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Modeling of hazardous situations on vehicles for estimation the occupational risk of drivers

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Abstract: The complex of factors related to road transport is analyzed, the most significant of them are outlined and occupational risk on motor transport is estimated, depending on the conditions of carrying out transport work and the duration of operation of the vehicle. Models of the onset of hazardous situations are developed during separate motor transport works. It is established that the reliability of the modeling is significantly influenced by the insufficient reasonableness of the causes of road traffic accidents and the large number of impacts on the occupational risk of individual elements of the "driver-car-environment" system. It has been shown that the procedure for the determination of occupational risks should be based on statistically significant data on the causes of accidents and the results of monitoring the technical condition of the vehicle systems that determine its accident rate. To evaluate the occupational risk of truck drivers, the SAPHIRE computer program was used, which allows using the Fusel-Veseli and Birnbaum criteria to calculate the probability of a hazardous situation occurring on the basis of a plurality of probabilities of basic events. The professional risk of drivers in case of nonobservance of norms of occupational safety and the presence of defects in the responsible parts of the system (units) of the truck is calculated, as well as the degree of risk reduction of emergency transport situations after the introduction of appropriate measures of safety, in particular after removal of defects in the technical condition of the truck. The application of this approach to the assessment of drivers' occupational risk factors makes it possible to compare the impact of hazardous factors of different kinds and to determine the overall degree of danger, taking into account the contribution of each individual factor.

Keywords: road accident, modeling of hazardous situations, occupational risk, tree failure, technical condition of a truck.

1. Introduction

Road transport accidents (RTA) with various consequences may occur during road transportation, in particular with injuries to road users. For the most part, among the causes of RTA indicate unsatisfactory covering of motor roads, neglect of drivers of the traffic Rules, lack of control of the heads of motor transport enterprises (subdivisions) by the technical condition of motor vehicles, etc. [1]. These reasons are manifested comprehensively and predetermine the high level of occupational risk of truck drivers, not only during the transport of dangerous goods [2], but also in case of, for example, exceeding the load-carrying capacity of a vehicle or the transportation of oversized agricultural machinery.

In order to develop measures to prevent road traffic accidents of truck transport, it is necessary to analyze the complex of factors related to road transportations, to isolate the most significant and to assess the occupational risk on road transport depending on terms of performance of transportation works [3]. For such an analysis, mathematical modeling of hazardous (emergency) situations on motor transport with the involvement of logical operators and the probability theory apparatus is effective [4, 5]. However, the insufficient reasonableness of the magnitudes of the probabilities of manifestation the causes of accidents which are in the calculations by the basic events, and the large number of impacts on the occupational risk of individual elements of the system "driver-car-environment" ("D-C-E") now limits the authenticity of modeling [6, 7].

Nowadays, different approaches to describing links within the framework of developed models are used to simulate hazardous situations [8, 9]. In most of the work published over the past 10 years and devoted to the problem of assessing occupational risks, not only discuss the definition of occupational risk, but also offer methods for taking into account the influence of numerous circumstances of dangerous situations [10, 11]. But, despite the large number of risk assessment algorithms in production, there are currently no acceptable methods for assessing the risk on technology processes using technical means, especially for the automotive branch in Ukraine. Often the recommended methods are characterized by significant disadvantages in terms of their practical application (due to the complexity, incorrectness of input the initial data in the calculations, do not take into account the duration of the influence of dangerous factors).

The assessment of the risks of hazardous situations on motor transport should be based on the results of monitoring the technical condition of vehicles, statistics on the causes and circumstances of accidents, as well as on the results of simulation of hazardous events, their impact on the level of occupational injuries [12–14].

2. Materials and methods

In this paper a methodology for calculating the occupational risks of truck drivers, which provides for the possibility of taking into account the organizational, technical and psycho-physiological causes that lead to injuries in the branch is developed. The method is based on Event Tree Analysis. The application of this approach for assessing occupational risk indicators on motor transport allows us to compare the impact of hazardous factors of different nature and species, and to determine, taking into account the contribution of each individual factor, the overall degree of danger.

To calculate the occupational risk of truck drivers, an adapted SAPHIRE computer program, which allows with using the Fusel-Veseli and Birnbaum criteria to calculate the probability of a traumatic situation occurring on the basis of a plurality of probabilities of basic events, was used [15].

In the developed models of the accident, the probability of the basic events, which corresponds to the organizational, technical and psychophysiological causes of occupational injuries, asked according to statistical indicators of the causes of accidents on motor transport [16], and the assessment of the impact of technical malfunctions of the truck on the probability of an accident provide taking into account the length of operation of the car.

Models of occurrence of dangerous situations were constructed for typical accidents: rollover of the car as a result of skidding on the turn on unfavorable weather conditions; rollover of the car while driving on a slope; collision of a car with a moving (immovable) obstacle or riding from the road in a ditch.

3. Results and discussion

In models that describe the circumstances of an accident should take into account the risk factors that affect to the probability of getting into an accident and possible severity of the accident (excess speed, the presence of alcohol or drug intoxication, fatigue or bad driver's eyesight, dark time of day or insufficient visibility through weather conditions; unsatisfactory overall technical condition of the vehicle or separately defective braking system condition; non-compliance with periodicity of technical reviews; unsatisfactory road conditions; insufficient fastening of the cargo, non-use of safety belts, etc.). Determining the significance of each of the risk factors is a difficult task.

The degree of gravity of the consequences of an accident will increase, for example, in case of emergence of a fire after an accident, leakage from the car of flammable liquids, delays in providing medical care to the victim, and the difficulties in saving the victims. These dependencies are not linear. Thus, according to research [17, 18], the risk of traffic accidents with injuries to road users is proportional to the square of speed of the vehicle's; the probability of a serious traffic accident is proportional to the speed in the cube; the likelihood of an accident with a fatal outcome - to the speed in the fourth degree.

The psycho-physiological state of the driver, namely the feeling of internal discomfort, the fatigue, reaction speed, culture and driving skills, in particular observance of the established speed mode of movement, the use of safety belts, the presence of alcohol or drug intoxication, etc. is essentially effects on the safety of the traffic.

These and other circumstances of the accidents can be fully reflected in the multi-factor models creating of hazardous situations, but in order to quantify the risk of an accident occurrence, the calculation model must include certain values of the determining parameters which must be substantiated. So in the developed method of calculation of professional risk it is proposed to display in the models of the Event tree as the main causes of road accidents those, which are contained in the acts of investigation of accidents in motor transport and quantitatively statistically estimated in the annual sectoral reporting.

Among the main (common) causes of accidents most often indicate the following:

- unsatisfactory technical condition of vehicles;
- violations of labor and production discipline by road users;
- violation of traffic rules;
- violation of safety requirements during operation of vehicles;
- violation of the technological process of cargo transportation;
- psycho-physiological reasons connected with fatigue or painful state of the driver, etc.

The comparison of the definitions of these causes and the causes of occupational injuries, indicated in [16], shows that their conformity is not complete. Just as the basic events for the calculation models were introduced by nearest equations for the reasons indicated in [16], for which the statistical coefficients (indicators of the risk of injury) are known. The sum of these coefficients, as according to statistics [16], was to be equal to units.

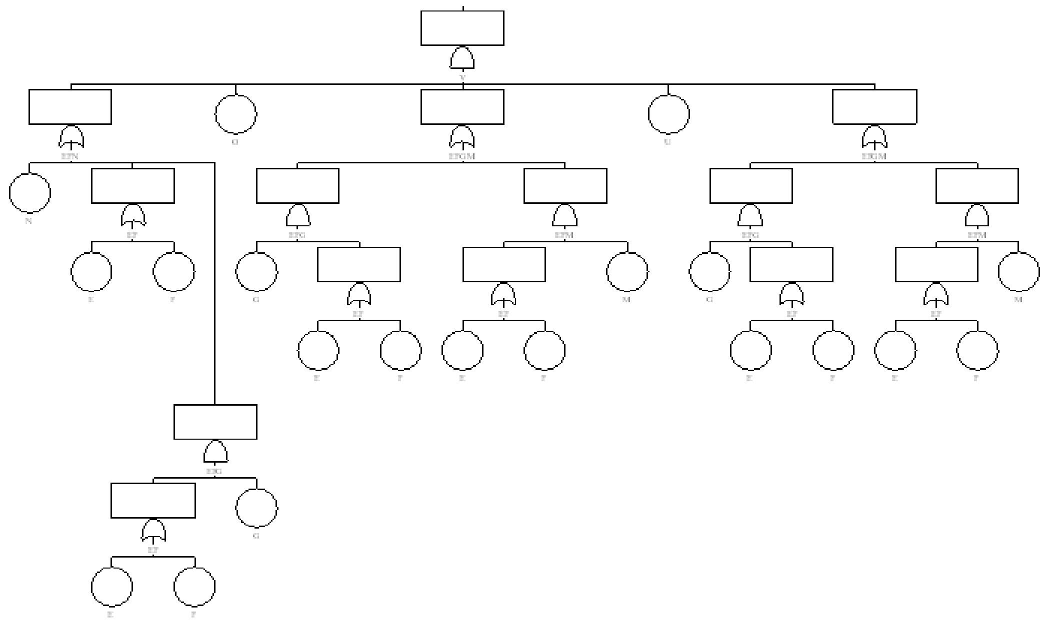

Figure 1. Block diagram of the logic-simulation model of a dangerous situation "the rollover of a car (tractor) as a result of skid on the turn".

As an illustration of this approach, in this paper, the calculation of the risk of rollover of a vehicle (tractor) as a result of skid in adverse weather conditions is presented. Such accidents occur, in particular, on roads outside settlements, where small radius of turns are arranged and there are other road traffic problems. The logic-simulation model of such a traumatic situation is presented in Figure 1.

The meaning of the elements of the logic-simulation model of a dangerous situation “the rollover of a car (tractor), as a result of skidding on the turn” presented in Table 1, where the quantitative values of the basic events are given. The quantitative values of the probability of the basic events were combined in Table 1 in order to keep compliance with the data of statistical bulletins “Traumatism in the production in 20__”, prepared by the State Statistics Service of Ukraine on the basis of the data of forms of state statistical observation № 7-tnv "Report on injuries on production in 20__ year ".

Table 1. Semantic meaning of the elements of the logic-simulation model of the road accident.

Elements symbol (basic events)	Brief description of elements (basic events)	Quantitative value of probability of basic events
E	Disadvantages during the training of drivers the safe working methods (in the actual absence of occupational safety and health at the enterprise)	0.15
F	Absence or poor quality of a medical examination or professional recruitment of drivers (unsatisfactory activity of occupational safety and health)	0.1
EF	Unsatisfactory condition of occupational safety and health at the enterprise	
G	Violation of the technology of cargo transportation (due to the lack of respectively prepared drivers able to drive a vehicle under difficult conditions)	0.25
EFG	Low professional level of employees hired to work	
N	Unsatisfactory technical condition of vehicles (due to insufficient funds for updating the material and technical base of the enterprise)	0.2
EFGN	Operation of a tractor (car) with worn-out tread of the wheels above the permissible level or presence of defects in details of the steering system and the braking system	
O	Unfavorable atmospheric phenomena on the road or performance of work in the dark time of day	0.15
M	Low level of labor discipline and driver's work culture (use of alcohol, psychotropic or narcotic substances during work)	0.1
EFM	Driver's stay while working in alcohol or drug addiction	
EFGM	Violation of traffic safety rules - exceeding the permissible speed of the tractor (car)	
$EFGM^1$	Sudden (emergency) braking	
U	Imperfection of the technological process, its non-compliance with safety requirements (presence of steep turns on roads or defective road cover)	0.05
V	Rolling over the car as a result of skidding on the turn	$6.561 \cdot 10^{-4}$

As an example, in the work, the risk of a dangerous situation (overturning a vehicle) was calculated for two discrete cases that characterize the impact of a dangerous manufacturing factor: virtually no action of a dangerous factor (probability of influence of 0.01) and its defining action (probability of influence 0.5). In Table 2 shows how the risk of rollover of a vehicle has changed due to the predominance of certain elements of the model, in particular after a significant deterioration of the technical condition due to the presence of defects in the responsible parts of the vehicle systems.

Table 2. Changes of risk indicators for the logic-simulation model of the dangerous situation "roll-over of a car (tractor) due to skidding on the turn".

Dangerous factor (action, event, situation)	Quantitative value of probability of basic events	Calculated risk indicator, P	Change in the risk indicator in the presence of danger, times
E	0.01	$2.887 \cdot 10^{-4}$	–
	0.5	$1.574 \cdot 10^{-3}$	5.45
F	0.01	$4.2 \cdot 10^{-4}$	–
	0.5	$1.705 \cdot 10^{-3}$	4.06
G	0.01	$2.062 \cdot 10^{-4}$	–
	0.5	$1.125 \cdot 10^{-3}$	5.45
N	0.01	$3.432 \cdot 10^{-4}$	–
	0.5	$1.268 \cdot 10^{-3}$	3.69
O	0.01	$4.375 \cdot 10^{-5}$	–
	0.5	$2.186 \cdot 10^{-3}$	49.97
M	0.01	$4.874 \cdot 10^{-4}$	–
	0.5	$1.406 \cdot 10^{-3}$	2.88
U	0.01	$1.312 \cdot 10^{-4}$	–
	0.5	$6.548 \cdot 10^{-3}$	49.91

In Table 3 presents the risks of occurrence of a dangerous event (probability of influence 0.5) in the form of a diminutive row, which allows to assess the most significant risks.

Table 3. The row of risk increases of a dangerous event in the logic-simulation model.

The model element	M	N	F	E	G	U	O
The estimated risk indicator	2.88	3.69	4.06	5.45	5.45	49.91	49.97

Important, demonstrative and necessary for further analysis are not the absolute values of the calculated risk, which depend on the structure of the proposed model of the onset of the emergency situation, changes in risk indicators, which characterize the impact of a certain production factor. Before consideration it is necessary to take a given on the basis of statistics the significance of the factor taking into account the change of risk within the closed system of basic events.

By analyzing the calculation of the relative importance of the underlying events by the Fusel-Vesely criterion, it can be noted that in all variants of the risk-taking situation events take part in events O and U which are the most significant among all other events and have the same coefficients of significance (Table 4).

Table 4. Indicators of the relative importance of primary (basic) events by the Fusel-Veseli criterion.

Event name	Number of variants of process development	Probability of basic event	Fussell-Vesely importance	Risk reduction ratio	Risk increase ratio
O	4	$1.5 \cdot 10^{-1}$	1.0	-	6.65
U	4	$5.0 \cdot 10^{-2}$	1.0	-	19.91
G	2	$2.5 \cdot 10^{-1}$	$7.142 \cdot 10^{-1}$	3.499	3.142
E	2	$1.5 \cdot 10^{-1}$	$5.999 \cdot 10^{-1}$	2.50	4.398
F	2	$1.0 \cdot 10^{-1}$	$3.999 \cdot 10^{-1}$	1.666	4.597
M	2	$1.0 \cdot 10^{-1}$	$2.856 \cdot 10^{-1}$	1.40	3.57
N	2	$2.0 \cdot 10^{-1}$	$1.934 \cdot 10^{-1}$	1.286	2.842

Analyzing the calculation data of the absolute significance of the underlying events according to the Birnbauom criterion, one can also note that events O and U take part in all variants of a risk-taking situation events, while the coefficient of significance of the event O is much smaller than the coefficient of significance of the event U (Table 5).

Table 5. Indicators of absolute significance of primary (basic) events by the Birnbaum criterion.

Event name	Number of variants of process development	Probability of failure	Birnbaum importance measure	Risk reduction difference	Risk increase difference
O	4	$1.5 \cdot 10^{-1}$	$1.307 \cdot 10^{-2}$	$6.561 \cdot 10^{-4}$	$1.241 \cdot 10^{-2}$
U	4	$5.0 \cdot 10^{-2}$	$4.368 \cdot 10^{-3}$	$6.561 \cdot 10^{-4}$	$3.712 \cdot 10^{-3}$
G	2	$2.5 \cdot 10^{-1}$	$2.623 \cdot 10^{-3}$	$3.936 \cdot 10^{-4}$	$2.229 \cdot 10^{-3}$
E	2	$1.5 \cdot 10^{-1}$	$2.623 \cdot 10^{-3}$	$2.624 \cdot 10^{-4}$	$2.360 \cdot 10^{-3}$
F	2	$1.0 \cdot 10^{-1}$	$1.87 \cdot 10^{-3}$	$4.686 \cdot 10^{-4}$	$1.405 \cdot 10^{-3}$
M	2	$1.0 \cdot 10^{-1}$	$1.87 \cdot 10^{-3}$	$1.874 \cdot 10^{-4}$	$1.686 \cdot 10^{-3}$
N	2	$2.0 \cdot 10^{-1}$	$1.67 \cdot 10^{-3}$	$1.782 \cdot 10^{-4}$	$1.596 \cdot 10^{-3}$

The indicated results of the conducted studies give the opportunity to focus attention on the riskiest primary (basic) events for the development of effective preventive measures to prevent such and similar accidents.

4. Conclusions

The assessment of the risks of hazardous situations in motor vehicles should be based on statistical data on the causes and circumstances of accidents, the results of monitoring the technical condition of vehicles, as well as the results of simulation of hazardous events, their impact on the level of occupational injuries.

The results of the calculation of the elements of the logic-simulation model allow to estimate the risk of an accident during a traffic accident as a result of a certain correlation of reasons of an organizational, technical and psycho-physiological nature, in particular due to the accumulation of defects in the responsible parts of the nodes. The obtained values, which correspond to unacceptable occupational risk, should be the basis for observance of normative terms of technical maintenance of vehicles and replacement of damaged parts.

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