



Ranking of management factors for safe maintenance system based on Grey Systems Theory

Joanna Tabor¹ 

¹ Czestochowa University of Technology, ul. J.H. Dąbrowskiego 69, 42-201 Częstochowa, Poland
Corresponding author e-mail: joanna.tabor@pcz.pl

Article history

Received 09.05.2021
Accepted 30.06.2021
Available online 06.09.2021

Keywords

occupational safety
maintenance system
management factors
Grey Systems Theory
MCDM

Abstract

The maintenance system is a key system that provides continuity and safety of the operation of production systems and that affects the safety of people working in these systems. At the same time, the maintenance system is a set of work processes carried out by people under specific environmental conditions, using specific equipment and within a specific organizational and management structure. The purpose of this article is to identify the main management factors that affect occupational safety and to rank these factors in terms of their effectiveness in ensuring safe maintenance, using the grey systems theory. Based on the literature analysis, 12 key management factors were identified and then subjected to expert assessment. In order to rank the factors, a decision model based on the grey systems theory (GST), i.e. systems with incomplete and uncertain information about structure and behavior, was developed and verified. The use of GST in the area of ensuring safety in maintenance is original. The findings of the article will be very useful for managers in implementing safe maintenance systems in various sectors of the economy.

DOI: 10.30657/pea.2021.27.26

JEL: M11, J28, C02

1. Introduction

Increasing competitiveness forces companies to improve product quality, increase efficiency and verify their skills, methods and manufacturing practices, which are now become crucial to preserve the good reputation and success (Kisefáková et al., 2020; Sharabi, 2014). Enterprises feel a strong pressure to reduce production costs (Wang et al., 2007), and this significantly affects those aspects of operation that, in the traditional sense, do not generate added value, i.e. maintenance. At the same time, most organizations are moving towards improving manufacturing flexibility (Singh and Sharma, 2014), therefore they must focus on improving the efficiency of the maintenance system. In addition, the automation of manufacturing processes, which is accelerating, increases the importance of maintenance departments and the selection of appropriate maintenance policy (Ding et al., 2014), and also highlights the need to develop more and more effective maintenance management systems (Abreu et al., 2013). The competitiveness and efficiency of manufacturing companies depend on the availability, reliability and productivity of their manufacturing equipment. Practical confirmation of this fact in recent years has led to a drastic change in

the perception of maintenance, evolving from "necessary evil" to act with "added value" (Van Horenbeek and Pintelon, 2011). Appropriate maintenance management system can result in significant improvements in efficiency, productivity and profitability of organizations (Teplická and Hurná, 2021; Lofsten, 1999). Currently, the maintenance system is a key system that not only ensures the continuity and safe operation of production systems (Crespo et al., 2009), but also a system that significantly affects the safety of people working in these systems (Leong et al., 2012; Sheikhalishahi et al., 2016).

At the same time, the emphasis is systematically growing on the problems of ensuring occupational health and safety, both in the sphere of direct use and service throughout the life stage of facilities (Parida and Chattopadhyay, 2007). Enterprises must not only provide a high-quality product at a competitive price, but also ensure environmental protection and safety for people working in various positions (Alsyof, 2004). The hazards to which maintenance workers are exposed can be very specific depending on the task being performed, but most generally they include physical, chemical, biological and psychosocial hazards (Niciejewska and Kiriliuk, 2020; Kapustka, et al., 2020; Carrillo-Castrillo et al., 2015; Tabor, 2014). Chronic exposure to certain groups of threats can cause serious health

problems such as asbestosis, cancer, hearing problems, skin diseases, respiratory diseases, and musculoskeletal disorders; and consequently lead to a higher rate of sickness absenteeism than usual (Tabor, 2014; Blaise et al., 2014; Lind and Nenonen, 2008).

The type of maintenance can be different depending on the sector in which the task is performed (Kučera and Kopčanová, 2020), hence the consequences of working in inappropriate conditions can be very diverse. For example, during corrective maintenance, maintenance workers are exposed, among others, to psychosocial risks in the form of high professional demands and intense time pressure. Exposure to such stressors can cause not only occupational diseases, but in many cases lead to an increase in the number of accidents (Antti and Mats, 2011). Therefore, it is widely recognized that maintenance itself is a high risk activity (Pollard et al., 2014; Reason and Hobbs, 2003; Kelly and McDermid, 2001). It is estimated that about 10-15% of all fatal accidents and 15-20% of all accidents are related to widely understood maintenance (EASHW, 2010).

In this context, the problem of carrying out maintenance tasks by external companies is also important. The sector of repairs, maintenance and minor alterations is developing dynamically and the number of accidents in this sector is also systematically growing (Carol et al., 2011; Nenonen, 2011). The clear relationship between maintenance, safety and the company's productivity (Abdul Raouf, 2004) make the effective assurance of safety during the implementation of maintenance works a strategic dimension for the organization.

The purpose of this article is to identify the main management factors that affect occupational safety and to rank these factors in terms of their effectiveness in ensuring safe maintenance.

The article consists of five parts. Part 2 reviews the literature related to safe maintenance and grey systems theory. Part 3 contains the research methodology, including the algorithm of the factor ranking procedure based on the concept of distance from the ideal alternative using the grey number comparison operation. Part 4 includes the results and discussion of their relevance. The summary and conclusions are included in the last part of the work.

2. Literature review

According to the European standard EN 13306, maintenance covers all technical, administrative and management activities that are carried out during the life cycle of the facility and whose purpose is to maintain or restore such a state of the facility, in which it can perform the required functions while protecting it against failure or loss of these functions. The maintenance object may be: a workplace, building, work equipment or a means of transport. Usually, "maintenance" is considered purely technical activities such as the removal and replacement of spare parts, lubrication, repair, etc.

However, maintenance activities also include inspection, monitoring, testing, overhaul, measurement, adjustment, repair, modification, rebuild, fault finding, servicing. In practice, maintenance covers an even wider range of activities and

includes numerous additional tasks, such as: selection of appropriate tools, selection of appropriate chemicals, place preparation (e.g. by removing uninvolved staff, traffic control and sign placement), preparation of machines for shutdown, transport of spare parts, preparing the necessary measures to ensure the safety, etc.

The two basic factors that dominate the strategic dimensions of the safety of maintenance activities are: the broadly understood human factor and the effective flow of relevant information.

All initiatives and decisions concerning the improvement of safety and health protection in the performance of maintenance works require the approval and active involvement of the top management (Yorio and Wachter, 2014; Vredenburg, 2002). Support from managers manifests itself through appropriate actions and attitudes, e.g. appropriate allocation of resources for OHS as well as by giving health and safety a proper status in relation to costs and production targets (Woźny, 2020; Vredenburg, 2002). The top managers make the final decisions, so it is essential that they are convinced of the importance of OSH initiatives and that they are aware of the various benefits that these initiatives can bring. In the situation that maintenance works are performed by external employees, managers should require inclusion of health and safety principles in the contract specifications (Carol et al., 2014; Azadeh et al., 2014), and compliance with them should be one of the main criteria for evaluating performance. In order to build a sense of safety at all levels of the organization, the involvement and participation of regular employees is crucial (Liu et al., 2020). Involvement enables the use of employees' unique knowledge of their own work, for example in terms of practical ways to eliminate or reduce the risks associated with their work.

Moreover, the involvement of employees is an important way to gain acceptance for change, as well as an effective way to encourage compliance with health and safety rules (Walters and Wadsworth, 2019; Vredenburg, 2002). It is important to involve employees in health and safety management at all stages of the maintenance process (Carol et al., 2014). In particular, employees should be involved in the initial risk assessment as well as in the risk assessment at various stages of the task they perform. Employee participation in the basic assessment and learning the guidelines on how to carry out a risk assessment at different stages of maintenance work will allow employees to better understand the work process itself and possibly carry out risk assessment adjustments already during the performance of tasks (Carrillo-Castrillo et al. 2015; Wijeratne et al. 2014; An et al., 2009).

Risk assessment before starting any maintenance work usually results in the implementation of specific preventive measures. It is important to always apply measures according to the right hierarchy, starting with actions aimed at eliminating risks. When hazards cannot be completely eliminated, the risk should be minimized by other measures, of a technical and organizational nature.

Training and information as preventive measures are also important as they provide the employee with the knowledge

needed to safely perform maintenance tasks (Carol et al., 2014; Caputo et al., 2013).

It should be emphasized that safety measures are more effective when they work in combination, which means that, for example, conducting risk assessments, implementing safety procedures and safe systems of work should be supported by management initiatives in the field of behavioral safety, training and information so that safety becomes a natural need (Carol et al., 2014; Vredenburg, 2002).

For each maintenance task, describe the workflow well and make sure that the results of the risk assessment and safe work procedures are understood by those involved (Vredenburg, 2002).

Safe work procedures must also be prepared for unexpected events - especially in life-threatening situations. For example, these procedures may identify the need for a new risk assessment before starting work again or indicate the need to consult other employees in the group or your line manager. The guidelines for the implementation of maintenance works should also include the possibility of stopping work in the event of an unforeseen problem, especially when its solution exceeds the competences of an individual employee or a working group.

The scope and means of communication should also be determined at the planning stage of maintenance work (Wetzel and Thabet, 2015; Tsang, 2002;). It is advisable to make all important information related to the ongoing conservation work available to all parties affected by the activities - direct and indirect contractors and employees who may work in adjacent positions at the same time. Such information is necessary for the proper and safe performance of the task, and includes primarily the results of risk assessments, safe work procedures, details of the necessary protective equipment, ways of reporting various types of problems and how to report the completion of the task (EASHW, 2010; Vredenburg, 2002).

The effectiveness of safety and health protection measures during maintenance activities should be constantly assessed and improved based on the results of audits and inspections carried out, as well as the results of incident, accident and failure investigations. Also important for the learning process is the feedback received from employees, external contractors and OSH staff (Tsang, 2002; Vredenburg, 2002). Employers are required by law to inform and train all employees who need it, including temporary workers and external contractors, on health and safety. In addition to the required skills and professional competences related to specific areas of professional responsibility, maintenance workers should be trained in identifying hazards and applying appropriate preventive measures in relation to specific tasks, as well as in the applied safe working procedures. The aim of this type of training is to build awareness, therefore the health and safety requirements relating to each task should be easy to understand and assimilate (EASHW, 2010; Gyekye, 2005; Tsang, 2002).

However, the most important thing is that the management, employees and external contractors equally perceive safety problems in maintenance works, including emerging hazards and the necessity of safety measures. This, in combination with safe work practices, is an essential part of shaping a

safety culture within an organization (Frazier et al., 2013; Choudhry et al., 2007). Adopting a holistic and sustainable approach to maintenance management becomes crucial to the success of modern enterprises (Liyanage et al., 2009) and plays a dominant role in sustainable production.

Grey Systems Theory (GST) is the latest methodology for analyzing and assessing systems in a situation where information about individual system elements / parameters is incomplete, information about the system structure is incomplete, information about system boundaries is incomplete and information about changes / system dynamics (environment / system environment) are incomplete (Liu et al., 2012a).

GST overcomes many necessary assumptions about the statistical methods, rough or fuzzy, and the results obtained with the use of grey numbers are more accurate than with other approaches (Liu et al., 2016b; Liu et al., 2012a, Liu et al., 2012b). GST does not require many assumptions about the size and distribution of the sample that is accepted for testing - the minimum number of data must not be less than 4. Therefore, it has an advantage over statistical methods, fuzzy or coarse sets (Liu et al., 2016b).

Using GST, it is possible to forecast future system behavior, assess the interdependence of observation vectors, evaluate the effectiveness of reactions to possible situations, make optimal decisions, as well as group and study clusters. Basic grey number operations are performed as follows (Liu et al., 2012b):

$$\text{Addition: } \otimes G_1 + \otimes G_2 = [\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2]$$

$$\text{Subtraction: } \otimes G_1 - \otimes G_2 = [\underline{G}_1 - \overline{G}_2, \overline{G}_1 - \underline{G}_2]$$

$$\text{Multiplication: } \otimes G_1 \times \otimes G_2 = [\min(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2), \max(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2)]$$

$$\text{Dividing: } \otimes G_1 \div \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\overline{G}_2} \right]$$

At the same time, the comparison of grey numbers follows the formula:

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{\max(0, L^* - \max(0, \overline{G}_1 - \underline{G}_2))}{L^*}$$

where: $L^* = L(\otimes G_1) + L(\otimes G_2)$ and L is the length of the grey number: $L(\otimes G) = [\overline{G} - \underline{G}]$.

As a result of comparing two grey numbers, three special cases are possible (Liu et al., 2012b):

- If $\underline{G}_1 = \underline{G}_2$ and $\overline{G}_1 = \overline{G}_2$ that $\otimes G_1 = \otimes G_2$, then $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$.
- If $\underline{G}_2 > \overline{G}_1$ that $\otimes G_2$ is larger than $\otimes G_1$, then $P\{\otimes G_1 \leq \otimes G_2\} = 1$.
- If $\overline{G}_2 < \underline{G}_1$ that $\otimes G_2$ is smaller than $\otimes G_1$, then $P\{\otimes G_1 \leq \otimes G_2\} = 0$.

GST is used in many disciplines of engineering and technical, medical and social sciences, as evidenced by the rapidly increasing number of publications on its practical applications

(Delcea, 2015b), including widely understood safety engineering and management of economic systems on various scales (Liu et al., 2016b; Delcea, 2015a; Liu et al., 2012b).

One of the rapidly developing applications is the use of GST in classic and modern multi-criteria decision making tools (Liu et al., 2016a, Tzeng and Huang, 2011).

3. Research methodology

As a result of the literature analysis, 12 management factors of key importance for ensuring the safety of maintenance work were identified: F1- management commitment and support, F2- promoting a safety culture, F3- commitment and active participation of employees, F4- a properly conducted risk assessment before starting work, F5- employee involvement in the risk assessment related to the work performed, F6- application of preventive measures in accordance with their hierarchy, F7- combining preventive measures from different categories, F8- application of safe work procedures, F9- efficient and effective communication between employees, F10- improvement of activities based on audits, inspections and learning from others, F11- training on safety and understanding of work-related hazards, and F12- applying clear guidelines for working in teams.

In order to rank the factors, a decision model using the concept of distance from the ideal alternative and the operation of comparing grey numbers was developed and verified. The concept of distance from the ideal alternative is currently the most widely applied ranking approach, which is used, for example, in all variants of the TOPSIS method.

The ranking of factors according to the model used is carried out in accordance with the following steps:

- 1) Assessment of decision criteria using linguistic variables,
- 2) Determining the significance of the decision criteria and aggregating these assessments with the selected method, (e.g. arithmetic mean method):

$$\otimes W_j = \frac{1}{K} [\otimes W_j^1 + \otimes W_j^2 + \dots + \otimes W_j^K] \quad (1)$$

where: $\otimes W_j^K = [\underline{W}_j^K, \overline{W}_j^K]$

- 3) Assessment of alternatives using linguistic variables and aggregation of assessments by the selected method, (e.g. arithmetic mean method):

$$\otimes G_{ij} = \frac{1}{K} [\otimes G_{ij}^1 + \otimes G_{ij}^2 + \dots + \otimes G_{ij}^K] \quad (2)$$

where $\otimes G_{ij}^K, (i = 1, 2, \dots, m; j = 1, 2, \dots, n)$ is the evaluation of the criterion by the k-th decision maker and is represented by a grey number of the figure: $\otimes G_{ij}^K = [\underline{G}_{ij}^K, \overline{G}_{ij}^K]$

- 4) Building a grey decision matrix:

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \dots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & & \otimes G_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \dots & \otimes G_{mn} \end{bmatrix} \quad (3)$$

- 5) Building a normalized grey decision matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \dots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & & \otimes G_{2n}^* \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \dots & \otimes G_{mn}^* \end{bmatrix} \quad (4)$$

using the profit criterion (the higher the value, the better) according to the formula:

$$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}} \right] \quad (5)$$

where: $G_j^{min} = \min_{1 \leq i \leq m} \{\underline{G}_{ij}\}; G_j^{max} = \max_{1 \leq i \leq m} \{\overline{G}_{ij}\}$

- 6) Building a weighted normalized grey matrix:

$$D_W^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \dots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & & \otimes V_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \dots & \otimes V_{mn} \end{bmatrix} \quad (6)$$

where: $\otimes V_{ij} = \otimes G_{ij}^* \times \otimes W_j$

- 7) Identification of the best alternative assuming that for a set of m possible alternatives $F = \{F_1, F_2, F_3, \dots, F_m\}$ the ideal alternative F^{max} is defined as:

$$F^{max} = \{\otimes G_1^{max}, \otimes G_2^{max}, \dots, \otimes G_n^{max}\} \quad (7)$$

where F^{max}

$$= \left\{ \left[\max_{1 \leq i \leq m} \underline{V}_{i1}, \max_{1 \leq i \leq m} \overline{V}_{i1} \right], \left[\max_{1 \leq i \leq m} \underline{V}_{i2}, \max_{1 \leq i \leq m} \overline{V}_{i2} \right], \dots, \left[\max_{1 \leq i \leq m} \underline{V}_{in}, \max_{1 \leq i \leq m} \overline{V}_{in} \right] \right\}$$

- 8) Calculating the distance between the compared alternatives F and the ideal alternative F^{max} , using the formula:

$$P\{F_i \leq F^{max}\} = \frac{1}{n} \sum_{j=1}^n P\{\otimes V_{ij} \leq \otimes G_j^{max}\} \quad (8)$$

- 9) Sorting the obtained values of P and thus of the alternatives F in increasing order (the smaller the distance from the ideal alternative, the better).

The adopted approach was verified as part of research conducted in four companies of the furniture industry (M1-M4).

For the purposes of the research, a questionnaire was developed including 12 management factors described in detail. Three randomly selected maintenance employees (E1-E3) from each company made an individual assessment. Each of the employees had at least 10 years of work experience. Individual management factors were assessed by the respondents according to the following linguistic scale, to which, at the stage of using the procedure, appropriate grey numbers were assigned: *insignificant* [0.0, 1.0], *low* [1.0, 3.0], *medium-low* [3.0, 4.0], *medium* [4.0, 5.0], *medium-significant* [5.0, 6.0], *significant* [6.0, 9.0] and *very significant* [9.0, 10.0].

On the other hand, the significance of assessments made by a given respondent was established on the basis of individual information from the questionnaire regarding the experience and qualifications gained in the maintenance department. The linguistic assessments of these criteria were also assigned appropriate grey numbers: *nonimportant* [0.0, 0.1], *low* [0.1, 0.3], *medium-low* [0.3, 0.4], *medium* [0.4, 0.5], *medium-important* [0.5, 0.6], *important* [0.6, 0.9], *very important* [0.9, 1.0].

4. Results and discussion

As a result of the implementation of the procedure described above, the significance of expert assessments in individual enterprises was first determined. Table 1 summarizes the grey assessments of experts from four enterprises and the aggregate assessment obtained after applying the formula (1) concerning aggregation according to the adopted arithmetic mean method.

Table 1. Grey grades of the importance of experts' opinions

	M1	M2	M3	M4
E1	[0.9,1.0]	[0.4,0.5]	[0.6,0.9]	[0.5,0.6]
E2	[0.4,0.5]	[0.6,0.9]	[0.9,1.0]	[0.4,0.5]
E3	[0.5,0.6]	[0.5,0.6]	[0.6,0.9]	[0.4,0.5]
	[0.6,0.7]	[0.5, 0.67]	[0.7,0.93]	[0.43,0.53]

Then, appropriate grey numbers were assigned to the linguistic assessments of individual management factors F1-F12, made by experts, in accordance with Table 2.

Table 2. Grey grades of management factors (F)

	M1	M2	M3	M4
F1	[4.0,5.0]	[3.0,4.0]	[3.0,4.0]	[5.0,6.0]
F2	[4.0,5.0]	[3.0,4.0]	[4.0,5.0]	[3.0,4.0]
F3	[4.0,5.0]	[5.0,6.0]	[5.0,6.0]	[4.0,5.0]
F4	[6.0,9.0]	[4.0,5.0]	[6.0,9.0]	[6.0,9.0]
F5	[5.0,6.0]	[6.0,9.0]	[4.0,5.0]	[3.0,4.0]
F6	[3.0,4.0]	[3.0,4.0]	[4.0,5.0]	[4.0,5.0]
F7	[4.0,5.0]	[5.0,6.0]	[3.0,4.0]	[3.0,4.0]
F8	[6.0,9.0]	[5.0,6.0]	[5.0,6.0]	[6.0,9.0]
F9	[3.0,4.0]	[4.0,5.0]	[4.0,5.0]	[3.0,4.0]
F10	[3.0,4.0]	[1.0,3.0]	[3.0,4.0]	[1.0,3.0]
F11	[5.0,6.0]	[6.0,9.0]	[4.0,5.0]	[6.0,9.0]
F12	[3.0,4.0]	[4.0,5.0]	[5.0,6.0]	[5.0,6.0]

As a result of aggregating the assessments of individual alternatives in accordance with the formula (2), the initial data for building a grey decision matrix was obtained, in accordance with the formula (3). Then, the values from the grey decision matrix were normalized using the formulas (4) and (5), and the data was obtained to build a normalized grey decision matrix, and after applying the formula (6), values were obtained to build a weighted normalized grey decision matrix – Table 3.

Table 3. Grey normalized and weighted grades of management factors (F)

	M1	M2	M3	M4
F1	[0.27,0.39]	[0.17,0.30]	[0.23,0.41]	[0.24,0.35]
F2	[0.27,0.39]	[0.17,0.30]	[0.31,0.52]	[0.14,0.24]
F3	[0.27,0.39]	[0.28,0.45]	[0.39,0.62]	[0.19,0.29]
F4	[0.40,0.70]	[0.22,0.37]	[0.47,0.93]	[0.29,0.53]
F5	[0.33,0.47]	[0.33,0.67]	[0.31,0.52]	[0.14,0.24]
F6	[0.20,0.31]	[0.17,0.22]	[0.31,0.52]	[0.19,0.29]
F7	[0.27,0.39]	[0.28,0.45]	[0.23,0.41]	[0.14,0.24]
F8	[0.40,0.70]	[0.28,0.45]	[0.39,0.62]	[0.29,0.53]
F9	[0.20,0.31]	[0.22,0.37]	[0.31,0.52]	[0.14,0.24]

F10	[0.20,0.31]	[0.06,0.22]	[0.23,0.41]	[0.05,0.18]
F11	[0.33,0.47]	[0.33,0.67]	[0.31,0.52]	[0.29,0.53]
F12	[0.20,0.31]	[0.22,0.37]	[0.39,0.62]	[0.24,0.35]

According to the formula (7), an ideal alternative was identified for M1 [0.40,0.70], M2 [0.33,0.67], M3 [0.47,0.93] and for M4 [0.29,0.53].

Using the rules for comparing two grey numbers and the formula (8), a summary of P values for M1, M2, M3 and M4 was obtained - Table 4.

Table 4. The distances between the compared alternatives and the ideal alternative

F	P{F _i ≤ F ^{max} }				Average
	M1	M2	M3	M4	
F1	1.00	1.00	1.00	0.83	0.9575
F2	1.00	1.00	0.93	1.00	0.9825
F3	1.00	0.77	0.78	1.00	0.8875
F4	0.50	0.92	0.50	0.50	0.6050
F5	0.84	0.50	0.93	1.00	0.8175
F6	1.00	1.00	0.93	1.00	0.9825
F7	1.00	0.77	1.00	1.00	0.9425
F8	0.50	0.77	0.78	0.50	0.6375
F9	1.00	0.92	0.93	1.00	0.9625
F10	1.00	1.00	1.00	1.00	1.0000
F11	0.84	0.50	0.93	0.50	0.6925
F12	1.00	0.92	0.78	0.83	0.8825

After the obtained P values and thus the F factors have been sorted in increasing order (step 9 of the procedure), the order of the factors is as follows:

$$F_4 > F_8 > F_{11} > F_5 > F_{12} > F_3 > F_7 > F_1 > F_9 > F_2 = F_6 > F_{10}$$

The conducted research shows that a properly conducted risk assessment before starting work, the use of safe work procedures and training in safety, including the understanding of work-related hazards, are the most important management factors influencing the safety of maintenance work. These are the basic factors that do not depend on the specific nature of the organization or the nature of the conservation tasks performed. And they concern both, activities performed by the company's employees and external contractors. Maintenance activities include high-risk activities, often carried out under unfavorable environmental conditions, sometimes under severe time pressure, therefore, in the opinion of the respondents, the implementation of the basic health and safety requirements, which are related to the above-mentioned basic factors identified during the research, is the most effective in ensuring the safety of maintenance works.

The obtained results may also indicate a limited perception of the importance of other activities in the area of OSH management, apart from the activities required by law, to ensure adequate protection of conservators and other people present at their workplace. This means that maintenance activities are not yet properly connected to the general requirements of the occupational health and safety management system of these companies.

5. Summary and conclusion

A maintenance system is a set of work processes carried out by people under specific environmental conditions, using specific equipment (Stadnicka et al., 2014) and within a specific organizational and management structure. The traditional maintenance system focuses on equipment, while the literature on the subject indicates that human involvement is important (Abdul Raouf, 2004). Maintenance is necessary not only to ensure the safety and reliability of technical facilities or the company's productivity, but regular maintenance plays an important role in ensuring safer and healthier working conditions. Lack of maintenance or inadequate maintenance can cause serious and fatal accidents or health problems not only for workers but also in the form of disasters for the general public.

There are many high-profile examples of what can happen if maintenance is neglected or not properly carried out. However, maintenance processes are associated with the performance of tasks under conditions of exposure to various types of dangers that may lead to negative consequences for health and even life. The decision model adopted in the article, using the concept of the distance from the ideal alternative and the operation of comparing grey numbers, made it possible to rank management factors and identify those that are most important for the effectiveness of ensuring safety in maintenance work. The ability to identify key factors helps reduce inconsistencies when managers make decisions about integrating maintenance into the overall health and safety management system. Because only the systems approach allows for effective planning, implementation and improvement of both preventive and corrective maintenance activities. Maintenance tasks and their health and safety aspects should be an integral part of any organization's overall health and safety management system.

The main contribution of this article is the use of grey systems theory (GST) in the area of maintenance. The article contains the original application of the GST concept in the area of maintenance management and fills the gaps in the use of the grey systems theory in occupational safety management. The grey systems theory based method is advantageous from the point of view of analyzes because it does not require a large sample of data.

Further research should deepen the analysis of the problem of integrating the maintenance management system with the OHS management system towards the identification of barriers and contributing factors.

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基于灰色系统理论的安全维修系统管理因素排序

關鍵詞

职业安全
维护系统
管理因素
灰色系统理论
MCDM

摘要

维护系统是一个关键系统，它提供生产系统运行的连续性和安全性，并影响在这些系统中工作的人员的安全。同时，维修系统是人们在特定环境条件下，使用特定设备，在特定组织和管理结构内进行的一套工作流程。本文的目的是使用灰色系统理论确定影响职业安全的主要管理因素，并根据它们在确保安全维护方面的有效性对这些因素进行排序。在文献分析的基础上，确定了12个关键管理因素，然后进行了专家评估。为了对因素进行排序，开发并验证了基于灰色系统理论（GST）的决策模型，即具有不完整和不确定的结构和行为信息的系统。在确保维护安全方面使用 GST 是原始的。本文的研究结果对于管理人员在各个经济部门实施安全维护系统非常有用。
