

DEVELOPMENT OF SIMULATION METHODS FOR LABOUR PROTECTION STATUS INDICATORS

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Summary. The course of analysis showed reasonability of using the method of group accounting of arguments for simulation of labour protection status indicators at the enterprises.

Key words: indicators, labour protection, mathematical model, traumatism.

INTRODUCTION

It is known [Bilostotska 2002] that during transition period of market economy formation with peculiar for it variability and ambiguity, due to inconsequent administrative decisions and imperfect current legislation, it's most reasonable to use mathematical methods of the analysis formalized as software. Under such approach it is possible to process data bulks and to determine economic indicators most substantially affecting the final result. In respect of labour protection the factor analysis task boils down to the determining of complete set of quantitatively measurable factors influencing the change of a resultant index - labour protection costs. It enables to establish dependences between the index and a certain set of factors. Foreign researchers also point to that, particularly, according to [Kristensen 1991] all factors leading to the accidents (A) are divided into external and internal. It means that factor analysis is the most convenient instrument of economic process research in relation to labour protection matters with the help of which it is possible to solve tasks concerning the determination of laws existing under influence of the internal and external reasons, and factors most influencing the process of reasoned administrative decision taking. It is necessary to mention that total number of the indicators considered (approximately 100) is formed by factors listed in the data of 7-tnv state statistical reporting form "Report on occupational traumatism and its financial effects".

RESEARCH OBJECT

Data stated above show the necessity of reporting under the factor analysis of large variety of labour protection indicators, but on the other hand modifications should be also made to the list of these indicators according to the probable transformations in the economy of Ukraine, that is also specified by [Stupnytska 1999] concerning reporting of occupational risks and latent damage connected with occupational traumatism. Therefore it is reasonable to investigate in greater length the peculiarities of influence of methods used for simulation of labour protection indicators at the enterprises.

RESULTS OF EXPERIMENTAL RESEARCH

It is stated in [Stupnytska 1999, Volodin 1973] that as a rule, the existing techniques of mathematical models construction and search of universal assessment criteria for trauma-hazardous situations at the engineering enterprises provide research of statistical trauma-related data set. And any statistical material collected by the researcher can serve only for verification of various hypotheses concerning the distribution type or for assessment of its parameters, and probabilistic occupational traumatism models should be available for any hypothesis concerning distribution of number of accidents. Among such models are: general model; binomial model; Poisson model; negative binomial model.

General probabilistic model is based on the principle that various hazardous situations occur during production process implemented by the workers of one or several professional occupations and can lead to some number N of accidents. And since these situations that can be divided into some number of groups $i = 1, 2, \dots, S$ of accidents with identical traumatizing probability p_i repeat during a working day according to the operational cyclicality, they possess identical probability of accident occurrence. To construct a model, it is necessary to know the character of daily changes of values S, N, p_i for each group of hazardous situations. It means that accident rate v_i

... v_s is a value in distribution of which we're actually interested, $v = \sum_I^S v_i$ is a general

number of accidents occurring at the enterprise within a working day.

Binomial model is peculiar to occupational staff consisting of the workers of one profession performing one and the same work under the same conditions and hazards ($S = 1$). Suppose that existing traumatizing reasons do not disappear and new reasons do not appear in this group, so N and p values are constant values for it, and the number of accidents per day is subject to binomial distribution, i.e. probability that k number of accidents per day will take place (at $k = 0, 1, 2, \dots, N; p > 0$) is defined as follows:

$$P \{v = k\} = C_N^k \cdot p^k (1 - p)^{N-k} . \quad (1)$$

In some productions hazard arises periodically, for example, during pressing under working press. The number of hazardous situations N is directly proportional to the number of working press cycles and quantity of site staff ($N \rightarrow \infty$). But the accidents occur infrequently, i.e. their probability p - is small ($p \rightarrow 0$) due to various labour

protection measures. In relation to any group of hazardous situations the product $N_i p_i$ is invariable during the observable period of time $N_i p_i = \lambda_i$, while in terms of great N_i and small p_i the probability that k_i accident will take place in i -group of hazardous situations is equal to:

$$P\{v_i = k_i\} = \frac{e^{-\lambda_i} \cdot \lambda_i^{k_i}}{k_i!}, \quad (2)$$

and it is referred to as Poisson distribution. Since the general number of accidents per day is equal to the sum of accidents occurred in each group of hazardous situations, and in respect of Poisson distribution the addition formula (summation theorem) is fair

($\lambda = \sum_I^s \lambda_i$), general number of accidents at the enterprise will make according to

Poisson's law:

$$P\{v = k\} = \frac{e^{-\lambda} \cdot \lambda^k}{k!}; \quad (k = 0, 1, 2, \dots; \lambda > 0). \quad (3)$$

It shows that such model does not assume identical probability of traumatizing for all groups of accidents. On the contrary, at $N_i p_i = \text{const}$ it presupposes daily change of p_i together with the number of hazardous situations.

According to [Kozlov 1989] Poisson distribution should not be always used for the analysis of an accident rate and traumatism, for example, at mines and in tote industry, as it is used in the case when the probability of event is small enough.

Negative binomial model is the generalization of Poisson one and presupposes that Poisson distribution parameter λ can vary from day to day in a random way complying with the general law referred to as gamma distribution. Thus the probability that number k of accidents will take place exactly per day is equal to:

$$P = (v = k) = \left(\frac{\alpha}{\alpha + \lambda}\right)^\alpha \cdot \frac{\alpha(\alpha + 1) \dots (\alpha + k - 1)}{k!} \cdot \left(\frac{\lambda}{\alpha + \lambda}\right)^k, \quad (4)$$

$(k = 0, 1, 2, \dots; \lambda > 0, \alpha \geq 0).$

This distribution depends on the parameters λ and α , known as negative binomial or compound Poisson distribution. In [Volodin 1973] the conclusion is drawn that in conditions of the steady-state production Poisson distribution seems to be most probable.

In work [Stupnytska 1999], on the basis of the analysis executed in [Kozlov 1989], the conclusion is drawn that the existing assessment criteria (accident frequency and severity rates) do not give a clear picture for traumatism dynamics, have low predictive value, and the assessment criteria on the basis of system component failure definition have restricted application due to limitation and complexity of formalization in respect of the majority of heuristic procedures taken as a basis for decision-making during planning of activities directed to prevention of occupational traumatism. Therefore there were distinguished two lines of investigations associated with injury risk assessment of manufacturing systems, the first of which [Korolev 1976, Minkh 1973], known as a synthesis method, allows to generalize the certain indicators and to develop general injury risk model for production area by a method of generalization and

formalization of tendencies concerning the reasons and consequences of accidents. The advantage of this method is that all reasons of occurrence of injury-risk situations are taken into account, and that the mathematical generalizations are simple under statistical information processing. Drawbacks of the method include limitation and unreliability due to the necessity when creating a generalization model to research not only immediate cases of traumatism, but also tendencies of their influence on the key performance indicators of the enterprise.

Another approach specified in [Hale 1972, Mason 1976] is based on the results of general sociological and statistical security ratings of the in-line and auxiliary equipment, etc. and conditionally named as a method of analysis under injury-risk assessment of production process. However the algorithm of mathematical model should take into account an opportunity of researching both separate factors and reception of complex injury-risk assessment criterion [Kozlov 1989].

In [Stupnytska 1999], on the basis of accident research, the following basic reasons of their occurrence are shown: technical; sanitary and hygienic; managerial; social and psychological; hereditary and anthropometric; psychophysiological; production - that corresponds to the reasons specified in [Arshava 1974, International symposium 1969]. However it should be noted that, despite of their complete description in [Gogitashvili 1993], most of the techniques are created without regard to the opportunities of current computer technology and require substantial reprocessing. Therefore special attention should be paid to the analysis of the existing safety evaluation criteria for machines and production processes, having laid special stress on the probability of hazardous situations or protection system failure, but the technique for evaluating of such probability is not specified.

It is specified in [Popsuyenko 1980] that there are absent in occupational safety system:

- the exact formula for object of management and standard hazard criterion because of what it is impossible to receive objective information concerning the state of object of management,
- opportunity to calculate or forecast the scope of traumatic and non-traumatic hazard effects,
- objective measurer of occupational hazard level that makes the uniformity of measurements impossible in the field of technology, economics, occupational health and safety arrangements.

It is suggested in the work [Supakov 1978] to use in the capacity of production process assessment criterion both safety indicator determined on the basis of timing observations or the morphological analysis of time outlays for risky job with due account for specified or statistically defined system failure probability, and workplace safety level, production safety level, etc.

According to [Ushakov 1972] local (for evaluating the object by individual hazardous factor) and integral (for object as a whole) principles are taken as a basis of safety and reliability criteria for production areas, as well as complex criteria of hazard R and safety S are determined (in points).

$$R = \left(1 - e^{-\sum_{i=1}^n a_i} \cdot 10^m \right), S = 1 - R = e^{-\sum_{i=1}^n a_i} \cdot 10^m. \quad (5)$$

The hazard level is assessed by the sum of mathematical expectations ($\sum_{i=1}^n a_i$) as a quality criterion of man-machine system:

$$\lambda T = \sum_{i=1}^n a_i, \quad (6)$$

where: λ - average intensity of injury-risk situations; T - duration of evaluation period.

According to [Voronin 1996] for the purpose of increase of objectivity during injury risk assessment of various machines and machine tools the indicator has been introduced:

$$Q = \frac{\omega \cdot k_{Tn}}{\sqrt{k_T}}, \quad (7)$$

where: ω - average traumatism percent under operation of the given type of machines, of total amount of occupational injuries for certain time interval; k_{Tn} - injury risk indicator per unit of the single-type machines; k_T - average indicator for severity of injuries.

Originally traumatism probability was attached to a working day, and then it was suggested in [Revuk 1995] to use the following safety criterion during operating safety evaluation for the certain period of time

$$\delta = \delta_1 + \delta_2 + \delta_3 + \delta_4, \quad (8)$$

where: δ_1 - probability of worker's injury stipulated by imperfection of technological process, equipment, mistakes of process engineers, etc.; δ_2 - probability of injury due to mistakes made during debugging and maintenance of equipment and its safety systems; δ_3 - probability of injury due to the mistakes made by the worker himself, including non-observance of procedures discipline by him, violation of safety rules, etc.; δ_4 - probability of injury due to engineering and design deficiency of equipment, networks, workshop facilities.

According to [Tkachuk 1999] it is recommended while calculating δ_1 , δ_2 , δ_3 to take into account psychophysiological state of a man.

It is pointed out in [Stupnytska 1999] that the approach stated in [Kozlov 1989] is most real currently and allows to use numerical techniques for assessment criteria formation which are based on the queueing theory fundamentals, since the integrated occupational safety assessment in complex production systems (workshop, plant) should be based first of all on traumatism statistics, and in case of insufficient scope of the latter - on the expert evaluation data of the workspace parameters or characteristics of traumatism flows.

Upon that it is necessary also to mention that while examining of accident flow provided in [Volodin 1973] it was specified that the authors also relied on the queueing theory in their investigations.

It is mentioned in [Kozlov 1989, Gogitashvili 1993] that while choosing one of the analyzed alternatives for realization during planning of activities directed to

prevention of occupational traumatism there is no certainty that the selected variant is optimal and there are no other more effective decisions for the task assigned.

In the opinion of [Kozlov 1989] computer realization of traditional methods of designing occupational safety and health tasks together with optimization of a choice will allow to make qualitative leap during planning of protection means and support systems for effective and safe working conditions, to decrease subjectivity of decision-making, to reduce planning terms and to increase efficiency of occupational protection activities.

The conclusion is drawn in [Stupnytska 1999] that in accordance with the investigations [Kozlov 1989, Gogitashvili 1993] there appeared a necessity to develop statistically mathematical, probabilistic, and economic and mathematical models where at the same time frequency, occupational injury severity and influence of the basic technical and economical requirements on the occupational health and safety status in production processes of the machine-building enterprises would be taken into account. Therefore [Stupnytska 1999] contains developed technique, algorithm and program for investigation of influence of occupational injury indicators on the engineering-and-economical performance of Ukrainian western regions' machine-building enterprises, realized with queueing theory application. On the basis of a regression analysis of statistical data under the Ferster technique [Ferster 1983] there was particularly investigated influence of eight basic technical and economic indicators of the enterprise on injury frequency rate with use for verifying the hypothesis concerning the compliance of distribution of their values to the normal law of distribution with Kolmogorov criterion use:

$$\lambda = \frac{|m_{\Sigma} - m_{\Sigma}^T|_{max}}{N} \cdot \sqrt{N}, \quad (9)$$

where: m_{Σ} - empirical cumulative frequency; m_{Σ}^T - theoretical cumulative frequency; N - statistical sample size for technical and economic performance values of machine-building production for m years in retrospective. In research there was defined coefficient of determination

$$B_{y.l...m} = \frac{b_l \cdot \sum_{i=1}^l [(xl_i - \bar{x}) \cdot (y_i - \bar{y})] + \dots + b_m \cdot \sum_{i=1}^l [(xm_i - \bar{x}) \cdot (y_i - \bar{y})]}{\sum_{i=1}^l (y_i - \bar{y})^2}, \quad (10)$$

by which it was estimated what power the coordination number has depending on technical and economic performance variation. It is established that only three factors from the latter influence on the occupational traumatism level – capital-labour ratio and available power, labour protection expenses.

It is shown in [Kruzhilko 2001] that it's possible to justify appropriation and disposition of funds to Health, Safety and Environmental Management System (HSE MS) with the help of mathematical models received as a result of statistical data processing. It is suggested to use conceptual mathematical formulation of HSE MS functioning at the enterprise in the form of:

$$\Omega = (X, Z, Y), \quad (11)$$

where: Ω_t - HSE MS status at the moment t , then $\Omega_1, \Omega_2, \Omega_3 \dots$ - HSE MS status in 1, 2, 3, ... intervals of simulated time; $X = \{X_{ij}\}$, $i = 1, \dots, n$ - set of input variables (working condition, status of equipment and processes, length of service, age of the workers, etc.) and n is a number of variables; $Z = \{Z_i\}$ - set of variables approximating amount of financing assigned for reduction of influence of the financing factors with restrictions:

$$\sum_{i=1}^n Z_i \leq Z_0, Z_i \geq 0, Z_i \leq Z_i^{max}, \quad (12)$$

where: Z_i - amount of financing allocated for activities directed at i -factor hazard level reduction (harmfulness); Z_0 - general amount of financing allocated for safety measures; Z_i^{max} - maximum possible amount of financing allocated for activities directed for full elimination of i -factor action; $Y = \{Y_{kj}\}$, $k = 1, \dots, m$ - set of output variables approximating the indicators of labour protection status at the enterprise (traumatism levels, disease incidence, etc.). It is supposed that values of these variables fall within range $Y_k^{min} \dots Y_k^{max}$, boundaries of which correspond to the minimal and maximum possible values of the given indicator, which can be accepted by any of m indicators.

Functional dependence of each of the indicators from the variety of factors has the following appearance:

$$Y_k = F_k(X). \quad (13)$$

In such formulation it is a discrete programming problem being solved with the help of nonlinear programming methods [Zaychenko 1988], but in that particular case, if the dependences Y_k are linear functions, it is solved with the help of linear programming methods.

For the purpose of mathematical modeling of indicators it was suggested in [Kruzhilko 2001] to use the formalized system reflecting the basic essentials of HSE MS functioning of the enterprise in accordance with the algorithm, executing mapping of input set X into output set Y . For this purpose self-organization method of models is used in work - method of group accounting of arguments (MGAA) which is alternative to the classical statistical analysis methods and which allows to solve structural identification problems in conditions of essentially bounded statistical data sample and effect of random non-stationary perturbation. For the purpose of model ranking it is recommended to use in addition to two selection criteria characterizing accuracy of constructed models and forecast accuracy, the criteria allowing to take into account certain minimal values of simulated indicators, incorrect from the viewpoint of real conditions of model, and permissible boundary values of the simulated indicators under linear search of various combinations of values influencing the factors.

According to [Kostenko 2002] for the purpose of improving the conditions of Ukrainian agricultural sector additional indicators of labour protection assessment which create scientific basis for single- and multiple factor regression analysis of potential hazards and planning of preventive labour protection activities in the event of cost optimization. The techniques of this analysis have allowed to receive a complex of mathematical models and to ascertain the degree of influence of safety factors on a resultant indicator. But being in the final form these models are useless for the mechanical engineering enterprises, as they are based on the indicators specific to an agriculture.

CONCLUSION

The executed analysis specifies that there has been recently outlined significant progress in use of various modeling methods for labour protection status indicators, that is very important from the point of view of perfection of a control system of protection of work of the average and large enterprises. It is considered that most preferable thing in the present conditions of economic development of Ukraine is to use for these purposes method of group accounting of the arguments capable to simulate indicators under limited statistical data sample and under influence of random non-stationary perturbation. For this it is necessary to carry out additional researches concerning the adjustment of assessment criteria which are necessary for taking into account in conditions of sites, shops and enterprise as a whole.

REFERENCES

1. Bilostotska V.O., Malykhin O.V. National measure algorithm for evaluation of labour protection equipments // Information bulletin concerning labour protection. – K.: NIOSH, 2002. – №3. – P. 14-15.
2. Human factor. Available in 6 volumes. Ergonomics is complex scientific and technical discipline: Translated from English / G. Kristensen, D. Master, P. Foly and other. – M.: Mir, 1991. – V.1. – 599 p.
3. Stupnytska N.V. Increase of efficiency for planning of activities directed at occupational traumatism prevention at the machine-building enterprises: Author's abstract of dissertation, Candidate of engineering science: 05.26.01 / SU "Lvivska Politehnika". – L., 1999. – 22 p.
4. Volodin I.N., Ioffe V.M. Probabilistic traumatism models and distribution of accident frequency rate at the industrial enterprises // Safety engineering matters: Subject collection – M., 1973. – P. 5-23.
5. Kozlov V.I. Methodology of labour protection in the man-machine systems. Riga: Zinatne, 1989. – 183 p.
6. Korolev G.F. Occupational traumatism methods of detection of their reasons. – M.: NIIMASh, 1976. – 41 p.
7. Minkh A.A. Sanitary and hygienic research reference book. – M.: Medicine, 1973. – 400 p.
8. Hale A.R., Hale M.A. A review of the industrial accidents research literature. –London: Comm. Safety Health Work, 1972. – 96 p.
9. Mason K. A system to list employers with poor accident experience. – Vancouver: Worker's Compensation Board, 1976. – 36 p.
10. Arshava V.G., Malov V.P., Saramud B.D. Structural and system analysis of the traumatism reasons // Occupational safety in industry, 1974. – №11. – P. 39-42.
11. International symposium on man-machine systems // Ergonomics, 1969. – Vol. 12. – №4. – P. 485-687.
12. Gogitashvili G.G. Labour protection at the enterprises of commercial building materials: Tutorial. – K.: ISDO, 1993. – 252 p.
13. Popsuyenko K.V. Fundamentals of optimal occupational safety planning and management. – Lvov: Higher school, 1980. – 140 p.
14. Supakov N.K. Technique of safety assessment of equipment on the basis of possible injury simulation of a man in the labour process and defining of the safety level. // Occupational safety problems: Theses of the lectures of the 3rd All-soviet union interuniversity conference. – Kishinev: Shtiintsa, 1978. – P. 42 - 43.

15. Ushakov K.Z., Sofonovsky B.I. Occupational safety forecast and evaluation of technical decisions // Occupational safety in industry. – M., 1972. – № 11. – P. 18-20.
16. Voronin M. Traumatism statistics demands cardinal questions // Labour protection. – 1996. – №11. – P. 3-4.
17. Revuk A.G. Scientific fundamentals concerning the increase of efficiency of airline labour protection management system: Author's abstract of dissertation, Doctor of Engineering: 05.26.01. – K., 1995. – 38 p.
18. Tkachuk S.P., Lesenko G.G., Tkachuk K.N., Luchko I.A., Vodyanik A.O. Methodological instructions concerning the determination of directions for effective labour protection investment at the enterprise. – K.: Osnova, 1999. – 80 p.
19. Ferster E., Rents B. Methods of correlation and regression analysis. – M.: Finances and statistics, 1983. – 302 p.
20. Kruznilko O.Y. Improvement of complex evaluation of labour protection status at the enterprises. Author's abstract of dissertation, Candidate of engineering science: 05.26.01 / K.: NIOSH, 2001. – 20 p.
21. Zaychenko Y.P. Operation research. – K.: Higher school, 1988. – 552 p.
22. Kostenko O.M. Improvement of methods and ways for complex analysis, forecast and prevention of occupational traumatism in the agricultural sphere: Author's abstract of dissertation, Candidate of engineering science: 05.26.01 / NIOSH. – K., 2002. – 23 p.

СОВЕРШЕНСТВОВАНИЕ МЕТОДОВ МОДЕЛИРОВАНИЯ ПОКАЗАТЕЛЕЙ СОСТОЯНИЯ ОХРАНЫ ТРУДА

Касьянов Н.А., Гунченко О.Н., Вишнеvский Д.А.

Аннотация. На основе выполненного анализа показана целесообразность использования метода группового учета аргументов для моделирования показателей состояния охраны труда на предприятиях.

Ключевые слова: показатели, охрана труда, математическая модель, производственный травматизм, система управления охраной труда, метод группового учета аргументов.