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An Integrated FUCOM-ARAS Model for Ergonomic Risk Assessment

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ABSTRACT

Many workers suffer from occupational musculoskeletal disorders and mental burdens in workplaces. A number of ergonomic risk factors such as human-related, cognitive, and physical contribute to inducing these burdens in the workplaces. Thus, ergonomic risk assessment is conducted to determine these risk factors and to reduce their negative effects by providing safer and healthy working environments. The aim of this study is to introduce a new ergonomic risk assessment approach for revealing the most important ergonomic risk factors and the worker who is most affected by these risk factors while performing tasks in a distribution center. For this reason, an integrated multi-criteria decision-making (MCDM) model which consists of the Full Consistency Method (FUCOM) and Additive Ratio Assessment (ARAS) methods to achieve the purpose of the study has been developed in this study. The FUCOM method is applied to calculate the weights of human-related, cognitive, and physical risk factors, separately. Then, the ARAS method is used to determine which worker has more exposed to ergonomic risks. This study can contribute to occupational safety managements of the companies to conduct more systematic ergonomic risk assessment activities and prepare effective ergonomic improvement programs.

Keywords: Ergonomics, Ergonomic risk assessment, MCDM, FUCOM, ARAS

INTRODUCTION

Occupational musculoskeletal disorders and high-level of mental burdens are serious health problems. Besides, many workers suffer from these problems in the workplaces every year. These problems cause losses in terms of workday, time, income, job, productivity and so on. The economic costs of these problems are also high. Many ergonomic risk factors may induce occupational musculoskeletal disorders and high-level mental workload. Thus, it is essential to conduct ergonomic risk assessment studies in the workplaces to analyze the current situations, measure the exposure levels of workers to ergonomic risks and determine the necessity of the ergonomic improvements.

Many factors and workers are included in ergonomic risk assessment process. Therefore, in recent years, it is considered as a multi-criteria decision-making (MCDM) problem in the literature. There are many MCDM techniques to solve decision problems. In the literature, these techniques have been successfully used in a variety of fields. However, in literature, to the best our knowledge, a few studies have been conducted using MCDM methods in the ergonomic risk assessment processes (see Table 1).

Table 1. Research studies using MCDM methods in ergonomic risk assessment process.

Author (year)	Sector	Method(s)	Aim(s) of the study
Talapatra et al. (2022)		Fuzzy AHP	Prioritization of risk factors
Khan et al. (2021)	Manufacturing	Fuzzy DEMATEL	Prioritization of risk factors
Upadhyay et al. (2021)	Online education	Fuzzy AHP	Prioritization of risk factors
Kılıç Delice and Can (2020)	Tube manufacturing	KEMIRA-M, BWM and MOORA	Prioritization of risk factors and ranking workers
Adar and Kılıç Delice (2020)	Local public transportation	AHP-COPRAS	Prioritization of risk factors and ranking workers
Mamak Ekinci and Can (2018)	Juice manufacturing	CRITIC-MAIRCA	Prioritization of risk factors and ranking workers
Khandan et al. (2016)	Arc Opal dishes manufacturing company	Entropy	Prioritization of risk factors

The aim of this study is to perform an ergonomic risk assessment activity in a different application field using a new integrated MCDM model. In this study, a MCDM-based ergonomic risk assessment model is developed to assess human-related, cognitive and physical ergonomic risk factors in a distribution center. Musculoskeletal and repetitive motion disorders are frequently occurred in distribution centers due to performing manual handling tasks, awkward working postures and other related tasks (Zhao et al. 2022). Thus, ergonomic risk exposures of workers who performing warehouse activities in a distribution center are evaluated by using Full Consistency Method (FUCOM) and Additive Ratio Assessment (ARAS) methods in the present study. The FUCOM method is utilized to find the importance weights of ergonomic risk factors in the workplace and the ARAS method is used to rank exposure levels of the workers to ergonomic risks.

The following sections present the methodology used, the application of the proposed model, the results obtained, and the conclusion part of the study, respectively.

METHODOLOGY

FUCOM Method

The criteria do not have the same degree of importance in real decision-making problems. Besides, determining the relative criteria weights is a significant problem since it also affects the final results. The weights of criteria can be calculated utilizing MCDM methods. In this study, the FUCOM method as a new MCDM method developed by Pamučar et al.

(2018) is proposed to obtain the criteria weights. The FUCOM method is summarized in the following steps (Pamučar et al.; 2018).

Step 1. The predefined criteria $C_j = \{C_1, C_2, \ldots, C_n\}$ are ranked. If C_1 is more important than C_2, this judgement is demonstrated as $C_{1(k=1)} > C_{2(k=2)}$. Here, j shows the number of criteria and k indicates the rank of criteria.

Step 2. The comparative priority of the criteria is computed using 1–9 scale (1: the lowest, 9: the highest). To determine the comparative priority, the rank of each criterion is compared with the rank of the next criterion. The comparative priorities are expressed as $\varphi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right)$

Step 3. The final relative weight values of the criteria $(w_1, w_2, \ldots, w_n)^T$ are computed. These values should satisfy the conditions given below.

Condition 1. The ratio of the weight values is equal to the comparative priority among the criteria $\left(\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}\right)$.

Condition 2. The final relative weight values of the criteria should satisfy the feature of mathematical transitivity $\left(\varphi_{\frac{k}{(k+1)}} \otimes \varphi_{\frac{(k+1)}{(k+2)}} = \varphi_{\frac{k}{(k+2)}}\right)$. Based on this feature, another condition is obtained as follows:

$$\frac{w_k}{w_{k+1}} = \varphi_{\frac{k}{(k+1)}} \otimes \varphi_{\frac{(k+1)}{(k+2)}} \tag{1}$$

The final relative weight values of the criteria can be determined using the following mathematical model:

$$\begin{aligned} &\min \chi \\ &\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \leq \chi, \forall j \\ &\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, \forall j \\ &\sum_{j=1}^{n} w_j = 1, \; w_j \geq 0, \; \forall j \end{aligned} \tag{2}$$

The final weight values of the criteria $(w_1, w_2, \ldots, w_n)^T$ and deviation from the full consistency (DFC:χ) are obtained by solving model in Eq. (2). If there is a maximum consistency, the DFC value is 0. Besides, the sum of weights is 1.

ARAS Method

A finite number of alternatives are ranked by evaluating them under various predefined criteria in decision-making problems. There are many MCDM methods used to sort alternatives and select the most appropriate one in the decision problem. ARAS method introduced by Zavadskas and Turskis in 2010 is suggested to rank the alternatives in this study. This method computes the utility degree of each alternative in the problem. The steps of ARAS method are described as follows:

Step 1. A decision matrix $X = \left[x_{ij}\right]_{mxn}$ is constructed and optimum values of criteria (x_{0j}) are calculated. Here, x_{ij} indicates the assessment values of alternative i against criterion j. In addition, m and n show the number of alternatives and criteria in the decision problem. If there is no information for the optimum values of criteria, Eqs. (3) and (4) are utilized based on the type of criteria.

$$\text{If } max_i x_{ij} \text{ is benefit}, x_{0j} = max_i x_{ij} \quad (3)$$

$$\text{If } min_i x_{ij}{}^* \text{ is cost}, x_{0j} = min_i x_{ij}{}^* \quad (4)$$

Step 2. The decision matrix is normalized. Eqs. (5) and (6) are used based on the type of criteria.

$$\overline{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \text{ for benefit criteria} \quad (5)$$

$$\overline{x}_{ij} = \frac{\frac{1}{x_{ij}}}{\sum_{i=0}^{m} \frac{1}{x_{ij}}} \text{ for cost criteria} \quad (6)$$

Step 3. The weighted normalized decision matrix $D = \left[d_{ij}\right]_{mxn}$ is constructed.

$$D = \left[d_{ij}\right]_{mxn} = \widehat{x}_{ij} = \overline{x}_{ij} \text{ x } w_j \quad (7)$$

where w_j indicates the weights of criteria.

Step 4. The optimality function values (S_i) are computed.

$$S_i = \sum_{j=1}^{n} \widehat{x}_{ij}, \quad i = 0, 1, \ldots, m \quad (8)$$

where S_i shows the optimality function value of ith alternative.

Step 5. Utility degrees (K_i) and rankings of alternatives are determined.

$$K_i = \frac{S_i}{S_0}, \quad i = 0, 1, \ldots, m \quad (9)$$

where S_0 shows the value of optimality function of dummy alternative. K_i are ranked from the highest to the lowest values.

Proposed Ergonomic Risk Assessment Model

The proposed MCDM model has two stages as obtaining the importance weights of ergonomic risk criteria, and ranking workers considering their ergonomic risk exposure levels through using FUCOM and ARAS methods. The methodology of the proposed ergonomic risk assessment model is given below.

First stage: Determination of ergonomic risk criteria sets and calculation of criteria weights.

Ergonomic risk factors were categorized into three main different criterion sets namely human-related (MC1), cognitive (MC2), and physical (MC3) risk criteria considering their different contents. There are three ergonomic risk factors in HR as age (RF1), body mass index (RF2), and musculoskeletal pain level (RF3). CR includes six factors of the NASA Task Load Index (NASA-TLX) method which are mental demand (RF4), physical demand (RF5), temporal demand (RF6), performance (RF7), effort (RF8), and frustration (RF9) factors. Besides, PR consists of three factors of the Rapid Entire Body Assessment (REBA) method which are total musculoskeletal risk score on neck, trunk, and leg segments (RF10), total musculoskeletal risk score on arms and wrist segments (RF11), and load weight (RF12).

The occupational safety expert group evaluates the importance of each criterion set in consensus. The weights of the main criteria and sub-criteria are calculated via the FUCOM algorithm. In this process, a total of four-dimensional FUCOM model is constructed. MS Excel Solver is used to solve these models.

Second stage: Computation of ergonomic risk exposures of alternatives and ranking alternatives with ARAS method.

Workers are the alternatives of the ergonomic risk assessment problem. A questionnaire is prepared and video records are utilized to obtain data needed for the analysis. The questionnaire includes individual and NASA-TLX workload assessment questions and it is implemented to the workers after they complete their task. Nevertheless, the video records are taken while the workers are performing the tasks. These records are used to calculate the risk scores of the three components of the REBA method. The NASA-TLX workload assessment and REBA methods are widely utilized and well-known techniques in the area of ergonomics. Thus, the implementation steps of these techniques are not presented in this study.

After obtaining data, ergonomic risk exposures level for each worker are computed using ARAS algorithm. Then, the rankings of workers respect to their ergonomic risk exposure level are determined. Later, ergonomic improvements are suggested to minimize the effect of the ergonomic risks on the worker who is most at risk.

APPLICATION OF THE PROPOSED MODEL FOR A DISTRIBUTION CENTER

In this study, the applicability of the proposed ergonomic risk assessment model is presented with a real application. The data was obtained from five workers who perform warehouse activities in a distribution center in Türkiye. Ergonomic risk factors were determined based on the literature review and the opinions of occupational safety expert group who work in this center. The ergonomic risk factors were considered as criteria of this ergonomic risk assessment problem. The workers were asked to respond the questions in the questionnaire prepared considering their individual and working conditions in the workplace. Video records were also taken to obtain related REBA risk scores.

The occupational safety expert group assessed the importance of all criteria in consensus in this study. The rankings of the main criteria (MC1, MC2, and MC3) and sub-criteria of each main criterion according to the opinion of expert group are shown in Table 2.

Table 2. Rankings of the main criteria and sub-criteria.

Criteria	Ranking
Main criteria	*MC3 > MC2 > MC1*
Sub-criteria of MC1	*RF3 > RF2 > RF1*
Sub-criteria of MC2	*RF5 > RF8 > RF6 > RF7 > RF4 > RF9*
Sub-criteria of MC3	*RF12 > RF10 > RF11*

Pairwise comparisons of criteria were performed by the experts for second step of the FUCOM algorithm according to the most important criterion in each set. The evaluation results of the main criteria and sub-criteria are demonstrated in Table 3.

Table 3. Evaluation scores of the main criteria and sub-criteria.

Criteria	Evaluations
MC1	5
MC2	2
MC3	1
RF1	6
RF2	3
RF3	1
RF4	6
RF5	1
RF6	3
RF7	4
RF8	2
RF9	7
RF10	2
RF11	5
RF12	1

The comparative priorities of the main criteria and sub-criteria are calculated as follows, respectively:

$$\varphi_{MC3/MC2} = 2/1 = 2; \varphi_{MC2/MC1} = 5/2 = 2.5; \varphi_{RF3/RF2} = 3/1 = 3;$$
$$\varphi_{RF2/RF1} = 6/3 = 2; \varphi_{RF5/RF8} = 2/1 = 2; \varphi_{RF8/RF6} = 3/2 = 1.5;$$
$$\varphi_{RF6/RF7} = 4/3 = 1.33; \varphi_{RF7/RF4} = 6/4 = 1.5; \varphi_{RF4/RF9} = 7/6 = 1.17;$$
$$\varphi_{RF12/RF10} = 2/1 = 2; \varphi_{RF10/RF11} = 5/2 = 2.5$$

The conditions explained in the third step of FUCOM algorithm were checked for main criteria and their sub-criteria. As an example, the results of two conditions obtained for main criteria were demonstrated as follows, respectively:

$$\frac{w_{MC3}}{w_{MC2}} = 2; \frac{w_{MC2}}{w_{MC1}} = 2.5$$
$$\frac{w_{MC3}}{w_{MC1}} = \frac{w_{MC3}}{w_{MC2}} \otimes \frac{w_{MC2}}{w_{MC1}} = 2 \otimes 2.5 = 5$$

Then, four mathematical models for all criteria were constructed and solved to determine their weights. As an example, the model constructed for main criteria was given as follows:

$$\min \chi$$
$$\left|\frac{w_{MC3}}{w_{MC2}} - 2\right| \le \chi \quad \left|\frac{w_{MC2}}{w_{MC1}} - 2.5\right| \le \chi \quad \left|\frac{w_{MC3}}{w_{MC1}} - 5\right| \le \chi,$$
$$\sum_{j=1}^{3} w_j = 1, \; w_j \ge 0, \; \forall j$$

The final weight values of main criteria and the DFC (χ) were computed as $(\mathbf{0.118}, \mathbf{0.294}, \mathbf{0.588})^T$ and $\chi = \mathbf{0.000}$, respectively through solving above model. After constructing and solving other models, the final weight values of sub-criteria were also obtained. The weight values of each criteria are shown in Table 4.

According to the result, it can be concluded that MC3: physical ergonomic risk criteria set is the most important main criteria and RF12: load weight is the most important sub-criteria.

Table 4. Final weight values of main criteria and sub-criteria.

Main Criteria	Sub-criteria	Final weights values of sub-criteria
MC1 (0.118)	RF1 (0.111)	0.118 ⊗ 0.111= 0.0131
	RF2 (0.222)	0.118 ⊗ 0.222= 0.0262
	RF3 (0.667)	0.118 ⊗ 0.667= 0.0787
MC2 (0.294)	RF4 (0.070)	0.294 ⊗ 0.070= 0.0206
	RF5 (0.418)	0.294 ⊗ 0.418= 0.1229
	RF6 (0.139)	0.294 ⊗ 0.139= 0.0409
	RF7 (0.104)	0.294 ⊗ 0.104= 0.0306
	RF8 (0.209)	0.294 ⊗ 0.209= 0.0614
	RF9 (0.060)	0.294 ⊗ 0.060= 0.0176
MC3 (0.588)	RF10 (0.294)	0.588 ⊗ 0.294= 0.1729
	RF11 (0.118)	0.588 ⊗ 0.118= 0.0694
	RF12 (0.588)	0.588 ⊗ 0.588= 0.3457

Table 5. Assessments results.

Alternatives	Criteria											
	RF1 (years)	RF2 (kg/m^2)	RF3 (score)	RF4 (score)	RF5 (score)	RF6 (score)	RF7 (score)	RF8 (score)	RF9 (score)	RF10 (score)	RF11 (score)	RF12 (kg.)
Worker1	26	21.4	70	55	100	90	85	100	55	6	4	8
Worker2	30	28.7	85	95	95	100	100	95	85	8	4	10
Worker3	35	24.3	65	70	100	75	90	90	85	8	3	8
Worker4	29	30.5	100	95	100	95	85	100	60	8	6	15
Worker5	27	25.5	100	50	90	100	85	80	100	6	3	13

Table 6. Ergonomic exposure levels and ranking results of workers.

Alternatives	S_i	K_i	Rank
Worker0 (optimal)	0.1979	1.0000	
Worker1	0.1380	0.6972	5
Worker2	0.1625	0.8209	3
Worker3	0.1434	0.7245	4
Worker4	0.1948	0.9844	1
Worker5	0.1635	0.8261	2

After determining weight values of criteria, the workers are assessed based on these ergonomic risk criteria. The assessment results are depicted in Table 5.

All ergonomic risk factors are considered as benefit criteria since it is aimed to sort the risk exposure levels of the workers in this study. The ARAS algorithm was used to determine the ergonomic risk exposures of workers. Table 6 presents the exposure levels and ranking results of the workers.

The rankings of workers based on the ergonomic risk exposure level were obtained as $Worker1 > Worker3 > Worker2 > Worker5 > Worker4$. As a result, the fourth worker is exposed to much more ergonomic risks than others. Therefore, ergonomic improvements should be made to reduce the exposure level to ergonomic risks in the workplace. Otherwise, many health problems, especially musculoskeletal disorders, may occur. For this purpose, break intervals at the workplace can be rearranged based on the workload, work area can be redesigned considering anthropometric measurements of workers, auxiliary equipment can be utilized for manual materials handling tasks, and an ergonomics awareness training program can be organized for workers in order to carry out the manual handling works accurately and to know right working posture while performing their tasks.

CONCLUSION

In this study, it is aimed to present a new ergonomic risk assessment model for determining the importance of ergonomic risk factors and the worker who are most exposed to ergonomic risks. Therefore, an integrated MCDM model consists of FUCOM and ARAS methods is developed in this study. The FUCOM method is proposed to obtain the weights of ergonomic risk criteria. In this process, four mathematical models depending on criterion sets are constructed to obtain optimum weights. In addition, ARAS method is proposed to rank the workers based on their exposure level to ergonomic risks in the workplace. This study has contributed to ergonomics literature since very few studies in the literature use MCDM models in ergonomic risk assessment process. In future studies, the model used in this study and the results obtained can be considered in the ergonomic improvement activities organized by the occupational safety managements of companies to reduce the impacts of ergonomic risk factors. Besides, other MCDM methods can be used to make comparison analyses and uncertainty issues can be taken into account to cope with subjectivity in the ergonomic assessment process.

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