



Aušra STANKIUVIENĖ

**RISK MANAGEMENT AND OPTIMIZATION
OF ACCIDENTS AT WORK IN CONSTRUCTION**

**Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)**

1567-M

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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General Characteristic of the Dissertation

Topicality of the Problem. A safe workplace is a path to a successful business. At the moment the labour world is changing rapidly alongside with work related health problems. All over the world the death toll in construction is three times higher than in other areas and the number of injuries is twice as much as that in other professions.

The death toll in the EU construction sector per 100 thousand employees is more than twice as much as the average death toll per 100 thousand employees in other sectors (this sector accounts for 13 fatalities per 100 thousand workers, compared to 5 fatalities in other sectors), i. e. more than 1 300 people perish due to fatal accidents every year. The losses incurred due to work related accidents amount to 2–4% of GDP in various countries.

Since Lithuania is a member of the European Union, the prevention of work related accidents is becoming one of the areas of the policy on safety and health at work. It is claimed that every third fatal and every fourth serious work related accident takes place in construction. Specific preventive measures aimed at reduction of work related accidents normally become the object of planning; they are given priority and are included in the action plans of an enterprise. Due to economic and financial reasons, quite a few enterprises introduce measures related to safety at work slowly, and even larger financial and social losses are incurred due to work related traumas as pecuniary penalties are to be paid and the damage to health is to be remunerated, and a potential labour force is lost. Preventive measures are usually very expensive and it is impossible to foresee all the circumstances of work related accidents as their cause is sometimes an employee himself/herself. It is important for an employer to know which measures preventing work related accidents are most efficient and how to allocate funds designated to the prevention of work related accidents in an optimal way. This would allow to reduce the number of work related accidents alongside with social insurance benefits.

Object of the Research. Serious and fatal accidents in the construction sector in Lithuania in the period 2000–2006.

Objective and Tasks of the Work. The work is aimed at preparing a mathematical model for the assessment of the efficiency of preventive measures and suggesting optimisation problems for selecting a preventive strategy in order to reduce the number of accidents at work.

Major Tasks of the Work:

1. To carry out the research on risk management process by analysing its individual elements in detail.
2. To survey mathematical methods suitable for the prediction of work related accidents and the assessment of the efficiency of preventive measures as well as management of funds designated to prevention.
3. To analyse the state of safety and health at work in the construction sector and determine the causes influencing work related accidents as well as their economic consequences.
4. To examine the possibilities of applying a matrix game and suggest general mathematic models for the assessment of the efficiency of preventive measures.
5. To select a mathematical probabilistic model for a random rate of accidents at work and on its basis apply stochastic programming to modelling the problem of prevention.

Scientific Novelty

1. It is the first time when a scientific work analyses the problems of risk management on the basis of the factual information of serious and fatal accidents in Lithuania in the construction sector in the period 2000–2006 and the resources available in a specific institution, recording work related accidents.
2. A mathematical model of an optimization problem to assess the efficiency of preventive measures related to accidents at work is presented.
3. The optimization problem in the strategy of selecting preventive measures is modelled by applying stochastic programming.

Research Methodology

The method of comparative analysis was used in analysing Lithuanian, foreign and international legislation regulating risk assessment and prevention of work related accidents as well as in examining the problems tackled by various scientists. Statistical methods (descriptive statistics, statistical non-parametric hypothesis testing, confidence interval for Poisson's distribution parameter λ) are applied to examine the data of serious and fatal accidents in construction companies. In order to assess the efficiency of preventive measures and determine the optimal allocation of funds designated to the prevention, optimisation methods were applied (a matrix game and stochastic programming).

Practical Value. Mathematical optimization methods applied – matrix game and stochastic programming – and properly selected weight coefficients of preventive measures as well as percentages of the evaluation of the prices of preventive measures allow to model optimal planning and the most efficient allocation of funds designated to the prevention of accidents at work as well as to assess the efficiency of preventive measures. The results obtained also suggest methods for application of scientific research in the field of occupational safety and health and may be used in the process of studies.

Statements Defended

1. The possibilities of predicting accidents at work.
2. The mathematical model of deterministic matrix game for the assessment of the efficiency of preventive measures of accidents at work and optimal allocation of funds designated to prevention.
3. Problems of stochastic programming, modelling the problem of optimal selection of accident at work prevention.

The Scope of the Scientific Work. The scientific work consists of six chapters, including introduction and conclusions, the list of references, the list of author's publications and annexes.

1. The State of Risk Management and Development Trends

This chapter looks into the concept of risk management, analyses the main risk management principles, surveys the main global trends related to safety and health at work, analyses the main risk factors in the working environment, their impact on accidents at work and incapacity for work of the employees, surveys the possibilities of support provided for the implementation of preventive measures and examines the aspects of general risk elimination and prevention management of accidents at work.

It has been established from the analysis of references that accidents in construction companies cause negative consequences to labour market and economic development of the country at the national level, and reduce the activity efficiency at the company level. The main reasons for accidents in construction companies are failure to comply with the provisions of the statutory legislation, improper organisation of workplaces, failure to apply safety measures, insufficient employee training. Due to the aforementioned reasons risk management in construction companies is a topical area of the policy on safety and health at work. Therefore, it is necessary, having analysed the state of safety and health at work in Lithuanian construction companies and

on the basis of data available, to assess economic consequences on the economy of the country due to failure to apply preventive measures and to suggest methodology for determining the efficiency of accident prevention measures in construction companies as well as for optimal allocation of funds designated to prevention. On the basis of this concept the tasks of the research were specified.

2. Research Methodology

The methodologies for integrated processing and assessment of the statistical data on accidents at work are presented in the chapter.

Statistical methods (descriptive statistics, statistical non-parametric hypothesis testing, confidence interval for Poisson's distribution parametre λ) were applied to examine a random variable, i. e. the rate of accidents at work causing serious and fatal accidents at work during a time unit. 176 reports on fatal accidents at work and 340 reports on serious accidents at work, which occurred in construction companies in the period 2000–2006, were analysed by the time of the accident, its causes and damaging factors.

To assess the efficiency of preventive measures and to determine the optimal allocation of funds designated to the prevention, optimization methods (a matrix game and stochastic programming) were applied.

Economic consequences of accidents at work for the economy of the country were determined by applying a statistical-analytical method.

3. The Analysis of Safety and Health at Work in Construction

The research on the state of safety and health at work was carried out in order to approve the proposed research methodology and substantiate its application peculiarities in the territory of the whole Lithuania.

The state of safety and health at work in construction companies is determined by examining whether the working conditions and working instruments comply with the requirements set out in the statutory legislation on safety and health at work, by assessing professional risk in workplaces or other places of an enterprise where employees may be during their working hours.

Examination of the state of safety and health at work is based on the information about the state of safety and health at work in place in enterprises as well as the information from reports on work related accidents accumulated by the State Labour Inspectorate of the Republic of Lithuania. While analysing serious and fatal accidents in Lithuanian construction companies which took place in the period 2000–2006, 176 reports on fatal work related accidents and 340 reports on serious work related accidents were examined.

Directive 89/391/EEC is the most important in terms of safety and health at work in the EU legislative framework. It is complemented by individual directives based on Article 16 of Directive 89/391/EEC or other directives stipulating safety and health requirements for certain products or areas of activity. It is necessary to note that since 1 May 2004 the principle of supremacy of the EU legislation has been in effect in Lithuania.

Lithuania is leading among other member states as far as the indicator of transposition of the EU directives into the national law is concerned (the transposition deficit of the provisions regulating safety and health at work into the national law amounts to 0,4%). Comparison drawn between transposition indicators of the EU directive requirements related to safety and health at work into the national law and indicators of application of legislation in enterprises indicates an obvious gap. On average, companies do not comply with 30% of these requirements.

The results of analysis indicate that employers in almost 50% of construction companies face difficulties in conducting risk assessment as there is nobody to provide them with practical assistance. Internal control of working environment is introduced slowly in the better part of small construction companies. Risk assessment is conducted in less than a half of such companies, one third only manage to prepare plans for the improvement of working environment. In conducting risk assessment in workplaces little consultations with employees take place in determining the existing risks as well as foreseeing preventive measures, they are limited to the issues of the improvement of working conditions, microclimate and work instruments, yet the issues of company management, work organisation, employees' training and skill improvement are not assessed. On numerous occasions employees are forced to make decisions on work execution and technological decisions themselves, which normally are not qualified and precondition work related accidents.

In the period 2000–2006 20 198 accidents at work occurred in Lithuanian companies, out of which 18 274 were minor, 1 239 – serious and 685 – fatal. This data is presented in a graphical form in Figure 1. The dynamics of accidents at work, which took place in Lithuanian construction companies in the period 2000–2006 and amount to 3 253 accidents, out of which 2 739 were minor, 338 – serious and 176 – fatal, is presented in Figure 2. Compared to the total number of accidents at work in the country, minor accidents at work in construction companies account for 15%, serious – for 27,3% and fatal – for 25,7% of all accidents at work in the country.

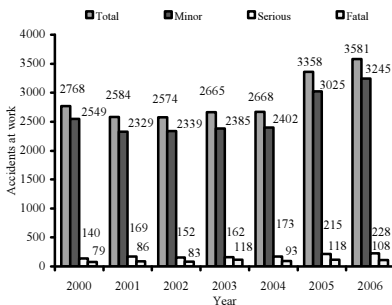


Figure 1. Total number of accidents at work in the country in the period 2000–2006

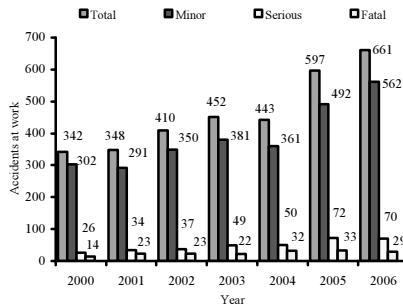


Figure 2. Total number of accidents at work in construction companies in the period 2000–2006

The analysis of accidents at work in construction companies by cripple factors indicates that one fourth of accidents take place due to falls from a certain height, one sixth – due to falling because of a slippery surface or stumbling, one tenth – due to the impact of a road vehicle. The data on accidents at work by cripple factors is presented in Figure 3.

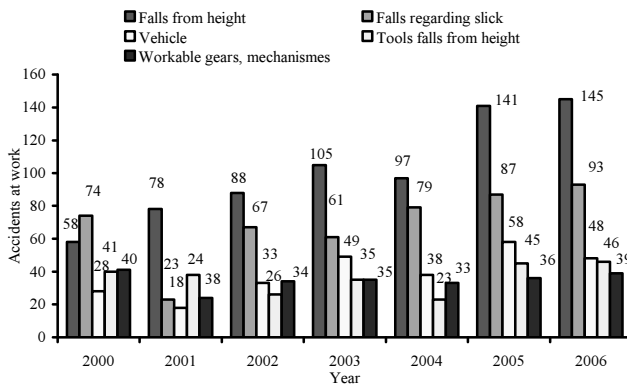


Figure 3. Total number of accidents at work in construction companies by cripple factor in the period 2000–2006

carried out on the roofs, in the buildings, on the constructions, planking, platforms, scaffolds, passageways and other.

While analysing accidents at work it is obvious that the most frequent cripple factor of accidents at work in construction companies is a fall from a certain height. The risk of falling or tumbling in construction sites always exists when works are

Upon Lithuania's accession to the EU, the phenomenon of a constantly changing labour force became particularly evident. Those in their first years of employment are injured three to five times more often than those having a work experience longer than five years. They are the ones who are not properly qualified, are not aware of the dangers in construction sites, their consequences and precautions which should be taken in order to ensure safety. Employers fail to ensure high quality awareness raising of employees and their representatives by explaining about the dangers and hazardous risk factors. It is extremely important in small companies.

Another increasingly frequent phenomenon, boosting the number of accidents at work, is employees under the influence of alcohol. Due to their fault serious and fatal accidents at work take place. 144 employees were involved in serious and fatal accidents at work in construction companies due to the influence of alcohol in the period 2000–2006.

The existent problems affect economic development of the country as social insurance benefits and accident at work benefits are to be paid. Due to accidents at work in the period 2000–2006 the gross domestic product (GDP) amounting to LTL 38 567 thousand was not produced in the country. LTL 136 587 thousand were spent on benefits paid from the social insurance fund and the losses incurred due to accidents at work during the aforementioned period amount to LTL 153 120 thousand.

4. Optimization of Risk Management

In the light of efficient management of accidents at work surveyed in the second chapter of the thesis, by applying the methodologies suggested in the third chapter and by assessing the results of the analysis of the present state of safety and health at work in construction companies obtained in the fourth chapter, mathematical models for the assessment of the efficiency of preventive measures of work related accidents are suggested and stochastic programming problems are solved to select an optimal plan for trauma prevention.

Being aware of the fact that the most severe and serious consequences are caused by serious and fatal accidents at work, fatal and serious accidents were separated from the fairly accurate statistical data available on work related accidents in construction in the period 2000–2006 and analysed. The work related accidents were grouped into seven groups and analysed by their causes (damaging factors).

To find out whether a monthly rate of work related accidents which occurred due to different causes is a random variable distributed according to Poisson's Law, non-parametric hypotheses on Poisson distribution was tested.

The method of descriptive statistics was applied to initial quantitative processing of random variables, and the tools of *Microsoft Excel 2002* software functions *Data Analysis* were used for the analysis of the data available. Thus, the most important statistical parameters of the rate of work related accidents were obtained (sample mean, sample root-mean-square deviation, sample variance).

Hypotheses on monthly rate of serious and fatal accidents at work which took place due to falls from a height or were caused by a vehicle, tools falls from height, tumbling down of a person, earth slipping, workable gears and other factors were tested. There are no grounds to reject the hypothesis for the number of events caused by vehicles only with a significance level of 0,01. In all other cases where a significance level of 0,05 was used it may be claimed that the statistical data does not contradict the hypothesis suggesting that this number is a random variable distributed according to *Poisson's Law*.

To find out whether the stream of fatal and serious accidents at work, which took place due to specific causes, as random events is the simplest (*Poisson*), statistical non-parametric hypotheses suggesting that the time interval, measured in working days, between two accidents at work is a random variable distributed according to the exponential law were tested.

Hypotheses were tested by using the *univariate* procedure of the SAS system. The test of these non-parametric hypotheses by using significance level $\alpha = 0,05$ revealed that there were no grounds to reject them and the statistical data available did not contradict them either. Three statistical significance criteria were applied: *Kolmogorov-Smirnov*, *Cramer-von Mises* and *Anderson-Darling*. The conclusion was drawn that the streams of accidents at work, occurring due to different causes, can be reckoned to be the simplest (*Poisson*) streams of random events.

Given the average time between random events is $\overline{X} = \frac{1}{\lambda}$, then the intensity of the simplest stream (average rate of events during a time unit) is λ . After replacing the time unit of one working day by the time unit of one month (28 working days), the intensities of streams of accidents at work occurring due to various factors were recalculated according to formula $\lambda = \frac{1}{\overline{X}} 28$. Table 1 shows statistical estimations of the average time between accidents at work and average monthly rate of accidents at work obtained by making the aforementioned theoretical assumptions and calculating the arithmetic average of the monthly rate of accidents at work.

Table 1. *Statistical estimations of accidents at work*

Damaging factors	Average time interval between accidents in days	Average monthly accident rate	Average yearly accident rate
Falls from height	11,88	2,36	28,29
Vehicle	32,48	0,86	10,34
Tools falls from height	23,48	1,19	14,31
Falls regarding slick	38,18	0,73	8,80
Earth sliding	102,94	0,27	3,26
Equipment in operation	98,23	0,28	3,42
Other factors	130,56	0,21	2,57

On the basis of an assumption that the stream of work related accidents as random events is the simplest, the probabilities that during time at least one accident, not less than accidents or not more than accidents k will take place can be calculated.

The probabilities that work related accidents k caused by a specific factor will take place during the period of six months are shown in Table 2.

Table 2. *Probabilities of an exact number of accidents at work during the period of six months*

Causes	k							
	0	1	2	3	4	5	6	7
Falls from height	0,00000	0,00001	0,00007	0,00034	0,00120	0,00340	0,00801	0,0162
Vehicle	0,00567	0,0293	0,0759	0,131	0,169	0,175	0,151	0,111
Tools falls from height	0,00078	0,00559	0,0199	0,0477	0,0853	0,122	0,145	0,149
Falls regarding slick	0,0123	0,0539	0,119	0,174	0,192	0,169	0,124	0,0778
Earth sliding	0,195	0,319	0,260	0,142	0,0578	0,0189	0,00513	0,00120
Equipment in operation	0,181	0,309	0,264	0,151	0,0644	0,0220	0,00628	0,00154
Other factors	0,276	0,355	0,229	0,0980	0,0315	0,00812	0,00174	0,00032

Each of the described probabilities has its confidence interval as parameter λ has its confidence interval.

The same measures or similar may be applied to eliminate different causes of traumas. Let weight coefficient s_{ij} indicate to what extent cause j is eliminated by preventive measure i . Given a_j is a predicted average number of

work related accidents, which will take place due to cause j , the sum $b_i = \sum_{j=1}^n s_{ij} a_j$ is an average number of traumas which will occur due to various causes and which may be averted by implementing preventive measure i .

Let a_{jk} be the rate of work related accidents which will take place due to cause j predicted by expert k . Thus, $b_{ik} = \sum_{j=1}^n s_{ij} a_{jk}$ is the number of work related accidents which will be averted by implementing preventive measure i if the prediction of expert k is correct. Another possible interpretation of coefficient a_{jk} is an average number of traumas which occurred due to cause j in year k .

One of the ways to select a preventive strategy is the maximin strategy in matrix game $\|b_{ik}\|$, obtained by solving a linear programming problem:

$$\begin{aligned} & \max V, \\ & \sum_{i=1}^m b_{ik} x_i \geq V, \quad k = 1, 2, \dots, r, \\ & \sum_{i=1}^m x_i = 1, \quad x_i \geq 0. \end{aligned} \quad (1)$$

A preventive plan $(x_1, x_2, \dots, x_m)$ would allow to avert not less than V accidents (on average). The most efficient preventive measures normally are the most expensive. An experienced expert could accurately estimate price c_i of preventive measure i . Given the amount of money required for the implementation of all preventive measures is marked as C and it is equated to 100, coefficients c_i can be expressed as a percentage of the total amount.

When the funds allocated to the prevention are limited, an optimal preventive plan is obtained by solving the following problem:

$$\begin{aligned} & \max V, \\ & \sum_{i=1}^m b_{ik} x_i \geq V, \quad k = 1, 2, \dots, r, \end{aligned} \quad (2)$$

$$\sum_{i=1}^m c_i x_i = C, \quad x_i \geq 0,$$

where $C < 100$.

When 16 preventive measures (Table 3) aimed at eliminating of the causes of work related accidents and the matrix of weight coefficients s_{ij} as well as price coefficients (percentages) c_i were selected and problems (1) and (2) solved once again, a different arrangement of preventive measures according to their efficiency was obtained. When the price of a preventive measure is taken into account and when it is not.

Table 3. *List of preventive measures*

i	Preventive measure
1.	Scaffolding or/and lifting devices
2.	Enclosures, fencing
3.	Covers, safety nets
4.	Roof ladders, steps
5.	Safe roads for movement
6.	Appropriate marking
7.	Reinforcement
8.	Safe areas
9.	Equipment in good technical order
10.	Ergonomic workplace
11.	Training
12.	Health checks
13.	Workwear
14.	Harnesses with a safety rope
15.	Safe distance keeping
16.	Slope constructions

When the price of preventive measures is not taken into account, it could be expected that on average not less than 3,908 accidents at work can be averted per month by implementing eight best preventive measures (11, 6, 2, 10, 1, 5, 3, 13, 7). The implementation of the rest preventive measures would increase this number only by 1,022.

When the price of preventive measures is taken into account, it could be expected that on average not less than 3,568 accidents at work can be averted per month by implementing eight best preventive measures (10, 5, 11, 6, 15, 7, 2, 3, 12). The implementation of the rest preventive measures would increase this number only by 1,362.

It is possible to solve stochastic programming problems by regarding the coefficients of matrix $\|b_{ik}\|$ as random variables. Such modelling enables to select the preventive strategy which together with the selected confidence level would allow to expect a certain number of accidents averted. Certainly, this number depends on the amount of funds invested into the prevention of accidents at work.

General Conclusions

1. In the period 2000–2006 3 253 accidents at work took place in Lithuanian construction companies, out of which 2 739 were minor, 338 – serious and 176 – fatal. The rate of accidents at work in construction companies remains high because compared to the total number of accidents at work in the country, minor accidents at work in construction companies account for 15%, serious – for 27,3%, fatal – for 25,7% of all accidents at work in the country.

2. The most common factors causing accidents at work in construction companies are falling from a height (one fourth of all accidents at work), stumbling due to a slippery surface or tumbling (one sixth of all accidents at work), vehicle (one tenth of all accidents at work). This situation is preconditioned by the lack of discipline and the absence of control over employees in construction companies as well as minimum investments into the improvement of working conditions.

3. The existent problems in construction companies make a negative impact on the economic development of the country as social insurance benefits and accident at work benefits are to be paid. The gross domestic product (GDP) amounting to LTL 38 567 thousand was not produced due to accidents at work in construction companies in the period 2000–2006. LTL 136 587 thousand were spent on benefits paid from social insurance fund and the losses incurred due to fatal accidents at work during the aforementioned period amount to LTL 153 120 thousand.

4. Statistical data on accidents at work and their causes in construction companies indicates that the stream of fatal or serious accidents at work as random events, grouped by their causes, can be reckoned as the simplest (*Poisson*), and the number of these events during a time unit – a random variable distributed according to *Poisson's Law*.

5. By selecting an adequate mathematical (probabilistic) model for the situation examined and evaluating distribution parameters, i.e. by determining their point and interval estimations, probability estimations of various random events related to the rate of accidents at work can be calculated.

6. Deterministic matrix game may be applied as a mathematical model to assess the efficiency of preventive measures of accidents at work. When

assessing the prices of preventive measures alongside with the efficiency, another sequence of „the best“ preventive measures is obtained.

7. Stochastic programming problems can be modelled by reckoning the elements of matrix game as random variables. Such modelling determines a preventive strategy which together with the selected confidence level allows to expect a certain number of accidents at work averted. It is possible to examine how this number depends on the amount of funds allocated to the prevention of accidents at work.

List of Published Works on the Topic of the Dissertation

In the periodical publications:

1. Čyras, P.; Šukys, R.; Jakutis, A.; Stankiuvienė, A. 2004. Economical and social consequences of accidents at work and occupational diseases. *Technological and Economic Development of Economy* [Ūkio technologinis ir ekonominis vystymas] 10(1): 26–31 (in Lithuanian). ISSN 1392-8619.
2. Stankiuvienė, A.; Šukys, R.; Čyras, P. 2006. Changes in occupational safety and health after becoming Lithuania member of EU. *Technological and Economic Development of Economy* [Ūkio technologinis ir ekonominis vystymas] 12(2): 146–151 (in Lithuanian). ISSN 1392-8619.

In the other editions

3. Šukys, R.; Čyras, P.; Stankiuvienė, A. 2005. Analysis and strategy of occupational safety and health according European Union requirements, in *Selected papers of the 6th International Conference “Environmental Engineering”*, held in Vilnius on May 26–27, 2005. Vol 1. Vilnius: Technika, 287–291. ISBN 9986-05-850-3 (Thomson ISI Proceedings).
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NELAIMINGŲ ATSITIKIMŲ RIZIKOS VALDYMAS IR OPTIMIZAVIMAS STATYBOJE

Mokslo problemos aktualumas. Saugi darbo vieta – kelias į sėkmingą verslą. Dabar, kai darbo pasaulis greitai keičiasi, kartu keičiasi ir su darbu susijusios sveikatos problemos. Visame pasaulyje statybininkai beveik 3 kartus dažniau žūsta ir 2 kartus dažniau susižaloja nei kitų profesijų atstovai.

Europos Sąjungos šalių statybų sektoriuje žuvusiųjų skaičius 100 tūkst. darbuotojų yra daugiau nei dvigubai didesnis negu vidutinis žūčių skaičius 100 tūkst. darbuotojų kituose sektoriuose (100 tūkst. statybos sektoriaus darbuotojų tenka 13 žuvusiųjų, palyginti su 5 kituose), t. y. kasmet nelaimingų atsitikimų metu žūsta daugiau nei 1300 žmonių. Nuostoliai dėl nelaimingų atsitikimų darbe įvairiose šalyse siekia nuo 2 iki 4% BVP.

Lietuvai įstojus į Europos Sąjungą, nelaimingų atsitikimų darbe prevencija tampa viena iš darbuotojų saugos ir sveikatos politikos sričių. Teigiama, kad kas trečias mirtinas ir kas ketvirtas sunkus nelaimingas atsitikimas įvyksta statybose. Konkretios prevencinės priemonės nelaimingiems atsitikimams darbe mažinti paprastai tampa planavimo objektu, joms teikiama pirmenybė ir jos įtraukiamos į įmonės veiksmų planus. Dėl ekonominių ir finansinių priežasčių nemažai statybos įmonių lėtai diegia saugias darbo priemones, o dėl įvykstančių nelaimingų atsitikimų darbe patiriama dar didesnių finansinių ir socialinių nuostolių mokant pinigines baudas ir atlyginant darbuotojų sveikatai padarytą žalą, prarandama potenciali darbo jėga. Prevencijos priemonių kainos dažnai labai didelės, o visų nelaimingo atsitikimo darbe aplinkybių numatyti iš anksto negalima, nes jo priežastis kartais būna pats darbuotojas. Darbdaviui svarbu žinoti, kurios nelaimingų atsitikimų darbe prevencijos priemonės yra efektyviausios ir kaip optimaliai paskirstyti nelaimingų atsitikimų darbe prevencijai skirtas lėšas. Tai leistų sumažinti nelaimingų atsitikimų darbe skaičių ir kartu sumažinti socialinio draudimo išmokas.

Darbo tikslas ir uždaviniai. Darbo tikslas – parengti matematinį modelį prevencijos priemonių efektyvumui įvertinti ir pasiūlyti optimizavimo uždavinius prevencijos strategijai pasirinkti, siekiant sumažinti nelaimingų atsitikimų darbe skaičių.

Pagrindiniai darbo uždaviniai:

1. Atlikti rizikos valdymo proceso tyrimą, detalai analizuojant atskirus jo elementus.
2. Išnagrinėti matematinių metodų taikymą nelaimingiems atsitikimams darbe prognozuoti ir prevencijos priemonių efektyvumui įvertinti bei prevencijai skirtoms lėšoms valdyti.

3. Išanalizuoti darbuotojų saugos ir sveikatos būklę statybos sektoriuje ir nustatyti nelaimingus atsitikimus darbe sukeliančias priežastis bei ekonomines pasekmes.
4. Išnagrinėti matricinio lošimo taikymo galimybes ir pasiūlyti bendruosius matematinius modelius prevencijos priemonių efektyvumui įvertinti.
5. Parinkti matematinį tikimybinį modelį atsitiktiniam nelaimingų atsitikimų darbe skaičiui, juo remiantis naudoti stochastinį programavimą prevencijos problemai modeliuoti.

Tyrimų metodika. Lyginamosios analizės metodas taikytas analizuojant Lietuvos, užsienio valstybių ir tarptautinius teisės aktus, reglamentuojančius rizikos vertinimą ir nelaimingų atsitikimų darbe prevenciją, taip pat nagrinėjant skirtingų mokslininkų gvildenamas problemas. Statistiniai metodai (aprašomoji statistika, statistinis nparametrinės hipotezės tikrinimas, pasikliautinis intervalas Puassono skirstinio parametrai λ) taikyti tiriant įvykusių sunkių ir mirtinų nelaimingų atsitikimų statybos įmonėse statistikos duomenis. Prevencijos priemonių efektyvumui įvertinti ir lėšų, skirtų prevencijai, optimaliam paskirstymui nustatyti panaudoti optimizavimo metodai (matricinis lošimas ir stochastinis programavimas).

Praktinė vertė. Taikyti matematiniai optimizavimo metodai (matricinis lošimas ir stochastinis programavimas) ir tinkamai parinkti prevencijos priemonių svorio koeficientai bei procentiniai prevencijos priemonių kainų vertinimai leidžia modeliuoti optimalų lėšų, skirtų nelaimingų atsitikimų darbe prevencijai, planavimą ir efektyviausią paskirstymą bei įvertinti prevencijos priemonių efektyvumą. Taip pat gauti rezultatai siūlo mokslinių tyrimų taikymo darbuotojų saugos ir sveikatos srityje metodus ir gali būti panaudoti studijų procese.

Ginamieji teiginiai

1. Nelaimingų atsitikimų darbe prognozavimo galimybės.
2. Determinuoto matricinio lošimo matematinis modelis nelaimingų atsitikimų darbe prevencijos priemonių efektyvumui įvertinti ir optimaliam lėšų, skirtų prevencijai, paskirstymui gauti.
3. Stochastinio programavimo uždaviniai, modeliuojantys optimalaus nelaimingų atsitikimų darbe prevencijos pasirinkimo problemą.

Darbo apimtis. Darbą sudaro bendra darbo charakteristika, 4 skyriai, bendrosios išvados, literatūros sąrašas, publikacijų sąrašas ir 3 priedai.

Pirmajame disertacijos skyriuje pateikta literatūros šaltinių apžvalga darbo tema, suformuoti uždaviniai ir jų sprendimo būdai. Antrajame aprašomos tyrimo metodikos. Trečiajame pateikta darbuotojų saugos ir sveikatos būklės statybos įmonėse 2000–2006 m. analizė ir nelaimingų atsitikimų sukeltų ekonominių pasekmių šalies ūkiui įvertinimas. Statistinių duomenų apie statybos įmonėse įvykusius nelaimingus atsitikimus ir jų priežastis matematinės statistinės analizės rezultatai ir nelaimingų atsitikimų prognozavimo galimybės pateikiamos ketvirtajame darbo skyriuje. Šiame skyriuje pateikiamas determinuoto matricinio lošimo matematinis modelis nelaimingų atsitikimų prevencijos priemonių efektyvumui įvertinti bei optimaliam lėšų, skirtų prevencijai, paskirstymui gauti. Sukurti stochastinio programavimo uždaviniai, modeliuojantys optimalaus nelaimingų atsitikimų prevencijos pasirinkimo problemas.

Bendrosios išvados

1. Lietuvos statybos įmonėse nuo 2000 m. iki 2006 m. įvyko 3 253 nelaimingi atsitikimai darbe, iš kurių 2 739 – lengvi, 338 – sunkūs ir 176 – mirtini. Nelaimingų atsitikimų darbe skaičius statybos įmonėse išlieka didelis, nes, palyginti su visais šalyje įvykusiais nelaimingais atsitikimais darbe, statybos įmonėse įvykę lengvi nelaimingi atsitikimai darbe sudaro 15%, sunkūs – 27,3%, mirtini – 25,7% visų šalyje įvykusių nelaimingų atsitikimų darbe.

2. Atlikus nelaimingų atsitikimų statyboje analizę, nustatyta, kad dažniausi nelaimingus atsitikimus darbe sukeliantys veiksniai yra kritimas iš aukščio (įvyksta ketvirtadalis visų nelaimingų atsitikimų darbe), žmogaus griuvimas dėl slidumo ar dėl kliuvinio (įvyksta šeštadalis visų nelaimingų atsitikimų darbe), kelių transporto priemonė (įvyksta dešimtadalis visų nelaimingų atsitikimų darbe). Tai įtakoja drausmės stoka, menka darbuotojų kontrolė ir minimalus investavimas į darbo sąlygų gerinimą.

3. Esamos problemos statybos įmonėse daro neigiamą įtaką šalies ekonominiam vystymuisi dėl socialinio draudimo išmokų ir dėl nelaimingo atsitikimo darbe išmokų. 2000–2006 m. dėl įvykusių nelaimingų atsitikimų darbe šalyje nepagaminta bendrojo vidaus produkto (BVP) už 38 567 tūkst. Lt. Išmokoms iš Socialinio draudimo fondo panaudota 136 587 tūkst. Lt, o nuostoliai dėl mirtinų nelaimingų atsitikimų darbe per minėtą laikotarpį siekia 153 120 tūkst. Lt.

4. Statistinių duomenų apie nelaimingus atsitikimus darbe ir jų priežastis statybos įmonėse analizė rodo, kad išskaidytų pagal priežastis mirtinų arba sunkių nelaimingų atsitikimų darbe, kaip atsitiktinių įvykių, srautą galima

laikyti paprasčiausiu (Puassono), o šių įvykių skaičių per laiko vienetą – atsitiktiniu dydžiu, pasiskirsčiusiu pagal Puassono dėsnį.

5. Parinkus adekvatų matematinį (tikimybinių) modelį nagrinėjamai situacijai, įvertinus skirstinio parametrus, t. y. suradus jų taškinius ir intervalinius įverčius, galima apskaičiuoti įvairių atsitiktinių įvykių, susijusių su nelaimingų atsitikimų darbe skaičiumi, tikimybes.

6. Determinuotą matricinį lošimą galima pasitelkti kaip matematinį modelį nelaimingų atsitikimų darbe prevencijos priemonių efektyvumui įvertinti. Kai kartu su efektyvumu įvertinamos prevencijos priemonių kainos, gaunama kita „geriausių“ prevencijos priemonių eilės tvarka.

7. Laikant matricinio lošimo elementus atsitiktiniais dydžiais, galima modeliuoti stochastinio programavimo uždavinius. Toks modeliavimas randa prevencijos strategiją, kuri su pasirinktu pasikliautinumo lygmeniu leidžia tikėtis tam tikro išvengtų nelaimingų atsitikimų darbe skaičiaus. Galima iširti, kaip šis skaičius priklauso nuo lėšų, skirtų nelaimingų atsitikimų darbe prevencijai, dydžio.

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Padėka

Autorė širdingai dėkoja darbo vadovui už suteiktus originalius mokslinius patarimus bei pastabas rengiant disertaciją. Dėkoja mokslinei konsultantei, kurios mokslinės konsultacijos padėjo kvalifikuotai parengti disertaciją. Katedros kolegoms vienaip ar kitaip prisidėjus įgyvendinant mokslines idėjas. Šeimai už paramą ir palaikymą rengiant disertaciją.

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**RISK MANAGEMENT AND OPTIMIZATION
OF ACCIDENTS AT WORK IN CONSTRUCTION**

**Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)**

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