STUDYING AND ASSESSING SAFETY AT WORK ON UNDERGROUND TRANSPORTATION SELF-PROPELLED EQUIPMENT

candidate of technical sciences, associate professor Makashev B. K.,
candidate of technical sciences, associate professor Khamitova G. ZH.,
master Maigeldinov A. U.

Kazakhstan, Zhezkazgan, Zhezkazgan University named after Academician O. A. Baikonurov

ARTICLE INFO
Received 15 March 2018
Accepted 30 March 2018
Published 12 April 2018

KEYWORDS
safety at work, safe operating rules, underground transportation, self-propelled equipment, occupational injury

© 2018 The Authors.

It is known that to assess safety at work at any enterprise two statistic indices are used: the frequency rate and injury severity rate [1].

The frequency rate \( K_f \) is calculated as follows:

\[
K_f = \left( \frac{A}{B} \right) \cdot 1000, \quad (1)
\]

where \( A, B \) are the corresponding number of injured people and the listed number of employees at the enterprise in the reporting period, people.

The injury severity rate \( K_s \) is:

\[
K_s = \frac{C}{A}, \quad (2)
\]

where \( C \) is the total number of disability days of all injured people during their illness period, temporal disability of whom ended in the reporting period; \( A \) is the number of injured people (except dead people) in the reporting period, people.

According to the logics of this method and following our recommendation in the underground mines of «Kazakhmys» corporation they have applied such statistic indices as the accident frequency rate \( K_{sa} \) per 100 machines and machine downtime rate due to the accidents \( K_{pa} \) for three years in order to assess safety operation of underground transportation self-propelled equipment (UTSPE).

\[
K_{sa} = \frac{M_a}{M_c} \cdot 100, \quad (3)
\]

where \( M_a \) is the number of the machines which had accidents because of faults and malfunctions, items.; \( M_c \) is the listed number of the machines in the mine in the reporting period, items.

\[
K_{pa} = \frac{D}{M_a}, \quad (4)
\]
where \( D \) is the total number of machine downtime because of the accidents, days.

It should be noted that these indices to some degree can allow to assess the condition of safe operating the UTSPE only on one part of the underground mine and cannot analyze actual safety at work and chose optimal operating parameters of technological processes to load and transport ore in the whole mine.

According to Russian scientists (MGGU, MADI, etc.) assessment of safety at work at the enterprise (by \( K_c \) and \( K_t \)) has its drawbacks [1]. They note that it is passive by character because it reflects and generalizes the facts of traumatism which have already happened and does not allow to see injury risk factors and background causes such as mine geological conditions and parameters of the applied machines and technologies. These coefficients are not acceptable to optimize technological parameters which can provide minimal or no traumatism, and to predict safety at work assessing different variants of technical solutions.

To improve management efficiency of targeted actions as to safety at work it is necessary to have a reliable criterion to assess safety at work including safety on the underground ore transportation.

The analysis proves that accidents and breakdowns which happened on ore transportation in the underground mines as a rule are accidental cases with a complicated causality and their nature is of probability character. That is why cases of accidents and traumatism can be considered as a flow of random cases which is described by the law of Poisson [2]. By this law the probability of the case that time of machine’s accident-free operation \( «T» \) is bigger or equal to the designed time \( «T_z» \) can be accepted as a safety at work criterion of the machine’s operation \( «B» \) that is:

\[
B(T) = P[T \geq T_z] \tag{5}
\]

The case probability that the time of machine’s accident-free operation is less than \( «T_z» \) can be accepted as a criterion of machine’s safe operation \( «O» \) that is:

\[
O(T) = P[T < T_z] \tag{6}
\]

The expression (5) means that safety at work is the function of distributing time of UTSPE accident-free operation.

In the considered case we accept 20 days \( (T = 20 \text{ days}) \) for the span of accident-free operation time, then intensity of breakdowns or injury cases on UTSPE is their mathematical expectation [2] that is:

\[
I = n / T, \tag{7}
\]

where \( n \) is the number of breakdowns or accidents during the time \( «T» \).

As it is determined that dynamics of breakdowns (traumatism) in time can be expressed by the law of Poisson

\[
B = e^{-\lambda} = e^{-\lambda T} \tag{8}
\]

then

\[
O = 1 - e^{-\lambda} = 1 - e^{-\lambda T}, \tag{9}
\]

where \( B \) is the probability that during the time \( «T» \) no breakdown happens; \( O \) is the probability that during the time \( «T» \) at least one accident happens.

The general formula of accidents is as follows:

\[
n = f(x_1; x_2; x_3; \ldots x_n), \tag{10}
\]

where \( f \) is the function which sets the algorithm between the quality criterion of the machine function and its operating parameters; \( x_1; x_2; x_3; \ldots x_n \) are operating machine parameters.

The parameter \( «n» \) depends upon the type of UTSPE [3]: for the underground dump truck of ore MoA3-7405
for the underground dump truck MoA3-7508

\[ n = 0.60 + 0.0019q - 0.018f + 0.009L + 0.039v + 0.0013B - 0.045S_v \]  
(11)

for the underground dump truck TORO 40D

\[ n = 0.157 + 0.0039q - 0.014f + 0.009L + 0.059v + 0.0026B - 0.083S_v \]  
(12)

for the underground truck loader TORO 501 DL

\[ n = 0.197 + 0.0019q - 0.039f + 0.0088L + 0.035v + 0.0048B - 0.089S_v \]  
(13)

\[ n = 0.551 + 0.002q - 0.004f + 0.01L + 0.001v + 0.0016B - 0.061S_v , \]  
(14)

where \( q \) is water inflow, m³/h; \( f \) is the coefficient of ore hardness by the scale of professor M. M. Protodiakonov; \( L \) is the rock mass transportation length, m; \( V \) is the motion speed of ore auto-transportation, km/h; \( B \) is the number of working people who are in transportation or refining pits, or who are on temporal visits, people; \( S_v \) is the excavation cross-section area, m².

The designed regressive models of accidents intensity depending on particular mine geological conditions, mine technical and other factors for different standard size UTSPE, the received results are based on the analysis and processed statistical data of breakdowns and accident which happened on the underground transportation self-propelled equipment in the mines of «Kazakhmys» corporation.

The formula (7) lets us make a quantitative assessment of the actual operating safety on UTSPE while transporting and loading the rock mass with the account of the formulae (11–14) for the corresponding type of UTSPE and particular mine geological and mine technical conditions.

The results of our calculations of actual safety on UTSPE underground dump truck and ore underground truck loader are given bellow:

<table>
<thead>
<tr>
<th>UTSPE</th>
<th>MOA3-7405</th>
<th>MOA3-7508</th>
<th>TORO 40D</th>
<th>TORO 501DL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual safety</td>
<td>0.41</td>
<td>0.45</td>
<td>0.58</td>
<td>0.49</td>
</tr>
</tbody>
</table>

The data given proves that the most dangerous is the underground dump truck MoA3-7405 and the least dangerous is the underground dump truck автосамосвал TORO 40D.

If the actual safety of diesel pits in all underground pits is known it is possible to calculate its value for the whole industry branch (e.g. for «Kazakhmys» corporation) by the expression [4]:

\[ B = B_1B_2B_3...B_n = \prod_{i=1}^{n} B_i \]  
(15)

Mine geological parameters \( q \) (water inflow) and \( f \) (the coefficient of ore hardness) are not controlled, so their values are put into regressive models of accident or traumatism intensity as constants in particular conditions.

Mine technical parameters \( L \) (transportation length), \( S_v \) (excavation cross-section area), \( V \) (UTSPE motion speed), \( B \) (number of working people) are variable and controlled. The parameter «\( B \)» depends on the work regime, whereas «\( S_v, v, L \)» are calculated by definite data.

After calculating the parameter «\( n \)» depending on the type of UTSPE use the actual safety «\( B \)» is calculated by the expressions (11-14).

The research proves that increasing the ore transportation length «\( L \)» and motion speed of the underground dump truck «\( v \)» above the optimal values always leads to accident growth on the ore transportation equipment and consequently to decrease of operating safety. The increase of cross-section area of transportation pits «\( S_v \)» to 20 m² and more always promotes improving safety at work.

The developed models of accidents and injury intensity objectively reflect conditions of work on UTSPE at the present moment and make it possible to find such value of technological (mine
technical, operating, and etc.) parameters when safety at work will be maximum for the used machine and technology.

In order to decrease accidents and injury on the underground ore transportation as the most dangerous chain link the following actions should be done:

1. To reduce the length of underground ways to the maximum degree which do not meet the requirements of the normative documents; to put temporal signs warning drivers and pedestrians about dangers in the pits with non-standard gaps; to set special unloading cameras near the ore slopes which provide safety of unloading the dump truck, to provide reliable underground lightning of transportation and refining pits; to analyze loading, delivering and unloading processes in order to reduce the number of accidents and occupational injury; to improve technological and occupational discipline of workers and engineering-technical employees; to strengthen responsibility of engineering-technical staff for quality and timeliness of the given instructive coaching on safety operating rules of UTSPE; to control implementation of the actions developed by the investigation results of accidents and injury cases.

2. In order to make grounded decisions to reduce the number of accidents and injury cases it is recommended to assess further on actual and prognosis safety on the underground ore transportation according the described methodology.

Intensity of accidents and injury cases on UTSPE with account of the project values \(L, S_o, v, B_o\) and types of self-propelled equipment are determined by the regressive expressions (10–14).

By the calculation results the variant when \(B_o\) has a maximum value is given priority. Moreover, the predicted values of the parameters \(L, S_o, v, B_o\) on the new mine horizons must provide efficiency of the value \(B_o\) more than the actual one achieved for the corresponding type of UTSPE.

In some cases the higher value \(B_o\) require accepting such parameters as \(L, S_o, v, B_o\) while projecting the underground ore transportation on the new horizon or new mine when the technical economic efficiency of UTSPE’s work is lower than needed. In this case the final decision can be one of the following:

1. If in comparison with the projected ones some reduction of the technical economic values (TEV) of UTSPE’s work takes place after higher safety at work \(B_o\) is achieved it should be accepted. This decision is supported by the fact that increased safety at work as a rule is accompanied by labor productivity growth which can compensate the project reduction of economic values admitted in order to increase safety at work at the enterprise and the social effect.

2. If the higher value of work safety \(B_o\) causes significant increase of TEV when rollback is used it is necessary to develop a set of particular managerial technical and social economic actions to create safe and healthy conditions of work on UTSPE.

While designing the safer underground ore transportation the variant with a maximum TEV is chosen. In this case safety of \(B_o\) is determined and compared with the achieved actual one. In case when the predicted value of \(B_o\) is higher than the actual one this type of ore transportation is finally accepted. If the designed value of \(B_o\) is less than the actual one it is recommended to follow the above given instructions.

Conclusions. This methodology would allow to analyze actual and prognosis safety at work, to chose optimal parameters of technological processes on underground transportation deliveries and loadings for particular mine geological conditions in order to reduce the number of accidents and injury cases.

REFERENCES