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# OPTIMIZATION MODEL FOR PLANNING SET OF MEASURES TO PREVENT OCCUPATIONAL INJURIES IN MACHINE-BUILDING ENTERPRISES

## Model optymalizacji dotyczący planowania pakietu środków służących zapobieganiu urazów w miejscu pracy w przedsiębiorstwach budowy maszyn

**Abstract:** *Criteria of occupational injuries potential risk in the machine-building industry are described in the article. Systemic analysis of the structure of the measures to prevent occupational injuries is given. Main tasks to reduce the risk of industrial injury at the machine-building enterprise are analysed. The methodology for optimal planning of accident prevention measures at the machine-building enterprise is described. A mathematical interpretation of the problem is given. The objective function is an argument of the maximum integral effectiveness for the set of planned measures to prevent occupational injuries. Constraint set of the optimization model describes the impossibility to exceed the allowable limit of cost, the feasibility and the possibility of implementing the measure's plan reasoning from the technological and construction requirements of existing production engineering.*

**Keywords:** safety, occupational injury, accident, risk, injury source, optimization model

**Streszczenie:** *W artykule opisano kryteria potencjalnego ryzyka urazów w pracy w przemyśle maszynowym. Podano analizę systemową struktury środków służących zapobieganiu urazów w miejscu pracy. Dokonano analizy głównych zadań mających na celu zmniejszenie ryzyka urazów w przedsiębiorstwach budowy maszyn. Przedstawiono matematyczną interpretację wspomnianego problemu. Funkcja celu jest argumentem maksymalnej integralnej skuteczności w odniesieniu do pakietu środków służących zapobieganiu urazów w miejscu pracy. Ograniczony pakiet modelu optymalizacyjnego opisuje niemożność przekroczenia dozwolonego limitu kosztów, wykonalność oraz możliwość wdrożenia uzasadnionego planu działania na podstawie wymagań technologicznych i konstrukcyjnych istniejącej technologii produkcji.*

**Słowa kluczowe:** bezpieczeństwo, uraz w miejscu pracy, wypadek, ryzyko, źródło urazu, model optymalizacji

# 1. Introduction

The International Labour Organization (ILO) estimates that about 2.8 million fatal accidents around the world occur annually in manufacturing. This means that about 7,700 people die daily from work-related illnesses or injuries! Worldwide, there are around 340 million occupational accidents and 160 million victims of work-related illnesses annually [13]. Work-related accidents in the mechanical engineering industry have always been among the most massive and difficult [12]. Unfortunately, the level of injuries at work during an economic crisis is not reduced. Employers try not to associate the greatest number of accidents with production to avoid fines and penalties. They only try to provide official indicators for the inspection agencies [9,14]. The gross underreporting of occupational illnesses or injuries, including fatal accidents, is giving a false picture of the scope of the problem [11]. Moreover, many experts think that the reduction in the frequency of industrial accidents is primarily due to an incomplete account of minor injuries.

Ensuring a Safety Lifecycle System (SLCS) is the basis of new IEC Standard 61511 [6]. It is entitled ‘Functional safety - Safety instrumented systems for the process industry sector’. It is a technical standard which sets out practices in the engineering of systems that ensure the safety of an industrial process through the use of operational actions and measures to reduce the risks of injury at the industrial enterprise. SLCS system consists of interconnected parts: the analysis subsystem (risk assessment and probabilistic analysis of potential hazards in the workplace), the planning subsystem (measures planning to reduce the risks of injury) and the subsystem for implementation and monitoring actions to ensure safety operations [6,8]. Only basic recommendations for the implementation of such a system are given in the standard. Creating a Computer-Aided Planning System to implement the basic ideas of the standard is an important scientific task. The development of mathematical support is the most important prerequisite for the implementation of this system.

The following tasks need to be addressed to develop a system of operational planning of actions to reduce the risk of industrial injury in machine-building enterprises: establishment of the real state of equipment and production environment hazard for each certain shop and workplace [3]; determination of the optimal range of actions for the prevention of occupational injuries and work-related illnesses, the implementation of which will minimise the integral safety criteria for the given production conditions [7]; determination of the optimal volume and priority of the actions to prevent injuries, which will achieve a minimum level of risk to workers in the shortest possible time with minimal costs and will not exceed the costs allocated to the safety measures for a given enterprise [2].

## 2. Criteria of potential risk of occupational injuries in machine-building industry

Most of the existing methods used to analyse the work-related injury hazards of machines and the working conditions for engineering enterprises are based on the known theses of the reliability theory on the statistical probability of the engineering elements failure [4,5]. The main evaluation criteria that characterize the safety of workers in these methods are the probability of unsafe manufacturing conditions or acts, such as dangerous situation due to objective or subjective reasons, the probability of the industrial equipment protection systems failure or deliberate violation of the safety technique by workers.

Let's consider the structure of the manufacturing subdivision of the machine-building enterprise in order to create a mathematical model for analyzing the existing occupational safety and health system.

As the objective sources ( $a_{ij}$ ) of work-related injury or illness in the machine-building shop can be: main manufacturing equipment (machines, tools, etc. ($\left(a_{1j};\ j=\overline{1,A}\right)$); auxiliary manufacturing equipment (devices, adjustments, fixtures, etc. ( $a_{2j};\ j=\overline{1,B}$ )); transport and warehouse equipment (cranes, stackers, electric cars, etc. ( $a_{3j};\ j=\overline{1,C}$ )); network's equipment (electricity, pneumatic, gas, steam, hydraulic supply, etc. ( $a_{4j};\ j=\overline{1,D}$ )); constructions and transport routes $\left(a_{5j};\ j=\overline{1,E}\right)$. The total number of work-related injury sources is denoted by $J$ ($J=A+B+C+D+E$).

Each $a_{ij}$ -th source is characterised by a certain total level of occupational injury risk. Risk ratio ($R_{ij}$) is used in the statistical analysis of the data studies to estimate the strength of the association between danger source and probabilistic injury result [10]. In order to optimize the planning of measures to improve working conditions for each given source, it is necessary to differentiate the total of injury risk for the $j$-th source on such components as ($R_{ijk}$): the risk ratio $R_{ij1}$, caused by the possibility of falling objects due to the unregulated unlocking of load, unsatisfactory state of constructions, etc.; the risk ratio $R_{ij2}$, caused by the possibility of mechanical injury by the moving or rotating objects; the risk ratio $R_{ij3}$, arising from the probability of a worker falling from a dangerous height; the risk ratio $R_{ij4}$, caused by the possibility of a traffic accident; the risk ratio $R_{ij5}$, due to extreme temperatures; the risk ratio $R_{ij6}$, arising as a result of injury by the crushed parts of the workpiece or tool; the risk ratio $R_{ij7}$, caused by the probability of an electric shock; the risk ratio $R_{ij8}$, due to the possibility of exposure to harmful substances, noise, vibration, radiation, etc.

It is obvious that for certain $a_{ij}$ -th injury source, only some of the above-listed causes of injury are representative, for others, it is possible to consider $R_{ijk}=0$.

The total risk ratio for $a_{ij}$ -th work-related injury source can be calculated as:

$$R_{ij} = k_{lf} \cdot (1 - (\prod_{k=1}^{K} (1 - R_{ijk}))^{1/M} \tag{1}$$

where $k_{ltf}$ is the Lost Time Injury Frequency Rates (LTIFR) [10]. It is the average coefficient of disability, which simultaneously takes into account the injury frequency, durability and severity rates and determines the number of disability days per 1000 workers, who serve the $a_{ij}$ -th injury source. $k = \overline{1, K}$ above-listed causes of accident. *M* is the number of workers serving or located in the zone of operation of this danger source.

The foregoing dependencies make it possible to determine the potential risk of injuries for the abstract engineering subdivision provided with specific equipment operating under specified manufacturing conditions. However, for the analysis of a particular occupational injury danger level, it is necessary to adjust the calculated risk ratio $R_{ijk}$ [5], taking into consideration the actual hazardous working conditions and state of protective systems for each $a_{ij}$ -th injury source by the formula:

$$R_{ijk}^{Real} = R_{ijk} \cdot r_{1ijk} \cdot r_{2ijk} \cdot r_{3ij} \cdot r_{4ij}, \tag{2}$$

where $r_{1ijk}$ is the coefficient characterising the absence of regular ( $r_{1ijk} > 1$) or the presence of additional ( $r_{1ijk} < 1$) protection and blocking system, fences in *j*-th workplace of *i*-th type injury source to prevent *k*-th cause of possible injury; $r_{2ijk}$ is the coefficient determined by the installation of additional automation equipment for work performed in dangerous conditions in *j*-th workplace of *i*-th type injury source to prevent *k*-th cause of possible injury ( $r_{2ijk} < 1$); $r_{3ij}$ is the coefficient that takes into account the real manufacturing and ergonomic working conditions of $a_{ij}$ -th potential injury source operation ( $r_{3ij} < 1$ for the light duty working conditions; $r_{3ij} > 1$ when working in hard or extreme conditions); $r_{4ij}$ is the coefficient that is characterized by the actual duration of $a_{ij}$ -th potential injury source running ( $r_{4ij} \leq 1$- when a lifetime less than the resource of $a_{ij}$ -th source; $r_{4ij} > 1$ when the real operating time of $a_{ij}$ -th potential injury source is more than fixed service life period).

The general index of occupational injury risk for the *l*-th engineering subdivision of the machine-building enterprise is determined by the formula:

$$R_{l\Sigma} = \prod_{i=1}^{I} \prod_{j=1}^{J} \prod_{k=1}^{K} R_{ijk}^{Real}, \tag{3}$$

In addition, the average ratio of the potential work-related injury or illness should be calculated:

- by the typical sources of occupational injury:

$$R_{li} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(R_{ijkl}^{Real} \cdot \beta_{ij})}{I}, \tag{4}$$

where $\beta_{ij} = 1$, if the *j*-th equipment belongs to the *i*-th type of potential injury source; $\beta_{ij} = 0$ – otherwise.

- by the possible causes of occupational injury

$$R_{lk} = \frac{\sum_{i=1}^{I}\sum_{j}^{J}\sum_{j=1}^{J}(R_{ijkl}^{Real} \cdot \gamma_{kj})}{K}, \tag{5}$$

where $\gamma_{kj} = 1$, if *k*-th cause of injury is characteristic for *j*-th engineering equipment; $\gamma_{kj} = 0$, otherwise.

Potential sources of occupational injury or illness must be sorted in the order of decreasing the risk ratio $\left\{R_{ijkl}^{Real}\right\}$ to determine the priority and importance of introducing measures to reduce it. These data are to be entered into the database of the Computer-Aided Planning System for Occupational Safety and Health.

## 3. System analysis of the structure of the measures to prevent occupational injuries

Measures for the prevention of occupational injuries and work-related illnesses ($b_{mn}$) in the manufacturing subdivision (shop) of machine-building enterprise can be subdivided into: technical $\left(b_{1n}\ \left(\text{m=1; } n = \overline{1,G}\right)\right)$; organization $\left(b_{2n}\ \left(\text{m=2; } n = \overline{1,H}\right)\right)$; sanitary $\left(b_{3n}\left(\text{m=3; } n = \overline{1,P}\right)\right)$; psycho-physiological $\left(b_{4n}\ \left(\text{m=4; } n = \overline{1,Q}\right)\right)$. The total number of measures is denoted by $N$ $(N=G+H+P+Q)$.

Each $b_{mn}$ preventative measure is determined by the tuple of the parameters:

$$b_{mn} =< B_{1mn};\ B_{2mn};\ B_{3mn;}B_{4mn} >, \tag{6}$$

where $B_{1mn}$ is the total balance cost of the $b_{mn}$-th measure; $B_{2mn}$ is the coefficient of efficiency of the $b_{mn}$-th measure; $B_{3mn}$ is the coefficient of implementation expediency of the $b_{mn}$-th measure; $B_{4mn}$ is the coefficient of productivity change of the manufacturing equipment as a result of implementation of the $b_{mn}$-th measure.

The total balance cost of the $b_{mn}$-th measure is determined by the formula:

$$B_{1mn} = S_{1\,mn} + S_{2\,mn} + S_{3\,mn} + S_{4\,mn} + S_{5\,mn} + S_{6\,mn} + S_{7\,mn} \tag{7}$$

where $S_{1\,mn}$ is the cost of the basic equipment and materials necessary for the implementation of the $b_{mn}$-th measure; $S_{2\,mn}$ is the cost of the additional materials needed for the implementation of the $b_{mn}$-th measure; $S_{3\,mn}$ is the salary for workers, who carry out installation and construction works for the implementation of the $b_{mn}$-th measure; $S_{4\,mn}$ is the cost of installation and construction works for the implementation of the $b_{mn}$-th measure; $S_{5\,mn}$ is the cost of planning and research works for the implementation of the $b_{mn}$-th measure; $S_{6\,mn}$ is the cost of equipment functioning while the implementation of the $b_{mn}$-th measure; $S_{7\,mn}$ is the economic effect or loss resulting from the change in the productivity of the manufacturing equipment caused by its downtime during installation works or more intensive use as a result of the implementation of the $b_{mn}$-th measure.

The economic effect of the introduction of the $b_{mn}$-th preventive measure relates only to the introduction of technical measures ($m$ = 1) for the main manufacturing equipment ($j$ = 1) and is calculated as:

$$S_{7\,mn} = \sum_{j=1}^{A}\sum_{n=1}^{G}\left(\overline{C_j}\cdot\left(1-\frac{(T_{inst\,nj}+T_{ts\,nj})}{\overline{T_{mt\,j}}}\right)\cdot k_{chp\,jn}\cdot\alpha_{jn}\right), \tag{8}$$

where $\overline{C_j}$ is the average cost of products' parts manufactured by the $j$-th model of machine (that is $j$-th potential source of injuries); $k_{chp\,jn}$ is the coefficient taking into account the increase ($k_{chp\,jn}$<1) or decrease ($k_{chp\,jn}$>1) of the $j$-th equipment productivity as a result of the introduction of the $b_{1n}$-th preventive measure; $\alpha_{jn} = 1,$ if the $b_{1n}$-th measure is proposed for the installation of $j$-th equipment, ($\alpha_{jn} = 0,$ otherwise); $T_{inst\,nj}, T_{ts\,nj}$ is the time for installation and technical service of protective equipment for the prevention of occupational injuries as a result of the implementation of $b_{1n}$-th measure; $\overline{T_{mt\,j}}$ is the average machining time of technological operation on the *j*-th tool machine.

In order to determine the coefficients of the effectiveness of the alternative measures $B_{2mn}$, it is necessary to carry out statistical studies of the impact of each $b_{mn}$-th injury prevention measure for the retrospective *T* years ($t=\overline{1,T}$). That is, the analysis of the possibility to avoid (or mitigate the consequences) of each accident during the recordable period need to be made. Therefore, the value of the actual disability ratio $k_{dt}$ in each retrospective year is determined and the causes of injury are analysed. The Boolean variable will be accepted $\varphi_{vn}$ = 1, if the cause of occupational injury in v-th accident is eliminated as a result of timely implementation of the $b_{mn}$-th injury prevention measure; $\varphi_{vn}$ = 0, otherwise. Then, the value of the efficiency factor is as follows:

$$B_{2mn}=\frac{\sum_{t=1}^{T}k_{dt}}{\sum_{t=1}^{T}\sum_{v=1}^{V}\left(\left(\frac{D_{vt}\cdot 1000}{G_t}\right)\cdot\varphi_{vn}\right)}, \tag{9}$$

where the actual disability ratio $k_{dt}$ in *t*-th retrospective year can be calculated as:

$$k_{dt}=\sum_{v=1}^{V}\left(\frac{D_{vt}\cdot 1000}{G_t}\right), \tag{10}$$

where $D_{vt}$ is the number of working days lost in consequence of the worker disability as a result of the *v*-th accident in *t*-th retrospective year; $G_t$ is the average number of workers at a given manufacturing subdivision in *t*-th recordable year.

The coefficients of the effectiveness of the technical measures $B_{2mn}$ are declaratively assigned to considerably more than 1 in case of fatal or permanent disability injury (for example, 10 or 5, respectively), that is, with an unconditional priority in front of other measures.

The coefficient $B_{3mnj}$ of implementation expediency of each $b_{mn}$-th measure for every $a_{ij}$-th source of occupational injuries is caused by the possibility of practical implementation of this measure from a technological and design view point.

The calculated coefficient of implementation expediency of each $b_{mn}$-th measure for every $a_{ij}$-th danger source is determined by the formula:

$$B_{3mnj}^{calc} = k_{TRnj} \cdot k_{CRnj} \cdot k_{PRnj} \cdot k_{SRnj} \cdot k_{Anj}, \tag{11}$$

where $k_{TRnj}, k_{DRnj}$ are the coefficients that determine the possibility of technological or construction realisation of *n*-th prevention measure in the *j*-th workplace (i.e. on the tool machine which is the source of injuries), respectively ($k_{TRnj} = 1;\ k_{DRnj} = 1$, if possible, respectively; $k_{TRnj} = 0;\ k_{DRnj} = 0$, otherwise); $k_{PRnj}, k_{SRnj}$ are the coefficients of technical and operational complexity of the *n*-th protective measure introduction in the *j*-th workplace ($k_{PRnj} = 1;\ k_{SRnj} = 1$, if technical or organization complexities are absent and experience for the service of the such equipment exists, respectively; $k_{PRnj} < 1;\ k_{ORnj} < 1$, otherwise); $k_{Anj}$ is the coefficient that determines the presence of similar safety systems and equipment, which already operate in the *j*-th workplace (source of injuries), needed for the implementation of *n*-th prevention measure ($k_{Anj} = 1$, if there is no such equipment; $k_{Anj} = 0$, otherwise).

Since the actual coefficient $B_{3mnj}$ of the implementation expediency of each $b_{mn}$-th measure can be 0 (in case of inappropriateness) or 1 (if applicable) only, then its definition is carried out by the following conditions:

$$\begin{cases} B_{3mnj} = 1, \text{ if } B_{3mnj}^{calc} \geq 0,5; \\ B_{3mnj} = 0, \text{ if } B_{3mnj}^{calc} < 0,5. \end{cases} \tag{12}$$

The coefficient of productivity change of the manufacturing equipment $B_{4mn}$ takes into account the reduction or increase in manufacturing total productivity as a result of the protection equipment or implementation and installation of organization events provided during the implementation of the $b_{mn}$-th measure. That is, $B_{4mnj} = 1$ in the absence of the influence of the $b_{mn}$-th measure realisation on the total productivity of the *j*-th tool-machine (as injuries source); $B_{4mnj} < 1$, if total productivity decreases; $B_{4mnj} > 1$, if total productivity increases.

The average value of the coefficient of manufacturing equipment total productivity change $B_{4mn}$ can be calculated as:

$$B_{4mnj} = \frac{T_{inst\,nj} + T_{ts\,nj} + \overline{T_{mt\,j}} \times k_{chp\,nj}}{\overline{T_{mt\,j}}} \tag{13}$$

where $T_{inst\,nj}, T_{ts\,nj}$ are the times for installation and technical service of protective equipment for the prevention of occupational injuries as a result of the $b_{mn}$-th measure implementation, respectively; $\overline{T_{mt\,j}}$ is the average machining time of technological operation on the *j*-th tool machine; $k_{chp\,jn}$ is the coefficient taking into account the increase ($k_{chp\,jn}$ <1) or decrease ($k_{chp\,jn}$ >1) of the manufacturing productivity as a result of the introduction of the $b_{mn}$-th preventive measure in the *j*-th tool machine (as a potential source of injuries).

## 4. Mathematical optimization model of the safety measures planning in machine-building enterprises

The complex structural-parametric optimization model should reflect the technical, organizational, economic and social aspects of planning system of measures to prevent accidents in machine-building enterprise. The general index of occupational injuries for the *l*-th engineering subdivision should be used as the optimization criterion. The limits and conditions of the mathematical model should reflect the possibility of technical and economic implementation of the plan, with a condition to achieve the greatest effect from the implemented measures $\{b_{mn}\}$ for the given engineering subdivision containing $\{a_{ij}\}$ potential sources of injury.

In general, the mathematical model is described as the following system of equations:

$$P_l = \arg\max\left( \sum_{i=1}^{I} \sum_{j=1}^{F} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{n=1}^{N} (R_{ijk} \cdot B_{2mnjk} \cdot r_{1ijkn} \cdot r_{2ijkn} \cdot r_{3ijkn} \cdot r_{4ij} \cdot \alpha_{jn}) \right) \tag{14}$$

$$B_{1mnj} = \sum_{j=1}^{J} \left( S_{1\,mn} + S_{2\,mn} + S_{3\,mn} + S_{4\,mn} + S_{5\,mn} + S_{6\,mn} + S_{7\,mn} \right) \le [S] \tag{15}$$

$$\begin{cases} \prod_{k=1}^{K} B_{2mnjk} > 1; \ \left|\alpha_{jn} \ne 0; \right. \\ \forall\ n = \overline{1,N}; (N = G + H + P + Q); \forall\ j = \overline{1,J}; (J = A + B + C + D + E); \end{cases} \tag{16}$$

$$\begin{cases} \wedge_{\mathrm{m}=1}^{\mathrm{M}} B_{3mnj} = 1; \ \left|\alpha_{jn} \ne 0; \right. \\ \forall\ n = \overline{1,N}; (N = G + H + P + Q); \forall\ j = \overline{1,J}; (J = A + B + C + D + E); \end{cases} \tag{17}$$

$$\begin{cases} \sum_{n=1}^{G} \overline{T_{mt\,j}} \cdot B_{4mnj} \cdot \alpha_{jn} \le \dfrac{60 \cdot F_j \cdot \eta_j}{N}; \\ \forall\ j = \overline{1,A}; \end{cases} \tag{18}$$

The objective function (14) is an argument of the maximum integral coefficient effectiveness for the set of planned measures $P_l$ to prevent occupational injuries and work-related illnesses at the certain subdivision of the machine-building enterprise.

The constraint set of the optimization model (15)-(18) describes the next conditions and limitations:

Constraint function (15). The economic costs for the implementation of each *n*-th prevention injury measure $\left(n = \overline{1, N}\right)$ of the *m*-th type should not exceed the predetermined marginal cost $\left[S\right]$.

Constraint function (16). The effectiveness of all measures should be positive, i.e., realisation of each of *n*-th prevention injury measure $\left(n = \overline{1, N}\right)$ of the *m*-th type for every *j*-th $\left(j = \overline{1, J}\right)$ source of accident should ensure a reduction in the total level of the accident’s hazard.

Constraint function (17). All injury prevention measures proposed to be included to plan should be expedient for the *j*-th accident source with the viewpoint of the possibility of technological or construction realisation.

Constraint function (18). The average value of the manufacturing time for the technological operations on each *j*-th equipment $\left(j = \overline{1, J}\right)$, changed due to the implementation of the *n*-th technical prevention injury measure $\left(n = \overline{1, G}\right)$, should not exceed the output production cycle time ($F_j$ is the total annual operation time of manufacturing equipment (for example, for two-shift operation of the main technological equipment $F_j$ = 4020 h); $\eta_j$ is the loading of the *j*-th source of injury (as a rule, $\eta_j$ = 0.7...0.85); *N* is the annual output programme of the manufactured products).

The above mathematical model is a task of integer programming with Boolean variables [1]. The algorithm for discrete combinatorial optimization task solving this problem uses a directional search procedure by heuristic rules. This algorithm includes the next stages.

1. For every investment alternative *n*-th prevention injury measure $\left(n = \overline{1, N}\right)$, the coefficients of effectiveness $B_{2mn}$ for every *j*-th $\left(j = \overline{1, J}\right)$ source of accident in accordance with the formula (9) are calculated.

2. The next stage of the system's operation is a subprogramme of ranking all alternative measures $\{b_{mn}\}$ on the condition of decreasing the efficiency indicator $B_{2mn}$. That is, an ordered list of injury prevention measures is created in which the serial number of the measure $g=\overline{1,N}$ is selected, based on the condition of the indicator reduction $B_{2mn}$: $g = f\left(Rank\left[B_{2mn}\right]\right)$.

3. The logical sequence procedure for the development of an injury prevention efficiency improvement plan $\{b_g\} \in P$ is implemented as follows:

3.1. First, number 1 (g = 1) is appointed as the most effective measure, and this measure is conditionally included in the action's plan.

3.2. The economic constraint is satisfied if the cost of $b_g$ -th measure $S_g$ does not exceed the allowable costs $[S]$ in accordance with the formula (15). In the positive case of the implementation of the condition $S_g \le [S]$, we proceed to step 3.3. Otherwise, this $b_g$ -th measure is ignored, we proceed to the next action $b_{g+1}$ and repeat the verification of this step.

3.3. Next verifications check if the possibility and the expediency of realisation of the $b_g$ -th prevention measure in accordance with constraint functions conditions (16)-(18) been ensured. In the positive case we can move to step 3.4. Otherwise, this measure $b_g$ is ignored, we proceed to the next action $b_{g+1}$ and repeat the verification of the previous step 3.2.

3.4. We finally include the given measure to the action plan $\{b_g\} \in P$, change the current value of the accessible cost as $[S\;] = [S\;] - S_g$ and move to the next measure $b_{g+1}$ from the ordered list (step 3.2).

4. The iterative procedure for forming a plan with accident's prevention measures is carried out until the full list of the measures for every $a_j$ -th $\left(j=\overline{1,J}\right)$ source will be exhausted.

The developed system is a classic example of the implementation of the Computer-Aided Planning System for Occupational Safety and Health (CAPS OS&H).

# 5. Conclusions

1. Most important potential sources of the occupational injuries and work-related illnesses in the production subdivisions of machine-building enterprises and most dangerous causes of accidents were analysed and systematized.

2. The basic criteria of accident's danger, which significantly influence the mechanical production safety and efficiency as well as the cost of the manufactured products, are proposed. The methodology of the complex assessment of occupational injury for the mechanical production subdivision was developed, which allows to obtain the structure of quantitative indices of injury for each potential injury source for every possible reason, taking into consideration the real state and operating conditions of the equipment in the given machine-building enterprise.

3. The structural-parametric optimization model for the Computer-Aided Planning System for Occupational Safety and Health (CAPS OS&H) is developed. This mathematical model is a task of integer programming, which is used to describe the algorithm for discrete combinatorial optimization task. A directional search procedure by heuristic rules is used for solving this problem.

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