UDC 331.45: 614.8: 331,103,253

Evaluation RISK OF INJURY tractor-driver in performing OBSLUHOVUVANNYATA Agricultural machinery repair

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The article demonstrated the use of continuous Markov chains to evaluate the risk of injury tractor-driver due to falling tractor trailer raised during maintenance and repair of machine and tractor units with defective hydraulic system of the tractor.

The risk of accidents, tractor-driver.

Problem. Despite the gradual reduction of accidents among machine operators APC observed in recent years, the profession of the tractor-driver continues to be one of the most traumatic in the agricultural sector. First of all, it is because their work is related to the operation of mobile agricultural machinery (tractors, combines and other self-propelled agricultural machines) that by its nature is a source of danger. These technical means of production used in conjunction with many agricultural units to perform various operations agrotechnological - preplant and post-harvest tillage, planting crops, care, harvest and so on. It is natural that in the operation of these technical means of production there is a need for their periodic maintenance or repair even when that may happen numerous accidents with the staff. In particular, the maintenance or repair tractor unit (hereinafter - MTA) for a faulty hydraulic tractor can

lead to the onset of many hazardous situations, the effects of which can be different injury severity among tractor-driver.

This is confirmed by the State Service of Mining Supervision and Safety of Ukraine occupational injuries with lethal consequences. Thus, during the years 2004-2013 in Ukraine AIC was fatally injured falling trailers is 10 machine during maintenance or repair MTA.

In order to develop and implement effective measures to prevent injury tractor-driver must thoroughly study the processes of nucleation, formation and occurrence of traumatic situations, to their qualitative and quantitative analysis and establish indicators of occupational risk during machine maintenance and repair of the AIT. Existing studies to determine the risk of injury tractor-driver in the performance of various mechanized work in agriculture, including the maintenance and repair of MTA makes it difficult to carry out deep analysis of current traumatic situations that adversely affect the development and implementation of appropriate preventive measures. Therefore, further research on finding the most suitable methods for the quantitative determination of occupational hazards machine AIC is relevant.

Analysis of recent research. Today the issue of qualitative analysis and quantitative determination of occupational risk, finding ways to reduce its level to acceptable limits attracts both scholars and specialists labor protection services businesses and organizations. Publications of many scientists in the field of labor point to the existence of different approaches and methods to research the problem of occupational injuries in general and occupational risk in particular. Thus, some experts focusing only on the analysis of hazardous factors and reasons for getting work-related injury without conducting qualitative and quantitative analysis of flow processes themselves traumatic situations and their consequences [1-5].

However, other scientists to study the effects of industrial accidents have become increasingly use methods of logical and mathematical modeling [6-9]. These methods allow to quantitatively establish the risk of injury when performing certain operations that enables the camera to develop and implement effective preventive measures.

Among these methods should single out the method of "fault tree" as one of probabilistic analysis methods are determined using quantitative and qualitative characteristics of occupational injuries and accidents [8, 9]. This method is quite effective and user-occupational risk assessment, but did not fully investigate allows the process flow traumatic situation. In particular, the method makes it possible to determine the transition probabilities performance system "man-machine-production environment" from one state to another, returning the system to its previous state, as well as to predict the probabilities of the value system in the medium and long term. This makes methods lie in the plane of the theory of differential equations. However, these methods do not allow to determine the degree of influence of each primary (basic) events, a cause-effect main event.

Thus, only through the combination of the "fault tree" with the methods of the theory of differential equations can be most precise and profound study processes of nucleation, formation and occurrence of traumatic situations.

Formulation of scientific problem.

To address these shortcomings, in this paper was applied a technique which is based on mathematical tools Markov random process with discrete states and continuous time. This made it possible to thoroughly analyze the dynamics of the process flow traumatic situation of its possible consequences.

The purpose of research is a probabilistic analysis of "mechanic-ITA-production environment" and the qualitative and quantitative description of the process flow traumatic situations during the operation of various agricultural mechanization technology.

Results. A detailed and in-depth study of the causes of accidents that occurred during the operation of mechanization their tractors, combines and other self-propelled agricultural machines indicates certain patterns and processes of nucleation onset. On the other hand, based on a systematic approach to study the phenomenon of occupational injuries, consider any MTA configuration and machine operators, and in some cases, factors of production environment, as elements of an integrated system that are in constant interaction with each other, in which the change of state any of the elements of the system entails a change in the initial state of the system [10].

For the mathematical description of processes of nucleation, formation and occurrence of accidents applied mathematical tools developed in probability theory for Markov random processes with discrete states and continuous time in which the transition system "mechanic-ITA-production environment" (hereinafter - the system S) with one state to another is possible in any, is not known in advance, random time t.

When considering random processes with discrete states and continuous time convenient to represent transitions S system from one state to another as taking place under the influence of certain streams of random events. This transition probability density λ are content intensities corresponding flow of events. The process that runs in the system S, is Markov if all these events are Poisson streams (ordinary, without aftereffect, constant or time-dependent intensity) [11-14].

For example, probabilistic analysis system "mechanic-ITA-production environment" was chosen one of the most common adverse events occurring with tractor-driver while operating various MTA and self-propelled agricultural machines, namely - injury of machine falling tractor trailer during maintenance or repair the MTA.

Count current status of the specified adverse events are presented in Fig. 1.

From Fig. 1 shows that since the introduction of the AIT system in operation is in good condition S0, where it can be the entire period of his work, until decommissioning. However, practice shows that after a period of time under the influence of flow events with intensity λ01 system can go out of whack S1 (in this case - to work with a defective hydraulic system). However, this does not affect the ability of our system to continue to operate in a given mode.

Working in state S1 under flow events with intensity λ10, the system can return over time back to state S0 (bring hydraulic tractor in good condition). However, because of some errors of machine, under the influence of flow events with intensity λ12, the system can go into a state S2, which is characterized hit machine operators in a dangerous situation - namely, getting into the danger zone possible fall trailers during maintenance or repair by MTA faulty hydraulic tractor.

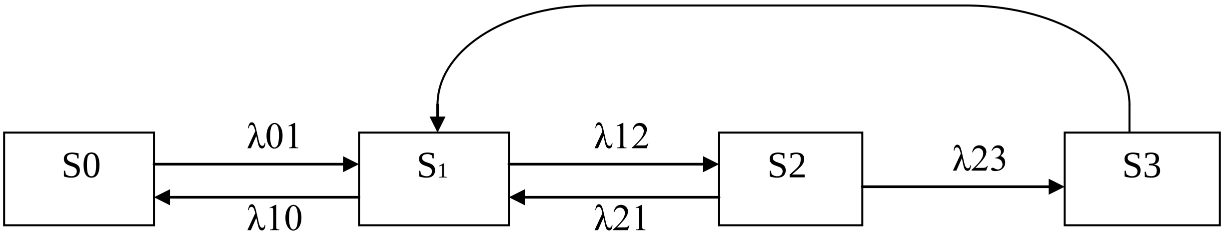

Fig. 1. Count current status of unwanted events "injury of machine falling tractor trailer during maintenance or repair MTA": S0 - system is in good condition; S1 - system is out of whack (tractor hydraulic system failed); S2 - hit machine operators in a dangerous situation (hitting machine operators in the danger zone possible fall trailers during maintenance or repair ITA) S3 - Jump dangerous situation in a critical situation (injury incident of machine trailer).

Then there are several variants of adverse events:

a) under flow events with intensity λ21 system returns to its previous state S1, which can continue to work in the future, or later under flow events with intensity λ10 returns to the initial state S0;

b) under flow events with intensity λ23 system goes into S3, which is characterized by the transition to a critical dangerous situation (injury incident of machine trailer) and subsequent return under flow events with intensity λ31 in state S1, in which a system like circumstances for point and may continue to operate or later, under the influence of flow events with intensity λ10, return to the initial state S0.

Knowing tagged state graph, we can determine the probability of the state of our system $P_0(t), P_1(t), P_2(t)$ and $P_3(t)$ as a function of time.

Specifically, these probabilities satisfy the system of differential equations Kolmogorov-Chapman, which are unknown functions of probability states of the system [13, 14]:

$$\begin{cases} \frac{dP_0(t)}{dt} = -\lambda_{01}P_0(t) + \lambda_{10}P_1(t), \\ \frac{dP_1(t)}{dt} = \lambda_{01}P_0(t) - (\lambda_{10} + \lambda_{12})P_1(t) + \lambda_{21}P_2(t) + \lambda_{31}P_3(t), \\ \frac{dP_2(t)}{dt} = \lambda_{12}P_1(t) - (\lambda_{21} + \lambda_{23})P_2(t), \\ \frac{dP_3(t)}{dt} = \lambda_{23}P_2(t) - \lambda_{31}P_3(t) \end{cases}$$

with the normalization condition $P_0(0) + P_1(0) + P_2(0) + P_3(0) = 1.$

Introducing consideration to vector function $\vec{P}(t) = (P_0(t), P_1(t), P_2(t), P_3(t))$ and a matrix of intensities:

$$\Lambda = \begin{pmatrix} -\lambda_{01} & \lambda_{10} & 0 & 0 \\ \lambda_{01} & -\lambda_{10} - \lambda_{12} & \lambda_{21} & \lambda_{31} \\ 0 & \lambda_{12} & -\lambda_{21} - \lambda_{23} & 0 \\ 0 & 0 & \lambda_{23} & -\lambda_{31} \end{pmatrix}$$

we can rewrite the system of equations Kolmogorov as the following linear matrix differential equations:

$$\begin{cases} \frac{d\vec{P}(t)}{dt} = \Lambda\vec{P}(t), \\ 1\vec{P}(\cdot) = \sum_{i=0}^{3} P_i(0) = 1, \ P_i(0) \geq 0. \end{cases} \tag{1}$$

For the solution of system (1) can be used Laplace transform. According to [15] for functions $f(t)$ its Laplace transform has the form $F(p) = \int_0^\infty e^{-pt} f(t)dt.$ Then the original $f'(t)$ will match function $pF(p) - f(0).$

The inverse Laplace transform is as follows:

$$f(t) = \frac{1}{2\pi i}\int_{t-i\infty}^{t+i\infty} e^{pt}F(p)dp. \, . \vec{\pi}(p)$$

Let the vector function is as follows: $\vec{\pi}(p) = (\pi_0(p), \pi_1(p), \pi_2(p), \pi_3(p)),$ where $\pi_i(p), i = \overline{0,3}$ - The relevant features images of states $P_i(t), i = \overline{0,3}$ in the case of the Laplace transform. Then the differential system (1) becomes a linear algebraic system:

$$\vec{\pi} = Q\vec{\pi} + \vec{g}, \tag{2}$$

where the matrix Q and vector $\vec{g}$ in accordance with the form $Q = \frac{1}{p}\Lambda,$ $\vec{g} = \frac{1}{p}(P_0(0), P_1(0), P_2(0), P_3(0))$ Or in expanded form:

$$\begin{cases} \pi_0(p) = -\frac{\lambda_{01}}{p}\pi_0(p) + \frac{\lambda_{10}}{p}\pi_1(p) + \frac{P_0(0)}{p}, \\ \pi_1(p) = \frac{\lambda_{01}}{p}\pi_0(p) - \frac{(\lambda_{10} + \lambda_{12})}{p}\pi_1(p) + \lambda_{21}\pi_2(p) + \lambda_{31}\pi_3(t) + \frac{P_1(0)}{p}, \\ \pi_2(p) = \frac{\lambda_{12}}{p}\pi_1(p) - \frac{(\lambda_{21} + \lambda_{23})}{p}\pi_2(p) + \frac{P_2(0)}{p}, \\ \pi_0(p) = \frac{\lambda_{23}}{p}\pi_2(p) - \frac{\lambda_{31}}{p}\pi_3(p) + \frac{P_3(0)}{p}, \end{cases}$$

with the condition $\sum_{i=0}^{3}\pi_i(p) = \frac{1}{p}$.

Transform the system (2) to the form:

$$(I - Q)\vec{\pi} = \vec{g}. \quad (3)$$

There are two cases:

1) $\det(I - Q) \neq 0.$

Then there is a unique solution matrix system (3) in the form $\vec{\pi} = (I - Q)^{-1}\vec{g}$. Performance normalization condition check direct substitution obtained solution;

2) $\det(I - Q) = 0.$

In this case, the solution matrix system (3) does not exist for all the right parts $\vec{g}$ But only for those and only those $\vec{g}$ Satisfying the condition $P_{N((I-Q)^T)}\vec{g} = \vec{0}$. In this condition the set of solutions of the system will look like:

$$\vec{\pi} = (I - Q)^{+}\vec{g} + P_{N(I-Q)}\vec{c}.$$

For any vector $\vec{c} \in R^4$ Where the matrix $(I - Q)^{+}$ - Pseudoinverse Moore-Penrose on the matrix (I - Q) [15].

Performing the inverse Laplace transform and checking normalization condition, we find the desired distribution of states.

To calculate the ratios of intensities of transitions of the system used averages: State Statistics Service of Ukraine - on the number of tractor trailers that are registered agricultural enterprises, the State Committee of Ukraine - on injury cases falling trailers machine during maintenance or repair MTA and expert assessment specialists and direct contractors on operating time to refuse the tractor hydraulic system and the probability of some states the process flow traumatic situation.

An analysis of the relevant relationships that characterize each condition studied system, yielded the following ratios of intensities:

- The average number of tractor trailers that are registered farms - 72,940 units;
- The number of tractors with hydraulic system intact - 69,923 units ($\lambda 00 = 0,96$);
- The number of tractors with hydraulic system faulty - 3017 units ($\lambda 01 = 0,04$);
- The number of tractors, which shows the hydraulic system in good condition - 2112 units ($\lambda 10 = 0,7$);
- The number of tractors with defective hydraulic system that continues to operate - 905 units ($\lambda 11 = 0,3$);
- The number of tractors with defective hydraulic system whose operation led to the onset of dangerous situations - 724 units ($\lambda 12 = 0,8$);
- The number of dangerous situations that have fallen in critical - 29 cases ($\lambda 23 = 0,04$);
- Transfer of dangerous situations in defective condition - 695 cases ($\lambda 21 = 0,96$);
- The transition from critical situations in defective condition - 29 cases ($\lambda 31 = 1,0$).

Thus, based on the total number of tractor trailers - 72,940 units, of which 3017 units operated with a defective hydraulic system of the tractor, the intensity of the transition of the system from state S0 to state S1 be $\lambda 01 = 3017/72940 = 0,04$.

Whereas, in 3017 coming from faulty hydraulic system 2112 units were repaired (restored) in good condition, the intensity of the transition from a state system in state S0 S1 be $\lambda 10 = 2112/3017 = 0,7$.

With 905 tractors, which continued to operate with faulty hydraulic system, 724 units led to the occurrence of traumatic situations. Thus, the intensity of the transition of the system from state S1 to state S2 will be $\lambda 12 = 724/905 = 0,8$.

Further, of these 724 tractor with a defective hydraulic system whose operation led to the occurrence of traumatic situations 695 back in defective condition without any consequences for health damage mechanics. The intensity of the transition of the system from state S2 to state S1 in this case will be so $\lambda 21 = 695/724 = 0,96$.

With 724 tractors with defective hydraulic system whose operation led to the occurrence of traumatic situations in 29 units traumatic situation shifted in critical that saw injury mechanics. The intensity of the transition of the system from state S2 to state S3 will be $\lambda 23 = 29/724 = 0,04$. All 29 tractors with defective hydraulic system whose operation has resulted in potentially dangerous situations and injuries machine, then turned back into whack. Thus, the intensity of the transition of the system from a state to a state S3 S1 be $\lambda 31 = 29/29 = 1,0$.

Matrix transition of the system would look like this:

$$\Lambda = \begin{pmatrix} -0,04 & 0,7 & 0 & 0 \\ 0,04 & -1,5 & 0,96 & 1 \\ 0 & 0,8 & -1 & 0 \\ 0 & 0 & 0,04 & -1 \end{pmatrix}$$

Solving the Kolmogorov-Chapman and taking into account the condition of normalization, we obtain the probabilities of the family system:

$$\begin{cases} P_0(t) = -0,264c_1(0,116)^t - 0,026c_2(0,353)^t - 0,824c_3(0,703)^t + 0,996c_4, \\ P_1(t) = 0,793c_1(0,116)^t + 0,036c_2(0,353)^t + 0,356c_3(0,703)^t + 0,071c_4, \\ P_2(t) = -0,549c_1(0,116)^t - 0,712c_2(0,353)^t + 0,44c_3(0,703)^t + 0,057c_4, \\ P_3(t) = 0,02c_1(0,116)^t + 0,702c_2(0,353)^t + 0,028c_3(0,703)^t + 0,002c_4, \end{cases}$$

Add all probability, the sum should be unity. After adding obtain the following equation for constant c4:

$$0,996c_4 + 0,071c_4 + 0,057c_4 + 0,002c_4 = 1,126c_4 = 1.$$

Finally found $c_4 = 0,888$. Other constants can be arbitrary, but so that the sum of probabilities was essential. For example, if the first three constants put zero, the function of the state will be as follows:

P0 (t) = 0,884; P1 (t) = 0,063; P2 (t) = 0,051; P3 (t) = 0,002.

In fact, for all other cases (for any choice of constants) with increasing time points likelihood will go to the specified distribution, indicating that the steady state of the system.

Thus, the probability of system stay in state S0 is 0.884, a state S1 - 0,063, a state S2 - 0,051, a state S3 - 0,002. This means that 88.4% of tractors ekspluatuvatymutsya in good condition; 11.6% pass in defective condition, of which 6.3% still work on it without creating, while traumatic situations; operation of 5.1% would lead to the onset of traumatic situations without damaging the health of machine; operation of 0.2% would lead to the onset of traumatic situations and moving them to the critical (machine operators falling injury trailer tractor).

As seen from the example of the evaluation, the results can be used for medium- and long-term forecasting probabilities of the system "man-machine-production environment" in terms of occupational risk AIC machine.

Conclusions

1. The use of continuous Markov chains as a method of probabilistic analysis of random events makes it possible to quantify the

risk of injury tractor-driver while operating mobile AIT and allows you to find the desired probability of states of the system dynamics at all stages of the process flow of unwanted events.

2. Increase points in time virtually no effect on the initial probability distribution of the system, indicating that the stationary mode of operation. This means that the projected performance of state probabilities of the system in the medium and long term remain almost unchanged held constant, the current conditions of the system.

3. Thus, to reduce occupational hazards tractor-driver must reduce the intensity of the transition state of the system in a faulty state with subsequent transition to the traumatic and critical situation by taking appropriate preventive measures to avoid working with a defective hydraulic system MTA.

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In Article prodemonstryrovano Application of Markov chains neprerыvnыh for otsenki line travmyrovanyya traktorystov-mashynystov Due Fall podnyatoho tractor trailers TIME t tehnycheskoho Maintenance and repair of machine-traktornыh agregatov with neyspravnoy hydrosystemoy tractor.

Risk, Neschastny Sluchai, tractor-mashynyst.

In paper demonstrates the application of continuous Markov chains to evaluate the risk of injury to tractor drivers from falling tractor trailer raised during maintenance and repair of tractor units with faulty hydraulic system of tractor.

Risk, accidents, tractor-driver.