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To cite this article: E V Glebova *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 032063

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Accidents and Injury Rates Reduction in Petroleum Industry based on the Development and Implementation of the Automated Complex for the Employees' Professional Competences Assessment

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Abstract. One of the major factors making a negative impact on the conditions of industrial safety in the Russian Federation is the insufficient skill and personnel training level. In this research we have implemented an integrated approach to the assessment of the professional competencies of employees, which is providing a traditional assessment of professional knowledge and skills, as well as the identification of the professionally important qualities (attention, memory, a tendency to risk, etc.) and its level of development. For this purpose, we have for the first time developed the automated complex of assessment and improvement of employees' professionally important qualities (PIQ). On the one hand, the application of this complex decreases a probability of accidents' emergence, due to the increase of efficiency in the procedure of compulsory education and examination of industrial safety requirements of employees, and on the other hand, it reduces the extent of damage in the accidents by increasing the personnel readiness for localization actions. The main advantages of the developed automated complex are its systematic character both at the level of the software product and at the substantial level. An author's algorithm is used to calculate the integrated assessment of readiness for work in maintenance and repair of hazardous production facilities; it is based on the analysis of diagnostic information.

1. Introduction

At present, the oil and gas industry has a significant impact on the Russian economy, being the basis for the budget formation. It ensures the functioning of many related economic sectors. Therefore, the level of the industrial safety in hazardous production facilities in the oil and gas sector substantially determines the national security of the state national security level.

The main reasons for the increase of accidents at industrial facilities is not only a critical level of wear and tear on plant and equipment, but also low-quality/untimely performance in maintenance and repair technical devices. It is caused by low qualification of personnel, as well as by low technological and workplace discipline [1].

One of the priority directions of the state policy in the field of industrial safety is effective staff assistance for the industrial safety field. It should be provided by improving requirements for training



and examination of employees and their leaders to operate and maintain hazardous production facilities [1].

The comparative analysis of accident rates and fatal injuries at hazardous production facilities in the 2005-2017-years period indicates a general trend of increasing the safety level at such facilities. For the indicated period, the total number of accidents has decreased by 32% (for the main gas transport facilities - by 39%). At the same time, the number of fatal accidents has also decreased by 61% [2-17]. For the same period, about 60 - 70% of the equipment, which is used at hazardous production facilities, has worked out its normative terms of service [1]. In such conditions, the quality of repair works acquires a special importance. For example, while analyzing the accident rate statistical indicators in main gas pipelines for the last 15-year period, it has been discovered that 23.3% of accidents occur as a result of construction and installation work [17]. A behavior of employees, who were engaged in the process of preventive maintenance, as well as the improper actions of managers in controlling of performed work have directly caused the emergence of defects of constructions and installations. In addition, a technology violation of repair work could lead to corrosion damage.

All these violations can be caused by the underperformance function of industrial safety management system, an important element of which is the personnel competence assessment.

Competence assessment of employees in the field of industrial safety is based on an assessment of the ability to apply knowledge and skills in practice. A competent employee should be able to operate correctly and safely in the production, and also to implement acquired knowledge and experience in practice.

It is known that the level of PIQ development has a significant effect on the formation of employees' professional competences in the field of industrial safety. Therefore, in this research, the integrated approach in the assessment the professional competencies of employees, which includes some traditional methods of professional knowledge and skills assessment and the determination of the PIQ development level was implemented. For this purpose, the automated complex for the assessment and improvement of employees' PIQ has been developed for the first time. This complex uses the newly developed algorithm and mathematically calculated criteria. It allows not only to estimate, but also to increase the level of personnel readiness for work on maintenance and repair of hazardous production facilities, and also for the actions in emergencies.

The automated system includes the following structural components:

- a set of 15 diagnostic tests to assess the main PIQ of employees;
- a knowledge base, which includes decision rules and criteria for assaying the level of preparedness for repair work;
- a database that provides storage, processing, and survey presentation of results in the form of tables and graphs;
- a unit for analyzing test data, which implements automated processing of results and allows to obtain integral assessments of readiness for repair work;
- a module for the PIQ improvement, the main task of which is the automated training of employees' PIQ based on the principles of a single intellect.

The work of the proposed automated system could be estimated from the example of assessing and improving the employees' PIQ engaged in the repair of hazardous production facilities.

The scheme for solving this task is cyclic.

At the first stage, testing is carried out in the Labor Protection Service's offices or enterprise's Personnel Department on the basis of personal computers, the number of which is selected based on the number of predicted test participants. Before carrying out the test, respondent's data (name, surname, patronymic, date of birth, education, occupation, work experience, previous place of work) is entered in the user registration block. Further, in the dialogue mode, the process of testing employees, in accordance with selected methods, is carried out. During the survey it is possible both to conduct new and to continue the last unfinished testing.

Figure 1 shows a dialog box for testing using the “Black-and-red table” technique. This test allows to evaluate such qualities as operational memory and attention, which are necessary for the maintenance and repair of hazardous production facilities. The monitor screen provides a respondent with the table, which contains 25 red and 25 black digits, which should be selected in the following order: red in descending order, black in ascending order. Each time a pair of numbers is being indicated - one is black, the other is red. In case of an error, the last correct answer is prompted (see figure 1).

10	5	2	5	21	21	15
12	24	9	22	20	20	17
14	19	14	25	16	11	4
16	22	6	15	18	19	11
23	23	9	2	12	7	1
8	7	4	24	13	10	13
3	18	1	6	3	17	8

Time of examination: 22 seconds

Error
It is necessary to begin with couple
25 : 1

Test finish

Figure 1. Stimulant material test “Black-and-red table”.

On the next stage, survey results are mathematically processed, based on the algorithm for the method of expert-analytical multidimensional scaling. In accordance with this method, we calculate the integrated assessment of readiness for maintenance and repair work at hazardous production facilities based on a hierarchical scheme. In the first stage, the current test results for each diagnostic method, depending on the range of values they fall into, are converted into a 4-point normative-scoring scale. A scale for each of the tests, used in the system, is developed based on percentile ranks calculation from the employees’ test sample. At the same time, three reference points, which divide the entire test array into four categories, conventionally designated by points 2, 3, 4, 5, were identified. We used the 10, 35, and 75 percentiles while calculating the reference points. The aim of the second stage is to convert the test values into the integral evaluation of PIQ using the normalized desirability function.

Thus, based on an integrated assessment of each quality, given their importance coefficients, the final integrated assessment of readiness for work is calculated and interpreted in the following way:

“2” - low level of PIQ development (readiness for repair works is low, the forecast of successful work is unfavorable),

“3” - average level of PIQ development (the readiness for repair work is average, the forecast for the successful work is ambiguous),

“4” - rather high level of PIQ development (the readiness for repair works is quite high, the forecast of successful work is favorable),

“5” - high level of PIQ development (the readiness for repair works is high, the forecast for the successful work is the most favorable).

If the final integral assessment of preparedness for repair does not correspond to the required level (“2” and “3” estimates), the employee is invited to take an intellectual training course in the module for the PIQ improvement.

The employee is offered to accomplish a number of training tasks, each of which includes several exercises. The parameters of each of the exercises are located in the analysis database of the training results. Thanks to the built-in editor, one can create his/her own exercise course or modify the existing data. After completing each of the lessons, the results are being sent to the interim control block. If the employee collects the required number of points ("score points"), he is then being transferred to a new level of training and is allowed to move to the next lesson. Otherwise, the employee needs to undergo the session again.

A possible efficiency increase study of the employees' compulsory training in the field of the industrial safety is conducted using the PIQ training. This study is a part of the author's supervision on the implementation of the developed automated complex.

For this purpose, employees were organized in two groups: experimental and control. The experimental group consisted of 70 employees with the basic occupations. In this group, in addition to industrial safety traditional training, the PIQ training, which uses the developed automated system, is also applied. In the control group, which also consisted of 70 people, training and knowledge tests were conducted without the use of automated training. Experiment training results prove the possibility to increase the efficiency of the compulsory education in the field of the industrial safety by using developed automated complexes. This results are given by applying statistical calculations. The conducted calculations proved that the level of knowledge of safety requirements in the control group while carrying out the certification is significantly lower than the level of knowledge of safety requirements in the experimental group.

The average statistical (base) frequency of emergency depressurization of the gas pipeline was calculated in this study in order to assess the impact of the PIQ development level of employees performing technical maintenance and repair at hazardous industrial facilities on the likelihood of possible accidents.

An estimation of the expected accidents frequency at the facility is possible to be made on the basis of an analysis of statistical accident rates at similar facilities. In order to obtain the most reliable estimation of the initiating events frequency, it is necessary, that statistical data on already occurred accidents allow identifying the influence of significant factors, such as natural, anthropogenic, technical [18].

Any cause of the accident can be uniquely identified and assigned to one of the large classes of possible causes (including, possibly, as "unknown" or "other"). The number of such classes can be random. It is important that any actual cause of the accident necessarily falls into one and only one class of causes, so the cause classes will not overlap.

Based on the experience of classifying the causes of accidents on Russian gas pipelines by the Federal Environmental, Industrial and Nuclear Supervision Service (Rostekhnadzor) bodies, the number of such classes in this work was taken to be equal to five: 1 - corrosion of different types; 2 - defect of construction and installation works (including welding defect); 3 - generalized group of mechanical damages (including damages caused by natural phenomena, for example, landslide processes or erosion of soil on transitions through waterways); 4 - factory defects of pipes; 5 - other and unknown reasons.

The estimated frequency of accidents at any section of the pipeline is calculated as the sum of the depressurization frequencies for each of the cause classes [19, 20]:

$$F = \sum_{i=1}^S f_i \quad (1)$$

where f_i is the depressurization frequency for the i -th reason; S - the number of depressurization causes classes (in this case $S=5$).

The proposed methodical approach to calculate the frequency of depressurization of gas pipelines is based on the allocation of regularities that affect f_i for each of the possible depressurization causes classes and the subsequent summation of these functions in accordance with equation 1.

Knowing the number of accidents for each class and the total length of gas pipelines for the 2000-2016-years period according to [2-17], the average (base) frequencies of emergency depressurization of the gas pipeline were calculated. The calculated frequencies are showed in table 1. The calculation was carried out for two statistically distinguishable groups: employees with a low level of readiness for maintenance and repair work ("2", "3" estimates) and employees with a high level of readiness for maintenance and repair work ("4", "5" estimates).

Table 1. Distribution of the average (base) frequencies of emergency depressurization of gas pipelines for the period 2000 - 2016 for the main causes of accidents, given the level of readiness of employees to carry out maintenance and repair operations for main gas pipelines.

Reason	The relative proportion of accidents caused by this reason, %	The frequency of depressurization during work by employees with ratings of 2 and 3 / 4 and 5
Corrosion incl.	48.8	$5.68 \cdot 10^{-5} / 5.68 \cdot 10^{-5}$
Stress corrosion cracking (SCC)	42.4	$4.9 \cdot 10^{-5} / 4.9 \cdot 10^{-5}$
External corrosion without SCC	6.4	$0.78 \cdot 10^{-5} / 0.78 \cdot 10^{-5}$
Defect of construction and installation work incl.	23.3	$3.68 \cdot 10^{-5} / 2.21 \cdot 10^{-5}$
Welding defect	9.3	$1.47 \cdot 10^{-5} / -$
Damage during maintenance and repair operations for main gas pipelines	9.3	$1.47 \cdot 10^{-5} / 1.47 \cdot 10^{-5}$
Departure from the project	4.7	$0.74 \cdot 10^{-5} / 0.74 \cdot 10^{-5}$
Generalized group of mechanical damages incl.	17.2	$2.0 \cdot 10^{-5} / 2.0 \cdot 10^{-5}$
Carrying out land works in the security zone of main gas pipelines	9.8	$1.11 \cdot 10^{-5} / 1.11 \cdot 10^{-5}$
Natural effects	2.8	$0.32 \cdot 10^{-5} / 0.32 \cdot 10^{-5}$
Acts of terrorism	4.6	$0.57 \cdot 10^{-5} / 0.57 \cdot 10^{-5}$
Factory defects in pipes	8.4	$0.96 \cdot 10^{-5} / 0.96 \cdot 10^{-5}$
Other	2.4	$0.28 \cdot 10^{-5} / 0.28 \cdot 10^{-5}$
Total	100	$1.25 \cdot 10^{-4} / 1.11 \cdot 10^{-4}$

The calculated base frequencies are the values statistically averaged over all gas pipelines that are accounted by Rostekhnadzor statistics, i.e. corresponding to some "average" gas pipeline. Subsequently, while analyzing the risk, the obtained data is used to calculate the real frequencies of accidents given the characteristics of specific gas pipelines and the natural features of the route.

As a result of the calculation, it was found that the frequency of accidental depressurization of the gas pipeline while working with employees with a low level of readiness for maintenance and repair work is $1.3 \cdot 10^{-4}$ accidents / km, and while working with employees with a high level of preparedness for work on maintenance and repair – $1.1 \cdot 10^{-4}$ accidents / km.

2. Conclusion

Thus, the analysis of the basic frequency of emergency depressurization of the main gas pipeline has showed that while working with employees with only a high level of PIQ development, the average (basic) frequency of emergency depressurization of the main gas pipeline is reduced by 15%. Consequently, the implementation of the developed automated complexes of assessment and improvement of employees' PIQ provides the decrease in probability of accidents emergence due to the increase in efficiency of the procedure of compulsory education and an examination of industrial safety requirements of employees.

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