Nat. Volatiles & Essent. Oils, 2021; 8(4): 7795-7829

Evaluating The Effect Of Technical Devices On Safety Of Transportation Processes In Agro-Industrial Complex

Evgeny N. Khristoforov[1] , Nataliya E. Sakovich[1] , Vladimir E.Torikov[2] , Vladimir I.Samusenko[3] , Anton M.Nikitin[4] *

[1]en-x@bk.ru ORCID 0000-0002-1994-0831

[1]nasa2610@mail.ru ORCID 0000-0002-6154-4445

[2]torikov@bgsha.com ORCID0000-0002-0317-6410

[3]samvi64@mail.ru ORCID 0000-0002-5556-2161

[4]a.m.nikitin32@mail.ru ORCID 0000-0002-8261-1969

E-Mail: a.m.nikitin32@mail.ru

[1]Department of Life Safety and Ecological Engineering; Bryansk State Agrarian University, Russia

[2] Department of Agronomy, Selection, and Seed breeding; Bryansk State Agrarian University, Russia

[3] Department of Engineering Systems in Agrobusiness, Environmental Engineering, and Road Construction; Bryansk State Agrarian University, Russia

[4] Department of Electric Power Engineering and Electric Technologies; Bryansk State Agrarian University, Russia

Abstract. Farm workers are faced with a task of not only growing agricultural products, but also delivering them to consumers as a result of transportation and technological processes. At the same time, while performing transportation processes, the situations may arise that will lead to the death of people, damage, and destruction of transported agricultural products, for example, as a result of a road accident. In this sorrowful situation of accidents in the country, agro-industrial complex accounts for its portion.

According to the research results of scientists of the state scientific institution Research Institute for Rural Social Development, Federal State Budget Institution of Higher Education "Orel State Agrarian University", 10-12% of the total number of road accidents in the country per year occur in agricultural production. To solve the problem, it is proposed to conduct comprehensive studies of the “Driver–car–road–environment” system and the influence of the system's links on safety of transportation processes in agricultural production. The conducted research studies allowed us to pay considerable attention to the "driver–car" link, the results of which enable us to state that quite often failures and malfunctions of motor vehicles are the causes of complex and sometimes dangerous road situations leading to a road accident. It is suggested that safety of transportation processes should be increased by installing technical devices on motor vehicles, that enhance the reliability of automobile systems through improving faultless operation of automobile systems and reducing the risk of failures in the systems.

Keywords: automobile, driver, transportation process, safety of transportation processes, motor vehicle.

1. Introduction

Road accidents (RAs), resulting in deaths of people and inflicting significant material damage, are among the adverse effects arising from transportation processes in agro-industrial complex (AIC). According to the latest statistics, there are 7 main reasons for road accidents (RAs), including failures (malfunctions) in the elements of functional systems of motor vehicles. In 2019, technical malfunctions in motor vehicles caused 571 road accident on the country’s roads, with 86 persons died and 760 persons suffered from injuries of different degree of severity, with that, the scientific research has shown that numerous RAs occur in agricultural production sector. Although statistical data indicate that the number of RAs due to technical malfunctions is not very high, their consequences are often more severe than those occurred by other reasons (Nikulinetal., 2017; Baranov et al., 2018; Bystrovaetal., 2019; GazvanandAsp, 2006; Galyanov, 1995; STOP_newspaper, 2006; GOST, 2016; EvtyukovandVasiliev, 2005; BODIASRTSID, 2015; Khyarkanen, 2007; RFG (RFGovernment), 2018; Chvanov, 2000; Kupreenko et al., 2020; GIBDD.rf, 2020).

Safety of transportation processes in agro-industrial complex (AIC) is defined by the properties of “driver-car-road-environment” (DCRE) system and shows up only when transportation processes are underway in practice, hence, let the main stages of the activity of agricultural production auto transport companies (ATC), transporting agricultural cargoes, be considered. Figure 1 demonstrates three main stages in the activity performed by auto transport companies to deliver agricultural products.

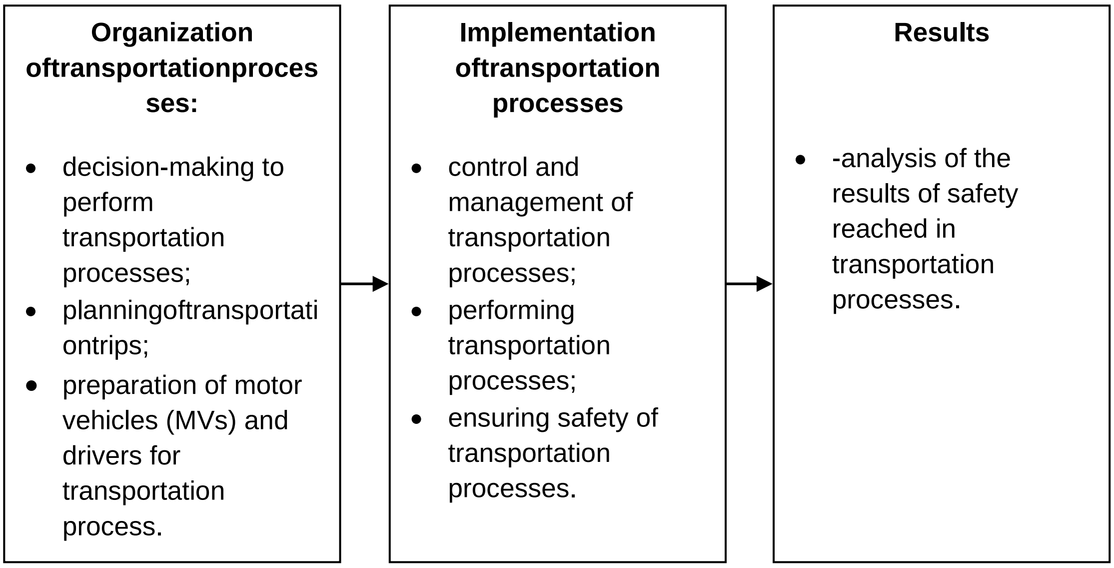

Fig. 1. Stages of the activity of auto transport companies in ensuring safety of transportation processes

Organization of transportation processes is a preliminary and most labour-intensive stage, involving making a decision to perform transportation processes, plan and prepare for them (Khristoforovetal., 2015; Pilipovich, 2007; RFG, 2014, 2018; RedkinandBorisov, 2006; Chvanov, 2000; Kupreenko et al., 2019; Melnikova et al., 2020).

The head of an enterprise makes a decision to implement transportation processes, based on the tasks facing ATC, availability and readiness of motor vehicles, means of control and assurance of safety of transportation processes, drivers' training and time available for preparation to perform these processes. Transportation trips are planned by the ATC management personnel, including compilation of orders, assignment of tasks for engineers and technicians to prepare motor vehicles (MVs) and make all trips. Preparation for transportation processes, organised by transportation department, implies preparation of drivers, dispatch service, motor vehicles, means for controlling and ensuring safety of transportation processes.

Assurance of safety in transportation processes is the main stage of ATC activity, when drivers make transportation trips as such. This stage involves control and management of transportation processes and their provision. Management of transportation processes involves actions of the chiefs of columns and departments on planning, coordinating, and facilitating these processes. Dispatch service on strict, reliable, and continuous regulation of MV traffic supervises the trips to make them successfully and ensure safety of transportation processes.

To ensure reliable operation of motor vehicles, to employ it effectively when transportation processes are underway, to prevent undesirable (dangerous) road situations and ensure safety of transportation processes, when they occur, engineering, meteorological, medical methods are used to enable trips. Of special importance is an engineering support provided by a company's engineering department. Engineering services are known to include motor vehicles' upkeep operations, adequate operation and maintenance, timely preparation of cars to setting out and their proper preservation. Chief engineer is in charge of calculating resources to prepare motor vehicles and ensure transportation processes. Foremen and chiefs of columns directly supervise the work of maintenance staff when preparing and operating motor vehicles.

Summarising (traffic safety day) is the final stage of performing transportation processes, when the results of ATC activity are summed up, the quality of work and safety of transportation processes are estimated, the problems are posed to enhance safety of transportation processes. Summarising is an important stage in the ATC activity (Pilipovich, 2007; RFG, 2018; Syschikovet al., 2017).

2. Material and methods

Properties of the DCRE system, which has been an object of studying safety of transportation processes, define their degree of safety. In general, DCRE system incorporates the following systems interacting with one another:

- the system of creating and manufacturing motor vehicles;
- staff training system;
- system of organising and performing transportation works and ensuring their safety.

Since safety of transportation processes and efficiency of using MVs show up only in the course of transportation trip, it is commonly supposed that DCRE system is a system of organising and performing transportation processes and ensuring their safety, namely, an independently functioning ATC. In this case, it should be clearly understood that safety level of transportation processes is specified when designing a MV, and, according to the quality of staff training, complexity of fulfilled tasks, can be better or worse implemented during the DCRE system functioning. Transportation process implies a successive transition from one road situation (characterised by traffic pattern, operation modes of individual systems, external conditions, and psychophysiological state of a driver) to the other. A set of road situations contains two subsets: normal (regular) and dangerous (special, non-routine) situations. When special (dangerous) situation, caused by some unfavourable factor, arises, a driver tries to eliminate the consequences of this impact. In some cases, arisen dangerous situation can stepwise alternate between one dangerous situation and another, until the process has its favourable or unfortunate outcome. Road accident is a result of MV reaching the extreme values of key parameters due to development of a dangerous situation. Since the incidence of reaching these values characterises safety of transportation processes, regularities in occurrence and development of dangerous situations, reasons for them, and measures taken for prevention and diminution of their effect are the subject of studying safety of transportation processes.

Ensuring safety of transportation processes involves working-out of a methodology for revealing regularities in occurrence and development of dangerous situations, development of criteria and methods for estimating their effect on the level of safety with the ultimate aim to control this level. In this regard, safety of transportation processes is primarily a practical theory.

The DCRE system, being a subject of studying safety of transportation processes, is a complex man-machine system. Hence, the theory of ergatic systems represents a scientific basis for safety of transportation processes. The properties of these systems are defined by not only the properties of particular technical devices and persons, that form this system, but also a correspondence between machinery properties and human capabilities, coordination between them, and social aspects of interaction among people. Hence it follows that to examine the quality of the DCRE system functioning, an in-depth study of properties of individual elements of this system is first needed, second, the methods for studying a combined operation of all the DCRE system elements must be developed, factors decreasing the stability of such operation have to be identified, and efficient measures to ensure safety have to be designed thereupon. When analysing functioning of the DCRE system, its specific features as follows must be taken into consideration:

1. When the DCRE system operates, the structure of connections among its certain elements can constantly change, forming new functional subsystems.

2. Hierarchical nature and variable structure of the DCRE system and changes in its parameters while functioning make it impossible to constantly control the system, requiring its ongoing correction. To ensure safety, this correction is made when prevention measures are developed and implemented, including efficiency of equipment, methods of its operation and use.

3. Complex hierarchic structure of DCRE system, active human involvement in its management, stochastic behaviour of functioning give rise to its properties, not inherent in isolated subsystems and elements contained therein.

As the main method for studying safety of transportation processes, there has been used a system-based method that implies comprehensive consideration of available interrelations between certain subsystems and links of the DCRE system, an in-depth study of cause and effect relationship between them. Taking into account stochastic behaviour of the DCRE system functioning, and, hence, randomness of dangerous situations, applying the probability theory and methods of mathematical statistics is seen as inevitable to study safety of transportation processes.

The use of system-based approach requires a unified description of parameters of various subsystems since output parameters of some subsystems are input parameters for others. In this case, not all relationships between subsystems can be described analytically. Some (predominant) of them have a logical connection, what adds some specific features in descriptions of the DCRE system properties and studies of its functioning. Not only quantity-, but also quality-related assessment of high-dimension traffic safety is made due to numerous parameters that define safety of transportation processes. Dimension reduction of the general DCRE system requires division of it into several subsystems. Such a solution makes it possible to single out the main subsystem (link), which performance influences the level of traffic safety.

Potential successful completion of transportation processes depends on the properties of the “driver-car” link, the main chain in the DCRE system Hence, when evaluating safety of transportation processes using probabilistic parameters, the central problem is in describing mathematically the driver’s actions to intentionally control a motor vehicle and eliminate the consequences of unfavourable factors. This is because the driver’s actions are discrete, variable, random, depend on the problems solved and psychophysiological state of a driver. Sometimes Delphi methods have to be employed to evaluate traffic safety due to the difficulties in providing a mathematical description of driver’s actions.

Since, with the existing accident incidence rates, RA is a frequent event, to accurately evaluate the safety level of transportation processes, a large array of statistical RA data is needed, obtainable only over some period of operation. Thus, to enhance the reliability of evaluating the safety level of transportation processes, the methods should be developed, which would allow using statistical data about not only RA, but also dangerous situations, which array is several orders higher than the RA array. To that effect, for each occurred dangerous situation its danger should be known, i.e. the probability of transforming it into a road accident, what requires an in-depth study of regularities in the development of dangerous situations.

Current situation of road accidents in the Russian Federation transport system shows that the approaches employed to solve the problem of ensuring safety of transportation processes have not been adequately studied. Large scale and complexity of this problem, taking into account present-day development rates of vehicles, require improvement of methods to analyse the reasons for road accidents and selection of efficient measures to reduce severity of their consequences.

Safety of transportation processes is affected by different factors: vehicle malfunction, a driver’s error, poor road conditions, unusual nature phenomena, and others. When a motor vehicle makes a trip, situations arise along its route that can be divided into normal and special (dangerous) (Fig. 2) (Porkhacheva, 2017; Khristoforovetal., 2017; Belous et al., 2019; Tokunaga et al., 2020; GIBDD.rf, 2020).

Special situation is a condition created when motor vehicle moves under the influence of an unfavourable factor. Depending on the degree of danger, special situations are divided into catastrophic, emergency, dangerous, and situations complicating traffic conditions.

Catastrophic situation is a particular situation when it is almost impossible to prevent people from dying.

Emergency situation is a special situation that requires specific emergency actions of a driver, whose professional skills are essential not to let this situation be transformed into catastrophic. Emergency situation requires terminating movement immediately.

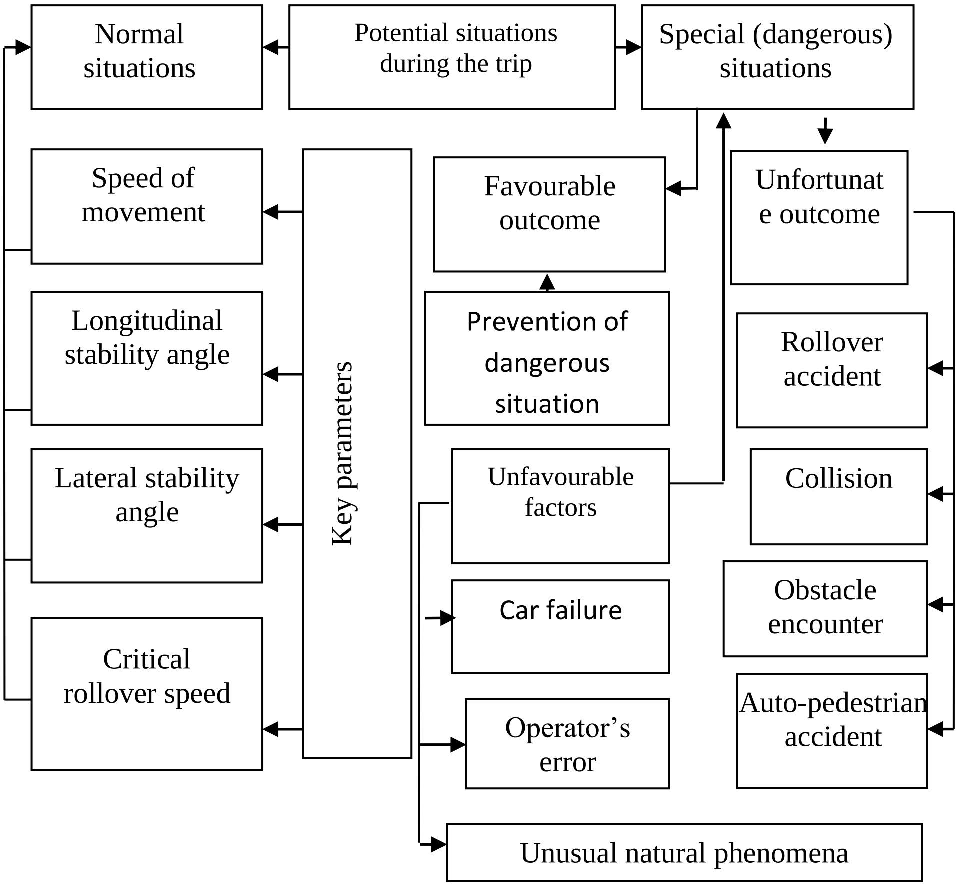

Fig. 2. Outcomes of transportation trips

Dangerous situation is a particular situation, to prevent which from transition to emergency or catastrophic timely and adequate actions of a driver are needed. Significant deterioration of traffic conditions can accompany dangerous situations, although, no immediate termination of movement is required.

3. Results and discussion

Motor vehicle movement parameters change in the course of dangerous situation. Those parameters that have constraints due to conditions of ensuring safety, are called the key parameters. Threshold value of the key parameter is the value of this parameter such that emergency or catastrophic situation occurs. Ensuring safety of transportation processes requires that, while moving, key parameters didn't reach their threshold values, i.e. some margin remains. The maximum value of a parameter, allowable when operation is in progress under conditions of ensuring traffic safety, is called a permissible value of the key parameter. A key parameter, which in a given special situation first reaches its threshold value, is called critical.

Key motor vehicle movement parameters have specific limit values: speed, longitudinal or lateral stability angle, critical rollover speed, stopping distance, and others. When one or several key parameters exceed threshold values, it will lead to a road accident, i.e. unfortunate outcome: rollover, collision, auto-pedestrian accident, or obstacle encounter (BorschenkoandGuselnikov, 2016; DidmanidzeandVarnakov, 2007; Porkhacheva, 2017; Khristoforov et al., 2017; Reshnyak, 2011; Belous et al., 2019; Tokunaga et al., 2020).

The road accident progress can be seen on the curve plotted in Figure 3.

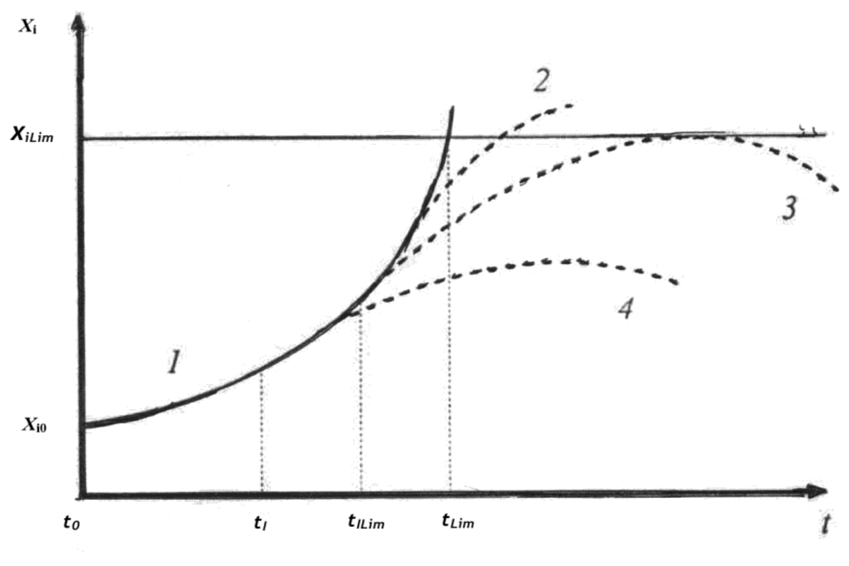

Fig. 3. Road accident progress curve

Figure 3 presents a graph of dependence of some movement parameter X_i on the time of a driver's intervention in motor vehicle driving t_I. With ill-timed intervention in operating MV, parameter X_i will exceed its threshold value X_{iLim} (curve 2), what can cause RA; with timely intervention in driving, parameter X_i will not exceed its threshold value X_{iLim}. In the first case, parameter $X_i$will only reach the limit but will not exceed it (curve 3), and, finally, witht_I< t_{ILim} parameter$X_i$will not reach the threshold value (curve 4). Timet_{ILim}= $t_A$is called an available time of driver's intervention.

The studies have shown that when dangerous situation occurs, to prevent RA, the time of driver's intervention in operating MV amounts to 1.2-2.0 sec (EvtyukovandVasiliev, 2005; Porkhacheva, 2017; Khristoforovetal., 2017; Razmi et al., 2020).

In practice, several ways exist to increase safety of transportation works, determined by the MV reliability:

The 1st way is associated with decreasing the risk of MV failures and malfunctions, i.e. reducing the probability of a driver's inability to prevent the consequences of these failures and malfunctions.

The 2nd way is associated with the need for improving such operating parameters of MV as: reliability, trouble-free operation of agricultural motor vehicles in transportation processes.

The 2nd way is the most acceptable, being a principal one in increasing safety of transportation processes. It is to ensure reliable operation of motor vehicles utilised in agricultural sector that major efforts of companies responsible for design, production, operation and repair of vehicles are directed. All engineering and technical measures taken by transport equipment maintenance staff are first intended to keep MV reliability high (Khristoforovetal., 2015;GazvanandAsp, 2006; DidmanidzeandVarnakov, 2007).

To estimate the efficiency of technical measures proposed to decrease the intensity of malfunctions in the elements of technical MV systems, we suggest that the following criterion K_{Q_λ} be adopted

$$K_{Q_\lambda} = \frac{Q_{T_2}}{Q_{T_1}}, \quad (1)$$

where Q_{T_1} – level of risk prior to taking technical measures;

Q_{T_2} – level of risk after taking technical measures.

To determine Q_T , the following formula is used:

$$Q_T = \frac{1-\ell^{-\lambda_{00}t}}{\lambda_{00}} \sum_{i=1}^{n} \lambda_{0_i} s_i \ , \qquad (2)$$

where λ_i – intensity of the i[th] unfavourable factor occurrence.

Suppose λ_i is an intensity of malfunctions in the elements of MV systems prior to taking technical measures:

$\lambda_i / K_{\lambda_i}$ – intensity of malfunctions in the elements of MV systems after taking technical measures, where $K_{\lambda_i} > 1$ and assuming that $\ell^{-\lambda_{00}t} \approx 1 - \lambda_{00}t$, the formula for the criterion will be obtained

$$K_{Q_\lambda} = \frac{\sum_{i=1}^{n} \lambda_i S_{T_i}}{\sum_{i=1}^{n} \frac{\lambda_i}{K_{T_i}} S_{T_i}} = \frac{1}{\sum_{i=1}^{n} \frac{\overline{Q_{T_i}}}{K_{\lambda_i}}} , \qquad (3)$$

where m – number of elements in the considered system;

$Q_{T_i} = \frac{\lambda_i S_{T_i}}{\sum_{i=1}^{k} \lambda_i S_{T_i}}$ – specific contribution of the i[th] element malfunctions to the level of risk, due to potential failures in the considered technical system.

Result (3) is supported by the fact that the measures to enhance reliability of MVs should primarily be taken for those functional systems of motor vehicles, which significantly affect the level of safety of transportation processes. The efficiency of technical measures for enhancing reliability of the most "alarming" j th element in the MV system is determined by formula:

$$K_{Q_{\lambda_j}} = \frac{\sum_{i=1}^{n-1} \lambda_i s_{T_i}}{\sum_{i=1}^{n-1} \lambda_i s_{T_i} + \frac{\lambda_j}{K_{\lambda_j}} S_{T_j}} \quad (4)$$

Substitution of the values into formula (2) $\frac{\lambda_j}{K_{\lambda j}} = \lambda_j + \frac{1-K_{\lambda_j}}{K_{\lambda_j}} \lambda_j$ gives the formula as follows:

$$K_{Q_{\lambda_j}} = \frac{K_{\lambda_j}}{K_{\lambda_j}(1-\overline{Q_{T_j}}) + \overline{Q_{T_j}}} \quad (5)$$

Changes in $K_{Q_{\lambda_j}}$ depending on K_{λ_j} at various $\overline{Q_{T_j}}$ are presented in Figure 4, whence it follows that an increase in K_{λ_j} leads to the increased safety of transportation works, the greater, the higher the $\overline{Q_{T_j}}$ values.

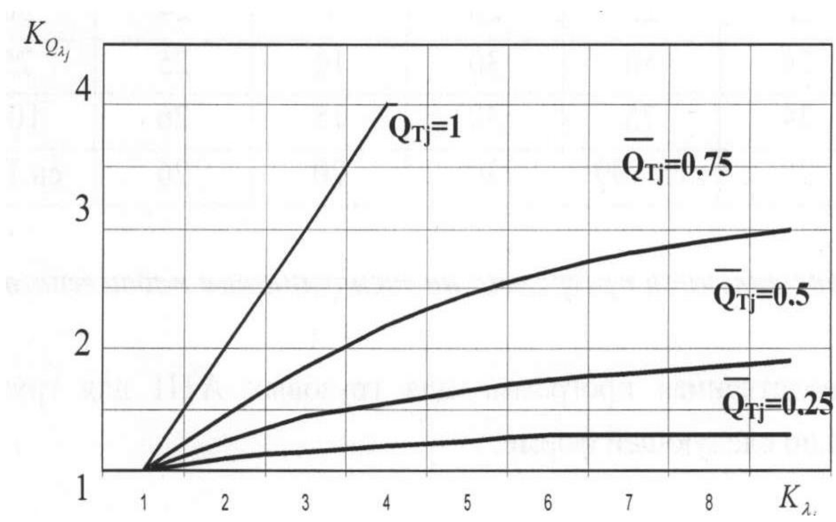

Fig. 4. Dependence of efficiency criterion of measuresondifferentspecificcontributionsofmalfunctions in vehicles

Ifthe element implies theentiresystem $\overline{Q_{T_j}} = 1$, formula (5) takestheform:

$$K_{Q_\lambda} = K_\lambda \qquad (6)$$

i.e. the risk level decreases as many times as the intensity of malfunctions in MV system elements decreases.

Expressions $(2.13) - (2.16)$ (3 – 6) are used to define the efficiency of engineering measures aimed at reducing probabilities of failure to prevent the consequences of malfunctions.

To make sure that this conclusion is valid, ratio $K_{Q_S} = \frac{Q_{T2}}{Q_{T1}}$ is taken as a criterion of efficiency of engineering measures, and probabilities of failure to prevent consequences of malfunctions after taking measures as being equal to S_{T_i} / K_{S_i}, where $K_{S_i} > 1$.

Hence it follows that at equal values of K_{Q_λ} and K_{Q_S}, in terms of quantity it makes no difference, in what direction the measures intended to enhance safety of transportation processes should be taken:

- increasing reliability rates of motor vehicles used in agricultural sector;
- decreasing the risk of malfunctions.

At that, if the MV malfunction causes, among other things, disruption in fulfilling a production task, the measures to increase reliability of equipment must first be taken under the above-mentioned conditions. Such measures must also be taken in cases when prevention of the consequences of malfunctions is difficult or impossible. If the equipment malfunction impedes no safe continuation of transportation processes, decreasing the degree of their danger becomes principal for such malfunctions.

Let the measures aimed at decreasing the degree of malfunctions danger be considered. These measures can be divided into two groups: technical and operational.

Technical measures are primarily related to the use of the means on MVs that decrease the time of driver’s intervention and increase his available time in case of malfunctions.

To decrease the time for driver’s intervention in operating the MV and to increase his available time, the systems of various signalling to a driver for malfunctions in technical systems need to be utilised on an automobile.

Operational measures are mostly related to training for drivers in identifying malfunctions and preventing their consequences, done on simulators or within training areas.

Note that when malfunctions occur, which cause conditioned intervention of a driver in driving, the time of his intervention almost defies training. When such malfunctions occur, drivers master their skills of recognising the source of malfunction by the MV behaviour and making decision on preventing the consequences of malfunctions.

Operational measures also imply recommendations to drivers in abrupt deceleration, deceleration in poor weather conditions. Therefore, an intense activity is recommended to a driver while operating the MV – in the simplest case, for instance, to hold on a steering wheel with two hands, not with one. Curves (Figure 5) illustrate practicability of such a measure.

The curves are constructed for the required levels of accelerative stimuli. P on these curves is the probability of a driver's intervention in operating over a given time t after a failure had occurred. It follows from the curves that when the available time is 1sec, a driver with probability of 0.58 timely intervenes in driving, if he held on a steering wheel with two hands, and with only 0.25 probability, if he did that with one hand.

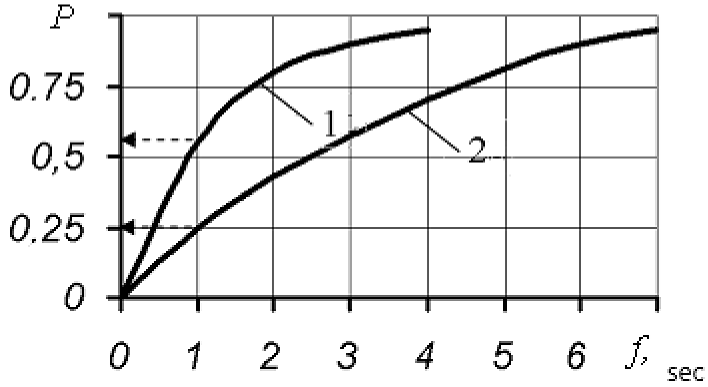

Fig. 5. Curve of distributing probabilityof intervention in driving: 1 – using two hands; 2 – using one hand

One of directions for ensuring safety of transportation processes suggests installation of technical devices on MVs that enable a driver to prevent or reduce consequences of failures in motor vehicle systems.

Technical devices that are responsible for enhancing safety of transportation processes, must have the following functions:

- to signal to a driver for malfunctions of MV systems;
- to control functioning of MV systems in operation;
- when failures and malfunctions in MV systems are identified, to automatically turn them off;
- to automatically connect fault-free standby systems or elements of systems;
- to automatically define the values of critical parameters of MV movement at different stages of transportation processes, and to signal to a driver for approaching a dangerous value.

The employed technical devices to enhance MV safety are divided into active and passive.

Active technical devices for enhancing safety of transportation works involve those devices that, by acting on controllable systems, MV controls, automatically prevent possible consequences of failed system.

Passive technical devices for enhancing safety of transportation works are those devices that only signal to a driver for arisen malfunction or when the parameters of automobile systems approach dangerous traffic condition, without elimination of consequences. A driver prevents consequences of malfunction and arisen dangerous situation by himself.

It is suggested that a partial criterion be applied that will allow evaluating the effect of technical devices installed on MV, on safety of agricultural transportation processes, taking the influence of efficiency of these technical devices into consideration (DidmanidzeandVarnakov, 2007; Syschikov et al., 2017; Khristoforovet al., 2017; Razmi et al., 2020).

Researchers face the following hypothetical problem. A technical device is installed on a motor vehicle to control the efficiency of a certain system. For example, a system of controlling the amount of service fluid in the brake system is installed on a motor vehicle; it, when the service fluid level lowers below permissible, automatically switches the engine ignition system off (Khristoforovetal., 2015, 2017; Orudzhova, 2017).

There is a need to evaluate the effect of the in-built control system on an increase in the probability of unfavourable completion of transportation process, related to the brake system malfunction due to lowering of the level of service fluid below permissible.

To evaluate the effect of the built-in control system on safety of transportation processes, the theory of Markov chains will be applied. The graph of potential system states is presented in Fig. 6.

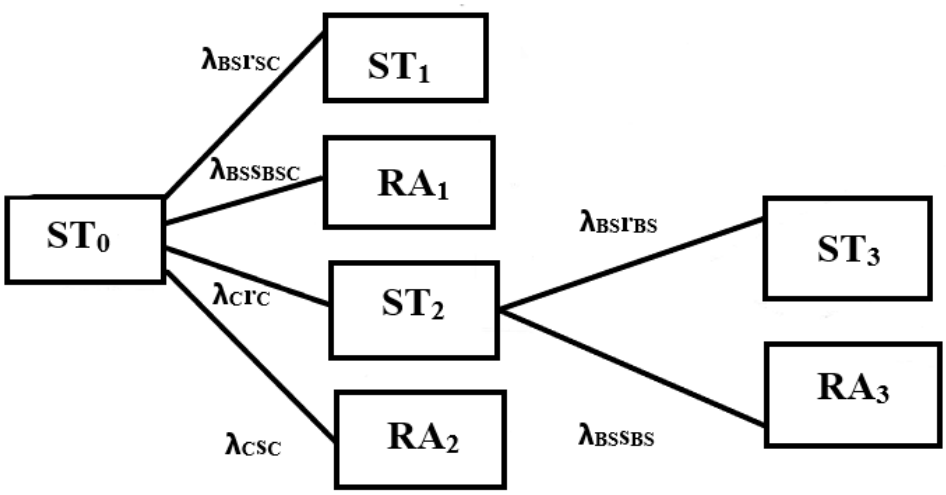

Fig. 6. System state graph

where λ_C– intensity of control system failures;

λ_{BS} – intensity of brake system failures;

r_{BSC} – conditional probability of preventing consequences of malfunction of brake system, with control system in operation;

r_{BS}– conditional probability of preventing consequences of the brake system malfunction;

r_C – conditional probability of preventing consequences of the brake system malfunction, with control system out-of-operation.

Conditional probabilities of failure to prevent consequences of malfunctions will be equal to:

$S_{BSC} = 1 - r_{BSC}$; $S_{BS} = 1 - r_{BS}$; $S_C = 1 - r_C$

In calculations, the assumption is used that the control system is out-of-operation, when the brake system fails.

Favourable completion of transportation process is denoted by ST_i(i=0.3) and unfortunate completion of transportation process, i.e. a road accident, by RA_3 (j=1.3). States ST_1 and RA_1 correspond to traffic outcomes when there are malfunctions in the brake system with the control system in operation, ST_2 and RA_2– when the control system fails, and ST_3 and RA_3 – when there is malfunction in the brake system with out-of-operation control system.

Let the probabilities of remaining in the ST_i safety state (safety traffic) be denoted by P_i, and in the RA state - Q_j.

Probabilities of favourable and unfortunate outcome of transportation work are determined by formulas:

$$P = \sum_{i=0}^{3} P_i \;, \quad Q = \sum_{j=1}^{3} Q_j \qquad (7)$$

Let the system of differential equations for probabilities of the system's remaining in various states be composed:

$$\frac{dP_0}{dt} = -\lambda_0 P_0; \frac{dP_1}{dt} = \lambda_{BS} r_{BSC} P_0;$$

$$\frac{dQ_1}{dt} = \lambda_{BS} s_{BSC} P_0; \qquad \frac{dP_2}{dt} = \lambda_C r_C P_0 - \lambda_{BS} P_2;$$

$$\frac{DQ_2}{DT} = \Lambda_C S_C P_0 \frac{DP_3}{DT} = \Lambda_{BS} R_{BS} P_2$$

$$\frac{DQ_3}{DT} = \Lambda_C S_C P_2,$$

where $\lambda_0 = \lambda_{BS} + \lambda_C$

On integrating this system of equations with initial conditions $P_0(0)=1$, $P_i(0)=Q_j(0)=0$ for $i, j=1,3$ and substituting the expressions found for Q_j in formula (2.9), the formula is obtained:

$$Q = \frac{\lambda_{BS}s_{BSC} + \lambda_C s_C - r_C s_{BS}\lambda_{BSC}}{\lambda_0}(1 - \ell^{-\lambda_0 t}) + r_C s_{BS}(1 - \ell^{-\lambda_{BS} t})$$

The degree of risk, when there are malfunctions in the brake system according to the formula of total probability will be equal to:

$$Q_0 = (1 - \ell^{-\lambda_{BS} t})S_{BS}$$

Usually $\lambda_0 t << 1$ and $\lambda_{BS}t << 1$, thus, $(1-\ell^{-\lambda_0 t}) = \lambda_0 t$ and$(1 - \ell^{-\lambda_{BS} t}) = \lambda_{BS}t$ can be assumed.

The efficiency of the control system action on reducing the probability of unfortunate outcome is estimated using the following formula:

$$K_Q = \frac{Q_0}{Q} \approx \frac{s_{BS}}{s_{BSC} + \frac{\lambda_C}{\lambda_{BS}} s_C} \qquad (8)$$

Expression (8) proves that highly reliable efficient control system, as compared to controllable systems, decreases the probability of unfavourable outcome of transportation work in proportion to the ratio S_{BS}/S_{BSC}, i.e. reduction in the risk of malfunctions.

If the control system is less reliable itself $\lambda_C > \lambda_{BS}$, and its malfunctions are as dangerous, as the brake system malfunctions $S_C>S_{BS}$, the control system will become ineffective, and it increases the degree of risk. It is clearly shown in Figure 7, where there has been depicted a dependence $K_Q = f\left(\frac{S}{S_{BS}}; \frac{\lambda_C}{\lambda_{BS}}; \frac{S_C}{S_{BS}}\right)$, at $\lambda_{BS} = 1 \times 10^{-3}$, 1/h, $S_{BS} = 0.2$. To enhance safety of transportation processes, the system and devices, intended to do this, should be more reliable themselves than the systems they control.

When there are failures in functional systems of an automobile, drastic changes in parameters of its movement are possible, which may create emergency or catastrophic situation. The driver's task involves prevention of such a dangerous change in parameters. If this task is difficult for a driver to handle, the automobile needs to be equipped with special technical devices to increase safety of transportation processes (Hudson and Hudson, 2020).

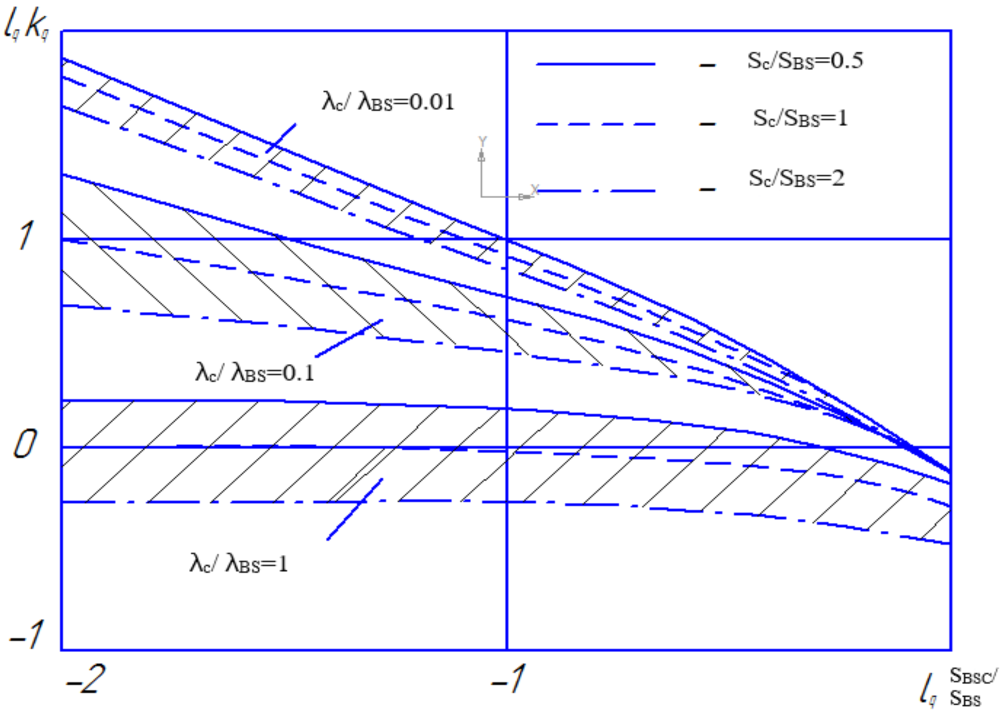

Fig. 7. Dependence of ratio K_Q on intensity of malfunctions and probabilities of failure to prevent their consequences

The effect of technical devices on safety of transportation processes can be evaluated using analytical criteria. It will be demonstrated with an example of failure in the automobile engine cooling system pump (ECSP), leading to engine overheating and failure, what may change the automobile movement and, finally, cause a road accident. Cooling system is equipped with an active technical device in the form of automatic controller (AC, Figure 8).

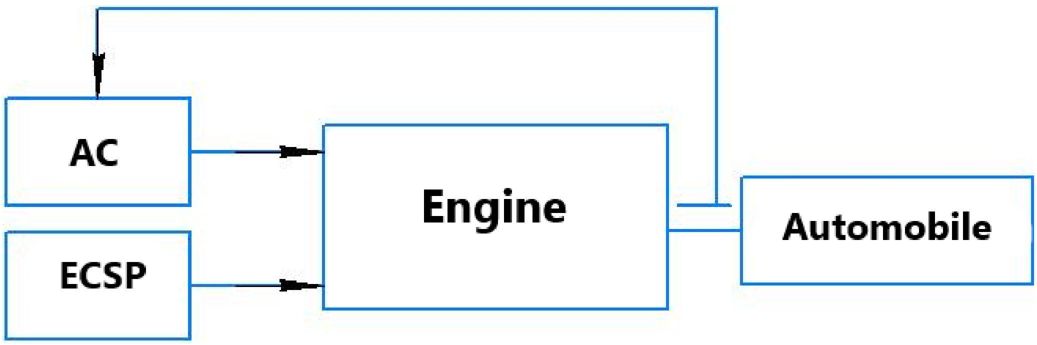

Fig. 8. Diagram of cooling system with automatic controller

The signals from the cooling system go to a back-up (emergency) pump and automatic controller, which, when there is a failure in the main cooling system pump, connects the back-up pump and disconnects the main pump. It will be assumed that no consequences of failure in the main pump of the automobile engine cooling system, when the back-up pump is fault-free, show up (they are prevented by switching the emergency pump on). Hence, the failure in the entire cooling system will occur when the back-up pump fails. At that, it can fail with the fault-free main pump or after its failure. Taking this in account, the following states of the system are possible (Figure 9).

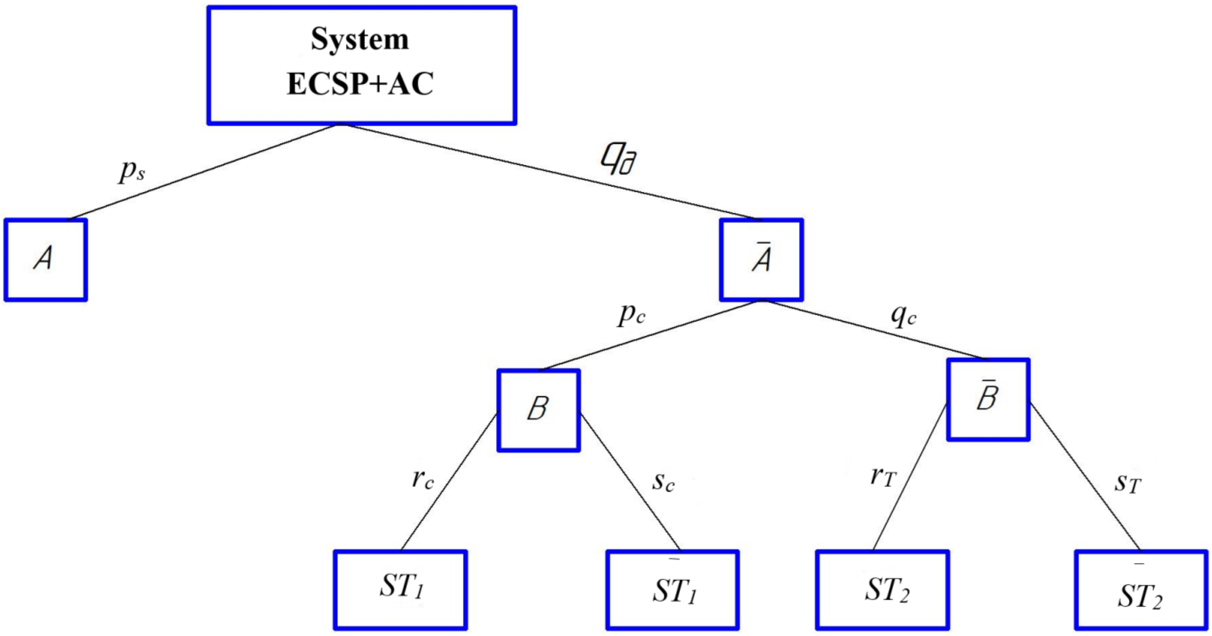

Fig. 9. Graph of the system states

A – all the system is fault-free with probability p_s;

$\overline{A}$ – failure in the main cooling system pump occurred with probability q_∂;

B – failure in the main pump occurred with fault-free with probability p_c automatic controller;

$\overline{B}$ – failure in the main pump occurred with failed with probability $q_c$automatic controller.

$$p_c + q_c = 1$$

where p_c – probability of favourable completion of road traffic with failed automatic controller;

q_c – probability of unfavourable completion of road traffic with failed automatic controller;

r_c – probability of driver's preventing the consequences of failure in automatic controller;

s_c – probability of driver's inability to prevent the consequences of failure in automatic controller.

$ST_1$and $\overline{ST}_1$– favourable and unfavourable outcomes of road traffic with driver's prevention and inability to prevent the consequences of failure in the main pump with automatic controller in operation with probabilities $r_c$and s_c respectively.

$ST_2$and $\overline{ST}_2$ – favourable and unfavourable outcomes of road traffic with driver's prevention and inability to prevent the consequences of failure in the main pump of engine cooling system, with fault-free automatic controller with probabilities r_T and s_T respectively.

The probability of unfavourable outcome (risk level) of transportation process can be determined by formulas:

1. With automatic controller

$$Q_{д+C} = q_i(p_C s_C + q_C s_T), \quad (1)(9)$$

2. Without automatic controller

$$Q_д = q_д s_T, \quad (2)(10)$$

The efficiency of using an automatic controller can be evaluated by relatively changing the level of risk:

$Q = Q_{д+с}/Q_{д} = S_c\,(1-q_c)+q_c$, (3)(11)

where $S_c = S_c/\overline{S_T}$

The results of calculations given in Figure 10 show that the risk level markedly decreases with highly reliable and efficient automatic controller.

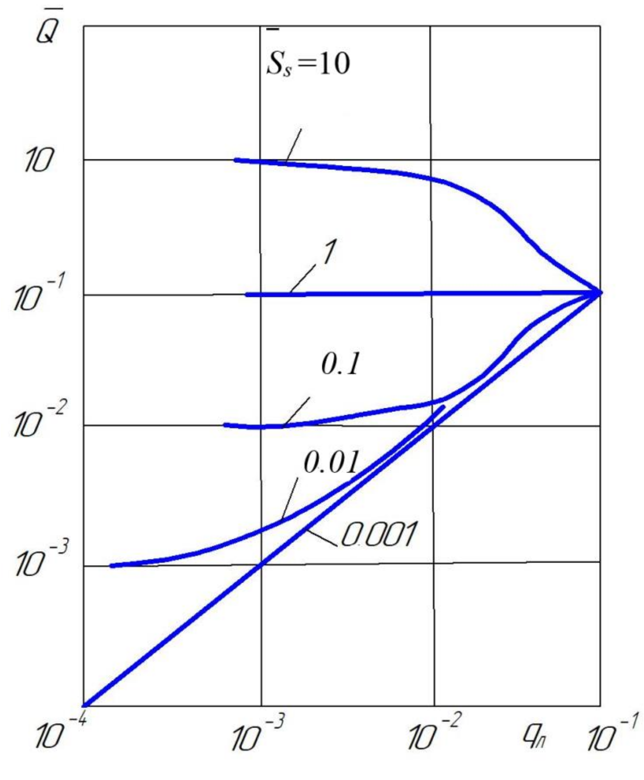

Fig. 10. Calculation results

Safety of transportation processes can be increased by enhancing the reliability of MV systems. In designing, there are scheme-based and constructive methods of increasing reliability. Scheme-based methods involve improvement of old and development of new schemes of creating technical devices. Scheme-basedmethodsimply:

- creation of simplest schemes with as low as possible number of elements;
- redundancy of elements and systems;
- development and use of in-built control means;
- creation of schemes withwider tolerances for changes in characteristics of elements.

Constructivemethodsinvolve:

- development and use of highly reliable elements;
- provision of elements and systems with more simplified operation modes;
- creation of highly advanced and serviceable structures;
- use of structural materials of a higher quality.

The main methods to increase reliability when manufacturing automobiles are as follows:

- improvement of technology and fostering production culture;
- automation of production, facilitating highly uniform process of manufacturing the elements of systems;
- training of elements and systems to stabilise the level of intensity of failures until operation stage;
- enhancement of methods for controlling the quality of manufacturing the elements.

The following measures are taken during operation to increase reliability:

- improvements to organisation and introduction of scientific methods of maintenance and operation;
- collection, record, and analysis of failures in automobiles, generalisation of experience learnt in operation;
- strengthening of relations with production facilities, design bureau, and scientific institutions;
- upgrade training of drivers and maintenance staff;
- enhancement of technology and quality of operation, maintenance, and repair works;

- introduction of means for controlling and forecasting the state of automotive equipment;
- enhancement of effectiveness of measures for preventing failures in the equipment.

Safety of transportation processes can be increased by decreasing the risk of failures in motor vehicles.

To do this, mostly practical measures can be taken:

- practical configuration of automobiles;
- restriction of speed and acceleration of controls movement;
- use of safety technical devices, and others.

For this purpose, technical devices need to be widely used on the present-day automobiles to control the efficiency of equipment and to inform drivers about its failures.

Agricultural motor vehicles are designed for transportation processes. Safety of transportation processes for such an equipment is not an end in itself, but a means to fulfil a production task, a condition for increasing operating efficiency. A need to take safety of transportation processes into account when evaluating the efficiency of utilising motor vehicles used in agricultural production stems from the fact that more intense production activity causes more accidents and crashes. This is due to, on the one hand, a necessity to utilise all MV capabilities in production when reaching higher velocities, on the other — a substantial increase in psychophysiological driver's load (BorschenkoandGuselnikov, 2016; Khristoforovetal., 2015, 2017; Syschikovetal., 2017; Reshnyak, 2011; GIBDD.rf, 2020).

Interrelation between safety of transportation processes and production efficiency is obvious in selecting traffic modes, type of safe manoeuvre and in other cases. Thus, for example, sometimes, to have a successful transportation process, an off-road movement is needed. However, here the probability of the MV stopping due to external conditions (terrain obstacles) increases. If the probability of fulfilling production task P_{TP} is taken as an indicator of efficiency of using MV considering safety of transportation processes, the following can be written

$P_{PT}=P_{ST}P_{STP}$

where P_{ST}– probability of fulfilling a production task, computed on condition that there is no road accident (safe task);

P_{STP} – probability of no RA by the reasons not related to the direct effect of external factors.

Interrelation between safety of transportation processes and production efficiency is more noticeable when restrictions are imposed on, e.g. speed, critical radius of turning, critical rollover speed and others, intended to prevent agricultural motor vehicles' reaching hazardous traffic modes. The probability of RA occurrence depends on the MV behaviour when approaching the hazardous mode (for instance, critical rollover speed) and driver's actions when reaching this mode. The less the dynamic properties change in hazardous mode, the more the probability is that a driver is able to control the MV properly, prevent the consequences of reaching this mode. It is evident that in such cases a closer approach to the considered hazardous mode can be admitted, what expands production capabilities of motor vehicles utilised in agricultural sector. But if, when reaching such modes, a sharp deterioration of dynamic MV properties, e.g. loss of stability or steerability, is seen, a driver faces problems when operating the MV, and he can prevent RA with less probability. In this case, when imposing restrictions, it is necessary to make a provision for a greater margin of the parameter, that characterises the hazardous mode, to make a constraint more "tight", what, naturally, will decrease production capabilities of agricultural transport equipment.

Let the problem about imposing a restriction on the critical rollover speed be considered as an example. Suppose that certified studies have provided the dependence of probability P_{STP} on the value of critical rollover speed, depicted in Fig. 11.

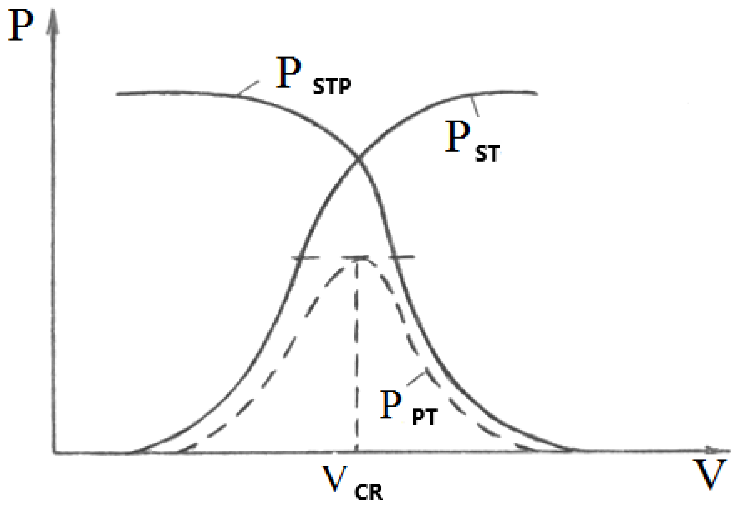

Fig. 11. Dependence of probability of fulfilling the production task on the value of critical rollover speed

It is seen that when the value of speed V_R increases, starting from some value thereof, a decline in probability P_{STP} is seen. To ensure safety when performing turning, the movement speed should be reduced, what may cause manoeuvrable, and, respectively, operational MV capabilities, characterised by the probability of fulfilling a production task P_{PT}, to become unsatisfactory.

Maximum probability of successful completion of production task P_{PT} should be a criterion for specifying the V_R constraint. The production task will be successfully fulfilled, if two events occur simultaneously: fulfilment of the production task and absence of the RA. If the probabilities of fulfilling the production task P_{ST} and the RA absence P_{STP} are curves plotted in Figure 11, the probability of fulfilling a production task $P_{PT}=P_{ST}P_{STP}$ will be maximum at the V_{R1} speed. It serves no purpose to specify a permissible value of critical rollover speed V_R, that differs markedly from V_{R1}.

4. Conclusion

The following conclusions can be drawn from the conducted studies of theproblem of ensuring safety of transportation processes:

1. It has been identified that the problem of ensuring safety of transportation processes in AIC is important and requires a particular attention since RAs cause deaths and injuries to persons, a significant material damage is inflicted on agricultural enterprises.

2. The “Driver–car–road–environment” system plays a big role in the system of ensuring safety of transportation processes in AIC. The “Driver–car” link occupies a central place in the system: more than 50% of RAs in agricultural sector occur through a fault ofdrivers and out-of-run motor vehicles.

3. It has been found that in AIC companies no methodology exists on ensuring safety of transportation processes, there are no methods, pursuant to regulatory documents, for evaluating the efficiency of developed measures for ensuring traffic safety, decreasing the number of road accidents, reducing severity of their consequences.

4. It has been established that the reasons for road accidents in AIC have a stochastic behaviour, however, insufficient attention is given to the use of probability theory in analysing safety of transportation processes.

It can be inferred from the conducted studies and drawn conclusions that:

1. The study is relevant since there are worrisome rates of accident incidence and road traffic injuries in AIC, injuries of operators of transport and mobile power-operated vehicles, employed in agricultural production, most accidents occurred due to design-manufacturing defects of equipment, automobiles, in particular, dump trucks, dump trailers with hydraulic truck tippler.

Hence, the article aims at increasing safety of transportation processes in AIC, revealing the reasons for, factors, and circumstances of road accidents, reducing severity of their consequences.

A system-oriented approach became leading in studying the problem, involving scheme-based and constructive methods that enable systematic consideration of the questions related to enhancing safety of motor vehicles used in agricultural sector, an increase in reliability of which facilitates reduction in the number of road accidents for technical reasons and decreases severity of their consequences in agricultural production.

The article reveals certain reasons for having RAs, specifically, due to failure to use technical devices of motor vehicles, which finally make it possible to enhance safety of transportation processes. A criterion has been developed that allows evaluating the efficiency of technical measures, proposed to decrease the intensity of failures in the elements of MV technical systems. A partial criterion has been developed appropriate for estimating the effect of technical devices installed on MV, on safety of agricultural transportation processes, considering the influence of efficiency of these technical devices.

Recommendations. The article materials are of practical value to the vehicle manufacturing industry, officers of research institutions and higher educational institutions, heads of agricultural enterprises and all concerned (masters, postgraduates, engineers).

References

Baranov, E. F.; Galvanovskiy, L. M.; Golberg, I. M. (2018). Russian Statistics Yearbook. Moscow: Rosstat Publ.

Belous, I. N.; Shapovalov, V. F.; Malyavko, G. P.; Prosyannikov, E. V.; Yagovenko, G. L. (2019). The effectiveness of chemicals in the cultivation of winter rye on soil contaminated by radiation. Amazonia Investiga, 8(23), 759-766.

BODIASRTSID (Bryansk Oblast DIA State Road Traffic Safety Inspection Department). (2015). Information and analytical digest 1991–2015. Bryansk Oblast DIA State Road Traffic Safety Inspection Department: Bryansk Russia: BODIASRTSID Publ.

Borschenko, Y. A.; Guselnikov, Y. A. (2016). Ensuring safety of road traffic based on professional competence of automobile transport experts. Transport systems of Siberia. In: Proceedings of International Research and Practice Conference Development of transport system as a catalyst for the country's economic growth materials 2016. KrasnoyarskRussia: Siberian Federal University Publ., pp.480-488.

Bystrova,T. Yu.; Zhileva,E. P.; Klorshtein,V. E. Bryansk Oblast, 2019 Statistical digest. Bryansk Russia: Bryanskstat Publ., 2019. 432p.

Chvanov,V. V. Comparativestudyofinternationalstatisticaldataonroadaccidents. In: MADIProceedings. . MoscowRussia: Moscow Automobile and Road Institute Publ., 2000. pp. 111-120.

Didmanidze, O. N.; Varnakov, D. V. Increasing parametric reliability of auto engines. RepairRenovationModernization, v.5, pp.2-7, 2007.

Evtyukov,S. A.; Vasiliev,Y. V. Vehicle-pedestrianroadaccidentmechanismmodel. Saint-PetersburgRussia: St. Petersburg University of Architecture and Civil Engineering Publ., 2005. pp. 300-302.

Galyanov, I. V. Predicting the number of road accidents and those injured therein.In: Proceedings of conference Theoretical and practical aspects of labor protection in the agro-industrial complex, 1995.OrelRussia: VNIIOT Publ., 1995. pp. 96-101.

Gazvan,A. Kh.; Asp,K. Internationalmodelsforevaluatingthelevel oftrafficsafety.ScienceandTechnologyinroadsector, n.3, pp.3-9, 2006.

GIBDD.rf. Official website of the State Automobile Inspectorate. Retrieved from: http://www.гибдд.рф. Access date 20.10.2020

GOST 33997-2016 Wheeled vehicles. Operation safety requirements and verification procedures. Moscow Russia: GOST Publ., 2016.

Hudson, T. G. L.; Hudson, P. T. W. 2020. Risk space - Understanding the complexity of operational risk. In: Society of Petroleum Engineers - SPE International Conference and Exhibition on

Health, Safety, Environment, and Sustainability 2020, HSE and Sustainability 2020 SPE-199401-MS. 27 - 31 Jul 2020 Virtual Conference and Exhibition (COT; UTC-5). SPE International.

Khristoforov, E. N.; Sakovich, N. E.; Nikolaev, M. Y. Concerning the question on ensuring safety of transportation processes in agricultural production. GOSNITI Trudy, v.129, pp.112-118, 2017.

Khristoforov,E. N.; Sakovich,N. E.; Samusenko,V. I.; Nikitin,A. M. Ensuringsafetyoftransportationprocesses, definedbyreliabilityoftrucks.BulletinofBryanskStateTechnicalUniversity, v.2, no.46, pp.88-92, 2015.

Khyarkanen, K.Ensuring safe road traffic in Finland. Science and Technology in road sector, v.1, pp.30–32, 2007.

Kupreenko, A. I.; Isaev, K. M.; Grin, A. M.; Mikhailichenko, S. M.; Kolomeichenko, A. V.; Kuznetsov, Y. A.; Kalashnikova, L. V. Automated distribution system of feed mixture by using feeding carriage. INMATEH Agricultural Engineering, v.58, no.2, pp.239-246, 2019.

Kupreenko, A. I.; Isaev, K. M.; Kuznetsov, Y. A.; Mikhailichenko, S. M.; Kravchenko, I. N.; Kalashnikova, L. V. Modeling of mobile tmr mixer operation. INMATEH Agricultural Engineering, v.61, no.2, pp.193-198, 2020.

Melnikova, O. V.; Torikov, V. E.; Kononov, A. S.; Kosyanchuk, V. P.; Prosyannikov, E. V.; Osipov, A. A. Efficiency of the solar energy usage by winter wheat plantings made with different crop cultivation technologies. Journal of Environmental Treatment Techniques, v.8, no.2, pp.657-663, 2020.

Nikulin, V. V.; Sakovich, N. E.; Khristoforov, E. N.; Nikolaev, M. Y. Analysing road safety of vehicles in Bryansk Oblast. GOSNITITrudy, v.127, pp.81-85, 2017.

Orudzhova, O. N. On ensuring automobile road traffic safety with growing level of automobilization. In: Proceedings of Xth International research and practice conference on the 85 anniversary of Dr. of Engineering Science, Prof. L.G. Reznik birth: Organization and safety of road traffic, in 2Ch., 16 Marth 2017. Tumen Russia: Tyumen Industrial University, 2017. pp.112-115.

Pilipovich,A. Digitaltachographsintransitionperiod.Automobiletransport, v.8, pp.53-55, 2007.

Porkhacheva, S. M. On the question about investigating road accidents. Tyumen Russia: Tyumen Industrial Institute Publishing House, 2017.

Razmi, R. S.; Farah, H.; Taale, H., van Arem, B.; Hoogendoorn, S. P.Design and operation of dedicated lanes for connected and automated vehicles on motorways: A conceptual framework and research agenda. Transportation Research Part C: Emerging Technologies, v.117, 102664, 2020. https://doi.org/10.1016/j.trc.2020.102664

Redkin,V. M.; Borisov,O. Yu. RoadtrafficaccidentsinRussiawithinthe 1990–2005 periodandthewaysforreducingtheirnumber. Lifesafety, v.11, pp.34–42, 2006.

Reshnyak,M. G. Contemporaryproblemsofensuringroadtrafficsafety.BulletinofInternationalLawInstitute, v.1, n.37, pp.28–35, 2011.

RFG (RFGovernment). OntheFederalSpecial-PurposeProgramme “Increasingroadtrafficsafetywithinthe 2013–2020 period”: RFGovernmentDecreedated 3.09.2014 №864. Moscow Russia: RFG Publ., 2014.

RFG (RFGovernment). RoadtrafficsafetystrategyinRFfor 2018–2024: RFGovernmentDecreedated 8 January 2018 №1. Moscow Russia: RFG Publ., 2018.

STOP_newspaper. StateReportonroadtrafficsafety. STOP newspaper, v.9, pp.1–23, 2006.

Syschikov,D. A.; Tarabrin,D. A.; Gavrikov,V. A. Reductionofroadaccidentsinvolvingtrucksthroughchoosingsaferoutes. Tyumen Russia: TyumenIndustrialInstitutePublishingHouse, 2017. 159p.

Tokunaga, Y.; Nakahara, N.; Itadani, M. Development of Ultra-Low-Friction and Zero-Leakage

Mechanical Seal for High-Speed e-Mobility Shaft Sealing Applications. SAE Technical Paper 2020-01-1090, 2020. https://doi.org/10.4271/2020-01-1090.