Development of the occupational safety in the food industry with regard for the risk-based approach

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Keywords:

Safety
Labor
Traumatism
Risk

Article history:

Received 22.01.2016
Received in revised form 16.03.2016
Accepted 24.03.2016

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Abstract

Introduction. The prediction of occupational risks and making the conditions for the prevention of injuries based on it is one of the promising scientific directions of the workplace safety development in industry, as it is directly connected with the manufacturing process.

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; the method of principal components; the expert evaluation method for improving the method of prediction of injury risks; the method of apriori ranking of factors in the processing of the results of expert grades.

Results and discussion. Because of the performed investigation, the 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 the safety development in the manufacturing process is the prediction of occupational injury risks, directly connected with the manufacturing process, and making the conditions for preventing traumatism basing these predictions. The results of the comparative analysis of retrospective prediction according to the methods of regression analysis (prediction) and the improved method of combined prediction based on the method of principal components combined with the expert evaluation method indicate that the statistical prediction of the number of injured employees at the food industry enterprises shows larger deviations from the actual number of injured employees (the standard error equal to 2.53) than the combined prediction (standard error equal to 0.85). Thus, it is possible to conclude 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.

Conclusions. 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.

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 the conditions that do not comply with the occupational safety norms and regulations. At the workplaces of food enterprises, increased level of noise and vibration is registered, illumination and microclimatic parameters do not comply with the sanitary requirements. Mandatory medical inspections are often performed formally and incompletely. A substantial level of traumatism, occupational deceases and accidents with severe and lethal consequences are the consequence. 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 considered as satisfactory [1].

Development of 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 manufacture control. In this case, the contradiction appears that may lead to increase of occupational injuries. It is connected, on one hand, with the necessity of occupational safety development, necessarily reducing to additional expenses at the above-listed works and to the products' manufacturing cost increase. On the other hand, a decrease in the productions expenses may lead to the increase of occupational traumatism.

As there is the substantial number of scientific sources that consider the problem of organization of occupational safety and prevention of traumatism, however, most of them do not include deep investigation of the problem of complex development of the occupational safety and analysis of the occupational injuries in the food industry [6-10].

One of the promising scientific directions of the safety of the manufacturing process increasing is the prediction of occupational risks directly connected with the manufacturing process and making the conditions for the prevention of injuries on its basis. Analysis of the existing risk prediction methods enables us to draw the conclusion on the necessity of improvement for most of them, with the aim to adapt them to the features of enterprises of the food industry and to make complex evaluation of risks of occupational injuries at the enterprise.

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

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

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

1. To perform the statistical analysis of accidents in the food industry.
2. To develop methods of investigating the cause-and-effect relations of the injury processes in the food industry.
3. To improve the methods of predicting the risk of occupational injuries.
4. To investigate the cause-and-effect relations that lead to injuries 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 work conditions in the industry, determine the rational directions of preventive measures of occupational injuries, and justify the 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

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

Results of discussion

Basing on the analysis of the statistics of occupational injuries in the food industry of Ukraine between 2003 and 2011, 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 for the efficient cooperation with the industry and corresponding state organs. The analysis and prediction of indices of the state of labor protection is the important function of labor protection control. Thus, the question of how to form an SLPC that will consider the problem of labor safety at the enterprises of the food industry complexly, with regard for its future state, arises.

The situation of taking a decision in the SLPC on reducing the level of occupational injuries 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 proceeding 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 alternative managerial decisions realization; 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 proceeding from which the state of labor protection is evaluated in the previous time interval and managerial decision is taken:

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

One of the promising scientific directions of increasing the general level of safety of the manufacturing process is the prediction of risks of occupational injuries $Y^{t+\Delta t}$ and making the conditions of injury prevention based on 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 ones has the form

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

where q_{onm} is the optimal managerial decision; $y_j^{t+\Delta t}$, $y_\Gamma^{t+\Delta t}$ are, consequently, the predicted and limiting (specified) values of the injury index at the moment $t+\Delta t$; C_j, C_Γ are, consequently, the predicted and limiting (admissible) expenses for the realization of the preventive measures of injuries. 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 about the necessity of their improvement with the aim of their adaption to the features of enterprises of the food industry and complex evaluation of the risks of occupational injuries at the enterprise, which determines the necessity to solve the urgent scientific-applied problem of *the development of a technique for increasing the labor safety in the food industry basing on the prediction of risks of occupational injuries.*

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 injuries [2] were developed, and the methods of labor protection control based on combined predictions of risks [2-3] were improved.

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

$$R = \sum_{i=1}^{n} S_i P_i \,, \tag{3}$$

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 a process of injury, we used a scheme of an accident emergence represented by the statistical data on the direct causes of occupational injury (Fig. 1) [3].

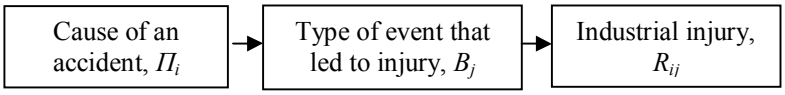

Fig. 1. The scheme of the emergence of an accident represented by statistical data on direct causes of occupational injury

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 $R_{П1B1},...,R_{П16B15}$ are the values of injury risks for binary complexes "cause of injury risk – type of injury event"; $i=1,...,16$ 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; $j=1,...,15$ is the number of the main types of injury events.

For the prediction of occupational injuries in the work, we used the method of principal components, as a minimum error of prediction is provided due to its main properties. For example, let the initial investigated p-dimensional vector of observations X be replaced by the vector $Z=\left(z^{(1)},z^{(2)},...,z^{(p')}\right)^T$ of smaller dimensionality p', in which each component is a linear combination of p initial (or auxiliary) features without too much information loss. 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 corresponding linear combinations $z^{(1)},z^{(2)},...,z^{(p')}$. 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 $\Delta=\left[\Delta_{ij}\right]$, 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 best prediction $x^{(i)}$ in the least-squares sense at the components $z^{(1)},z^{(2)},...,z^{(p')}$. The error of prediction of X from Z is given as a certain defined function of the elements of the matrix $\Delta=\left[\Delta_{ij}\right]$, i.e., $\sigma=f\left(\Delta\right)$, where $f\left(\Delta\right)$ determines a certain criterion of prediction quality.

The following measures of prediction error can be used:

1. $f\left(\Delta\right)=Tr\left(\Delta\right)=\Delta_{11}+\Delta_{22}+...+\Delta_{pp}$ on the basis of the trace of the matrix $\Delta=\left[\Delta_{ij}\right]$;
2. $f\left(\Delta\right)=\left\|\Delta\right\|=\sqrt{\sum_{i=1}^{p}\sum_{j=1}^{p}\Delta_{ij}^2}$ on the basis of the Euclidean norm of the matrix $\Delta=\left[\Delta_{ij}\right]$.

It was proved that both measures simultaneously attain their maximums if only the first p' principal components of the vector X are chosen as $z^{(1)},z^{(2)},...,z^{(p')}$, and the value of the prediction error $\sigma=f\left(\Delta\right)$ 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 $\lambda_{p'+1},...,\lambda_p$ of the sample covariance matrix $\hat{c}$ constructed from the observations $X_1,X_2,...,X_n$. In particular,

$$\text{for } f(\Delta) = Tr(\Delta): \sigma \approx \lambda_{p'+1} + \lambda_{p'+2} + ... + \lambda_p;$$

$$\text{for } f(\Delta) = \|\Delta\|: \ \sigma \approx \sqrt{\lambda^2_{p'+1} + \lambda^2_{p'+2} + ... + \lambda^2_p}.$$

Thus, basing on the methods of regression and component analysis, the model of occupational injury risk is formed. It complexly relates 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 the regression analysis on principal components, with the linear model in the form

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

where R is the dependent index or a characteristic of the process or phenomenon investigated, Y_k is the value of the first principal components for the objects of investigation, $k = 1, 2, 3, ..., p$; $b_0 ... b_k$ are the coefficients of the regression equation; ε_k is the 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 basing on the *expert evaluation method* usage, with the aim 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 based on the combining of the statistical analysis, expert evaluation with ranking of factors and combined prediction of risks of occupational injuries are considered. In the work, we propose an algorithm of formation of decisions (Fig. 2) about organization and providing safe work conditions basing on the risk prediction, where the main stages of the process of decisions formation on the basis of combined prediction of risks are presented.

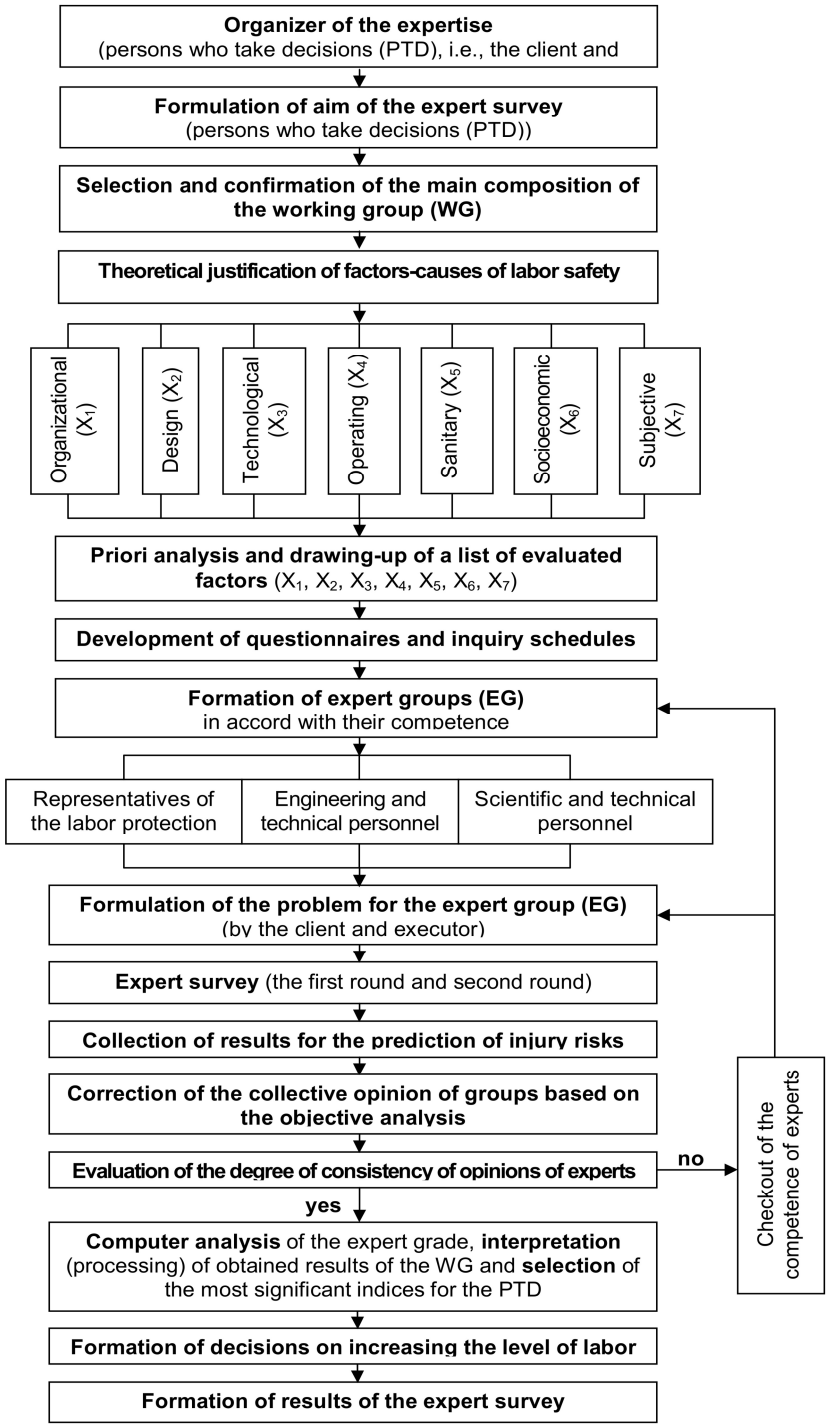

Fig. 2. Algorithm of formation of decisions on the organization and ensuring of safe working conditions based on the prediction of risks

Applying the models and methods developed using data for the period between 2001 and 2012, we investigated the statistics of occupational injuries with the methods of regression analysis, construction of multifactor regressive models and performed combined prediction for the period between 2012 and 2013.

Basing on the corresponding time series, mathematical models of trends and predictions of the future behavior of time series were constructed. In the Fig. 3, the dynamics of the number of injured employees for the different types of events is shown for an example. 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%, indicating the applicability of the proposed approach to the prediction of the dynamics of time series of occupational injury [4].

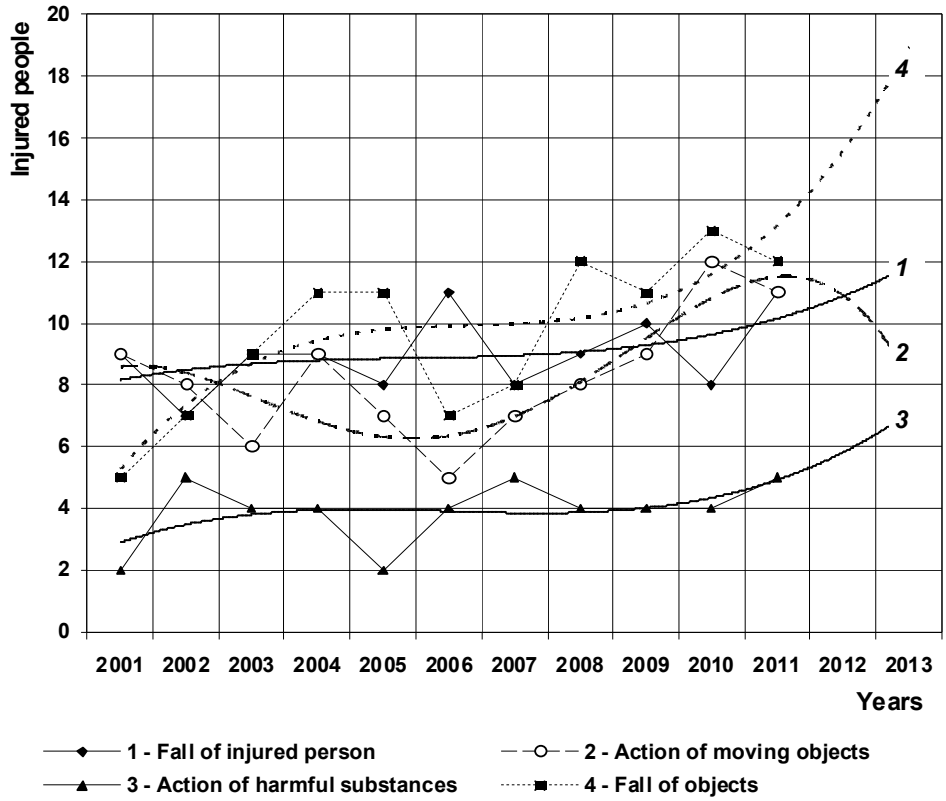

Fig. 3. Dynamics of the number of injured employees for different types of events

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:

$y = 0{,}0289x^3 - 0{,}549x^2 + 3{,}5282x + 2{,}2576,\ R^2 = 0{,}8474$

To evaluate the efficiency of predicting the level of injuries basing on the method of combined prediction, we compared the prediction grades using 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.

$$A = -0,06112 + 0,6754X_{nl} + 0,8718X_{n2} + 1,5954X_{n3} - 0,8534X_{n4} + 0,2794X_{n5} +$$
$$+0,2953X_{c1} + 0,3732X_{c2} + 0,3609X_{c3} + 0,4207X_{c4} + 0,7141X_{c5}$$

Errors of the prediction with 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 the combined prediction by the refined grades based on expert evaluation, the aim of which is to refine the influence of the factors on the occupational injuries. With the results of processing, we constructed diagrams of ranks, which refine the values of the factors of influence on the occupational injuries (Fig. 4). Professions most susceptible to traumatism, causes of intentional violation of safety requirements, potential causes of traumatism, factors that cause injuries during the technological process performance, factors of the most dangerous (in terms of injury) equipment, and labor protection measures were investigated analogously.

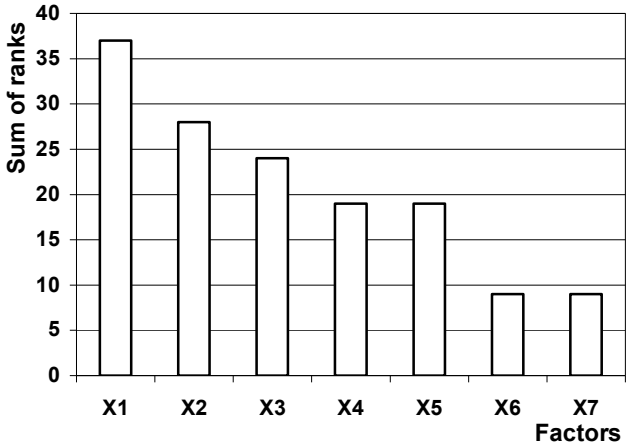

Fig. 4. Diagram of ranks of production and technical factors

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

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

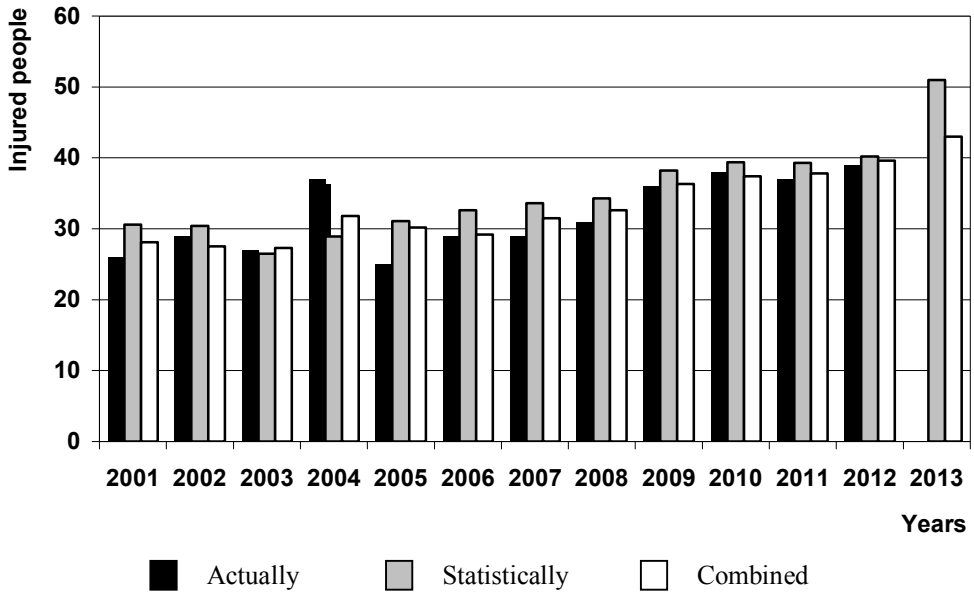

Fig. 5. Comparison of statistical and combined predictions of risk of occupational injuries in the food industry

As we see in the Fig. 5, 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 (standard error equal to 2.53) than the combined prediction (standard error 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.

Basing on the obtained theoretical and practical results, in the work we justified measures and means for preventive measures of risk with the help 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" [5].

Conclusions

As a result of the performed investigations, we have developed a technique for increasing the level of labor safety in the food industry basing on the prediction of risks of occupational injuries, which is of great importance for prevention of dangers and hazards with the aim of providing favorable work 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 injuries, which is directly connected with the manufacturing process, and making the conditions for preventing traumatism using these predictions. The analysis of the existing risk prediction methods enables us to draw

the conclusion that they need improvement with regard for the features of the food industry and complex evaluation of risks of occupational injuries.

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 complex influence of the whole range of manufacturing and socioeconomic factors on injuries and constructed on the fundament of a scheme of an accident emergence, 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 injuries, 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 taken from the expert evaluation method, which makes it possible to use it for predicting injury risks in case of the substantial correlation of the initial statistical data and insufficient conditionality of the system of normal equations in the determination of regression coefficients and in case of presence of errors in the determination of the initial indices and a shift of grades of traumatism.

The methods of labor protection control have been further developed basing on the combination of statistical analysis, expert evaluation with ranking of factors and combined prediction of risks of occupational injuries with the realization of the algorithm of formation of propositions to the improvement of the work conditions at enterprises of the food industry. Thus, it becomes possible to develop managerial decisions on providing safe work 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 basing on the prediction of risks of occupational injuries formed the base of the algorithm of monitoring of causes and circumstances that lead to occupational injuries in the food industry and of the informational support formation for personnel training on urgent problems of labor protection. On the base of the indicated technique, recommendations were created on the analysis of the causes and circumstances that lead to injury of an employee at a specific working place and on the complex of the most reasonable antitraumatic measures was determined.

The developed models and methods have new and novel properties and make it possible to increase the efficiency (precision) of prediction, on the average, by 60%, based on 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 injuries 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 injuries, 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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