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Management decision-making algorithm development for planning activities that reduce the production risk level

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ABSTRACT

Purpose: Algorithm development for a measures phased expert assessment to reduce production risk at an industrial enterprise to adapt the expert method to the conditions for specific problem solving.

Design/methodology/approach: To develop an algorithm for making management decisions, a step-by-step solution process was used. If the problem is solved under conditions of complete or partial uncertainty, an expert method of estimation was applied. In the mathematical model of management decision-making used criterion approach. At the same time, the methods of Sevij, Wald, and Hurwitz are considered to determine the criterion for choosing management decisions.

Findings: A phased expert assessment of measures that reduce production risk at an industrial enterprise with the introduction of weighting factors in specified criteria is proposed. The expediency of applying the method of expert assessments and the Hurwitz criterion when planning measures to reduce industrial injuries is justified, since this approach links the preventive measures in the field of labour protection with the results of risk assessment and reduces subjectivity in making management decisions.

Research limitations/implications: The proposed algorithm for expert assessment of measures to reduce production risk is universal for industrial enterprises.

Practical implications: An algorithm has been developed to substantiate managerial decisions to reduce the production risks of the occurrence of traumatic events when planning preventive measures, which involves applying criteria for selecting measures based on the method of expert assessments and applying the Gurwitz criterion.

Originality/value: Developed a consistent model of industrial risk management, which is based on a component method of assessing the risk of traumatic events and a mathematical model of management decisions. This model differs from the existing ones, taking into account all available risk-relevant information of the enterprise, stimulates preventive activity, and allows establishing the dependence of the level of industrial risk on the validity of measures on occupational safety and reducing the influence of the subjective component of expert judgments.

Keywords: Safety and health management, Risk assessment, Algorithmization

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

The production (working) environment includes everything that surrounds a person in the process of labour activity. As a rule, a person in the course of his work activity is affected by dangerous and harmful factors: increased temperature [1,2], the presence of fine dust or nanoparticles in the air of the working area [3,4], emergency situations and injuries [5], etc.

Workers safety and health management in a production plant is an activity based on solving problems of organizing safe working conditions and aimed at reducing the risk of injury, accidents and occupational diseases, as well as improving working conditions. The safety methods and means choice should be based on the identification of harmful and dangerous factors inherent in a particular production equipment or process. Often, industrial plants use toxic gas sensors [6], actual technological processes are replaced by computer simulation methods [7,8], etc. However, in many cases it is not possible to limit the worker's stay in the danger zone. Therefore, it is extremely important that the organization of workplaces, favourable working conditions, a high level of safety in the interaction of a person with equipment, should be provided at each enterprise. Any improvement in the safety of the working environment begins with a risk assessment, conducting a risk assessment has a positive effect on production efficiency.

However, the risk assessment process, as the basis of occupational health and safety management system, needs to be improved, which is currently being actively pursued both in the world and in Ukraine. A particularly important role is played by a combination of scientific research and production experience [9-11]. The mechanism of expert risk assessments has been studied and is widely used both in sociological and economic research [12], ecological research [13,14], as well as in solving a wide range of labour protection management tasks. Therefore, the study purpose is development of algorithm for a measures phased expert assessment to reduce production risk at an industrial enterprise to adapt the expert method to the conditions for specific problem solving.

It is a phased evaluation of events considered as algorithmization. At the same time, certain stages need a criterial or mathematical justification.

2. Materials and methods

To develop an algorithm for making management decisions on planning activities that reduce the level of industrial injuries, a step-by-step refinement method (improvement) was used. This method is widely used to algorithmize processes in various fields of science [15-17]. According to this method at each step one solution is selected from the set of solutions allowed at this step. Moreover, a solution is selected that optimizes a given target function or criterion function.

If the problem is solved under conditions of complete or partial uncertainty, an expert method of estimation is applied [18-20]. The essence of this method lies in the fact that the group of experts is given for consideration a set of alternatives and decision rules for their evaluation, according to which the best option is selected.

In the mathematical model of management decision-making used criterion approach. At the same time, the methods of Sevij, Wald, and Hurwitz are considered to determine the criterion for choosing management decisions. It was taken into account that in a decision-making situation, the choice of one of the possible criteria is an additional uncertainty. The choice of the Sevage, Wald, and Hurwitz criteria for the study is due to the satisfaction of the condition of complete uncertainty of the mathematical problem.

3. Results and discussion

3.1. Management decision algorithm

The organizer of expert survey determines the survey purpose and carries out the selection of experts depending on the task, purpose and external conditions (restrictions on the solution of the problem, the complexity of the task, the state of information support, etc.). In the selection of experts (specialists competent in the issue under review who are capable of solving the set task), the expert organizer is guided both by his own point of view and by the available information about the experts (such information should contain information about the expert's experience in similar expertise, his experience, qualifications, availability of a degree, subject publications, etc.). The selection of experts can also be based on the results of solving test problems, interviews and the like.

The expert evaluation development algorithm for making management decisions is presented in Figure 1.

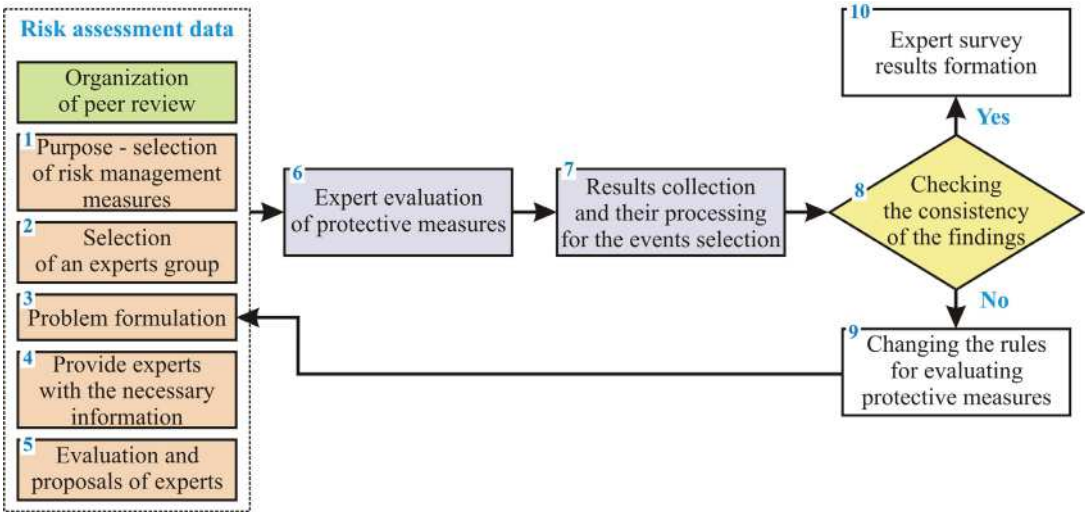

Fig. 1. The expert evaluation development algorithm for making management decisions

According to the presented algorithm (Fig. 1), at the initial stage the goal of the expert study is determined. For this, according to preliminary estimates (statistical, analytical, etc.), the basic research concept is formed with the expected result. When forming the research concept, it is planned to obtain qualitative and quantitative data characterizing the level of injury as an expected result. Based on these results, further management decisions are planned.

At the second stage, selects experts (position 2, Fig. 1) depending on the task, goal and external conditions (restrictions on the task, the complexity of the task, the state of information support, etc.).

After forming the group of experts, the head (the examination organizer) carries out the formulation of the task (third stage).

The conditions for the expediency of applying expert methods are as follows:

- The task has to be set must be sufficiently relevant and cannot be solved by one person;
- Available experts in the required quantity, competent in a selected range of issues representing the object of examination;
- Available information on the object of examination of the required nomenclature and volumes, intended for use by experts in the process of solving the task.

When formulating a task based on the conclusions of the initial stage, it is necessary to take into account the possibility of changing the decision rules (stage nine).

The fourth stage involves working with the source data. When solving problems of production risk management at enterprises, the available data are not only of quantitative, but also of qualitative nature. To solve the task, the experts are provided with the necessary information on the subject of expertise. Some of the information provided by the organizer of the examination is in the form of a set of alternatives and decision rules (scales, evaluation criteria, etc.), and some of the information is provided to experts in the form of information materials (information about the subject matter of the examination). In particular, an important informational material is a data array on the risk level of the onset of a traumatic event, calculated on the basis of averaging the distribution of their frequency of manifestation according to indications.

For the fifth stage, it is proposed to use an expert assessment method, when the expert group selects the most effective risk reduction methods according to certain criteria.

The decision of a decision-making task consists in a reasonable choice of one of a set of certain alternatives on the basis of the chosen criterion. At the same time, if the problem is solved under the conditions of complete or partial uncertainty, expert assessment methods are applied.

At this stage it is necessary to determine the main criteria for measures to reduce production risks. For this it is necessary to determine the weighting factors of the criteria.

3.2. Determination of weights of criteria for selecting measures to reduce production risks

Consider, as an example of expert evaluation, experts determine the weights of the criteria for selecting measures to reduce production risks. The organizer of the expert survey determined the condition: the sum of the relative weights set by each expert should be equal to one.

Consequently, the sum of the average values of the weighting factors set by the experts will also be equal to one (1):

$$\sum_{s=1}^{m} v_s = 1, \qquad (1)$$

where v_s – weight factor s-th criterion, evaluated by expert way; s = 1, ..., m – alternate serial number.

The results of assessing the criteria for choosing measures to reduce industrial risks by a group of experts are presented in Table 1.

Table 1.
Results of expert evaluation of criteria for choosing measures to reduce industrial risks

Criterion	Expert			Weight factor
	1	…	n	
K_1	v_{11}	…	v_{1n}	$v_1 = \frac{1}{n}\sum_{j=1}^{n} v_{1j}$
…	…	…	…	…
K_m	v_{m1}	…	v_{mn}	$v_m = \frac{1}{n}\sum_{j=1}^{n} v_{nj}$

Based on the table summarizing expert assessments, the weighting factors for each criterion were calculated: (v_s). This value is an indicator of the ranking of measures, the growth of which is carried out by sorting them in the corresponding listings.

The degree of consistency of expert assessments is verified using the Kendall criterion, which calculates the concordance coefficient by the formula (2):

$$W_m = \frac{12 \cdot D}{n^2 \cdot (m^3 - m)}, \qquad (2)$$

where $D = \sum_{i=1}^{n} \Delta_i^2$ – the variance of the sum of ranks of factor i by all experts; $\Delta_i = \sum_{j=1}^{m} b_{ij} - B_{cp}$ – the variance of the sum of ranks of factor i by all experts; $B_{cp} = n \cdot \frac{m+1}{2}$ – average amount of ranks.

The concordance coefficient values Wm in equation (2) can vary in the range from 0 to 1, that is $0 \le W_m \le 1$. Moreover, in the case when the assessment of all experts coincides, then W_m = 1, and when all experts presented different estimates, then W_m = 0. If the concordance coefficient is 0, then it is recommended to assess the competence of experts and, if necessary, replace inappropriate experts.

If the condition for the coherence of expert judgments is fulfilled, then it is necessary to proceed to the results formation of an expert survey – the formation of a list of indicators sorted in descending order of the benefits determined by the sum of ranks.

To perform the sixth and seventh stages of the proposed algorithm, a mathematical approach to managing managerial decisions to reduce production risk should be used.

3.3. Mathematical model of making managerial decisions on reducing industrial risk

The formalized formulation of the problem of decision-making is to substantiate the choice of the best (optimal) alternative from a plurality of managerial decisions by applying the appropriate criterion. The search for an optimal solution is a task of maximizing (minimizing) the value of a criterion calculated for a set of alternatives.

The mathematical model of making managerial decisions on reducing industrial risk has the form (3):

$$a_o = \arg(Q(E), A, Z), \qquad (3)$$

where a_o – chosen solution ($a_o \in A$); Q – criterion of choice of managerial decisions; $E = \{e_{ij}\}$ – the set of expected results of the implementation of management decisions, that is, the assessment of the implementation of the i-th alternative, provided that the external environment will be in the j-th state (the values of the elements of the set E are determined by calculation or expert way); $A = \{a_i\}$, $i = 1, ..., m$ – a set of alternative management solutions (alternatives) that can be used to solve a task of management; object of management - risks, the level of which is determined higher than acceptable, and needs to be reduced, that is, unacceptable and average level of risks; $Z = \{z_j\}$, $j = 1, ..., n$ – set of possible states of the environment.

The condition for the development of managerial decisions is the use of a hierarchy of risk reduction: elimination, substitution, technical control, administrative control, and means of protection. For unacceptable risks, an additional condition is the mandatory application of the measures of the three higher levels of the hierarchy as the most effective.

For the considered variants of planning, there are such possible states of the environment: positive (the growth of demand for products of the enterprise, the growth of production volumes and the wage fund, and, therefore, the cost of labour protection, the updating of technological equipment; the state of the safety of the production environment is improving); stable (volumes of production, labour costs, safety at work remains unchanged); negative (deterioration of the state of industrial safety due to a decrease in demand for enterprise products and the cost of labour protection).

An array of initial data for decision-making tasks under uncertainty (that is, the external environment may be in one of a plurality of states, the probability of occurrence of these states unknown) is given in Table. 2.

Table 2.
An array of initial data for decision making purposes

Alternatives	Expected results of the implementation of alternatives			The criterion value
	z_1	…	z_n	
a_1	e_{11}	…	e_{1n}	Q(E)
…	…	…	…	…
a_m	e_{m1}	…	e_{mn}	Q(E)

First of all, it should be noted that with the traditional technology of decision making, the formation of sets A, Z and E is carried out by the head and experts, that is, the accuracy of the initial data is determined by the degree of their awareness and level of competence.

As the analysis of scientific works on decision-making theory shows, there is currently no universal approach to the choice of criterion Q [21]. Therefore, the choice of criterion remains the prerogative of the manager and is based on the results of the analysis of the decision-making situation, as well as the experience and intuition of the head. In order to solve the tasks of management in the field of occupational safety, the criteria for Sevig, Wald and Hurwitz [22] were most widely used.

Obviously, in the decision-making situation, the choice of one of the possible criteria is a source of additional uncertainty, which can only worsen the result.

The results of the peculiarities of the application of these criteria are given in Table. 3.

When applying the Wald criterion, it is assumed a priori that the environment «behaves in the worst manner» for the control objects. Consequently, this criterion corresponds to the position of the greatest caution of the head. The use of his criterion is justified when it is necessary to exclude any risk, under no circumstances obtain a result worse than expected. The analysis shows that this criterion can be used in planning and organizing the realization of tasks, the failure to fulfil which can result in significant material as well as human losses.

When applying the Hurwitz criterion, managers assume that the external environment may be in the most favourable for the object of control, with a probability of α, and in the most unfavourable, with a probability of 1–α.

Table 3.
Peculiarities of application of criteria of justification of managerial decisions in the field of labour protection

Mathematical expression of the criterion	Terms and conditions of application
Seventh criterion: $a_{optimal} = \min_i[\max_j(\max_i e_{ij} - e_{ij})]$	Conditions of complete uncertainty. It is necessary to use the available resources rationally
Wald criterion: $a_{optimal} = \max_i \min_j e_{ij}$	Conditions of complete uncertainty. It is necessary to avoid any risk, under no circumstances to prevent a negative event
Hurwitz Criterion: $a_{optimal} = \max_i\left((1-\alpha)\cdot\min_j e_{ij} + \alpha\max_j e_{ij}\right)$	Conditions of complete uncertainty. The head through the α factor evaluates the onset of the most favourable external environment

Obviously, there are two limiting cases of application of this criterion: pessimistic (α value is equal to 0, we get the Waldo criterion) and optimistic (α value is equal to 1). Therefore, the result of applying the Hurwitz criterion depends largely on the correct choice of the confidence factor α (0 ≤ α ≤ 1), the magnitude of which is proportional to the degree of confidence of the manager in the most favourable state of the environment. As practice shows, the choice of the value of the trust coefficient expertly may not be sufficiently substantiated.

Therefore, taking into account the above considerations, it can be argued that the Hurwitz criterion is the most universal one; for its effective application it is proposed to calculate the confidence factor on the basis of a mathematical model that establishes the dependence of the production risk on the set of influencing factors.

To determine the confidence factor, it is proposed to use the normalized value of the calculated indicator, which is calculated by the formula (4):

$$\alpha = 1 - \frac{R_r - R^{min}}{R^{max} - R^{min}}, \ \alpha \in [0; 1], \tag{4}$$

where R_r – the calculated value of the production risk indicator; R^{max}, R^{min} – respectively the maximum and minimum possible value of this indicator.

For the case where the production risk assessment is in the range [0; 1], namely $R^{min} = 0$, $R^{max} = 1$, formula (4) takes the form (5)

$$\alpha = 1 - R_r. \tag{5}$$

Thus, the confidence coefficient will be inversely proportional to the value of the production risk obtained by calculation.

The application of the proposed approach is appropriate at enterprises where there are production risks and methods of their assessment are introduced.

Be sure to complete the eighth stage. At the same time, the necessary condition is the availability of experts capable of evaluating alternative options for measures to reduce industrial risks. Using the Hurwitz criterion allows taking into account the estimated magnitude of the production risk of the onset of each traumatic event. In order to provide automated calculations, database maintenance and visualization of results, it is necessary to develop an information system that will ensure the fulfilment of all stages of data processing in the process of substantiating decisions on reducing industrial risks at the enterprise.

At the tenth stage, on the basis of priority measures determined by the experts, a draft program for the implementation of measures to reduce the risk of traumatic events in the enterprise is being prepared. Scheduling of activities is carried out cyclically with the periodicity determined by the enterprise.

A 6-year study of the risk assessment process in the occupational health and safety management system at industrial enterprises in the construction and food industry was conducted. It was established that there is a difference between the factors that have the highest degree of risk according to expert estimates, and the factors that led to real injury at the enterprise. This difference is caused, first of all, by the subjective component in assessing risks by working personnel.

The proposed algorithm and the adapted method for assessing risk-sensitive information, namely:

- the occurrence of traumatic events in the past (injury statistics),
- the current state of threats to human life and health (current non-compliance with safety requirements identified through inspections, hazard reports, etc.),
- the future state of industrial environment threats (forecasting, modelling, designing),

are providing an opportunity to reduce the influence of the human factor on risk assessment.

Moreover the set of risk-relevant information indicators may be increased or reduced depending on the data available at the enterprise. The more available for analysis of risk-relevant information, the more relevant the risk assessment process is to the real hazardous factors at work [23].

An example is the solution to the problem of planning measures to reduce production risk, where the risk of collision with a moving vehicle is unacceptably high and must be reduced. Dangerous factors are movement inside the production room where collisions with electric loader are possible, and outside the production room where collisions with freight and passenger vehicles are possible.

Many possible environmental conditions:

z_1 – Demand for enterprise products is projected to increase, production volumes increase;

z_2 – Stable demand for the company's products is projected, production volumes remain unchanged;

z_3 – The demand for the production of the enterprise is projected, production volumes decrease.

Estimated risk levels of traumatic event:

$R_r = 8.1\,\%$ – The possibility of the occurrence of this traumatic event "Collision with a moving vehicle" (risk level – unacceptable);

$R^{max} = 11.9\,\%$ – The possibility of this traumatic event "Action or contact with dangerous substances" (risk level – unacceptable);

$R^{min} = 0.2\,\%$ – The possibility of the occurrence of this traumatic event "Physical action from the side of another person" (risk level – acceptable).

Decision-making criterion: Hurwitz criterion, the coefficient of confidence calculated by formula (4) is 0.32.

Many alternatives to measures to reduce the level of production risk, expert evaluation of the results of implementation of alternatives, as well as the calculated values of the Hurwitz criterion are given in Table. 4.

Table 4.
Data to justify measures to reduce production risk

Alternative measures to reduce production risk	Expected results of alternative implementation			Criterion value
	z_1	z_2	z_3	
α_1. Removing dangerous factors (separating pedestrian and transportation barriers where possible)	0.95	0.35	0.10	0.34
α_2. Replacement of hazardous factors (automatic conveyor transfer of materials and products instead of transportation by mobile forklifts)	0.75	0.75	0.33	0.35
α_3. Technical control of dangerous factors (installation of traffic lights, inspection mirrors spherical in shape, technical limitation of the speed of traffic, light and sound indication of the movement of vehicles back)	0.70	0.65	0.50	0.38
α_4. Warning signs and administrative controls (warning signs, pedestrian floor markings, driver training for electric forklifts and pedestrians)	0.50	0.33	0.45	0.27
α_5. Personal protective equipment (shoes with metal soles, reflective vests for employees and visitors)	0.25	0.65	0.40	0.29

The results obtained in the "Criterion values" column indicate that in this case the alternative α_3 with the highest calculated criterion value is optimal. So the objectivity of risk assessment will be improved.

4. Conclusions

As the study showed, when assessing risks in the management system of labour protection and industrial safety, the influence of the human factor is possible. This can subsequently lead to the choice of ineffective measures to reduce injuries. This problem can be reduced because in this study:

1. Adaptation of the expert method to the conditions for solving the problem is carried out – a step-by-step expert assessment of measures to reduce industrial risk at an industrial enterprise.
2. A step-by-step expert evaluation of measures reducing the production risk at an industrial enterprise using weighting factors in the given criteria is proposed.
3. The expediency of using the method of expert assessments and the Hurwitz criterion in the planning of measures to reduce occupational injuries has been substantiated, since such a campaign provides a link between preventive measures in the field of labour protection and the results of risk assessment and reduces the subjectivity in making managerial decisions.

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