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INCREASE IN THE LEVEL OF OCCUPATIONL SAFETY IN THE FOOD INDUSTRY WITH REGARD TOF THE RISK-ORIENTED APPROACH

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Introduction: One of the promising scientific directions of increasing the level of occupational safety in industry is the prediction of occupational risks, which is directly connected with the production process, and the creation of conditions for preventive measures and prevention of traumatism on its basis.

Materials and Methods: The investigation was performed on the basis of the following methods: the methods of statistical analysis of accidents that occurred in the food industry within the last decade for the determination of tendencies of traumatism; the method of regression analysis for the evaluation of cause-and-effect relations characteristic of injury processes; the method of principal components for the determination of the main factors of injury of employees in the food industry and prediction of the injury risks; the expert evaluation method for improving the method of prediction of injury risks; the method of a priori ranking of factors in processing of results of expert estimates.

Results and Discussion. As a result of performed investigation, a technique of increasing the occupational safety in the food industry was developed on the basis of the prediction of occupational injury risks. This technique is of great importance for preventing dangers and hazards with the aim of providing favorable working conditions, precluding failures, and preventing occupational diseases and accidents. One of the most promising scientific directions of increasing the safety of the manufacturing process is the prediction of occupational injury risks, directly connected with the manufacturing process and the creation of conditions for preventing traumatism on the basis of these predictions. The results of a comparative analysis of retrospective prediction by the methods of regression analysis (prediction) and improved method of combined prediction on the basis of the method of principal components in combination with the expert evaluation method indicate that the statistical prediction of the number of injured employees at enterprises of the food industry shows larger deviations from the actual number of injured employees (the standard error is equal to 2.53) than the combined prediction (standard error is equal to 0.85). Thus, it can be concluded that, on the average, the efficiency of prediction increases by 60% due to the combination of the method of principal components with expert evaluation method.

Conclusions. The developed models and methods have qualitatively new properties and make it possible to increase the efficiency (precision) of prediction, on the average, by 60% on the basis of combining the method of principal components with the expert evaluation method, which enables us to increase the total efficiency of preventive measures of occupational injury at enterprises of the food industry, on the average, by 18–23%.

The scientific results of the investigations are a contribution to the development of theoretical and applied fundamentals of labor protection in the part that concerns diagnostics, prediction, modeling of extreme situations, and evaluation of their consequences.

Keywords: safety, labor, traumatism, risk

Introduction

The basic equipment of the food industry of Ukraine is predominantly morally and physically obsolete, and its operation time is already 1.5–2.5 times greater than its design life. More than 50% of employees work under conditions that do not comply with the occupational safety norms and regulations. At working places of food enterprises, increased levels of noise and vibration are registered, illumination, and microclimatic parameters do not comply with the sanitary requirements. Mandatory medical inspections are often performed formally and incompletely. The consequence of this is a substantial level of traumatism and occupational deceases, and accidents with severe and lethal consequences. Within the last decade (2005–2014), more than 9.5 thousands of employees of the food industry were injured at enterprises, and 633 of them had a lethal outcome. All these facts indicate that the state of labor protection in the food industry of Ukraine cannot be thought to be satisfactory [1].

An increase in the level of safety of the manufacturing process is connected with substantial costs of its re-equipment, retraining of personnel, and introduction of modern systems of production control. In this case a contradiction connected, on the one hand, with the necessity of increasing the level of occupational safety, which necessarily leads additional expenses on above-listed works and to an increase in the manufacturing cost of products, and, on the other hand, to a decrease in the productions costs, which, in turn, can lead to an increase in occupational injury.

Though the substantial number of scientific sources that consider the problem of organization of occupational safety and prevention of traumatism exist, in most of them, the problem of increasing complexly the occupational safety and analyzing occupational injury in the food industry has not been adequately investigated.

One of the promising scientific directions of increasing the safety of the manufacturing process is the prediction of occupational risks directly connected with the manufacturing process and creation of condition for preventive measures and prevention of injury on its base. An analysis of the existing risk prediction methods enables us to draw the conclusion on the necessity of improving most of them with the aim to adapt to the features of enterprises of the food industry and evaluate complexly risks of occupational injury at the enterprise.

Thus, the scientific–applied problems of developing a technique of increasing the level of occupational safety in the food industry on the basis of prediction of risks of occupational injury are to be solved.

The aim of the investigation is to increase the efficiency of preventive measures of occupational injury at enterprises of the food industry due to on-line prediction of risks of injury.

To achieve the set aim, the following tasks of the investigation were specified.

1. To perform a statistical analysis of accidents in the food industry.

2. To develop methods of investigating the cause-and-effect relations characteristic of the injury processes in the food industry.

3. To improve of the methods of predicting the risk of occupational injury.

4. To investigate the cause-and-effect relations that lead to injury in the food industry and the influence of preventive measures on them.

5. To develop algorithms of functioning of the information-analytic system for the on-line analysis of working conditions in the industry, determine the rational directions of preventive measures of occupational injury, and justify organizational measures of labor protection.

The object of investigation is the prediction methods of occupational injury risk at enterprises of the food industry.

Materials and Methods

Methods of investigation. In the work, we used the following methods of investigation: the method of statistical analysis of accidents that occurred in the food industry within the period 2003–2011 for the determination of tendencies of traumatism; methods of regression analysis for the evaluation of the cause-and-effect relations characteristic of injury processes; the method of principal components for the determination of the main factors of injury of employees in the food industry and prediction of injury risks; the expert evaluation method for improving the method of prediction of injury risks; the method of a priori ranking of factors in processing of results of expert estimates. Moreover, the experience of analysis of accidents in branches of economy both in Ukraine and abroad was taken into account.

Results of Discussion

On the basis of the analysis of the statistics of occupational injury in the food industry of Ukraine within the period 2003–2014, the existing methods of injury prediction were analyzed, and the problems of the investigation were stated.

The process of improving the functioning of the system of labor protection control (SLPC) calls for the rational organization and well-organized cooperation of experts and heads of all structural divisions of the enterprise, and efficient cooperation with the industry and corresponding state organs. An important function of labor protection control is the analysis and prediction of indices of the state of labor protection. Thus, the question of how to form an SLPC that will consider complexly the problem of labor safety at the enterprises of the food industry with regard for its future state arises.

The situation of taking a decision in the SLPC on reducing the level of occupational injury is determined by the tuple $\{X, Y, Q, R, Z, S, E, C, T\}$, where X is the set of information data used in the formation of managerial decisions; Y is the set of indices from which the level of occupational injury is evaluated; Q is the set of managerial decisions admissible within the framework of the specified type of the problem; R is the formalized rule of choosing a managerial decision from the set of possible decisions; Z is the set of restrictions; S is the set of possible states of the external medium; E is the set of expected results of realization of alternative managerial decisions; C is the cost of injury preventive measures; T is the time factor.

The results of execution of the managerial decision in the time interval $t+\Delta t$ depend on the values of the set of indices from which the state of labor protection is evaluated in the previous time interval and taken managerial decision:

$$Y^{t+\Delta t} = f\left(\left[X^{t-n\Delta t}; X^{t}\right], Z, S^{t}, Q, C\right). \qquad (1)$$

One of the promising scientific directions of increasing the total level of safety of the manufacturing process is the prediction of risks of occupational injury $Y^{t+\Delta t}$ and the creation of conditions of injury prevention on the basis of these predictions. The labor protection control is aimed at minimization of risks. The mathematical expression for choosing an optimal decision from the set of possible decisions has the form

$$q_{onm} = q_j : y_j^{t+\Delta t} = \min_i\left(y_i^{t+\Delta t}\right),\ y_j^{t+\Delta t} \le y_{\Gamma}^{t+\Delta t},\ C_j \le C_{\Gamma}, \qquad (2)$$

where q_{onm} is the optimal managerial decision; $y_j^{t+\Delta t}$, $y_{\Gamma}^{t+\Delta t}$ are, respectively, the predicted and limiting (specified) values of the injury index at the moment $t+\Delta t$; C_j, C_{Γ} are, respectively, the predicted and limiting (admissible) expenses on the realization of injury preventive measures. Exactly the values $y_j^{t+\Delta t}$, $y_{\Gamma}^{t+\Delta t}$ will determine the degree of occupational injury risk at an enterprise.

The analysis of the existing methods of risk prediction enables us to draw the conclusion on the necessity of their improvement with the aim of adapting to the features of the enterprises of the food industry and evaluating complexly the risks of occupational injury at the enterprise, which determines the necessity to solve the urgent scientific-applied problem of *development of a technique for increasing labor safety in the food industry on the basis of prediction of risks of occupational injury.*

To improve the methods of prediction of occupational injury risks in the food industry, a general model of risk [2] and a method of determination of the cause-and-effect relations of the phenomenon of occupational injury [3] were developed, and the methods of labor protection control on the basis of combined predictions of risks [4-5] were improved.

In the general case, the risk of occupational injury can be determined as follows:

$$R = \sum_{i=1}^{n} S_i P_i, \qquad (3)$$

where S_i are consequences of an accident; P_i is the probability (frequency) of accidents; n is the number of accidents.

For the analysis of the direct cause-and-effect relations that take place in the process of injury, a scheme of the emergence of an accident that is represented by statistical data on the direct causes of occupational injury was used (Fig. 1) [6].

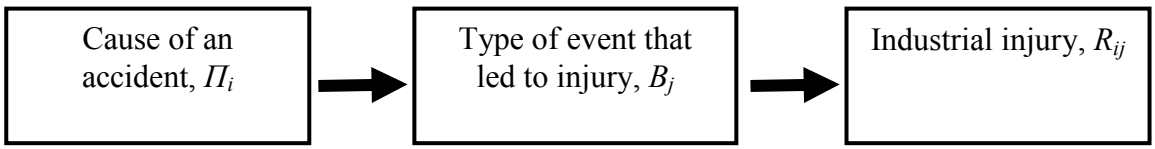


Fig. 1. Scheme of the emergence of an accident represented by statistical data on direct causes of occupational injury.

For the calculation of conditional probability, the Bayes formula is used

$$P_{Пi}\left(B_j\right)=\frac{P\left(B_j\right)P\left(П_i\right)}{\sum_{i=1}^{n}P\left(П_i\right)}. \tag{4}$$

The matrix of injury risks in the industry is calculated by formula (4):

$$R_{ij}=\begin{bmatrix} R_{П1B1} & R_{П2B1} & \cdots & R_{П16B1} \\ R_{П1B2} & R_{П2B2} & \cdots & R_{П16B2} \\ \cdots & \cdots & \cdots & \cdots \\ R_{П1B15} & R_{П2B15} & \cdots & R_{П16B15} \end{bmatrix}, \tag{5}$$

where $R_{П1B1},\ldots,R_{П16B15}$ are the values of injury risks for binary complexes "cause of injury risk – type of injury event"; $i=1,\ldots,16$ is the number of the main causes of injury in the industry $П_i$, which, at present, is fixed in the valid classification of the form of mandatory statistical accounting No. 7-tnv; $j=1,\ldots,15$ is the number of the main types of injury events.

For the prediction of occupational injury, in the work, we used the method of principal components, due to the main properties of which, a minimum error of prediction is provided. For example, let the initial investigated p-dimensional vector of observations X must be replaced by the vector $Z=\left(z^{(1)},z^{(2)},\ldots,z^{(p')}\right)^T$ of smaller dimensionality p', in which each component will be a linear combination of p initial (or auxiliary) features without loss of too much information. The informativeness of the new vector Z depends on the measure to which p' introduced auxiliary variables make it possible to "restore" p initial features with the help of the corresponding linear combinations $z^{(1)},z^{(2)},\ldots,z^{(p')}$. It can be imagined that the error σ of prediction of X from Z will be determined by the residual dispersion matrix of the vector X after subtraction of the best prediction from Z from it, i.e., by the matrix $\Delta=\left\lfloor\Delta_{ij}\right\rfloor$, where

$\Delta_{ij} = E\left\{\left(x^{(i)} - \sum_{l=1}^{p'} b_{il} z^{(l)}\right)\left(x^{(j)} - \sum_{l=1}^{p'} b_{jl} z^{(l)}\right)\right\}$. Here, $\sum_{l=1}^{p'} b_{il} z^{(l)}$ is the prediction that is the best in the least-squares sense $x^{(i)}$ with respect to the components $z^{(1)}, z^{(2)}, \ldots, z^{(p')}$. The error of prediction of X from Z is given as a certain defined function of the elements of the matrix $\Delta = \|\Delta_{ij}\|$, i.e., $\sigma = f(\Delta)$, where $f(\Delta)$ determines a certain criterion of prediction quality.

The following measures of prediction error can be used:

1. $f(\Delta) = Tr(\Delta) = \Delta_{11} + \Delta_{22} + \ldots + \Delta_{pp}$ on the basis of the trace of the matrix $\Delta = \|\Delta_{ij}\|$;

2. $f(\Delta) = \|\Delta\| = \sqrt{\sum_{i=1}^{p}\sum_{j=1}^{p} \Delta_{ij}^2}$ on the basis of the Euclidean norm of the matrix $\Delta = \|\Delta_{ij}\|$.

It was proved that both measures simultaneously attain their maximums if and only if the first p' principal components of the vector X are chosen as $z^{(1)}, z^{(2)}, \ldots, z^{(p')}$, and the value of the prediction error $\sigma = f(\Delta)$ is explicitly expressed in terms of the last $p - p'$ eigenvalues of the initial covariance matrix C or approximately in terms of the last $p - p'$ eigenvalues $\lambda_{p'+1}, \ldots, \lambda_p$ of the sample covariance matrix $\hat{C}$ constructed from the observations $X_1, X_2, \ldots, X_n$. In particular, for $f(\Delta) = Tr(\Delta): \sigma \approx \lambda_{p'+1} + \lambda_{p'+2} + \ldots + \lambda_p$; for $f(\Delta) = \|\Delta\|: \sigma \approx \sqrt{\lambda_{p'+1}^2 + \lambda_{p'+2}^2 + \ldots + \lambda_p^2}$.

Thus, on the basis of the methods of regression and component analysis, the model of occupational injury risk is formed. It relates complexly the probability of emergence of the accident to the frequency of emergence of accidents in the industry for the whole range of reasons.

In the work, we improved the combined method of principal components and regression analysis on principal components, the linear model of which has the form

$$R = b_0 + b_1 Y_1 + b_2 Y_2 + \ldots + b_k Y_k + \varepsilon_k, \quad (6)$$

where R is a dependent index or a characteristic of the process or phenomenon to be investigated, Y_k is the value of the first principal components for the objects of investigation, $k = 1, 2, 3, \ldots, p$; $b_0 \ldots b_k$ are the coefficients of the regression equation; ε_k is a normally distributed random quantity with a zero average and variance.

The necessity of improvement is caused by the correlation of indices, which determines the poor conditionality of the system of normal equations for the determination of the regression coefficients and by the presence of errors, which causes the shift of estimates. To prevent the indicated disadvantages, it is proposed to improve the combined method of regression analysis on principal components on the

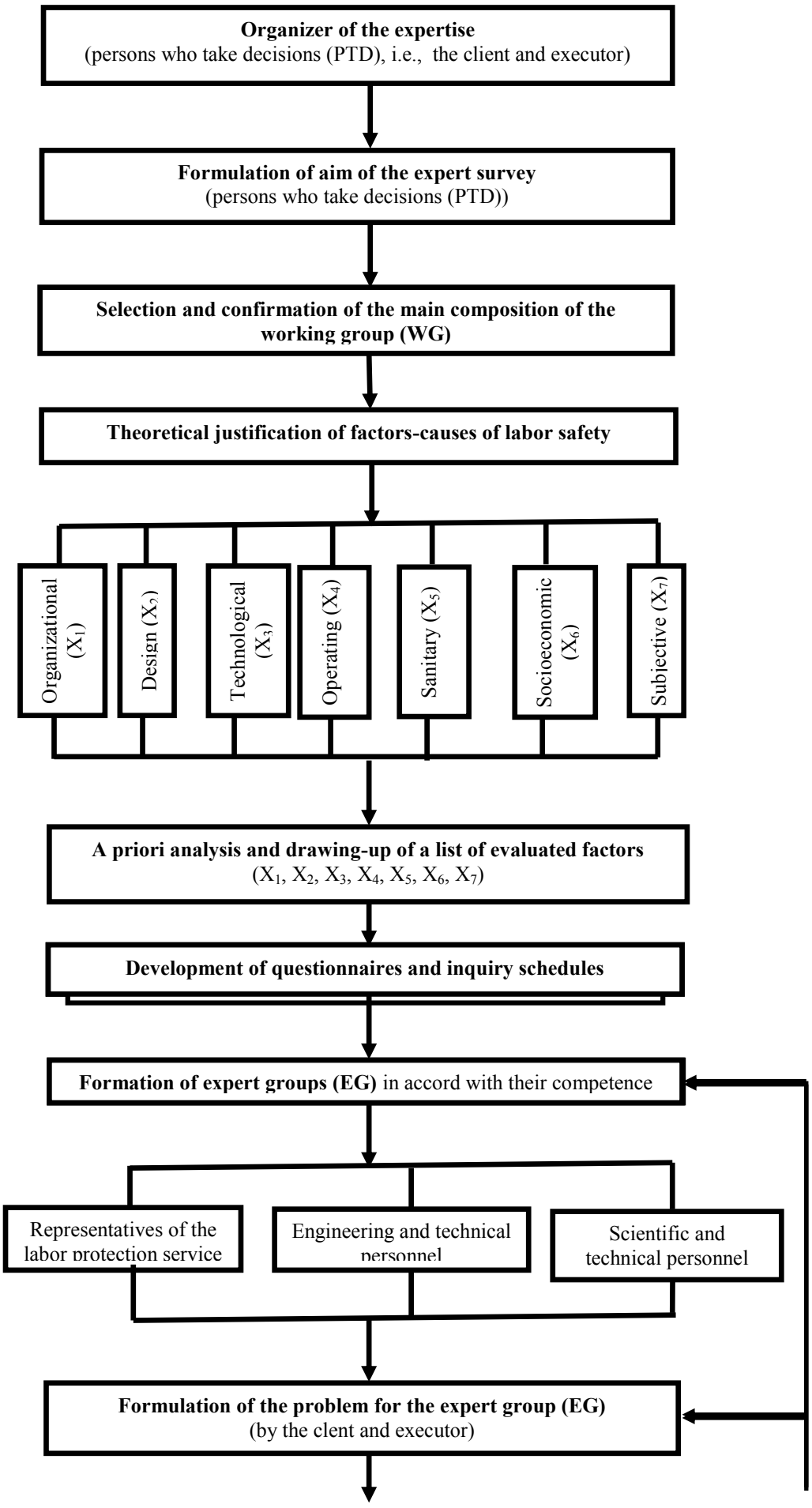
basis of using the *expert evaluation method*, the aim of which is to evaluate the significance (weight) of each factor (component) and the consistency of opinions of experts (Table 1).

Table 1

Matrix of Results of Expert Estimate of Indices

Experts	Factors / components				
	X_1	X_2	…	…	X_i
1	a_{11}	a_{12}	…	…	a_{1i}
2	a_{21}	a_{22}	…	…	a_{2i}
j	a_{j1}	a_{j2}	…	…	a_{ji}

Further, in the work, the methods of labor protection control on the basis of combining statistical analysis, expert evaluation with ranking of factors and combined prediction of risks of occupational injury are considered. In the work, we propose an algorithm of formation of decisions (Fig. 2) on the organization and providing safe working conditions on the basis of risk prediction, where main stages of the process of formation of decisions on the basis of combined prediction of risks are presented.


Organizer of the expertise
(persons who take decisions (PTD), i.e., the client and executor)
Formulation of aim of the expert survey
(persons who take decisions (PTD))
Selection and confirmation of the main composition of the working group (WG)
Theoretical justification of factors-causes of labor safety
Organizational (X_1)
Design (X_2)
Technological (X_3)
Operating (X_4)
Sanitary (X_5)
Socioeconomic (X_6)
Subjective (X_7)
A priori analysis and drawing-up of a list of evaluated factors
(X_1, X_2, X_3, X_4, X_5, X_6, X_7)
Development of questionnaires and inquiry schedules
Formation of expert groups (EG) in accord with their competence
Representatives of the labor protection service
Engineering and technical personnel
Scientific and technical personnel
Formulation of the problem for the expert group (EG)
(by the clent and executor)

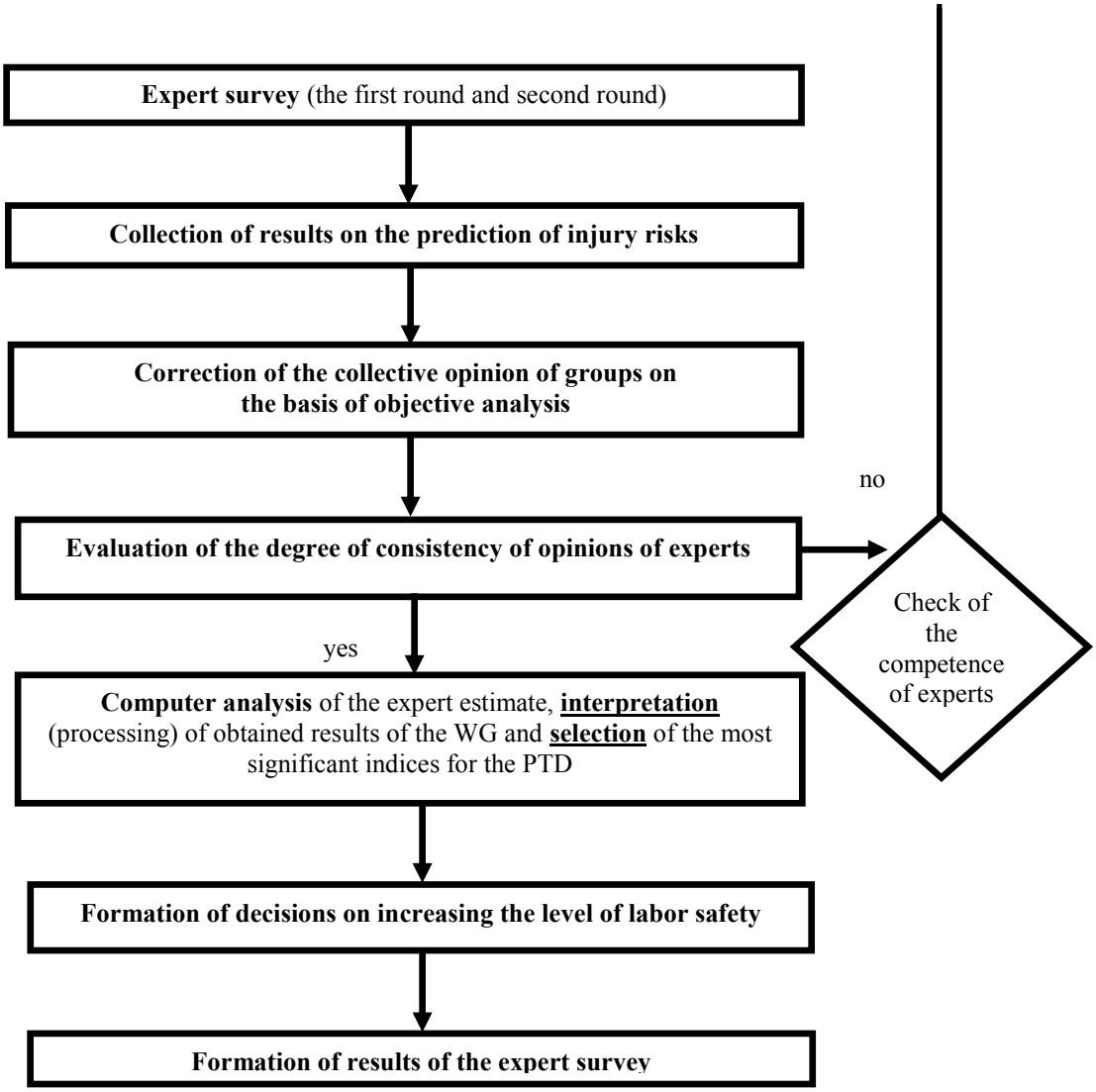
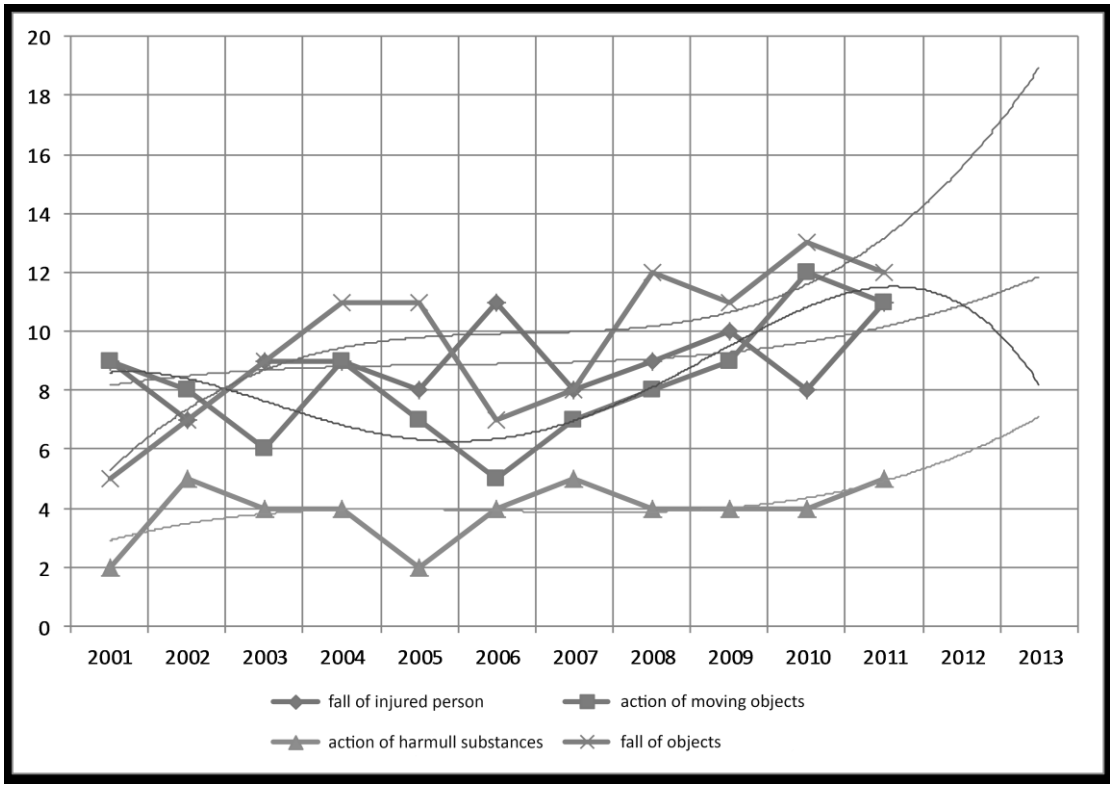


Fig. 2. Algorithm of formation of decisions on the organization and ensuring of safe working conditions on the basis of prediction of risks.

Applying the models and methods developed on the basis of data for the period 2001–2012, we investigated the statistics of occupational injury with the use of the methods of regression analysis and construction of multifactor regressive models and performed combined prediction for the period 2012–2013.

On the basis of the corresponding time series, mathematical models of trends and predictions of the future behavior of time series were constructed. In Fig. 3, as an example, the dynamics of the number of injured employees for different types of events is shown. The dynamics of the number of injured employees for different professions and different shops was determined analogously. The mean error of prediction is equal to 10–12 %, which indicates the applicability of the proposed approach to the prediction of the dynamics of time series of occupational injury [7-8].



fall of injured person $y = 0{,}0062x^3 - 0{,}1014x^2 + 0{,}5894x + 7{,}6667$ $R^2 = 0{,}885$	action of moving objects $y = -0{,}0061x^4 + 0{,}1455x^3 - 0{,}9962x^2 + 1{,}8522x + 7{,}6061$, $R^2 = 0{,}7172$
action of harmful substances $y = 0{,}0105x^3 - 0{,}1888x^2 + 1{,}0734x + 2$ $R^2 = 0.8256$	fall of objects $y = 0{,}0289x^3 - 0{,}549x^2 + 3{,}5282x + 2{,}2576$ $R^2 = 0.8474$

Fig. 3. Dynamics of the number of injured employees for different types of events.

To evaluate of the efficiency of predicting the level of injury on the basis of the method of combined prediction, we compared the prediction estimates on the basis of multifactor models of the dependence of the number of accidents on the causes-factors that led to accidents, and the dependences of the number of accidents on the types of events that led to accidents

$$A = -0.06112 + 0{,}6754X_{n1} + 0{,}8718X_{n2} + 1{,}5954X_{n3} - 0{,}8534X_{n4} + 0.2794X_{n5} +$$
$$+ 0{,}2953X_{c1} + 0{,}3732X_{c2} + 0{,}3609X_{c3} + 0{,}4207X_{c4} + 0{,}7141X_{c5}$$

Errors of prediction from this combined model are equal to 0.43–1.11 %, which is a better result than those obtained individually from each of the previous models.

It is reasonable to complement the methods of combined prediction by refined estimates on the basis of expert evaluation, the aim of which is to refine the influence of the factors on the occupational injury. From the results of processing, we constructed diagrams of ranks, from which the values of the factors of influence on the occupational injury are refined (Fig. 4). Professions most susceptible to traumatism, causes of intentional violation of safety requirements, potential causes of traumatism, factors that cause injury during performance of the technological process, factors of the most dangerous (in terms of injury) equipment, and labor protection measures were investigated analogously.

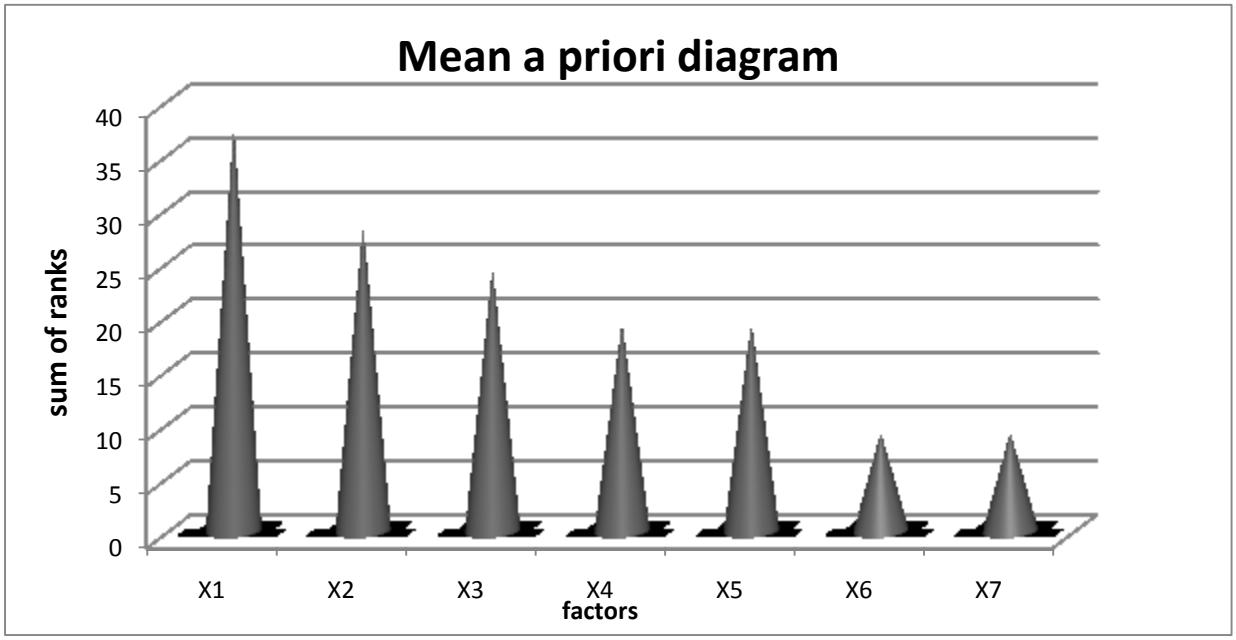


Fig. 4. Diagram of ranks of production and technical factors

Then we performed the general evaluation of the efficiency of the proposed theoretical results and justified measures and means for preventive measures of the risk of occupational injury.

The results of the comparative analysis of the retrospective prediction by the methods of regression analysis (prediction) and improved method of combined prediction on the basis of the method of principal components in combination with the expert evaluation method are shown in Fig. 5.

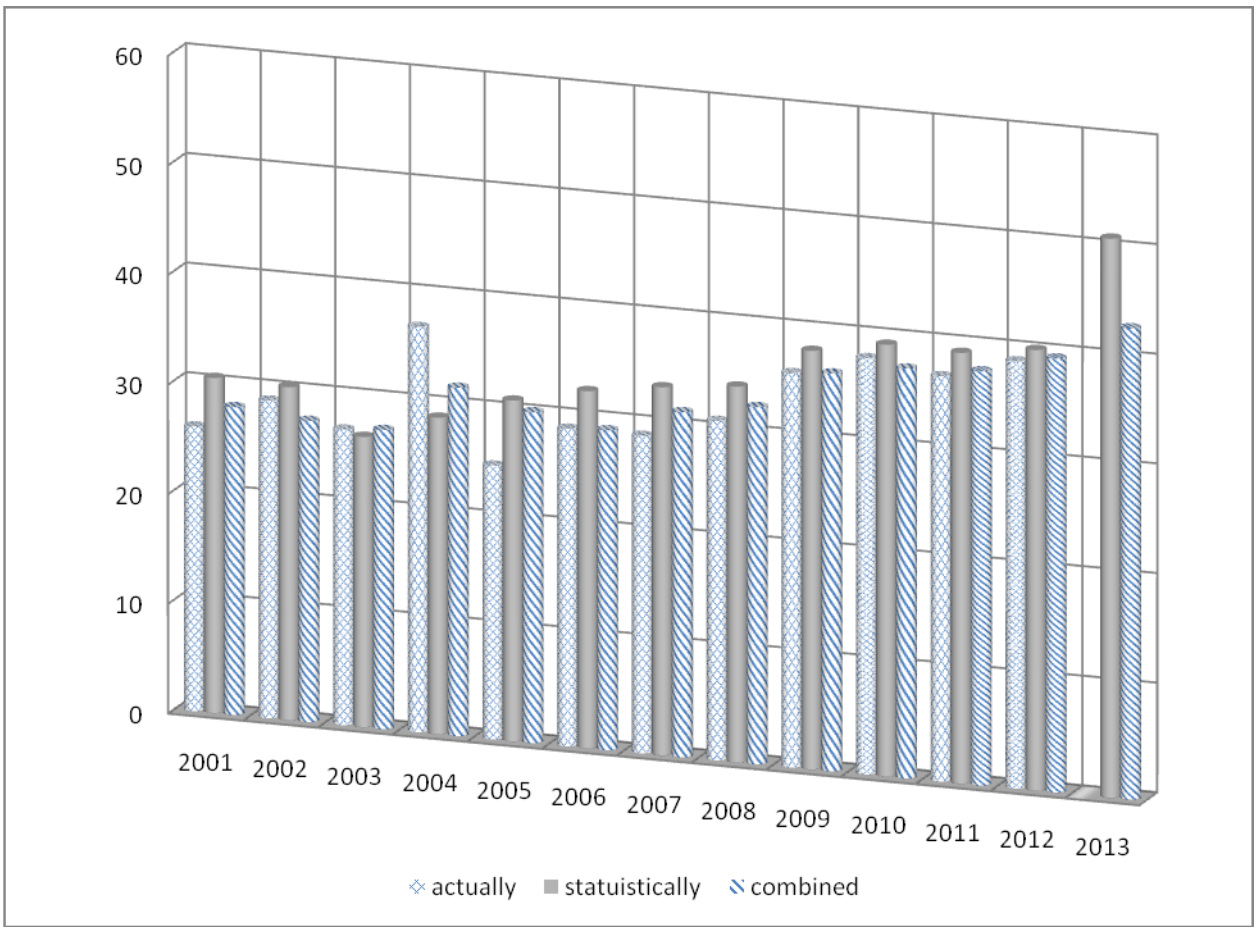


Fig. 5. Comparison of statistical and combined predictions of the risk of occupational injury in the food industry

As we see in Fig. 5, the statistical prediction of the number of injured employees at the enterprises of the food industry shows larger deviations from the actual number of injured employees (standard error is equal to 2.53) than the combined prediction (standard error is equal to 0.85). Thus, it can be concluded that, on the average, the efficiency of prediction increases by 60 % due to the combination of the method of principal components with the expert evaluation method.

On the basis of the obtained theoretical and practical results, in the work, we justified measures and means for preventive measures of risk on the basis of its prediction and developed a project of a complex of means of automation of labor protection control for the food industry, which consists of two software tools: "Automated system of accounting, analysis, and evaluation of accidents at enterprises of the food industry" and "Control of knowledge on labor protection of production personnel" [9].

Conclusions

As a result of the performed investigations, we have developed a technique for increasing the level of labor safety in the food industry on the basis of the prediction of risks of occupational injury, which is of great importance for prevention of dangers and hazards with the aim of providing favorable working conditions, preventing failures, and precluding occupational diseases and accidents.

One of the promising scientific directions of enhancing the safety of the manufacturing process is the prediction of risks of occupational injury, which is directly connected with the manufacturing process, and creation of conditions for preventing traumatism on the basis of these predictions. The analysis of the existing risk prediction methods enables us to draw the conclusion that they must be improved with regard for the features of the food industry and complex evaluation of risks of occupational injury.

For the first time, the model of risk of occupational injury in the food industry has been developed. This model is based on taking into account complexly the influence of the whole range of production and socioeconomic factors on injury and is constructed on the basis of a scheme of emergence of an accident, in which each fact of the accident is related to the prerequisite of its emergence. The indicated approach enables us to carry out an analysis of direct cause-and-effect relations that take place in the process of injury and to reveal both main and hidden causes of occupational injury, and types of events that lead to an accident.

The combined method of regression analysis on principal components has been improved. In contrast to the existing method, it additionally includes the results of refinement of the main influence factors on the basis of the expert evaluation method, which makes it possible to use it for predicting injury risks in the case of substantial correlation of the initial statistical data and insufficient conditionality of the system of normal equations in the determination of regression coefficients and in the case of the presence of errors in the determination of the initial indices and a shift of the estimates of injury.

The methods of labor protection control have been further developed on the basis of the combination of statistical analysis, expert evaluation with ranking of factors and combined prediction of risks of occupational injury with the realization of the algorithm of formation of propositions as to improving the working conditions at the enterprises of the food industry. This makes it possible to develop managerial decisions on providing safe working conditions for the personnel employed in the food industry on the basis of objective prediction of risks.

The proposed technique for increasing the level of safety in the food industry on the basis of prediction of risks of occupational injury formed the base of the algorithm of monitoring of causes and circumstances that lead to occupational injury in the food industry and formation of informational support for training of personnel on urgent problems of labor protection. On the basis of the indicated technique, recommendations on the analysis of the causes and circumstances that lead to injury of an employee at a specific working place and on the determination of the complex of the most reasonable antitraumatic measures.

The developed models and methods have qualitatively new properties and make it possible to increase the efficiency (precision) of prediction, on the average, by 60 % on the basis of the combination of the method of principal components with the expert evaluation method, which enables us to increase the total efficiency of preventive measures of occupational injury at enterprises of the food industry, on the average, by 18–23%.

The scientific results of the investigations are a contribution to the development of theoretical and applied fundamentals of labor protection in the part that concerns diagnostics, prediction, and modeling of extreme situations, and evaluation of their consequences. The results of the investigations have been introduced at a number of enterprises of the food industry.

A wide range of problems on the development of the methods of determination of the cause-and-effect relations of occupational injury, prediction of risks and development of efficient measures for improving the system of labor protection control in the food industry can be promising directions of further investigation.

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