PRACTICAL APPROACH TO ASSESSMENT OF EFFECTIVENESS AND EFFICIENCY OF MANAGEMENT SYSTEMS FOR OCCUPATIONAL SAFETY

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The main purpose of the research was development of a method-based approach and software for the assessment of the effectiveness and efficiency of OSH management system in the company through a predictive model for the assessment of the correlation of an accident risk and generalized desirability indicator based on Harrington function. OSH management system status in a company is proposed to be assessed using mathematical methods for the processing of individual indicators and calculating generalized desirability indicator based on Harrington "desirability curve". It is proposed to use an expert approach in order to determine individual indicators and assess their weight. It is suggested that such mathematical values as additive synthesizing function, weighted arithmetic mean, multiplicative synthesizing function, weighted geometric mean, should be calculated in «E^2» software. A methodology approach was developed involving mathematical processing of data in various source formats (shares, per cent, numbers, and words) so that Harrington "desirability curve" can be used to assess OSH management system effectiveness and efficacy in the company. A C# software code was developed to import and export Microsoft Excel data which significantly simplifies software use. A predictive model was developed showing the correlation between a professional accident risk value and generalized desirability indicator.

Keywords: OSH management system, effectiveness assessment, comparative analysis, Harrington function, multicriteria solution

1 INTRODUCTION

1.1 Actuality

Development and support of the functioning of an occupational safety and health (OSH) management system in the company aims at preventing occupational injuries and diseases [1]. However, the system requires continuous assessment of the effectiveness and efficiency of its functioning, this being the most important occupational safety procedure aimed at accident and occupational disease prevention (apriori approach) [2].

Regular internal audit procedures conducted on a regular basis aim at improving the efficiency of corporate occupational safety and health performance.

In turn, an effectiveness and efficiency assessment procedure for OSH management system in a company is an important process, which requires a special tool, software to enable company management to obtain timely and reliable information [3]. The results of the functioning of this tool include:

- assessment of the implementation of a corporate occupational safety and health policy;
- measurement of the effectiveness and efficiency of OSH management system procedures in numerical and temporal coordinates versus target and actual indicators;
- information to management on the need to take corrective actions based on changes in results or the outcomes of major breakdown and incident investigation;
- feedback from company structural units when planning their work, assessing current functioning status and intermediate (final) occupational safety and health reporting.
- It should be noted that the interest of company management in and convenient use of the OSH management system assessment tool by specialists with different training and qualification levels is a prerequisite to its effective functioning.

1.2 Literature review

In 2001, based on the tripartism principle (accounting for the employees', employers' and government authorities' opinion), the International Labor Organization (ILO) developed Guidelines on occupational safety and health management systems ILO-OSH 2001, which was a basis for the creation and implementation of OSH management system at the national and company level [4]. The tripartism principle enabled to create a fairly flexible management system oriented towards the development of a sustainable safety culture in the company, as well as continuous improvement of corporate safety indicators. It should be noted that ILO-OSH 2001 Guidelines are not stipulated as

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mandatory by any international or national regulations. ILO-OSH 2001 Guidelines do not contain detailed instructions on the implementation of individual management elements but just outline general recommendations for OSH management system development or improvement [5]. Thus, the efficiency of OSH management system implementation significantly depends on the motivation and competency level of employees in the company that will decide to implement ILO-OSH 2001 recommendations in its management system.

BSI OHSAS 18001-2007 "Occupational health and safety management systems. Requirements" is basically very similar to ILO-OSH 2001 Guidelines. Both documents are based on the PDCA methodology and both govern risk assessment and management procedures. BSI OHSAS 18001-2007 does not govern the nation-wide implementation of OSH management system since the standard was developed for companies. Furthermore, the management system proposed in this standard initially stipulated integration with management systems at the corporate level governed, for example, by such standard as ISO 14001:2015, Environmental management systems - Requirements with guidance for use.

In March 2018, International Organization for Standardization developed ISO 45001:2018, Occupational health and safety management systems - Requirements with guidance for use. The development of that international standard took into account the provisions BSI OHSAS 18001-2007, ILO-OSH 2001 Guidelines, ILO conventions and recommendations, as well as national industrial safety standards. Unlike ILO-OSH 2001 Guidelines and BSI OHSAS 18001-2007, ISO 45001:2018 International Standard describes an approach to occupational safety management governing both risk identification and assessment, as well as opportunity identification and assessment (ILO-OSH 2001 Guidelines and BSI OHSAS 18001:2007 consider risks only) [6].

ISO 45001:2018 outlines two risk and opportunity groups:

- employee safety and health risks and opportunities, i.e. risks and opportunities related to the employees' occupation and primarily, the hazards employees are exposed to; and
- other risks and opportunities for OSH management system in general, which are system-wide, e.g., changes in national laws, issuance of ordinances and fines by the regulator, change of senior management at the enterprise, etc.

Currently, the Russian Federation has a whole set of standards supporting OSH management system development and functioning in place, and many of them are identical to international standards. Thus, on April 01, 2021, GOST R ISO 45001-2020, RF National Standard, Safety and Health Management Systems - Requirements with guidance for use, took effect.

As regards OHS management system effectiveness and efficiency, it is worth considering GOST 12.0.230.3-2016, Occupational safety standards system. Management systems for occupational safety. Evaluation of effectiveness and efficiency. However, its practical use in companies demonstrated some weaknesses [7].

The studies of occupational safety risk management, as well as identification of major concerns hindering the non-biased implementation of the PDCA procedure within OSH management system is addressed by Bochkovskyi A. The researcher established that the effectiveness and functioning of occupational safety and health systems could be improved by managing separate parameters of adverse effects on an employee and substantiated the possibility of using an automated system of worker comprehensive protection against occupational hazards. A risk-oriented approach (proactive management) was applied to the assessment of OSH management system functioning based on the functioning principles of two small cycles during PDCA implementation [8].

Podgorski D. notes that despite the implementation of a systems-based approach to safety management at many companies, it is of interest to develop new methods for measuring OSH management system operational indicators aimed at the real improvement of safety management processes. The researcher developed a set of 109 indicators in 20 sections. By analyzing hierarchies, he ranged and prioritized key effectiveness indicators based on the set of SMART criteria (specific, measurable, achievable, relevant and time-bound). It is noted that this set of indicators must be adapted to a specific company environment, such as size, industry sector, types of hazards or maturity of safety management processes [9].

Bielikov A.S., Tairova, T.M., et al considered the improvement of hazards risk identification taking into account the employee's or employer's actions or inaction and developed a mathematical model of the Safety system and measures aimed at improving its efficiency in order to implement mechanisms that would encourage the employer to improve working conditions and employees to comply with regulatory occupational safety requirements. The researchers developed an OSH management system mathematical model, assessed its efficiency, and elaborated measures that would increase the efficiency of its functioning [10].

The work by Sklad A. contains the research where the impact of individual OSH management system processes on system effectiveness is based on the Fuzzy Cognitive Map (FCM) approach. MC FCM OSH model with 16 objects was developed to this end. Fifteen of these objects corresponded to OSH management system processes and one object corresponded to safety indicators. The researcher then performed a number of simulations successively predicting how the improvement of individual processes would impact overall safety indicators. For instance, it was proven that the safety indicators increased significantly subject to an improved leadership process. This proves that leadership, among all other processes in the system, has the greatest positive effect on system effectiveness [11].

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The work by Silva E.J., Rodrigues C. contains the overview of tools based on effectiveness and efficiency assessment. Their results show that it is possible to identify 36 main maintenance and operational activities for motorway technical systems which should be the focus when assessing the risk of major breakdowns and incidents [12].

Key reporting safety indicators at the company normalized to the average headcount per year include the numerical assessments of those injured in accidents with various degrees of disability, as well as the number of employees with first diagnosed occupational diseases [13].

Positive or negative changes in these indicators certify to the effectiveness and efficiency of OSH management system in the company. It is worth noting that this approach to occupational safety and health is based on experience (a posteriori). Company management may be quite satisfied with a reduction in the number of minor accidents from six to four in the reporting period.

The implementation of "preventive compliance models" and "Zero accident" is aimed at preventing violations that must be promptly evaluated in numbers followed by the development of operational response measures to eliminate any non-conformance [14].

1.3 Unresolved aspects of the problem

Currently, there is not adequate resolution for the issue of the practical use of software complexes that enable to assess the effectiveness and efficiency of OSH management system in the company, which will, in turn, help to develop a set of proactive measures aimed at preventing occupational injuries and occupational diseases.

1.4 Purpose

Development of a method-based approach and software for the assessment of the effectiveness and efficiency of OSH management system in the company through a predictive model for the assessment of the correlation of an accident risk and generalized desirability indicator based on Harrington function.

2 MATERIALS AND METHODS

The assessment of the occupational safety efficiency of a company is a multi-criteria challenge which can be handled using various methods to build a final indicator [15]. One of these methods includes Harrington generalized desirability function [16, 17], which helps to obtain numerical and linguistic indicators of OSH management system status in the company.

The methodology for OSH management system effectiveness and efficiency assessment and formation of a software algorithm is based on Harrington generalized desirability function with researcher-specific interpretation of study results.

A procedure for calculating generalized desirability indicator (D) consists of the following stages:

1. Determine effectiveness and efficiency indicators for a corporate OSH management system (I) by expertise;
2. Compare actual I and targets for the reporting period;
3. Determine weight factor w from 1 to 2 by expertise;
4. Calculate D in a computer program with the determination of linguistic and numerical ratings;
5. Make a plan of priority measures to improve OSH management system functioning based on the recommendations generated by computer software using mathematical and expert prioritization principles.

Let us consider each stage of the methodology in detail.

Stage 1 requires the company to identify groups and specific I based on its safety and health policy and goals taking into account the specifics of operations, scale (numbers and remoteness) of units, headcount, etc. It should be noted that I can be of any nature as their values can be expressed in numbers, shares and as percentage. We will provide examples of groups and specific I generated based on the Standard Regulations on the safety and health management system in the company and a number of other safety regulations in the Russian Federation, as well as international safety standards:

1. Occupational safety policy. Indicator example: top management rating based on safety management obtained based on the results of company employee surveys.
2. Involvement of employees and their representatives. Indicator example: number of workplaces assessed for professional risks involving employees.
3. Competency and training. Indicator example: relative share of employees with an advanced safety qualification.
4. Investigation of production accidents and occupational diseases. Indicator example: number of preventive measures taken based on the results of the analysis of accident and occupational disease causes.

Number of sections and I must correspond to compliance with government safety regulations and corporate standards of the enterprise, and be determined by expertise and approved by management.

Stages 2 and 3 imply the recording of indicator values in software based on schedule plans and approved company-wide reports for the reporting period.

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Stage 4 is completed by software with obtained results provided to the user.

At Stage 5, based on Stage 4 data, management adopts a priority activity plan generated taking into account the list of priority actions proposed by software.

The researchers used that algorithm as a foundation for a developed program code and calculation methodology and obtained a certificate for «E2» computer program that helps to calculate generalized desirability indicator D (Fig. 1).
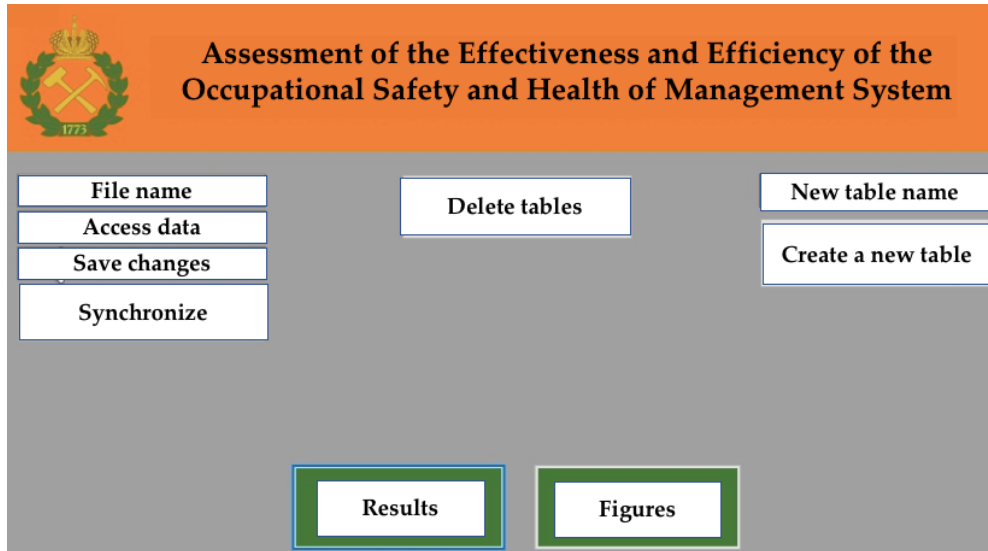

Assessment of the Effectiveness and Efficiency of the Occupational Safety and Health of Management System

File name		
Access data	Delete tables	New table name
Save changes		Create a new table
Synchronize		

| Results | Figures |

Fig. 1. «E^2» Interface

For the convenience of users, sections and *I* are introduced in *Microsoft Excel* tables.

Then a file with target and actual indicators is calculated by a *C#* program. Estimates are exported to *Microsoft Excel* to simplify data analysis [18; 19; 20]. The graphical description of the calculation procedure is shown in Fig. 2.
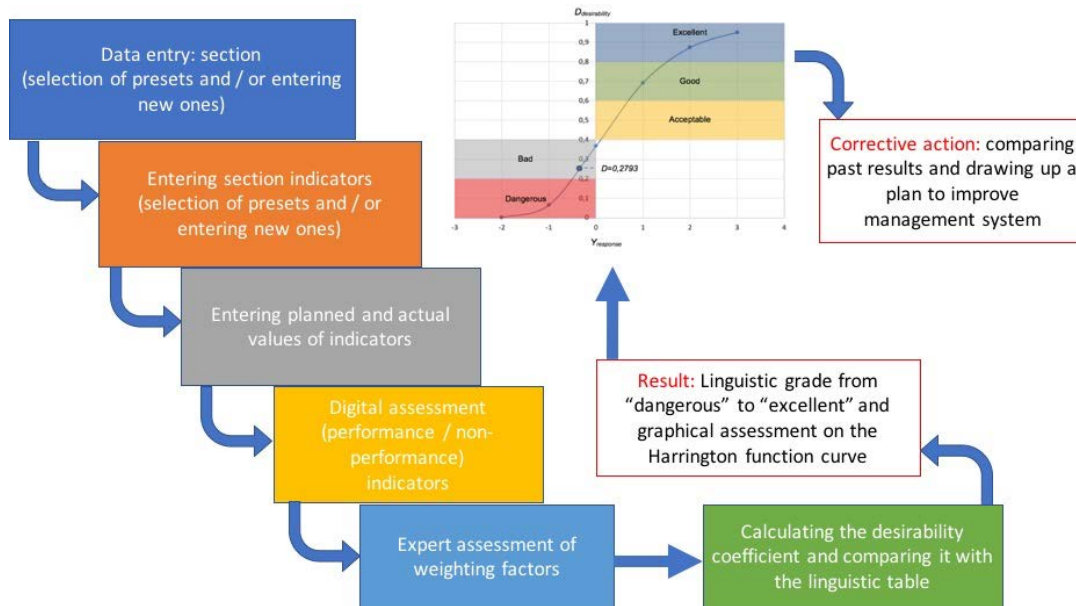

Fig. 2. Algorithm of «E^2» functioning

A calculation result is a graphical image for *D* indicator value with a current linguistic rating. Data update is accompanied by chart or diagram generation within temporal coordinates [21; 22; 23]. The program also offers a sequence of priority actions to the user aimed at improving OSH management system assessment in the company. Intermediate and final reports are provided to all managers involved and can be used to compare indicators in different branches of the company.

3 RESULTS AND DISCUSSION

We will give an example of the calculation of generalized desirability indicator (*D*) obtained based on external audit data at a coal mining company. OSH management system functioning was assessed based on 108 indicators from 19 sections.

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At the start of calculations, actual indicators are assessed to make sure they are formally implemented using the "Yes/No" principle. In order to do this, single indicator S is used. It takes into account the number of positive and negative indicators where "+ 1" is "achieved" and "-1" is "not achieved" and equals to:

$$S = \frac{(n^+ - n^-)}{(n^+ + n^-)},$$ (1)

where n^+ is the number of positive answers and n^- is the number of negative answers.

Then, an additive synthesizing weighted arithmetic average Q_a is calculated and the individual i^{th} indicator q_i is summed up with weight factor w_i:

$$Q_a = \frac{\sum_1 w_i q_i}{W},$$ (2)

where $W = \sum_1 w_i$.

It should be noted that Q_a does not allow to describe the criticality of the entire OSH management system status if an individual indicator is not achieved. It is a weakness to be removed by calculating a multiplicative synthesizing function, weighted geometrical mean Q_g, during calculation, the individual i^{th} indicator q_i is summed up with weight factor w_i:

$$Q_g = \left(\prod_1 q_i^{w_i}\right)^{\frac{1}{W}}.$$ (3)

A "weak" indicator for one element in function Q_g results in a "weak" indicator for the whole system.

Based on target and actual indicators, the software made the following calculations using the equations above:

Based on the equations submitted, the software made the following calculations: $S = -0.538$; $Q_a = 0.211$; $Q_g = 0.430$. With negative S, it should be interpolated to a positive value area to obtain $S = 0.231$ (Fig. 3).
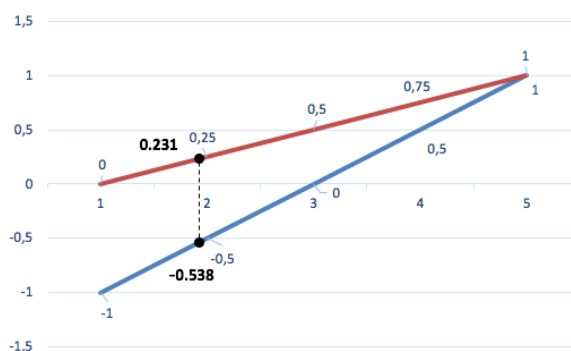

Fig. 3. Interpolation of single indicator S

The assessment of OSH management system effectiveness and efficiency in a company is based on Harrington generalized desirability function:

$$d = exp[-exp(-Y)].$$ (4)

Y axis represents the scale of specific indicators from -2 to 5 d axis represents a desirability scale divided into five ranges from 0 to 1. The agreement between desirability ratios in numerical and linguistic systems is ranged as follows: 0–0.19 "Dangerous"; 0.20–0.36 "Poor": 0.37–0.62 "Satisfactory"; 0.63–0.79 "Good"; 0.80–1.00 "Excellent".

A resulting specific indicator value for desirability d_i, based on the assessment of the ith I, is re-calculated together with others as generalized desirability indicator D:

$$D = \sqrt[n]{d(1)d(2)d(3) \dots d(n)}$$ (5)

"Desirability curve" changes slowly in the "excellent" and "good" area and changes fast in the mean ratings area ("poor" and "satisfactory"), which is typical for many safety characteristics. Therefore, Harrington scale basically shows the nature of the distortion of expert assessments due to their subjectivity. If expert estimates are void of this weakness, it would be necessary to match linguistic variables on the desirability scale with the same-length intervals.

Based on the results of completed computations, you will obtain a value of generalized desirability indicator $D=0.2793$ with a linguistic rating of "Poor".

It should be noted that the selection of Harrington function implies the sufficiency of at least one $I >= 0$ for D to have a value nearing zero, which points out to the low effectiveness and efficiency of OSH management system in the company. D is close to one when most I values are close to one.

Based on the methodology developed and «E²» program, we have a tool that helps to promptly and rather objectively assess OSH management system status in the company.

Taking the example of the coal mining company, we can assess quarterly reports for a two-year period with generalized desirability indicator values (Fig. 4).
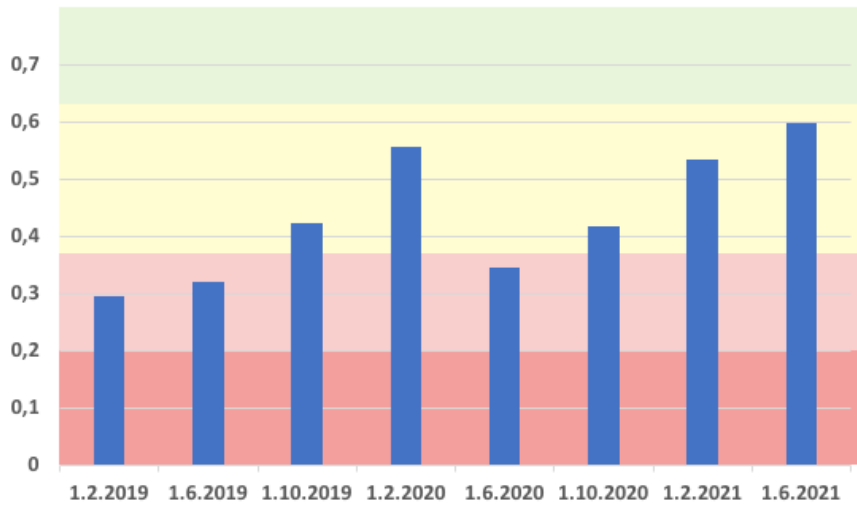

Fig. 4. Temporal trends of generalized desirability indicator *D*

Three industrial accidents were reported in the D assessment period between February 2019 through June 2021 (one major and two minor ones). Let us consider a major accident which happened in June 2019 due to an unsatisfactory work process. An employee was unloading metal structures from the truck. He could not keep balance and fell down onto the concrete base receiving multiple bruises and fractures. Moreover, the company had two more minor accidents in the period in question. Based on the results of the investigation of those accidents, workplace professional risks were re-assessed using the matrix-based method. As a result, H (high) (15), M (medium) (12) and M (medium) (9) risk level ratings were obtained. Calculation criteria for a risk level based on probability and severity are shown in the Table 1.

Table 1. Risk Assessment Matrix.

Probability / Severity	Once every three years and more (1)	Once every two years and more (2)	Once a year (3)	Once every six months (4)	Once every three months (5)
Fatal (5)	M (5)	M (10)	**H (15)**	H (20)	H (25)
Severe (4)	L (4)	M (8)	M (12)	H (16)	H (20)
Light (3)	L (3)	M (6)	**M (9)**	**M (12)**	H (15)
Microinjury (2)	L (2)	L (4)	M (6)	M (8)	M (10)
Dangerous action (1)	L (1)	L (2)	L (3)	L (4)	M (5)

Let us compare the values of a professional risk level and generalized desirability indicator characterizing OSH management system status in the months when the accidents happened (Fig. 5).
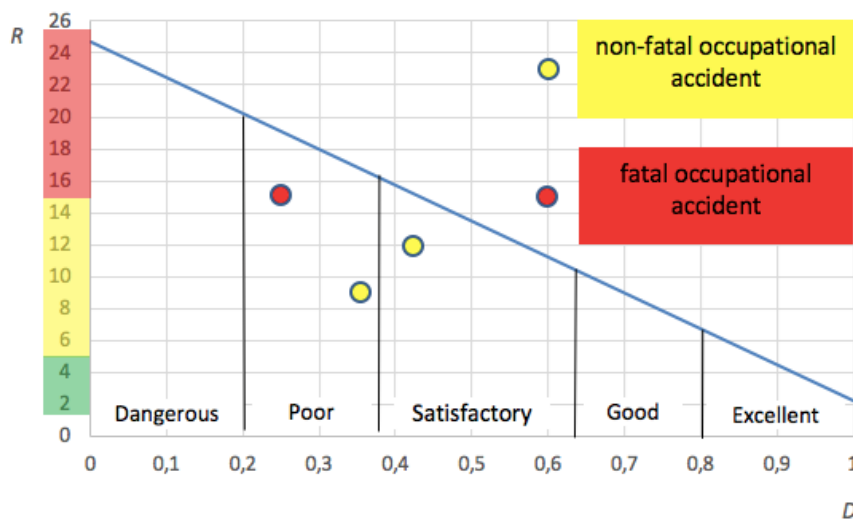

Fig. 5. Chart with the correlation of accident risk and generalized desirability indicator

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The digital and linguistic ratings of the OSH management system in the company is shown in the X axis. Y axis shows risk value in scores. The points corresponding to the value of an assessed risk and generalized desirability indicator in June and October 2019 (minor accident) are plotted in the chart. It can be concluded that the probability of "poor" rating of OSH management system increases the probability of an accident.

4 CONCLUSIONS

A predictive model with accumulated statistical data for this enterprise will help to assess the probability of accidents of various severity degrees. Presumably, with "dangerous and poor" D values, there is high probability of fatal and severe accidents. With "satisfactory and good" D values, minor accidents and microinjuries are more probable and with "good and excellent" values, there is probability of microinjuries and near misses (if they are accounted for). However, it is worth noting that the probability of a fatal accident is possible with all D ratings.

It should be noted that the investigation results of a severe accident also help to re-assess (increase the weight of estimates), such as:

- number of workplaces assessed for risk involving employees;
- relative number of the employees' suggestions aimed at the improvement of working conditions and work safety, per employee;
- relative share of occupational health and safety training courses revised based on professional risk assessment outcomes.

A generated software quarterly assessment report facilitates the development of a priority action plan to adjust OSH management system functioning. Changes in the D indicator certify to weaknesses in planning. The indicators are not generated quarterly, but are compiled for the entire year so that there is a shortfall at the start of the year.

The grouping of homogeneous information based on relevant signs is important for OSH management system status assessment. For instance, provision of employees with personal protective equipment needed for employees in various occupations. Based on the professional risk assessment procedure, employees must be provided with hand protection to guard against low temperatures. Issuance of PPE to employees may be an indicator to signal comprehensive efforts within the risk-oriented approach.

The importance of the visual representation of OSH management system assessment materials in the company is worth noting.

In a real production process, responsible employees can "adjust" the indicators to meet a required desirability level. However, it should be noted that it is crucial to secure the involvement of top management in the expert use of the indicators and their weight coefficients in this business since top management influences the allocation of financial, organizational and other resources needed for OSH management system improvement.

The important result of performance and efficiency assessment of OSH management system in the company is possibility to compare individual indicators and desirability indicators in general both in structural units and in subsidiaries.

5 ACKNOWLEDGEMENT

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