SYSTEM SAFETY: HUMAN - TECHNICAL FACILITY – ENVIRONMENT
6(1), 2024, pp. 192-200

HUMAN RELIABILITY MANAGEMENT ASSESSMENT FOR OCCUPATIONAL HEALTH AND SAFETY IMPROVEMENT

DOI: 10.2478/czoto-2024-0021
Received: 27/11/2024
Accepted: 10/12/2024

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Abstract: This paper analyses the possibility of evaluating human reliability management using the VIKOR (Vise Kriterijumska Optimizajica i Kompromisno Resenje) method, which belongs to the linear ordering methods, from the group of multi-criteria decision-making methods. Eight processes, implemented as part of human reliability management (HRM), were used as evaluation criteria, with the level of implementation of each process assessed independently by three experts, using a prepared questionnaire.
The research was carried out in seven companies in the furniture industry and focused on the process of operating production machinery as part of the manufacturing process of the main product. The process of operating production machinery was chosen because of its potential for health and safety improvement, confirmed by accident rates.
The application of the VIKOR method made it possible to rank the surveyed companies from the point of view of HRM in the process of operating production machinery and to identify the best and weakest company in this respect.
Keywords: Human Reliability, Management, VICOR, MCDM

1. INTRODUCTION

Human reliability can be interpreted as the accurate, efficient and error-free performance of a person's assigned tasks within a set period of time under both optimal and extreme conditions of the working environment (EN-62508: 2010).
Human reliability management (HRM), on the other hand, encompasses activities that aim to increase the likelihood of achieving expected employee performance outcomes and reduce the likelihood of human error. According to the guide to human issues in reliability, 'human error' is the discrepancy between an action taken or omitted and the intended action. At the same time, the guide defines 'human failure' as a deviation in an action that is required to achieve an objective, regardless of the cause of the deviation (EN-62508: 2010).
Human beings are part of every manufacturing and service system, and play a key role in them (Patriarca et al., 2020). The failure of human action affects the performance of the system as a whole. At the same time, a human can both bring about an adverse event in the system and limit its subsequent negative consequences. Therefore, in order to maintain the efficiency and safety of human-involved work, in-depth knowledge is needed regarding the analysis and assessment of human reliability (Gunda et al., 2023)

The literature on accident causation analysis shows that human error is the main risk factor in the nuclear industry with over 90% (Reason, 1990), in the chemical and petrochemical industries with over 80% (Kariuki and Lowe, 2007), in marine accidents with over 75% (Ren et al., 2008) and in aviation accidents with over 70% (Helmreich, 2000)

Viewed through the lens of the activities implemented, HRM essentially consists of two main parts: reliability analysis and assessment and reliability control. Within the analysis and assessment framework, three main activities are carried out: (a) identifying employee errors, (b) estimating the probability of these errors, and (c) assessing the impact of these errors on the achievement of the objectives.

In the area of reliability control, on the other hand, five basic activities are carried out: (a) analysing reliability control measures (that reduce and/or limit the possibility of errors), (b) deciding how to control reliability, (c) implementing reliability control activities/measures, (d) monitoring the activities/measures that reduce and/or limit the possibility of errors, and (e) evaluating the effectiveness of the implemented activities/measures that reduce and/or limit human fallibility. With each of these activities, there are specific problems to be faced during HRM.

A key problem at the human error identification stage is the correct selection of sources of information about potential errors and the use of appropriate methods to collect error information (Kirwan, 1998; Pan et al., 2017; Read et al., 2021; Tabor, 2021). The problem at the stage of estimating the probability of identified errors is the appropriate choice of estimation methods (e.g. qualitative, quantitative methods). Estimation methods are plentiful (Bell and Holroyd, 2009; EN-62508: 2010), but not all of them are appropriate in every situation (Williams, 1989; Kirwan, 1996; Laumann, 2020). A key problem at the stage of assessing the effects of errors on the achievement of the adopted objectives is the correct prediction of direct and indirect consequences (Forester et al., 2006). A key problem at the stage of analysing measures to reduce and/or mitigate errors, is the development of an appropriate methodology for selecting solutions. These solutions (e.g. measures, actions) should be analysed in terms of factors such as the effectiveness of the solution, cost-effectiveness, feasibility, implementation time, psychological effect, subjective perception by affected employees, etc. (Hollnagel, 1993; Kariuki and Lowe, 2007).

Related to deciding how to reduce and/or limit errors are the problems of proper planning of activities, allocation of resources, identification of responsible persons and setting a deadline for implementation in relation to potential implementation possibilities. To the stage of implementation of measures to reduce and/or limit errors relate the problems of practical implementation of planned activities in accordance with the adopted schedule, while to the stage of monitoring relate the problems of appropriate selection of the scope and detail of ongoing control of planned activities. The problems, related to the last stage of human reliability management, i.e. the assessment of the effectiveness of the implemented actions / measures for reducing and/or limiting errors, concern the correctness of the assessment of the actual reduction of the error probability level after the application of specific solutions.

All of these problems outlined above mean that it can be very difficult to achieve the goals of increasing employee performance and reducing the likelihood of employee errors within the activities being carried out. Therefore, it is important to look for tools that can help

managers to effectively implement measures to improve employee reliability. Such support may be the tools offered by multi-criteria decision-making methods.
In the field of multi-criteria decision-making, a wide variety of methods can be found in the literature. A distinction is made between additive methods (e.g. SAW, SMART); analytical hierarchy and related methods (e.g. AHP, REMBRANDT, ANP, MACBETH); verbal methods (e.g. ZAPROS); methods from the ELECTRE family; methods from the PROMETHEE and EXPROM families, methods using reference points (e.g. TOPSIS, VIKOR, BIPOLAR) and interactive methods (e.g. STEM-DPR, INSEDECM, ATO-DPR) (Trzaskalik, 2014). These methods can, firstly, help to select the option (e.g. actions or measures) that best fits the decision-maker's preferences. They can also be used to rank the decision alternatives under consideration from best to worst. And finally, they can be used to assign the alternatives under consideration to a predetermined, pre-defined class of solutions. Each method is characterised by specific advantages, disadvantages and limitations, so the choice of method also requires a multi-criteria decision. This has the effect of discouraging the search for methods in a given area and consequently selecting the method that is the most popular and best developed in the literature, but not necessarily the most suitable for a given situation.
Taking the above into account, human reliability management assessment can be treated precisely as a multi-criteria decision-making problem. In the area of human reliability, there is a practical lack of validated tools that can be used to assess reliability management, which are based on multi-criteria decision-making methods. The use of the VIKOR method for human reliability management assessment presented in this paper is original, and is an attempt to fill the tool gap.

2. METHODOLOGY OF RESEARCH

The aim of the research carried out was to verify the feasibility of using the VIKOR method assess human reliability management towards improving occupational health and safety. The following 8 processes comprising HRM were adopted as evaluation criteria, according to the adopted reference model: C_1 - Identification of errors committed by employees; C_2 - Estimation of the probability of errors; C_3 - Assessment of the effects of errors on the achievement of objectives; C_4 - Analysis of measures to reduce and/or mitigate errors; C_5 - Decision-making on how to reduce and/or mitigate errors; C_6 - Implementation of actions/measures to reduce and/or mitigate errors; C_7 - Monitoring of actions/measures to reduce and/or mitigate errors, and C_8 - Evaluation of the effectiveness of implemented actions/measures to reduce and/or mitigate errors.
The level of achievement of each criterion was rated by three independent experts on a five-point scale, with individual ratings denoting respectively: 1 - very bad, 2 - poor, 3 - average, 4 - good, 5 - very good.
The assessment was made in relation to the process of operating production machinery as part of the manufacturing process of the main product. The production machinery operation process was chosen because of its potential for health and safety improvement, which has been confirmed by increasing accident rates in maintenance departments.
The research was carried out in seven companies in the furniture industry, with comparable employment size and similar production, in order to minimise the impact of external factors on the implementation of individual processes.

The research used a specially prepared questionnaire with a measurement scale for assessing the implementation of individual human reliability management processes, together with guidelines for evaluating the effects of activities within each process.

In contrast, the VIKOR method chosen for analysis (Opricovic and Tzeng, 2004) is a linear ordering method using reference points. The method assumes that each alternative can be evaluated by each criterion function and that the ranking of solutions can be represented by comparing the closeness of the solution to the ideal alternative (Kaya and Kahraman, 2011). The basis of the method is the so-called merit sum, which represents the distance of an alternative solution from the ideal solution, and indicates a compromise solution. Such a solution provides maximum '*group utility*' for the majority of alternatives and minimum '*individual regret'* for the minority.

The VIKOR method has already been validated many times, for various decision-making problems, related, for example, to the improvement of information protection systems (Ou Yang et al., 2009), to the improvement of air service quality (Liou et al., 2011), to the selection of materials (Jahan et al., 2011), to the selection of sub-suppliers (Vahdani et al., 2013), to the selection of lean tools (Anvari et al., 2014) or to the health and safety management system performance evaluation (Tabor, 2017).

The study used the VIKOR method procedure consisting of the following seven steps:

Step 1) Determination of bestf^* and worstf^- criterion values,

Step 2) Calculation of the weighting of each criterion based on the chosen method - the maximum deviation method (Wang, 1998) was used, using formulas (1), (2) and (3),

$$H_{ij} = \sum_{k=1}^{m} d\left(a_{ij}, a_{kj}\right), \text{ i} \in \{1, 2, ..., m\}, \text{ j} \in \{1, 2, ..., n\} \quad (1)$$

$$H_j = \sum_{i=1}^{m} H_{ij} \text{ i} \in \{1, 2, ..., m\}, \text{ j} \in \{1, 2, ..., n\} \quad (2)$$

$$w_j = \frac{H_j}{\sum_{j=1}^{n} H_j} \quad (3)$$

Step 3) Calculation of the *'group utility'* value *S* from equation (4),

$$S_k = \sum_{j=1}^{m} w_j \frac{\left|f_j^* - f_{kj}\right|}{\left|f_j^* - f_j^-\right|} \quad (4)$$

Step 4) Calculation of the *'individual regret'* value *R* from formula (5),

$$R_k = max_j \left\{ w_j \frac{\left|f_j^* - f_{kj}\right|}{\left|f_j^* - f_j^-\right|} \right\} \quad (5)$$

Step 5) Calculation of the comparison value *Q* from equation (6),

$$Q_k = \vartheta \frac{S_k - S^*}{S^- - S^*} + (1 - \vartheta) \frac{R_k - R^*}{R^- - R^*} \quad (6)$$

Stage 6) Arranging alternatives in terms of *S*, *R* and *Q,*

Step 7) Identification of the best compromise solution *Q min* assuming two conditions are met. Condition 1 - acceptable advantage - according to equation (7),

$$Q(a^{II}) - Q(a^{I}) \geq DQ \; whereDQ = \frac{1}{(J - 1)} \quad (7)$$

Condition 2 - acceptable decision stability: the alternative a^I must also be the best from the point of view of *S* and/or *R.* If condition 2 is not met, a compromise solution is possible: alternatives a^I and a^{II}.

3. RESULTS

Table 1 summarises the averaged ratings of the individual areas (criteria) of the level of human reliability management implementation (C_1-C_8) in the surveyed companies (E_1-E_7).

The arithmetic mean of the individual expert assessments was used to average the ratings.

Table 1

Assessments of the level of implementation of individual HRM processes

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
E_1	2.33	3.00	4.00	2.33	4.00	4.67	2.33	2.67
E_2	1.67	2.00	2.67	3.33	2.00	2.00	3.67	3.00
E_3	2.33	2.67	3.00	1.76	3.00	2.67	2.67	1.67
E_4	1.67	3.33	4.67	3.67	2.67	3.00	2.00	2.00
E_5	2.33	2.00	3.33	2.00	4.00	4.33	4.67	3.67
E_6	2.33	2.00	4.33	3.33	3.33	3.67	3.00	1.67
E_7	1.67	1.67	3.33	3.00	4.00	3.33	3.67	2.33

For the subsequent calculations, including, the calculation of the weights of the individual criteria, the basic characteristics of the individual criteria were calculated - Table 2.

Table 2

Summary characteristics of individual evaluation criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Average	2.047	2.381	3.619	2.774	3.286	3.381	3.144	2.430
Minimum	1.670	1.670	2.670	1.760	2.000	2.000	2.000	1.670
Maximum	2.330	3.330	4.670	3.670	4.000	4.670	4.670	3.670
Standard deviation	0.353	0.620	0.731	0.741	0.780	0.931	0.922	0.738

The highest mean value of scores was recorded for criterion C_3 - *Assessment of the effects of errors on the achievement of objectives* (3.619); and the lowest for C_1 - *Identification of errors made by employees* (2.047).

In contrast, the standard deviation reached the highest value for C_6 - *Implementation of actions/measures to reduce and/or mitigate errors* (0.931) and the lowest for C_1 - *Implementation of actions/measures to reduce and/or mitigate errors* (0.353).

Using formulae (1), (2) and (3), the weights of the individual evaluation criteria were calculated. Table 3 summarises the weights of the evaluation criteria, calculated according to the method of least deviation.

Table 3

Summary of weights determined according to the method of least deviation

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
H	0.353	0.620	0.731	0.741	0.780	0.931	0.922	0.738
Weight	0.061	0.107	0.126	0.127	0.134	0.160	0.159	0.127

Criterion C_6 - *Implementation of actions / measures to reduce and/or limit errors* received the highest weighting of 0.160, followed by criteria: C_7 - *Monitoring of actions / measures to reduce and/or limit errors* (0.159) and C_5 - *Decision-making on how to reduce and/or limit errors* (0.134).

Using formulae (4) and (5), the value of '*group utility*' *S* and the value of 'individual regret' were calculated *R* for alternatives E_1-E_7. Using formula (6), the comparative value *Q was* calculated, taking the weight of maximum '*group utility*' to be 0.5 on average. The results of the calculations for weights set according to the arithmetic mean are shown in Table 4.

Table 4
Summary of S_k, R_k and Q

	E_1	E_2	E_3	E_4	E_5	E_6	E_7
S_k	0.355	0.691	0.708	0.515	0.302	0.461	0.522
R_k	0.139	0.160	0.127	0.159	0.111	0.127	0.107
Q	0.368	0.980	0.688	0.753	0.037	0.385	0.271

According to the assumptions of the VIKOR method, in order to make a comparison, and identify the best alternative, the values of *S*, *R* and *Q* must be ranked from smallest to largest. According to Table 4, the ordering of the companies by the value of *Q* is as follows: E5 $\succ$ E7 $\succ$ E1 $\succ$ E6 $\succ$ E3 $\succ$ E4 $\succ$ E2, where $\succ$ stands for 'advantage'.
The fulfilment, by the alternative with the minimum value of Q, of condition 1 was then verified (formula 7). For condition 1 (acceptable advantage): DQ = 0.167; $Q(E_7) - Q(E_5) = 0.234 > DQ$. This means that condition 1 is satisfied. Also condition 2 (acceptable decision stability) is satisfied because: $S(E_5) < S(E_7)$ $0.302 < 0.522$.

4. DISCUSSION

Eight detailed processes were used as criteria for assessing the level of implementation of human reliability management. This is not the only reliability management reference model available in the literature, but it is the one best known to experts who assess processes. The level of implementation of each criterion was rated by three independent experts on a five-point scale and the ratings were averaged in the simplest way, using the arithmetic mean method. It was therefore assumed that the experts' knowledge and experience regarding the implementation of the individual human reliability management processes were at a comparable level. And this is not always the case. At the same time, based on the averages obtained, it can be assumed that a seven-point rating scale would have differentiated the results of individual companies more.
The research focused on the process of operating production machinery as part of the manufacturing process of the main product. The operation of production machinery was found to be the most accident-prone, so improving safety in this area was at the forefront of managers' concerns.
The choice of the VIKOR method was based on its simplicity and the ability to use the simplest tool to perform the calculations.
A key problem with the procedure of this method was the determination of the weights of the individual criteria. The literature provides many examples of methods for determining weights (Roszkowska, 2013). The most commonly used approach is the subjective evaluation of the weights by the decision-maker or the use of averaged opinions of experts in the field. In contrast, the approach used in this study is the maximum deviation method. It assumes that if the values of a criterion differ little between alternatives, then such a criterion has little importance and low weight. On the other hand, if a certain criterion takes on very different values between alternatives, it plays an important role in the process of selecting the best solution and should be given a high weight.

The research presented here confirms the usefulness of the VIKOR method, as a multi-criteria decision-making tool in the area of human reliability, in identifying the best and worst performing human reliability management process.

5. CONCLUSION

Although there is a growing trend in the automation of human labour in every industry, the human factor still plays a key role in production and logistics systems (Sgarbossa et al., 2020)

The aim of the research presented in this paper was to verify the suitability of the VIKOR method in the area of human reliability for identifying the best and worst performing human reliability management process.

Currently, the main areas of human reliability research concern the development and validation of new human reliability analysis methods dedicated to specific industries and sectors, and the development and validation of state-of-the-art tools for the identification of human errors and performance of humans in the human-machine system (Tao et al., 2020). It is also important to identify new human performance factors in different work processes. Understanding these new factors is essential for the development of key strategies to minimise human error and improve safety and productivity in a situation of rapidly changing production processes (Jha et al., 2024).

In the context of the results obtained in the article, and the research directions identified in the literature in the area of human reliability, further research work is planned on the development of human reliability management in the modern environment of Industry 4.0.

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