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An advanced KEMIRA-M method proposal based on FARE method to perform ergonomic risk evaluation in a dishwasher assembly line

Bulaşık makinesi montaj hattında ergonomik risk değerlendirmesi gerçekleştirmek için FARE yöntemine dayalı gelişmiş bir KEMIRA-M yöntemi önerisi

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Öz

Ergonomik risk değerlendirmesi, işyerinde, işyeri koşullarında veya bunların bir kombinasyonunda genel sistem performansı ve insan refahı için zararlı olabilecek faktörleri veya eylemleri belirlemek için yapılan çalışmadır. İşyerlerinde pek çok farklı türde ergonomik risk faktörü bulunmaktadır. Bu nedenle bir montaj hattında farklı bölgeler için farklı risk faktörlerini dikkate alarak ergonomik risk düzeyi elde etmek zorlu bir iştir. Bu bağlamda, bu çalışma, bir bulaşık makinesi montaj hattındaki en riskli bölgenin belirlenmesi için Kemeny Median Indicator Rank Accordance Modified (KEMIRA-M) ve Factor Relationships (FARE) yöntemlerine dayalı yeni bir bütünleşik Çok Kriterli Karar Verme (ÇKKV) yaklaşımı geliştirmeyi amaçlamaktadır. KEMIRA-M, risk faktörleri birkaç alt kümeye mantıksal olarak ayırt edilebildiğinde ve her karar vericinin önceliklerine göre faktörlerin ağırlıklarını belirlemek için faktörler arasındaki etkileşimleri dikkate alır. KEMIRA-M aynı zamanda faktörlerin alt kümelerini dikkate alarak ağırlık çiftleri oluşturarak farklı montaj hattı bölgelerini aynı anda sıralayabilmektedir. Bu özelliklerine rağmen KEMIRA-M yönteminin faktörleri ağırlıklandırma prosedürü sezgisel olarak yapılmaktadır. Bu bağlamda KEMIRA-M'nin ağırlıklandırma sürecinde öznelliği ve sezgiselliği aşmak için bu çalışmada FARE yöntemi kullanılmıştır. FARE, faktörler arasındaki ilişkiye dayalı olarak çok sayıda faktörün ağırlıklarının belirlenmesine olanak tanır, hesaplamaların doğruluğunu arttırır ve uzman bağımlılığını azaltır.

Anahtar kelimeler: KEMIRA-M, FARE, Ergonomi, Montaj Hattı, Risk Değerlendirme

Abstract

Ergonomic risk assessment is the study performed to identify factors or actions in the workplace, workplace conditions, or a combination of these that may be harmful for overall system performance and human well-being. There are many different types of ergonomic risk factors in workplaces. For this reason, obtaining an ergonomic risk level considering different risk factors for different regions in an assembly line is a hard work. In this context, this study aims to develop a new integrated Multi-Criteria Decision Making (MCDM) approach based on Kemeny Median Indicator Rank Accordance Modified (KEMIRA-M) and Factor Relationships (FARE) for determining the riskiest region in a dishwasher assembly line. KEMIRA-M is used when the risk factors can be logically distinguished a few subsets and considers interactions between factors for setting factors' weights based on their priorities for each decision maker (DM). KEMIRA-M can also rank different assembly line regions by forming weight pairs considering factors' subsets simultaneously. Despite these features, the factors' weighting procedure of KEMIRA-M is utilized intuitively. In this context, FARE method was used in this study to overcome subjectivity and intuitiveness in the weighting process of KEMIRA-M. FARE allows the determination of weights of a large number of factors based on the relationship between the factors, increases the accuracy of computations, and reduces expert dependency.

Keywords: KEMIRA-M, FARE, Ergonomics, Assembly Line, Risk Assessment

1 Introduction

Designing workplaces considering ergonomic principles is important for production productivity. In this concept, ergonomic risk assessments have a vital role in providing production productivity. Ergonomic risk assessment aims to determine the ergonomic risk levels for the tasks, workstations, or production regions and to evaluate the ergonomic conditions of tasks, workstations, or production regions. However, quantifying ergonomic risk factors is not sufficient for developing a plan to prioritize tasks, workstations, or production regions in terms of their risk levels and to implement measurable improvements for tasks, workstations, and regions. There are many different types of ergonomic risk factors in workplaces such as noise, lighting, posture, humidity, etc. For this reason, obtaining an aggregated risk level considering different ergonomic risk factors for tasks, workstations, and regions is hard work. To provide flexibility to compute an aggregated risk level, Multi criteria decision making (MCDM) tools can support this computation. For the ergonomic risk assessment process, ergonomic risk factors can form criteria; tasks, workstations, or regions can form alternatives, and experts related to this evaluation can form decision maker (DM) group. In this concept, this study also proposes a new ergonomic risk assessment approach based on Kemeny Median Indicator Rank Accordance Modified (KEMIRA-M) and Factor Relationships (FARE) integration. The proposed integration was implemented for ergonomic risk level evaluation for the different regions of a dishwasher assembly line in this study.

MCDM tools can rank different alternatives for different criteria by considering different opinions of DMs. KEMIRA-M is also one of the new-generation MCDM methods. KEMIRA-M advanced

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by Krylovas et al. (2016) can compute criteria weights and determine rankings of alternatives simultaneously [9]. KEMIRA-M is a method that can work with both qualitative and quantitative criteria values. In addition, the method determines the order of the alternatives by considering both the priority evaluations of the DMs regarding the criteria weights.

The KEMIRA-M method is a useful tool when the number of criteria to be considered in the decision process is high. The method analyses these large numbers of criteria by dividing them into groups according to their structural similarities. Any number of groups can be created according to the similarity of the criteria. This provides flexibility in the decision process, as the number of criteria considered can be high. However, when the number of groups is more than two, it becomes difficult to solve manually. Therefore, the need for the use of different coding languages arises.

Another factor that needs to be developed regarding the KEMIRA-M method is the intuitiveness and subjectivity that emerge in the process of determining the criteria weights. It computes criteria weights considering criteria priorities for each DM. KEMIRA-M aggregates the criteria priorities of each DM by using Kemeny Median Approach. This aggregated priority is called Median Priority Components (MPCs). The priority of DM which minimizes the sum of distances to the priorities preferred by all DMs is chosen as MPCs. MPC is determined for each criterion group. The criteria weights are assigned according to the MPC, and their sum is "1". KEMIRA-M minimizes the sum of squared weighted mean differences of two criteria sets (objective and subjective criteria, etc.) for the alternatives while the intersection of the set of the best alternatives for two criteria sets is maximized. For this reason, as with all MCDM methods, it is also important for KEMIRA-M to obtain criteria weights in a logical manner.

When the literature was researched, it is seen that in the studies carried out using KEMIRA-M, researchers focus on developing computational approaches to increase the number of criteria groups and improve the criterion weighting process of the method. In this context, this study aims to improve the criteria weighting procedure of KEMIRA-M. For this aim, the integration of Factor Relationships (FARE) and KEMIRA-M was proposed. FARE was used to compute criteria weights reflecting the MPCs.

In many MCDM methods, it is seen that DMs are effective in determining the criteria weights. It is a well-known fact that the accuracy of the DM's evaluation has a strong dependency on the number of criteria chosen for the decision. The bigger the number of criteria, the more complicated it is for the DMs to compare the alternatives and determine the weights. In this study, the reason why the FARE method was preferred in the weighting process in KEMIRA-M emerges precisely at this point. FARE developed by Ginevičius (2011) allows the determination of weights of many criteria based on the relationship between the criteria. FARE also allows us to increase the accuracy of computations. It is also a well-known fact that the accuracy of the decision reached while using the MCDM methods depends on the determination of the criteria weights which are based on their interrelationship with each other [6]. FARE considers the relationship degree of a criterion between the other criteria and the effect degree of a criterion on the other criteria when determining criteria weights. Quantitative criteria values are more useful for FARE to obtain a relationship degree and effect degree. However, qualitative criteria values can be used in the FARE process. In this study, criteria rankings for different groups were obtained by determining MPC for each group. Then, the most important criterion for each group is obtained considering MPC. The criteria weights were obtained by considering the relationship level of the most important criteria determined for each group with other criteria and the effect level on other criteria in FARE. Finally, by using the weights of the criteria in different groups obtained with the FARE, combinations were created from these weights and weight sets emerged. In KEMIRA-M according to each weight set, the alternatives are ranked according to the weight set that minimizes the absolute difference of the weighted normalized values for each alternative.

The contributions of this study to KEMIRA-M literature can be listed as follows:

- The FARE method is suggested to be used for weighting the criteria used in the KEMIRA-M method. The suggested method allows the formation of criteria weight groups as many as the number of decision makers.
- With the FARE method, decision makers are included in the decision process both in the MPC determination stage and in the stage of obtaining the weights by comparing the criteria with each other according to the MPC.
- By using the FARE method in the weighting phase of the KEMIRA-M method, the relationships between the criteria can be considered.

KEMIRA-M&FARE integration was applied for a dishwasher assembly line that has 10 production regions with 210 workstations. One worker performs his task on each workstation. For these reasons, 210 workers and tasks were considered to obtain the ergonomic risk level of each region. Ergonomic risk criteria were divided into two groups as worker-related criteria (WRC) and posture-related criteria (PRC). A total of 11 criteria were considered under these two groups. FARE was applied to compute ergonomic risk criteria's weights. KEMIRA-M was utilized to obtain rankings of production regions in the related assembly line. All considered criteria have measurable values and it is important for these ergonomic risk criteria to consider the relationship and effect degrees between them because ergonomic risk level arises based on these relationships and effect degrees. DMs' evaluations are also important for ergonomic evaluation. It is a situation that is desired to evaluate whether the ergonomic conditions in the production environments are suitable for the workers or not. However, objective values are expected to emerge by measuring the criteria while determining the risk level. Although it is necessary to evaluate the ergonomic risk level in terms of production areas by combining measurements and DMs' evaluations, any study in this direction has not yet been carried out in the literature. In this context, this study can contribute to both MCDM and ergonomics literature.

The rest of the paper was organized as follows: the second section includes a literature review for FARE and KEMIRA-M. In this section, recent developments were debated for FARE and KEMIRA-M. The proposed integration was explained in the third section with its implementation for a dishwasher assembly line. Results and conclusions were given in the fourth section. The last section includes a discussion. In this section, future research opinions were given, the limitations of the study were debated, and the advantages of the proposed approach were explained.

2 Literature Review

This section includes a literature review for KEMIRA-M and FARE. When the studies implementing KEMIRA-M for different decision problems are examined in the literature, a limited number of studies can be seen. These studies are given below in a detailed manner.

Krylovas et al. (2016) developed KEMIRA-M at first and they applied KEMIRA-M to select the best construction site for a non-hazardous waste incineration plant. They considered two different criteria groups as engineering factors and urban and social factors. There are four criteria under engineering factors and three criteria under urban and social factors. At the end of the study, they mentioned that KEMIRA-M is superior in comparison with Analytical Hierarchy Process (AHP) and Fuzzy Additive Ratio Assessment (ARAS-F) integration [9]. Sarıçalı and Kundakçı (2017) used KEMIRA-M for the selection of the most suitable forklift to be used in storage in a textile firm by considering seven criteria under external and internal criteria groups. They stated that KEMIRA-M is suitable when the criteria can be divided into groups, and it is suitable for situations where the number of criteria in each group is not high. The method requires less initial information than AHP and Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) used to determine criteria weights [15]. Toktaş and Can (2018) performed Quality Function Deployment (QFD) and KEMIRA-M integration to determine the construction site that has the lowest risk. They obtained the rankings of construction sites by evaluating these sites with 11 criteria under numerical indicators and measure indicators. They aimed to advance the criteria weighting procedure of KEMIRA-M and they obtained rankings of criteria by QFD. Then, they used the Kemeny Median approach to determine the criteria weights [16]. Toktaş and Can (2019) proposed a stochastic version of KEMIRA-M by integrating it with stochastic AHP. They implemented the proposed approach for shopping mall selection considering six sub-criteria under technical criteria and seven sub-criteria under universal design criteria. In this way, KEMIRA-M could provide consistent criteria weights. They benefited from discrete uniform distribution to obtain consistent relationship matrices of AHP considering MPCs. They aimed to overcome the dependency on the limited number of experts and to determine criteria weights in a heuristic manner. Additionally, they wanted to present the effect of the number of experts on criteria weightings and alternatives' ranking process. The most consistent weighting results were obtained by using this stochastic process by utilizing it until acquiring approximate consistency ratios [17]. Kundakçı and Sarıçalı (2019) implemented KEMIRA-M to select a gang saw for a marble mill. Criteria weights were obtained with the KEMIRA-M and the most suitable marble cutting machine for the marble mill was chosen with the Complex Proportional Assessment (COPRAS) method by totally considering seven criteria under internal and external criteria groups. They stated that the application of the criteria weights obtained with the MPCs approach, which is used for ranking the criteria in the KEMIRA-M, in other alternative ranking methods will yield more sensitive results [10]. Kış et al. (2020) used KEMIRA-M for selecting the favorable warehouse location. They carried out KEMIRA-M with two criteria groups as firm related and environmental criteria groups. There are twelve criteria in these groups. They stated that since different sets of criteria weights can be reached by using KEMIRA-M, experts can evaluate different rankings in terms of alternatives [13]. Delice and Can (2020) integrated Best-Worst Method (BWM) and KEMIRA-M to select the worker who has the highest ergonomic risk level in tube manufacturing. They determined MPCs than they used BWM to obtain criteria weights. Finally, the rankings of workers were determined via utilizing Multi-Objective Optimization on the Basis of Simple Ratio Analysis (MOOSRA), Multi-objective Optimization by Ratio Analysis (MOORA) ratio, MOORA reference point and COPRAS to present how worker rankings differ despite using the proposed weighting approach based on KEMIRA-M and BWM integration. They considered ten criteria under human-related criteria and lifting-related criteria groups in total. At the end of the study, to obtain final rankings of workers they implemented the Technique of Precise Order Preference (TPOP) to aggregate different rankings produced by MOORA, MOORA reference point, and COPRAS methods [5]. Arslan and Delice (2020) used KEMIRA-M to select the best drone with the help of seven criteria under two criteria groups as internal and external criteria groups [1]. Pakdil et al. (2020) proposed to develop a methodology for the prioritization and selection of Six Sigma projects via implementing KEMIRA-M. They grouped 18 sub-criteria under two main criteria as cost type and benefit type to prioritize 10 six sigma projects. They used Rank Exponent Weight Method (REWM) and Rank Order Centroid Weight Method to determine the criteria weights. Finally, the minimum distance between the weighted normalized values of criteria groups for projects was found by REWM and the rankings of projects were determined according to weights obtained from REWM [14]. Can and Toktaş (2021) proposed an advanced stochastic risk assessment approach based on the integration of an advanced version of QFD (AV-QFD) and KEMIRA-M. A novel weighting procedure for criteria based on uniform, symmetric triangular, left asymmetric triangular, and right asymmetric triangular distributions was advanced. Three different correlations were included in AV-QFD as correlations between criteria (top roof of QFD), risk degrees (RDs) of risk types (RTs) (customer needs part of QFD), correlations between RTs and criteria sets (CSs) (in the middle of QFD) to determine the criteria priorities. Additionally, correlations on the top roof cover three different types of correlations as correlations between criteria in the first CS, correlations between criteria in the second CS, and correlations between criteria in both CSs. Additionally, Fine–Kinney method was performed in AV-QFD to compute RDs of RTs in the customer needs part. Then for each expert, the correlation-based importance degree (CBID) of each criterion was computed to rank the criteria for each CS. They used MATLAB codes to see the effect of different trial numbers and replications on risk assessment. As a result of the study, it was seen that uniform distribution provides the best value, and the same alternative ranking was obtained for all distributions. The distribution to the best value rapidly was determined as the right asymmetric triangular distribution. Eleven criteria were considered under numerical indicators and measure indicators groups to select the construction site which has the lowest risk degree [4]. Tutuş et al. (2021) evaluated RTs that may arise in thrombolysis catheter production processes using KEMIRA-M considering 7 criteria under two criteria groups as first and second criteria groups for 10 RTs in the production process [19]. Arslan and Delice (2021) integrated Failure Modes and Effects Analysis (FMEA) and KEMIRA-M for risk assessment in emergency services. They determined risk criteria' priorities by using FMEA and ranked measures with KEMIRA-M. Thirty-nine risk criteria were considered to rank 8 measures in the study [2]. Türker and Can (2021) applied KEMIRA-M to select the best casting-forging supplier for a firm that produces tractors. In the study, a total of 10 criteria were considered under the first-priority and second-priority criteria groups affecting production [20]. Meriç and Can (2021) examined four health institutions according to the green hospital criteria considered in the study. Thirteen criteria were separated into two groups as qualitative and quantitative criteria groups. Results obtained from traditional KEMIRA-M and Entropy & KEMIRA-M integration were compared. The authors stated that the rankings of the health institutions were determined the same for two different approaches. As expected, criteria weights were obtained at different values because, in the KEMIRA-M, the weights are determined intuitively according to the MPC, while in the Entropy, the uncertainty in the criteria values is considered [12]. Ay et al. (2022) tried to eliminate the subjectivity in the weight assignment stage of KEMIRA-M and to overcome the consensus requirement between experts for determining the criteria weights. This is the first study implemented for KEMIRA-M including four different criteria groups. Additionally, this study prevented some criteria from taking a weight value of "0", as in other studies using KEMIRA-M. Three different ranking-based weighting methods as Rank Sum (RS), Rank Exponent (RE) and Rank Reciprocal (RR) were applied based on MPCs to determine which weighting method for which criterion group is more suitable. MATLAB codes were used to provide flexibility for the application of the proposed approach in a supplier selection problem [3]. Toktaş and Can (2022) proposed a new three-stage risk assessment based on KEMIRA-M and Decision-Making Trial and Evaluation Laboratory (DEMATEL) integration for occupational safety and health related risk assessment. A systematic weighting procedure of KEMIRA-M was suggested by using DEMATEL. This was the first study to consider the risk criteria, the danger sources, and measures at the same time [18].

After Krylovas et al. (2016)'s study, studies were carried out in different fields using KEMIRA-M. KEMIRA-M was first applied for selecting the best construction site for a non-hazardous waste incineration plant in the related study [9]. After this study, KEMIRA-M was implemented to select the most suitable forklift to be used in storage in a textile business [15] to determine the construction site that has the lowest risk level [16], to select a gang saw for a marble mill [10], to select the best shopping mall [17], to select the favorable ware house location [13], to select the best drone [1], to select the worker who has the highest ergonomic risk level [5], to evaluate the risks that may arise during thrombolysis catheter production processes [19], to assess risks in emergency services [2], to select supplier [20], [3], to evaluate of health institutions according to green hospital criteria [12], to prioritize of six sigma projects [14], to propose a three-stage ergonomic risk assessment [18]. As seen from the literature, KEMIRA-M is mostly used for supplier selection. This is followed by the most important production risk selection and the most suitable construction site selection.

When the KEMIRA-M-related studies were examined, it was seen that researchers generally try to improve KEMIRA-M's weighting procedure. For this aim, different methods as Stochastic AHP [17], QFD [16], RS, RR, RE [3], BWM [5], Stochastic QFD and Fine-Kinney [4], FMEA [2], Entropy [12], DEMATEL [18] were implemented. The difference between the studies in the literature and this study is that decision makers were used both to determine the MPC and to determine the weight according to the MPC with the FARE method. Thus, decision makers were more involved in the weighting process.

A literature review for FARE is also given in this section. When a literature search was conducted on the FARE method, it was seen that there were much fewer studies in the literature compared to the studies that performed the KEMIRA-M application. These studies are mentioned below.

Ginevičius (2011) stated that the accuracy of expert evaluation decreases with the increase in the number of criteria in AHP. Additionally, FARE considers relationships between criteria when the criteria weights are determined [6]. Girdzijauskaitė et al. (2019) determined the requirement to test the internationalization of Higher Education Institutions (HEIs) through quantitative methods and they stated that qualitative analysis methods are used in such research mostly. In this context, they used to computer-assist qualitative data analysis (CAQDAS) with Nvivo software to determine the main key performance indicators by executing semi-structured interviews with the top managers of international branch campuses globally to analyse gathered data. FARE was implemented to compute key performance indicators for the competitiveness of HEIs [7].

Considering that FARE makes a powerful MCDM method such as AHP applicable even in conditions where the number of criteria increases, it is thought that it will be beneficial to use it in different MCDM studies. However, the advantages of the FARE method have not been sufficiently exploited to date. In this study, the FARE method was used to make the weighting phase of the KEMIRA-M method more effective.

3 Materials and Methods

3.1 Materials

The proposed approach was implemented for a firm producing dishwashers. There are four assembly lines in the related firm producing different models of dishwashers. Because of having the highest product variety and the highest production quantity, the first assembly line was selected for ergonomic risk evaluation. Additionally, there are 210 male workers in the first assembly line having the highest number of workers. In the first assembly line, workers use their upper limbs intensively to perform their tasks. There are ten regions, and each region includes a different number of workstations in this assembly line. Each station employs a worker. The distributions of age and experience (in years) for the workers in the first assembly line is given in Figure 1 and Figure 2, respectively.

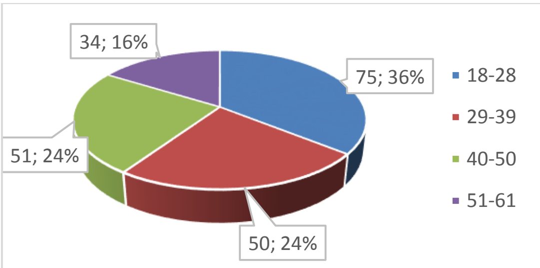

Figure 1. The distribution of the workers' age in the first assembly line

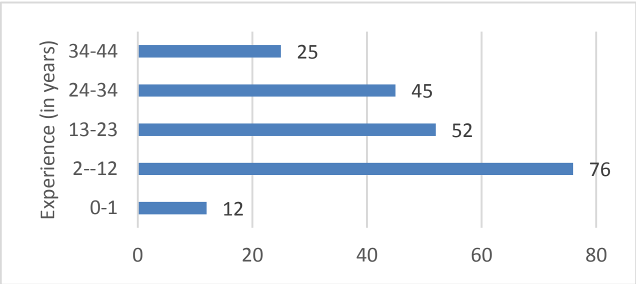

Figure 2. The distribution of workers' experience (in years) in the first assembly line.

Table 1 shows performed tasks in each workstation and some demographic information related to the workers for each region. A total of 148 different tasks are performed by workers in these 10 regions. For example, in region 5, there are 20 workers in 20 workstations that implement cabling. 5 workers perform tasks in each group. Refitting the drain motor and PVC cables tasks are performed by the first cabling group. Heater socket fitting, saltbox socket fitting, and circulation motor socket fitting tasks are implemented in the second, third, and fourth cabling groups by 5 workers in each group.

Table 1. Information related to each region for the first assembly line.

Region Number	Number of stations	Number of workers	Average Age	Average experience	Process definition
1	10	10	41.0	23.3	Electronic parts assembly
2	20	20	40.9	21.9	Structural parts assembly
3	50	50	46.6	27.6	Water path parts assembly
4	20	20	40.3	20.9	Mechanical parts assembly
5	30	30	27.6	8.8	Cabling
6	20	20	35.5	16.6	Chassis closing
7	20	20	42.9	23.9	Top basket assembly
8	20	20	29.3	10.3	Exterior door assembly
9	10	10	32.6	13.6	Isolation tasks
10	10	10	36.5	17.5	View group assembly

3.2 Proposed Approach: A Risk Assessment Method Using FARE-KEMIRA-M Integration

Stage I: Determining the priorities of the criteria.

Step 1.1 Define alternatives, criteria groups, and DMs.

Ten regions $(R_1, R_2, \dots, R_{10})$ in a dishwasher production line were evaluated considering 11 criteria. These regions are water path parts assembly (R_1), structural parts assembly (R_2), electronic parts assembly (R_3), mechanic parts assembly (R_4), cabling (R_5), chassis closing (R_6), top basket assembly (R_7), exterior door assembly (R_8), isolation tasks (R_9), view group assembly (R_{10}).

The criteria were divided into two groups as worker related criteria (WRC) $(x_1, x_2, \dots, x_8)$ and posture related criteria (PRC) (y_1, y_2, y_3). Table 2 shows the criteria groups and their definitions.

Table 2. Definitions of the criteria groups

Notation	Criteria	Definition
x_1	Experience (years)	The average experience of workers performing tasks in the relevant region.
x_2	Age (years)	The average age of workers performing tasks in the relevant region.
x_3	Mental demand (score)	The average amount of work where the execution of a specific task requires that workers perform mental processes for each region.
x_4	Physical demand (score)	The average level and duration of physical exertion generally required to perform tasks in each region.
x_5	Frustration level (score)	The average level of feeling irritated, stressed, and annoyed versus content, relaxed, and complacent during the tasks performed in each region.
x_6	Performance level (score)	The average level of feeling successful and satisfied during performing the task in each region.
x_7	Effort level (score)	The average level of difficulty that must be mentally or physically endured while performing the tasks to accomplish the expected performance in each region.
x_8	Temporal demand (score)	The average level of feeling time pressure due to the pace at which the tasks or task elements occurred in each region.
y_1	RULA score	The highest risk level of the posture exhibited in the task period by the workers working at the related region.

y_2	Posture time (sec)	The average period of the posture exhibited during the task by the workers working at the related region.
y_3	Load (kg)	The maximum weight value of the loads lifted by the workers working at the related region.

x_3, x_4, x_5, x_6, x_7 and x_8 were measured by implementing NASA Task Load Index (NASA TLX) [8]. y_1 was determined by using Rapid Upper Limb Assessment (RULA) tool [11].

Five experts were determined as DMs $(E_1, E_2, \ldots, E_5)$. Two of them were occupational safety experts with

5 years of experience. Two DMs were 10-year experienced mechanical engineers. The last one was an industrial engineer with 9-year experience in the dishwasher production.

Step 1.2. Form the initial decision matrix.

The initial decision matrix is formed as in Table 3. $x_i^{(k)}, i = 1,2, \ldots 8,\ k = 1,2, \ldots, 10$ shows the value of the ith worker related criterion for the kth region. $y_j^{(k)}, j = 1,2,3,\ k = 1,2, \ldots, 10$ is the value of the ith posture related criterion for the kth region.

Table 3. The initial decision matrix

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2	y_3
R_1	23.3	41.0	67.2	44.4	67.8	61.7	80.0	77.2	5.0	17.0	2.0
R_2	21.9	40.9	71.7	47.0	81.0	81.3	79.3	86.7	7.0	12.4	1.5
R_3	27.6	46.5	70.0	59.5	84.1	45.0	81.4	84.5	7.0	22.4	0.6
R_4	20.9	40.3	68.5	50.9	77.4	62.1	81.5	80.9	6.0	13.7	3.0
R_5	8.7	27.8	70.8	62.3	75.5	29.5	81.3	84.8	6.0	26.1	6.0
R_6	16.6	35.5	30.0	45.0	77.0	74.5	79.6	80.2	6.0	21.9	0.0
R_7	23.9	42.9	22.7	58.0	85.0	79.3	81.3	80.0	6.0	10.3	2.0
R_8	10.3	29.3	14.8	61.9	81.0	72.7	81.3	89.4	6.0	9.7	0.0
R_9	13.6	32.6	22.1	47.5	75.4	49.6	80.4	76.8	7.0	11.4	3.0
R_{10}	17.5	36.5	16.2	50.8	83.1	48.5	80.0	81.2	6.0	14.5	1.5

Step 1.3. Normalize the initial decision matrix.

In this study, the except for experience (x_1), all criteria are cost type. Eq.(1) is used for normalization of the elements of the initial decision matrix when the criterion is in WRC group $(x_i^{(k)})$.

$$\left(x_i^{(k)}\right)' = \begin{cases} \dfrac{x_i^{(k)} - \left(x_i^{(k)}\right)_{min}}{\left(x_i^{(k)}\right)_{max} - \left(x_i^{(k)}\right)_{min}}, & \text{the benefit type} \\ \dfrac{x_i^{(k)} - \left(x_i^{(k)}\right)_{max}}{\left(x_i^{(k)}\right)_{min} - \left(x_i^{(k)}\right)_{max}}, & \text{the cost type} \end{cases} \tag{1}$$

In Eq.(1), $\left(x_i^{(k)}\right)'$ shows the normalized value of the ith worker related criterion for the kth region. Similarly, $\left(y_j^{(k)}\right)'$ shows the normalized value of the jth posture related criterion for the kth region and is calculated as in Eq.(2).

$$\left(y_j^{(k)}\right)' = \begin{cases} \dfrac{y_j^{(k)} - \left(y_j^{(k)}\right)_{min}}{\left(y_j^{(k)}\right)_{max} - \left(y_j^{(k)}\right)_{min}}, & \text{the benefit type} \\ \dfrac{y_j^{(k)} - \left(y_j^{(k)}\right)_{max}}{\left(y_j^{(k)}\right)_{min} - \left(y_j^{(k)}\right)_{max}}, & \text{the cost type} \end{cases} \tag{2}$$

The normalized initial decision matrix is depicted in Table 4.

Table 4. The normalized initial decision matrix

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2	y_3
R_1	0.775	0.294	0.079	1.000	1.000	0.378	0.682	0.968	1.000	0.538	0.667
R_2	0.701	0.299	0.000	0.855	0.233	0.000	1.000	0.214	0.000	0.811	0.750
R_3	1.000	0.000	0.030	0.156	0.052	0.701	0.045	0.389	0.000	0.219	0.900
R_4	0.647	0.332	0.056	0.637	0.442	0.371	0.000	0.675	0.500	0.734	0.500
R_5	0.000	1.000	0.016	0.000	0.552	1.000	0.091	0.365	0.500	0.000	0.000
R_6	0.417	0.588	0.733	0.966	0.465	0.131	0.864	0.730	0.500	0.249	1.000
R_7	0.807	0.193	0.861	0.240	0.000	0.039	0.091	0.746	0.500	0.935	0.667
R_8	0.080	0.920	1.000	0.022	0.233	0.166	0.091	0.000	0.500	1.000	1.000
R_9	0.775	0.294	0.079	1.000	1.000	0.378	0.682	0.968	1.000	0.538	0.667
R_{10}	0.701	0.299	0.000	0.855	0.233	0.000	1.000	0.214	0.000	0.811	0.750

Step 1.4. Determine the criteria preferences.

Each DM $(E_l, l = 1,2, \ldots, 5)$ ranks WRC and PRC independently and separately as in Table 5. "1" shows the most important criterion among others for a DM.

Table 5. The criteria preferences of the DMs

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y_1	y_2	y_3
R_1	1	2	3	4	5	6	7	8	1	2	3
R_2	2	3	1	4	6	5	7	8	2	1	3
R_3	3	4	2	5	6	1	7	8	3	2	1
R_4	5	6	4	1	3	2	7	8	1	3	2

R_5	1	7	6	3	5	4	8	2	1	3	2

Step 1.5: Form the priority matrix for each DM for each criteria group.

According to priority preferences given in Table 6, the priority matrices for each DM are formed in this step. The priority matrices reveal the superiority relations of the criteria. $P_X^{(l)}, l = 1,2, \ldots, 5$ shows the priority matrix of lth DM for WRC. The elements of $P_X^{(l)}, l = 1,2, \ldots, 5$ are calculated as in Eq. (3).

$$p_X^{(l)}(i,t) = \begin{cases} 0, & i = t \\ 1, & rank(x_i) < rank(x_t) \\ 0, & rank(x_i) > rank(x_t) \end{cases} \quad (3)$$

Similarly, $P_Y^{(l)}, l = 1,2, \ldots, 5$ shows the priority matrix of lth DM for PRC. For example, the second DM ranked the PRC as $y_2 \succ y_1 \succ y_3$. The priority matrix of the second DM for the PRC $\left(P_Y^{(2)}\right)$ is given in Eq. (4). Since the order of y_1 only precedes y_3, $p_Y^{(2)}(1,3) = 1$ and $p_Y^{(2)}(1,1) = p_Y^{(2)}(1,2) = 0$.

$$P_Y^{(2)} = \begin{matrix} & y_1 & y_2 & y_3 \\ y_1 & 0 & 0 & 1 \\ y_2 & 1 & 0 & 1 \\ y_3 & 0 & 0 & 0 \end{matrix} \quad (4)$$

Step 1.6. Find the distance between priorities assigned by the DMs.

The priority distances $\rho_X^{(l_*)}, \ l_* = 1,2, \ldots, 5$ of each DM are computed as in Eq. (5).

$$\rho_X^{(l_*)} = \sum_{l=1}^{5} \sum_{i=1}^{8} \sum_{t=1}^{8} \left| p_X^{(l_*)}(i,t) - p_X^{(l)}(i,t) \right|, \quad l_* = 1,2, \ldots, 5 \quad (5)$$

Then, the minimum value of $\rho_{X_{l_*}}, \ l_* = 1,2, \ldots, 5$ is computed as in Eq. 6.

$$\rho_X = \min\left\{ \rho_X^{(1)}, \rho_X^{(2)}, \ldots, \rho_X^{(5)} \right\} \quad (6)$$

The priority distances of the DMs for WRC are computed as $\rho_X^{(1)} = 72$, $\rho_X^{(2)} = 58$, $\rho_X^{(3)} = 62$, $\rho_X^{(4)} = 76$ and $\rho_X^{(5)} = 100$. Since, E_2 provides the minimum value ($\rho_X = 58$), the priority ranking of E_2 is accepted as the MPC for WRC, that is, $x_3 \succ x_1 \succ x_2 \succ x_4 \succ x_6 \succ x_5 \succ x_7 \succ x_8$. In a similar way, $\rho_Y^{(1)} = 12$, $\rho_Y^{(2)} = 14$, $\rho_Y^{(3)} = 18$, $\rho_Y^{(4)} = 10$ and $\rho_Y^{(5)} = 10$ are calculated as the priority distance of each DM for PRC, respectively. Since, the priority rankings of the fourth and fifth DMs are the same, the minimum value is obtained as $\rho_Y = \rho_Y^{(4)} = \rho_Y^{(5)} = 10$. Therefore, the priority ranking of the fourth and the fifth DMs are accepted as MPCs for PRC, that is, $y_1 \succ y_3 \succ y_2$.

Stage II: Computing the criteria weights with FARE.

In this stage, FARE based criteria weighting procedure was proposed.

Step 2.1. Determine the most important criterion for each criterion set.

x^* and y^* show the most important criterion for WRC and PRC, respectively. According to MPC given in Step 1.6., $x^* = x_3$ and $y^* = y_1$ are determined.

Step 2.2. Determine the relationship between the most important criterion and other criteria.

In this step, the degree of relationship between the most important criterion and the other criteria is evaluated using the scale given in Table 6.

Table 6. The scores of relationships between criteria [6]

Degree of relationship	Score
Almost none	1
Very weak	2
Weak	3
Lower than average	4
Average	5
Higher than average	6
Strong	7
Very strong	8
Almost absolute	9
Absolute	10

The most important criterion was determined as $x^* = x_3$ for WRC. The evaluations of the relationships between x_3 and the other WRC for the lth DM are defined as $r_X^{(l)}(3,i), l = 1,2, \ldots, 5; \ i = 1,2, \ldots, 8$ and given in Table 7. While making these assessments, DMs are asked to assign a higher relationship score to the criterion that is close to $x^* = x_3$ in terms of rank, considering MPC. It is allowed to assign an equal correlation score to consecutive criteria.

Table 7. The relationship scores between x_3 and the other WRC for each the DM

$r_X^{(l)}(3,i)$	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
E_1	7	6	-	6	4	5	4	3
E_2	6	6	-	5	3	5	3	2
E_3	8	7	-	7	5	5	4	3
E_4	8	7	-	6	6	6	5	3
E_5	7	5	-	5	4	4	3	2

$y_* = y_1$ was found as the most important criterion among other PRC by MPC. Similarly, the evaluations of the relationships between y and the other PRC for the lth DM are defined as $r_Y^{(l)}(1,j), l = 1,2, \ldots, 5; \ j = 1,2,3$ and given in Table 8.

Table 8. The relationship scores between y_1 and the other PRC for each the DM

$r_Y^{(l)}(1,j)$	y_1	y_2	y_3
E_1	-	5	6
E_2	-	7	8
E_3	-	4	4
E_4	-	3	7
E_5	-	3	5

Step 2.3. Determine the potential effects of other criteria on the most important criterion.

The potential effects of $x^* = x_3$ on the ith work related criterion $i = 1,2, \ldots, 8; i \neq 3$ for each DM are calculated as in Eq. (7) and depicted in Table 9.

$$\hat{r}_X^{(l)}(3,i) = max - r_X(3,i), \quad i = 1,2, \ldots, 8; i \neq 3 \quad (7)$$

Table 9. The potential effects of $x^* = x_3$ on the other WRC for DMs

$\hat{r}_X^{(l)}(3,i)$	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
E_1	3	4	-	4	6	5	6	7
E_2	4	4	-	5	7	5	7	8
E_3	2	3	-	3	5	5	6	7
E_4	2	3	-	4	4	4	5	7

E_5	3	5	-	5	6	6	7	8

Similarly, the potential effects of $y^* = y_1$ on the jth posture related criterion $j = 2,3$ for each DM are calculated as in Eq. (8) and given in Table 10.

$$\hat{r}_Y^{(l)}(1,j) = max - r_Y(1,j), \;\; j = 2,3 \quad (8)$$

Table 10. The potential effects of $y^* = y_1$ on the other WRC for DMs

$\hat{r}_Y^{(l)}(1,j)$	y_1	y_2	y_3
E_1	-	5	4
E_2	-	3	2
E_3	-	6	6
E_4	-	7	3
E_5	-	7	5

In Eqs. (7) and (8), $max = 10$ is the maximum value of evaluation scale given in Table 6.

Step 2.4. Construct the comparison matrix of criteria sets for each DM.

The elements of the comparison matrix of WPC for each DM ($l = 1,2, \dots ,5$) are computed as in Eq. (9).

$$\hat{r}_X^{(l)}(i,t) = \begin{cases} \hat{r}_X^{(l)}(3,t) - \hat{r}_X^{(l)}(3,i), & i,t = 1,2,\dots,8 \\ -\hat{r}_X^{(l)}(t,i), & i \neq t\,,\; i \neq 3\,,\; i = 1,2,\dots,8 \end{cases} \quad (9)$$

The elements of the comparison matrix of PRC for each DM ($l = 1,2, \dots ,5$) are calculated as in Eq.(10).

$$\hat{r}_Y^{(l)}(j,u) = \begin{cases} \hat{r}_Y^{(l)}(1,u) - \hat{r}_Y^{(l)}(1,j), & j,u = 1,2,3 \\ -\hat{r}_Y^{(l)}(u,j), & j \neq u\,,\; j \neq 1\,,\; i = 1,2,3 \end{cases} \quad (10)$$

The comparison matrix of the first DM is depicted in Table 11 for WRC and Table 12 for PRC.

Step 2.5. Compute the total effect of each criterion.

For each DM, the total effect of the ith criterion which is the summation of the ith row of relationship matrix is computed as in Eq.(11).

$$f_X^{(l)}(i) = \sum_{t=1}^{8} \hat{r}_X^{(l)}(i,t)\,, \;\; i = 1,2,\dots,8 \quad (11)$$

In Eq.(11), $\sum_{i=1}^{8} f_X^{(l)}(i) = 0$ must be satisfied for each DM. The total effect of the jth criterion of the lth DM for PRC is given in Eq.(12).

$$f_Y^{(l)}(j) = \sum_{u=1}^{8} \hat{r}_Y^{(l)}(j,u)\,, \;\; j = 1,2,3 \quad (12)$$

Obtained results for WRC and for PRC are depicted in Table 11 and 12.

Step 2.6. Compute the actual total effect of each criterion.

First, the system effect of WRC is calculated as in Eq. (13).

$$f_X = max * (I - 1) = 10 * (8 - 1) = 70 \quad (13)$$

where I is the total number of WRC and max is the maximum evaluation score given in Table 6. Then, the actual total effect of the work related ith criterion for the lth DM is computed as in Eq. (14).

$$f_X^{(l)*}(i) = f_X^{(l)}(i) + f_X\,, \quad i = 1,2,\dots,8 \quad (14)$$

Similar equations are obtained for PRC as in Eq. (15) and (16).

$$f_Y = max * (J - 1) = 10 * (3 - 1) = 20 \quad (15)$$

where J is the total number of PRC.

$$f_Y^{(l)*}(j) = f_Y^{(l)}(j) + f_Y\,, \quad j = 1,2,3 \quad (16)$$

Again, the calculations of these step are given in Table 11 and 12 for the first DM.

Step 2.7. Compute the final criteria weights.

The final criteria weights are calculated by column normalization of actual total effects for WRC in Eq.(17) and for PRC in Eq.(18).

$$w_X^{(l)}(i) = \frac{f_X^{(l)*}(i)}{\sum_{i=1}^{8} f_X^{(l)*}(i)}, \;\; i = 1,2,\dots,8 \quad (17)$$

$$w_Y^{(l)}(j) = \frac{f_Y^{(l)*}(j)}{\sum_{j=1}^{3} f_Y^{(l)*}(j)}, \;\; j = 1,2,3 \quad (18)$$

The final criteria weights of WRC and PRC for the first DM are depicted in Table 11 and 12, respectively.

Table 11. The comparison matrix and FARE calculations of WRC for the first DM

$\hat{r}_X^{(1)}(i,t)$	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	$f_X^{(l)}(i)$	$f_X^{(l)*}(i)$	$w_X^{(l)}(i)$
x_1	0	1	-3	1	3	2	3	4	11	81	0.145
x_2	-1	0	-4	0	2	1	2	3	3	73	0.130
x_3	3	4	0	4	6	5	6	7	35	105	0.188
x_4	-1	0	-4	0	2	1	2	3	3	73	0.130
x_5	-3	-2	-6	-2	0	-1	0	1	-13	57	0.102
x_6	-2	-1	-5	-1	1	0	1	2	-5	65	0.116
x_7	-3	-2	-6	-2	0	-1	0	1	-13	57	0.102
x_8	-4	-3	-7	-3	-1	-2	-1	0	-21	49	0.088

Table 12. The comparison matrix and FARE calculations of PRC for the first DM

$\hat{r}_Y^{(1)}(j,u)$	y_1	y_2	y_3	$f_Y^{(l)}(j)$	$f_Y^{(l)*}(j)$	$w_Y^{(l)}(j)$
y_1	0	5	4	9	29	0.483
y_2	-5	0	-1	-6	14	0.233
y_3	-4	1	0	-3	17	0.283

All calculations in Stage II are repeated for all DMs. Table 13 shows the obtained FARE weights of WRC.

Table 13. Obtained FARE weights of WRC for all DMs.

	$w_X^{(l)}(1)$	$w_X^{(l)}(2)$	$w_X^{(l)}(3)$	$w_X^{(l)}(4)$	$w_X^{(l)}(5)$	$w_X^{(l)}(6)$	$w_X^{(l)}(7)$	$w_X^{(l)}(8)$
E_1	0.145	0.130	0.188	0.130	0.102	0.116	0.102	0.088
E_2	0.139	0.139	0.196	0.125	0.096	0.125	0.096	0.082
E_3	0.152	0.138	0.180	0.138	0.109	0.109	0.095	0.080
E_4	0.148	0.134	0.177	0.120	0.120	0.120	0.105	0.077
E_5	0.154	0.125	0.196	0.125	0.111	0.111	0.096	0.082

The final weights of PRC are depicted in Table 14 for all DMs.

Table 14. Obtained FARE weights of PRC for all DMs

	$w_Y^{(l)}(1)$	$w_Y^{(l)}(2)$	$w_Y^{(l)}(3)$
E_1	0.483	0.233	0.283
E_2	0.417	0.267	0.317
E_3	0.533	0.233	0.233
E_4	0.500	0.150	0.350
E_5	0.533	0.183	0.283

Since, there are 5 DMs, 25 possible pairs of weight sets are derived for Stage III.

Stage III: Ranking the alternatives.

Step 3.1: Form the weighted normalized vector of alternatives for each weight set.

For each DM, the weighted normalized vector of alternatives using each weight set in Table 13 is provided via using Eq.(19).

$$v_X^{(l)} = \begin{bmatrix} \left(v_X^{(l)}\right)_1 \\ \left(v_X^{(l)}\right)_2 \\ \vdots \\ \left(v_X^{(l)}\right)_{10} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{8} \left(x_i^{(1)}\right)' . w_X^{(l)}(i) \\ \sum_{i=1}^{8} \left(x_i^{(2)}\right)' . w_X^{(l)}(i) \\ \vdots \\ \sum_{i=1}^{8} \left(x_i^{(10)}\right)' . w_X^{(l)}(i) \end{bmatrix}, \quad l = 1,2,\dots,5 \qquad (19)$$

Similar to Eq. (19), Eq. (20) is obtained for the weight sets in Table 14.

$$v_Y^{(l)} = \begin{bmatrix} \left(v_Y^{(l)}\right)_1 \\ \left(v_Y^{(l)}\right)_2 \\ \vdots \\ \left(v_Y^{(l)}\right)_{10} \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{3} \left(y_j^{(1)}\right)' . w_Y^{(l)}(j) \\ \sum_{j=1}^{3} \left(y_j^{(2)}\right)' . w_Y^{(l)}(j) \\ \vdots \\ \sum_{j=1}^{3} \left(y_j^{(10)}\right)' . w_Y^{(l)}(j) \end{bmatrix}, \quad l = 1,2,\dots,5 \qquad (20)$$

The weighted normalized vectors of regions are obtained for WRC and PRC in Table 15.

Table 15. The weighted normalized vectors of regions for WRC and PRC

	$v_X^{(1)}$	$v_X^{(2)}$	$v_X^{(3)}$	$v_X^{(4)}$	$v_X^{(5)}$	$v_Y^{(1)}$	$v_Y^{(2)}$	$v_Y^{(3)}$	$v_Y^{(4)}$	$v_Y^{(5)}$
R_1	0.596	0.579	0.602	0.599	0.594	0.798	0.771	0.815	0.814	0.821
R_2	0.396	0.383	0.402	0.396	0.392	0.402	0.454	0.364	0.384	0.361
R_3	0.296	0.294	0.296	0.297	0.299	0.306	0.343	0.261	0.348	0.295
R_4	0.377	0.371	0.384	0.375	0.377	0.555	0.562	0.555	0.535	0.543
R_5	0.347	0.359	0.347	0.360	0.339	0.242	0.208	0.267	0.250	0.267
R_6	0.615	0.609	0.615	0.604	0.612	0.583	0.591	0.558	0.637	0.596
R_7	0.414	0.413	0.410	0.398	0.422	0.649	0.669	0.640	0.624	0.627
R_8	0.374	0.390	0.374	0.372	0.379	0.758	0.792	0.733	0.750	0.733
R_9	0.671	0.675	0.667	0.660	0.667	0.345	0.390	0.320	0.305	0.301
R_{10}	0.615	0.620	0.606	0.601	0.612	0.614	0.629	0.602	0.615	0.605

Step 3.2: Apply the selection procedure for each possible weight pair.

To find the appropriate rank of the regions, the selection procedure implemented given in Eq. (21) and Eq. (22). In Eq. (21), total deviations of weighted normalized vectors are calculated. Then, the weighted normalized vectors of WRC and PRC groups satisfying the minimum value of $F_{(m,n)}$ obtained in Eq. (22).

$$F_{(m,n)} = \sum_{k=1}^{10} \left| \left(v_X^{(m)}\right)_k - \left(v_Y^{(n)}\right)_k \right| \qquad (21)$$

$$F_{(m^*,n^*)} = \min_{\substack{m\in\{1,2,\dots,5\} \\ n\in\{1,2,\dots,5\}}} F_{(m,n)} \qquad (22)$$

In Table 16, total deviations of weighted normalized vectors are given. The minimum value is provided when $m^* = 5$ and $n^* = 5$, that is, $F_{(5,5)} = 1.447$.

Table 16. Total deviations of weighted normalized vectors

$F_{(m,n)}$	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$
$m = 1$	1.479	1.596	1.550	1.512	1.479
$m = 2$	1.517	1.541	1.518	1.469	1.488
$m = 3$	1.467	1.584	1.535	1.513	1.463
$m = 4$	1.499	1.617	1.547	1.554	1.482
$m = 5$	1.455	1.573	1.519	1.487	1.447

Step 3.3: Find the final ranks of the alternatives.

To find the final rank of the regions, Eq.(23) is used.

$$F^{*} = v_X^{(5)} + v_Y^{(5)} \quad (23)$$

In Eq.(23), the workstation corresponding to the element with the highest value of the F^{*} vector is determined as the least risky region. Table 17 shows the final ranking of the regions and the calculations.

Table 17. The final ranking of the region

	$v_X^{(5)}$	$v_Y^{(5)}$	$v_X^{(5)} + v_Y^{(5)}$	Rank
R_1	0.594	0.821	1.415	1
R_2	0.392	0.361	0.753	8
R_3	0.299	0.295	0.594	10
R_4	0.377	0.543	0.920	7
R_5	0.339	0.267	0.605	9
R_6	0.612	0.596	1.207	3
R_7	0.422	0.627	1.049	5
R_8	0.379	0.733	1.113	4
R_9	0.667	0.301	0.968	6
R_{10}	0.612	0.605	1.217	2

4 Results

In this study, FARE&KEMIRA-M integration was proposed to advance a novel ergonomic risk assessment approach and to improve KEMIRA-M's weighting procedure. According to MPCs obtained from KEMIRA-M, the age of workers was found as the most important criterion for WRC, and the RULA score was determined as the most important criterion for PRC. When the criteria were weighed by using FARE, these most important criteria were considered. Relationships between criteria were determined according to the age of workers for WRC and RULA score for PRC in FARE implementation. DMs identified the relationship degrees by evaluating the relationship degree between age and the other criteria for WRC and the relationship degree between RULA score and the other criteria for PRC. Then, DMs determined the effect degree of age on other criteria in WRC and the effect degree of RULA score on other criteria in PRC. Obtained relationship degrees and effect degrees were used to compute criteria weights in WRC and PRC. Results showed that all DMs thought that age is the most important criterion in WRC. FARE produced the highest weight value for age criterion based on DMs' evaluations. Additionally, the RULA score was found as the most important criterion for all DMs. The highest weight value for the RULA score criterion was obtained by FARE. It was seen that FARE gives results based on MPCs.

The age criterion is important in terms of the possibility of having a work accident, the level of experience, and the dominance of the task. As the age increases, it ensures that the task can be completed safely with the increase of experience and mastery of the task up to a certain point. However, as age increases, problems such as getting tired in the early period, inability to concentrate, and not exhibiting the expected production performance due to aging in the worker also arise. For this reason, it is important to employ workers in age ranges suitable for the task conditions.

Additionally, the RULA score is another important criterion to ensure safety in production regions. The RULA method was implemented to determine the risk level of working postures where upper limbs are used intensely. The higher the RULA score, the higher the level of danger the worker poses while performing the task. In such a case, the risk of contracting occupational musculoskeletal disorders of the workers increases. Due to these inconveniences, the worker becomes unable to perform his tasks, and the employer suffers losses due to insurance, treatment costs, and lost workdays.

Since five DMs determined the priorities of criteria for two groups, 25 weight pairs were obtained by using KEMIRA-M (see in Table 13 and Table 14). KEMIRA-M's optimization procedure was utilized to make a decision for which weight pairs give the effective solution related to rankings of alternatives. As a result of this optimization procedure, water path parts assembly region (R_1), view group assembly region (R_{10}), chassis closing region (R_6) were determined as the least risky regions. Despite that electronic parts assembly region (R_3), cabling region (R_5), structural parts assembly regions (R_2) were defined as the riskiest regions (see Table 17).

In the water path parts assembly region, there are 10 workstations and workers. These workers have an average age of 41 and an average experience of 23.3 (see Table 1). These values show that determining this region as the least risky region is a logical result. Compared to other regions, it is the region with one of the lowest numbers of workers. This means that the number of workers who may have a work accident or suffer different damages is low, and this makes the relevant region the safest production area. Additionally, it can also be said that the age and experience of a small number of workers working in this region are higher than workers working in other regions compared to workers working in many other regions. The fact that there are workers with high experience has also revealed this region as the safest area.

According to the results, the second safest region was found as the view group assembly region. In this region, there are 10 workstations and workers with 36.5 average age and 17.5 average experience (see Table 1). The number of workstations and workers is higher than the water path parts assembly region. As the number of workers in this region increases, the probability of work accidents and the number of workers who may be harmed will also increase. Additionally, the average age and average experience are less than the water path parts assembly region. As experience decreases, workers are more likely to make mistakes and be harmed compared to water path parts assembly region.

The third safest region was determined as the chassis closing region. There are 20 workstations and workers in this region. Workers have 35.5 average age and 16.6 average experience (see Table 1). The number of workstations and workers is higher than in water path parts assembly and view group assembly regions. For this reason, the probability of work accidents increases, and at the same time, the number of workers who can be harmed increases. According to the average age and average experience values, the chassis closing region has values less than water path parts assembly and view group assembly regions. This situation makes this region riskier than water path parts assembly and view group assembly regions.

According to the riskiest region results, the electronic parts assembly region was determined as the riskiest region. There are 50 workstations and workers in this region. These workers have 46.6 average age and 27.6 average experience (see Table 1). According to the number of workstations, workers, average age, and average experience values, the electronic parts assembly region has the highest values. Since the number of workers is the highest in this region, the probability of a work accident and the possibility of injury to the workers is also the highest. However, in terms of average age, the oldest workers also work in this region. Although the increase in age brings with it an increase in experience, the weaknesses caused by old age increase the probability of workers having occupational accidents. In addition, older workers are more affected by

environmental conditions and have more difficulty while working.
The second riskiest region was found as the cabling region. There are 30 workstations and workers in this station. Less number of workers compared to the electronic parts assembly region also reduces the risk level compared to the electronic parts assembly region. These workers have a 27.6 average age (see Table 1). This value is less than the electronic parts assembly region. Additionally, the average age is also less than the electronic parts assembly region. Younger workers working in this region than electronic parts assembly region created a mass of workers who could master the tasks in a shorter time. Therefore, this region has been designated as less risky. The cabling task required attention is a task where different cables are inserted into different inputs, where there is exposure to electric current. For this reason, younger workers can concentrate their attention at a higher level than older workers.
The third riskiest region was determined as the structural parts assembly region. There are 20 workers in these regions. This number is higher than the number of workers working in many other regions and this situation increases the risk level. The related workers have 40.9 average age and 21.9 average experience (see Table 1). These values are lower than the electronic parts assembly region and higher than the cabling region. Although it is higher than the cabling region, the reason why it is the third highest risk region is that workers are exposed to more danger sources due to electric current in the cabling task. The structural parts assembly task requires more knowledge of the task. Because here, the lower parts of the washing machine are combined into a whole. Therefore, there are more experienced workers in this area, which increases the level of safety a little more.
When the results were examined according to the other criteria, comments given below were available. The water paths assembly region defined as the least risky region has one of the highest values in terms of mental demand, performance level, effort level, posture time, and load criteria. Despite that this region has one of the lowest values in terms of frustration level, temporal demand, and the RULA score criteria. The water path assembly task is one of the tasks that requires attention. If the water pipes in the washing machine are not installed properly, it can cause leaks. The necessity of determining the connection points correctly causes the mental demand levels of the workers working in this region to be high. The necessity of making the correct connections of the pipes also increases performance anxiety in the workers. To achieve this performance, a high level of effort is required. However, experienced workers are employed in this region, as it is important to perform the task correctly. The workers in question do not feel time pressure as they have mastered the assembly task. Therefore, the temporal demand for this region is low. Again, the RULA score was low because the worker did not exhibit challenging working postures while performing the connection task, and the length of time the working postures were exhibited did not cause any problems due to this low RULA score. Due to the experience of the workers, the frustration level values are also low. Due to the weight of the connection equipment used when making pipe connections, the load is higher than in other regions. However, when we look at the weight, it is seen that no value will create a risk. It is understood by the low physical demand score that the workers are not forced due to the weight in question.
Electronic parts assembly region defined as the riskiest region has one of the highest values in terms of mental demand, physical demand, frustration level, effort level, temporal demand, RULA score, and posture time criteria. Despite that this region has one of the lowest values in terms of performance level, and load weight criteria. Electronic parts assembly is a complex and specialized task. Because electronic parts are sensitive, and they can be deformed suddenly. In addition, being exposed to the electric current during installation in this region makes the ambient conditions risky. Problems in the electrical systems may cause the machine not to work or not to wash it with the correct program. Since the related parts are small and must be assembled correctly, the points of mental demand, physical demand, frustration level, effort level, and temporal demand criteria are high in the workers who perform this task. For this reason, experienced workers are employed in this region. However, because the average age was high, the frustration level score was high. It is understood by this that the older workers are having difficulties. The fact that this region is the riskiest is a logical conclusion because it is seen from the evaluations of the workers that the physical and mental requirements of the task are high. For this reason, the frustration level score was also high. All this causes the workers to get tired and feel unsuccessful and increase the level of risk in the region. Workers working under these conditions will be more prone to accidents or mistakes.

5 Discussion

In this study, to determine the riskiest region in a dishwasher assembly line FARE&KEMIRA-M integration was proposed as an ergonomic risk assessment tool. In this context, FARE and KEMIRA-M were integrated for the first time in the literature to develop a novel ergonomic risk assessment approach. The proposed integration is valuable for the methodological development in that it improves the weighting procedure of KEMIRA-M and avoids confusion in pairwise comparisons for criterion weighting in AHP as a result of the increase in the number of criteria. Additionally, this integration is also valuable for ergonomics literature in term of developing a detailed ergonomic risk assessment tool. The proposed approach provides flexibility for ergonomic risk evaluation. In this way, different ergonomic risk criteria could be considered to decide which production region is the riskiest one. This result can create a work plan related to improvement actions for production managers. In this way, managers can determine what actions they need to do first to reduce the risk level in production areas and can rank these actions within a plan. The determination of the riskiest production region with the proposed method and the ranking of all production regions according to their risk levels also revealed that the managers should develop measures for the riskiest region.

6 Conclusions

This study is the first one in literature considering different ergonomic risk factors to determine the riskiest region in an assembly line. Additionally, this study has originalities in terms of developing a novel integrated ergonomic risk assessment tool based on KEMIRA-M&FARE. Methodological development of KEMIRA-M is another originality in this study. This study is also the first one improving KEMIRA-M's weighting procedure by applying FARE. However, there are many research alternatives related to the proposed approach. For example, other weighting methods that can accommodate a high number of criteria can be integrated into the weighting procedure of KEMIRA-M. Production regions can be sorted according to their risk levels, considering different risk criteria for different production regions. In this context, relevant improvement actions can be prioritized by determining the improvement actions to be done for the riskiest production area. The proposed method can be used for different decision issues. The third ergonomic risk criteria group can be added and the analysis can be performed more detailed.

Limitations and difficulties related to the performed study can be explained as follows: Manual decoding of the KEMIRA-M method is not possible when there are more than two sets of criteria. Coding knowledge is needed here. It is also necessary to know the questionnaires or ergonomic evaluation methods used to obtain the criteria values. Applying the aforementioned surveys or methods also brings the need for time and workforce.

In methodological manner, considering that KEMIRA-M has a structure suitable for working with many criteria, the method to be integrated to improve the weighting process of KEMIRA-M should also adapt to this feature. For this reason, to prefer FARE in the proposed integration is a logical selection.

MPC-based, intuitive, and consensus-requiring weight assignments were overcome by applying FARE. With the application of the FARE separately for each DM, the evaluations of the DMs were considered in weighting the criteria, but a more systematic way was followed. In addition, the relationship between the criteria and their effect levels was determined and criteria weights were obtained with the FARE application.

7 Authors' Contributions

The authors confirm contribution to the paper as follows: study conception and design: first author and second author; analysis: first author, interpretation of results: second author; draft manuscript preparation: first author and second author. All authors reviewed the results and approved the final version of the manuscript.

8 Declarations

Authors do not have any conflict of interests. There is no need for ethical approval for this study. All context of the study belongs to the authors. There is no need for informed consent related to this study. All context of the study belongs to the authors.

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