j4}$		Acceptable/ Not acceptable
					$t_3 = t_5 = t_6$		$R_j = R_{j3} + R_{j5} + R_{j6}$		Acceptable/ Not acceptable
					...		...		Acceptable/ Not acceptable
					t_m		$R_j = R_{j1} + ... + R_{jn}$		Acceptable/ Not acceptable

Table 2. The form of risk assessment cards from variable dangerous factors.

mally, the limit of acceptability of the risk level is determined based on the acceptable risk assessment matrix. The matrix for qualitative assessment of 5 by 5 was the most widespread in organizations (Maraboutis et al., 2023; Wang et al, 2020a). Taking into account the recommendations of ISO 31073:2019, where probability is a measure of the possibility of the occurrence of a hazardous event, which is given by a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty, appropriate scales can be defined (for example, with a conditional division into five categories) for the probability of the occurrence of a hazardous event and the severity of the consequences, where the main condition is their comprehensibility (Table 3). Hence, assume that the total risk level will be considered acceptable if the number of points is from 0 to 20, and unacceptable if more than 20.

4. RESEARCH RESULTS

For example, let us calculate the risk of an accident when transporting cargo from point A to point B along a route of more than 500 km, which involves movement through a large city in the transitional season of the year with a schedule that involves work in the night part of the day. From the conditions of the task, as well as from the analysis of the "DCRE" system, we establish the influence of dangerous factors that increase the probability of the occurrence of a hazardous event - a road accident and the severity of the consequences of its occurrence. Based on the analysis of road accidents, as well as the description of the main reasons that lead to road accidents (Liu et al., 2018; Rolison et al., 2018), we will focus on a few (as an example) that have a high probability of variability during the transport work performance: a change in the psychological state of a driver (DF_1), change in climatic conditions (DF_2), speeding (DF_3), difficulty driving on certain sections of the route (DF_4). The determination of the number of all possible combinations in a certain period of time, which is determined by the work shift, is given in the Table 4. Note that a change in the psychological state of the driver is possible due to the accumulation of fatigue, due to work during a night shift, due to a significant amount of time spent behind the wheel, because the route is more than 500 km (Rolison et al., 2014), therefore, the probability of the occurrence of a hazardous event determined under the influence of the mentioned factor is determined as such, which will surely happen. Also, during the transition season (spring, autumn), the variability of weather conditions increases significantly, which also leads to a significant probability of a hazardous event. Regarding the determination of the probability of a road accident on difficult road dividers and due to speeding, statistical data were taken into account, in which the main causes of incidents are stated (Rolison et al, 2014; Wang et al, 2020b).

As a result of the risk assessment, we can see that the presence of several dangerous factors at the same time leads to an unacceptable level of risk, which requires the introduction of adequate preventive measures (Table 4). At the same time, the need to analyze all possible combinations is dictated by the search for opportunities to reduce the impact of one or another dangerous factor or their combined effect with minimal financial costs.

From the given analysis, it becomes clear why it is not possible to consider only the worst situation, when all four dangerous factors will manifest themselves simultaneously. At the same time, having proposed appropriate preventive measures to reduce their probability of manifestation, it is not possible to guarantee that other combinations will also have an acceptable level of risk.

5. DISCUSSION

The model of the connection of dangerous factors of the internal and external environment of the organization, related to their negative impact on the increase in the probability of the occurrence of a hazardous event (incident) and the degree of severity over time, developed for use, allows predicting the unknown states of the "catalyst" (physical and mental state of the driver) on the basis of available information about the quality of professional activity. The forecasting process is associated with the uncertainty of a hazardous event appearance due to the change in the relationship over time, which allows considering various possible alternative scenarios (possible scenarios of behavior) to avoid the occurrence of a road accident (Sun et al., 2017). The proposed approach makes it possible to assess the level of risk taking into account all types of occurrences of these possible scenarios of the development of events. At the same time, the reliability of the obtained results of the analysis of changes in dangerous factors over time is significantly increased: by hours of a day, by days of a week, by season of a year, which the authors of the work also pay attention to. Moreover, it is noted that seasonal dynamics affect economic indicators, work efficiency (Yu et al., 2014).

The specified feature of the proposed approach, which is expressed through the interaction of three main components: the presence of a threat or danger, the interaction between a truck and a person, the influence of the physical and psychological state of the driver, allows to build a matrix that deter-

Points	Probability of a hazardous event in percent	Probability of the occurrence of a hazardous event in verbal expressions	Description of the consequences of a hazardous event	Conditional health loss
5	More than 0.9	A hazardous event will definitely happen	Catastrophic, complete loss of working capacity, disability 1 and 2 degrees, possible death	More than 70%
4	0.7 – 0.9	A hazardous event is bound to happen	Serious: significant loss of working capacity, head injuries, severe limb injuries, possible 3rd degree disability	30 – 70%
3	0.4 – 0.7	A hazardous event may occur	Significant: loss of working capacity occurs, partial recovery may occur, significant recovery period of more than a month, moderate limb injuries requiring long-term treatment	15 – 30%
2	0.2 – 0.4	A hazardous event is unlikely to happen	Moderate: loss of working capacity up to a month, rupture of a tendon, light injuries of limbs	5 – 10%
1	Less than 0.2	A hazardous event will occur	Minor: scratches, abrasions, bruises, loss of work capacity for several days	up to 5%

Table 3. Quantitative indicators for risk assessment from exposure to hazards, dangerous factors and consequences of a hazardous event.

Hazard number	Identification			Determining the level of risk of road accidents from DF_i in time - t_m					The first assessment of the level of OR from the corresponding DF_{ji}
	Hazard	A hazardous event	Consequences of a hazardous event	Time - t of exposure to DF	Time	Determination of the influence of DF		The risk of a road accident taking into account DF (points) - i	
				DF_{ji}	Time of effect of DF_i - t_i	Probability of a dangerous event (points)	The degree of severity of the consequences of a dangerous event (points)		
Calculation of the risk of road accidents from each DF_i, assuming that they operate separately from each other in time									
j	Car	Road accident	Significant loss of work capacity due to head injuries, severe limb injuries, disability	DF_1	t_1	4	4	16	Acceptable
				DF_2	t_2	4	4	16	Acceptable
				DF_3	t_3	4	4	16	Acceptable
				DF_n	t_4	3	4	12	Acceptable
Calculation of the total OR_{ji} with the simultaneous action in time of all possible combinations of DF_{ji}									
The number of the combination of the simultaneous action of dangerous factors DF_{ji}				Time		General OR_{ji} - R_j with simultaneous action of DF_{ji} in time			The first assessment of the level of OR from the simultaneous action in time of various combinations of DF_{ji}
1				0		0			Acceptable
2				$t_1 = t_{j2} = t_3$		$R_{j123} = R_{j1} + R_{j2} + R_{j3} = 48$			Not acceptable
3				$t_1 = t_{j2} = t_4$		$R_{j124} = R_{j1} + R_{j2} + R_{j4} = 44$			Not acceptable
4				$t_1 = t_3 = t_4$		$R_{j134} = R_{j1} + R_{j3} + R_{j4} = 44$			Not acceptable
5				$t_{j2} = t_3 = t_4$		$R_{j234} = R_{j2} + R_{j3} + R_{j4} = 44$			Not acceptable
6				$t_3 = t_4$		$R_{j34} = R_{j3} + R_{j4} = 28$			Not acceptable
7				$t_{j2} = t_4$		$R_{j24} = R_{j2} + R_{j4} = 28$			Not acceptable
8				$t_{j2} = t_3$		$R_{j23} = R_{j2} + R_{j3} = 32$			Not acceptable
9				$t_1 = t_4$		$R_{j14} = R_{j1} + R_{j4} = 28$			Not acceptable
10				$t_1 = t_3$		$R_{j13} = R_{j1} + R_{j3} = 32$			Not acceptable
11				$t_1 = t_{j2}$		$R_{j12} = R_{j1} + R_{j2} = 32$			Not acceptable
12				t_3		$R_{j3} = 16$			Acceptable
13				t_{j2}		$R_{j2} = 16$			Acceptable
14				t_1		$R_{j1} = 16$			Acceptable
15				t_4		$R_{j4} = 12$			Acceptable
16				$t_1 = t_{j2} = t_3 = t_4$		$R_{j1234} = R_{j1} + R_{j2} + R_{j3} + R_{j4} = 60$			Not acceptable

Table 4. The form of the register (maps) of road accident risk assessment from each DF_i, assuming that they operate separately from each other in time.

mines the dependence of the severity of the consequences on the occurrence of an accident, which is the basis of a dynamic model road accident risk assessment (Farkas et al., 2023). In turn, this approach has a number of advantages over stationary models, which do not allow to take into account the possibility of changing the driver attitude over time, that is, to identify the influence on the occurrence of an error or, conversely, the avoidance of an emergency situation. This, in turn, will increase the inconsistency of calculations. Let us assume that there is a "Technically defective truck" danger. In this case, the probability of an accident is 12 (points), then considering the positive/negative attitude of drivers to the performance of their duties, this probability will be equal to I2±Δ. Δ is the value of the probability of avoiding, or vice versa, the occurrence of an accident due to careless/skillful actions of a driver while driving a truck. That is, there is some basic probability of an accident due to a technically defective truck, the value of which does not depend on the human factor. In turn, a person attitude towards the performance of his duties is an additional factor that either increases the probability of a road accident or, on the contrary, reduces it (Liu et al., 2023). Thus, the probability of making a mistake when driving a truck decreases due to an increase in the level of attention, concentration, and responsibility, which helps to reduce the danger probability and a driver readiness for various developments. On the other hand, it can increase due to the manifestation of strong emotions, the appearance of fatigue, the presence of risky behavior, recklessness, indifference, self-confidence. In this case, the Bayes formula (Starikov et al., 2021) can be used to calculate the probability of an accident.

Application of the developed risk management process will allow establishing the current level of risk for each time period, which will allow understanding the main causes of incidents (Yu et al, 2014). This will allow setting priorities for ensuring appropriate measures to increase the level of transportation safety. This process must begin with the formation of a driver understanding of his/her own safety, which allows predicting a certain development of events with the subsequent determination of tools that will allow to avoid accidents or at least reduce the risks of road accidents. From here, you can already plan resources, actions, identify respon-

sible people, set control dates and track the implementation of implemented measures.

A lot of motor transport enterprises recognize that transportation safety is their biggest challenge, so they organize quarterly or monthly audits. This includes the collection of vehicle inspection forms, accident reports, incidents, complaints, training records, meeting records, as well as information on average vehicle speed, seat belt usage percentage, response time to calls or threats, and more. The collected information is systematized into appropriate graphs and tables, which are convenient to analyze, which allows establishing time intervals that are the most dangerous, from the point of view of the manifestation of negative factors. These indicators provide a link between the measures taken and the level of risk reduction.

6. CONCLUSIONS

The model was developed for assessing the risk of road accidents, as a cumulative effect of risks from all dangerous external and internal factors at the workplace, considering dangerous actions and without actions of drivers during cargo transportation. The proposed process of managing the occupational risks of road accidents, taking into account the change in the influence of dangerous factors on the probability of the occurrence of a hazardous event and the degree of severity of injuries from it, based on the matrix for determining the risk of changing dangerous factors over time. It is proposed that all dangerous factors can be divided into static factors, which do not change (almost do not change) over time during the year, and dynamic factors - which change in a period from one hour to a year, which will allow to determine the overall level of risk from the cumulative effect of dangerous factors, taking into account all their combinations manifestation in time. The form of the register (maps) of the road accident risk assessment of each road accident has been developed, assuming that they operate separately from each other in time.

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