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Ergonomics Risk Management in a Manufacturing Company Using ELECTRE

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Abstract

Background: In this paper the ergonomic risks factors which may influence health are assessed in a manufacturing company in 2014. Based on decision making model, different halls were classified in terms of action level.
Objectives: The aim of this study was to evaluate ergonomic risk factors in an industrial company using assessment of repetitive tasks (ART) method and to make priority of salons to implement corrective actions based on the results of the ELECTRE method.
Materials and Methods: This cross-sectional study considered all employees working in seven halls of an ark opal manufacturing (n = 240) and 13 tasks were included. Required information were gathered by demographic questionnaire and assessment of repetitive tasks (ART) method for repetitive tasks assessment. In addition, ELECTRE method was used to prioritize the studied halls. SPSS version 20 and MATLAB were used for analysis.
Results: The total ART score was equal to 30.[illegible] ± 12.4[illegible]. Data analysis from ART illustrated that 74.6% of 240 cases were in high and 13.8% were in medium level of risk. ART-ELECTRE results revealed that grading and pars naghsh halls were in the best and decoration hall was in the worst ergonomic conditions and should be placed in the top priority of action level.
Conclusions: The obtained results showed that the ELECTRE method can be used for ergonomic and human factor engineering challenges successfully. It seems that macro- and micro-ergonomic solutions along with employee's participation, based on the scientific decision-making procedures, can lead to effectiveness in health level enhancement of industrial settings increasingly.

Keywords: Ergonomics Risk Factors, Art Method, Multi-Criteria Decision Analysis, ELECTRE

1. Background

One of the most common disorders and occupational injuries are work-related musculoskeletal disorders (WRMSDs), which are the leading causes of workers' disability, so that these disorders are a reason for 7% of all diseases, 14% of referrals to doctors, and 19% of patient admissions to hospitals (1). According to global statistics, 48% of the total diseases caused by work are cumulative trauma disorders (CTDs), which is a part of work-related musculoskeletal disorders (2). In Canada, work-related musculoskeletal disorders are known as cause of about 10% of the costs of long-term disabilities (3). Furthermore, according to the reports published by the national institute for occupational safety and health (NOISH), musculoskeletal disorders ranked second after respiratory problems, so that make up more than 2.1 billion dollars direct costs and 90 million dollars indirect costs (4-6).

A survey was conducted in the United States and results illustrated that skeletal disorders led to loss of work time of more than one million workers, which cost more than 50 billion dollars per year (7). In contrast with many work-related diseases, musculoskeletal disorders are normally multi-factorial and accordingly when multiple risk factors are present at the same time, the damage would be intensified (8). In general, the upper parts of body such as arms and hands are the most important tools involved in many tasks, such as hand woven carpet industry, packaging and handy crafts, etc. ([illegible]). In these jobs, poor body position in view point of ergonomics, repetitive motions, excessive force exertion, traditional tools, contact stresses, and sometimes standing positions are abundant; all these factors are known as causes for musculoskeletal disorders (9). Occupations that need repetitive actions are very common and plentiful. Generally, spine and lower extremities are immobilized for a long time in these jobs and employees do their jobs only with the help of upper limbs (10, 11). Repetitive activities are particularly dangerous (12). Important risk factors affecting work-related musculoskeletal disorders are ergonomically awkward posture, repetitive tasks, and force to handle heavy objects (8). Musculoskeletal disorders are results of repetitive trauma caused over time or the result of an immediate or acute trauma (e.g. slip or fall) (13). Manufacturing industries such as Ark Opal, where most works are done manually and work pace and repetitive movements are high, result in a high incidence of musculoskeletal problems (14, 15). Due to multiplicity of factors affecting the incidence of musculoskeletal disorders, two issues are very important: firstly, selecting and applying appropriate method that assesses and measure risk factors in acceptable domains and second one is related to risk management and making a priority of assessed jobs or sectors to implement corrective actions. Using new ergonomics methods and decision making models can help this issue. These days, multi-criteria decision-making (MCDM) methods (such as ELECTRE, TOPSIS and AHP) are widely being used in several and different fields (16-21). This is because of the ability of these methods in modeling real issues and being easy to understand for most users. However, mathematical techniques and methods in planning and decision-making offer an optimum solution; but have this ability under certain conditions and assumptions. These techniques require precise preliminary data. In real issues, either it is not possible to provide them or the cost of this information is high. On the other hand, it is not possible to consider all aspects of the problem in these methods, but some aspects are quantitative and their measurements and assessments are cost-effective. Therefore, in general, many effective variables and conditions that are qualitative cannot be applied through models. Therefore, since the methods of MCDM are able to consider qualitative and quantitative variables and conditions simultaneously, their applications have expanded (22). Inaccuracy in decision-making requires paying the cost of errors. The greater the powers of management are, the higher the cost of wrong decision is (23).

2. Objectives

The aim of this study was to evaluate ergonomic risk factors in an industrial company using assessment of repetitive tasks (ART) method and to make priority of salons to implement corrective actions based on the results of the ELECTRE method.

3. Materials and Methods

This cross-sectional study was carried out in operational units of a manufacturing company located in central sector of Iran in 2014. A total of 240 employees of the company within seven operational halls were studied. In addition, a questionnaire was used to collect demographic data, and age, gender, work experience, number of training courses in ergonomics or work, and level of education were asked. ART of the upper limbs was applied to evaluate the ergonomic risk factors. This tool was introduced by the health and safety laboratory (HSL), in cooperation with health and safety executive (HSE) in 2007. This method is a good tool to study the upper limbs in repetitive tasks (24). Its usability has been proven by researchers and experts (24).

ART contains four parts to assess (25): Frequency and repetition, force, awkward postures, and additional factors, and qualitative and quantitative assessments are performed for each stage. In total, 12 factors are examined in ART; each one receives its own score and there would be a final score of the method. It should be noted that the ART technique investigates another factor known as psychosocial factor (D5), but it is not involved in the scoring system and is only for subjective evaluation. Each state is assigned a specific score in the quantitative assessment and low, medium and high risk levels take place in qualitative assessment (25).

Finally, the gathered data was utilized to prioritize the studied salons to conduct corrective actions. This part of analysis was conducted through developing the elimination et choice translating reality (ELECTRE) method.

3.1. Elimination et Choice Translating Reality

This method is one of the important methods of MADM. The main feature of this method is the minimum need for inputs ([illegible]). The ELECTRE method takes the following steps ([illegible]). It should be noted again that the decision criteria in the present study were the factors mentioned in the ART method.

3.1.1. Step 1

This step is to calculate the normalized decision matrix from the decision matrix and Equation 1.

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad (1)$$

This step depicts the normalized ergonomic risk factors.

3.1.2. Step 2

This step calculates the weighted normalized decision matrix using Equation 2. It makes use of the known weights vector and normalized decision matrix.

$$V = N_D.W_{n\times n} \quad (2)$$

$W=\{W_1, W_2, \ldots, W_n\} \approx$ *Consider as a duty of Decision Maker.*

Weighted normalized decision matrix as follows:

$$\begin{bmatrix} V_{ll} & \cdots & V_{ln} \\ \vdots & \ddots & \vdots \\ V_{ml} & \cdots & V_{mn} \end{bmatrix}$$

Using weights of ergonomic risk factors and output of the first step resulted in their weighted normalized decision matrix.

3.1.3. Step 3

This step determines the concordance and discordance set. For each pair of alternatives k and l, k, l = 1, 2,...,m ; l $\neq$ k, the set of decision attributes J = {j| j = 1, 2,. . ., n}is divided into two distinct subsets:

The concordance set (S_{kl})and discordance set (D_{kl}) of A_k and A_l determine the concordance and discordance set (S_{kl}) and (D_{kl}).

$S_{kl} = \{j|r_{kj} \geq r_{lj}\}$

The complementary subset is called discordance set, which is:

$D_{kl} = \{j|r_kj < r_{lj}\} = J - S_{kl}$

In this study, the concordance set showed the ergonomic risk factors that with respect to them, saloon k was preferred to saloon l. The discordance set cont other risk factors that were not included in S_{kl}.

3.1.4. Step 4

This step calculates the concordance index and establishes the concordance matrix (Table 1) by Equation 3. The concordance index reflects the relative importance of A_k with respect to A_l.

$$I_{k,l} = \frac{\sum_{j\in S_{k,l}} w_i}{\sum_{j=1}^{n} w_i} \quad (3)$$

The fourth stage could illustrate the importance of a specific saloon compared with another one.

3.1.5. Step 5

This step calculates the discordance index and establishes the discordance matrix. For decision making problem with real number attributing values, the discordance index can be calculated by the following Equation 4:

$$NI_{k,l} = \frac{max|V_{kj} - V_{lj}|j \in D_{kj}}{max|V_{kj} - V_{lj}|j \in J} \quad (4)$$

According to the abovementioned, we can calculate all alternatives discordance indexes, and then set up matrix NI. It would say how a production hall is worse than the other.

3.1.6. Step 6

This step determines the concordance dominance matrix. This matrix can be calculated by concordance index and a parameter $(\overline{I})$; this parameter can be calculated using Equation 5:

$$\overline{I} = \sum\nolimits_{k=l}^{m} \sum\nolimits_{l=1}^{m} \frac{I_{kl}}{m\,(m-1)} \quad (5)$$

Then, through comparing all the elements in concordance matrix and the value of $(\overline{I})$, the concordance dominance matrix F can be established, the elements of which are defined as:

$$f_{k,l} = 1 if I_{k,l} \geq \overline{I}$$

$$f_{k,l} = 0 if I_{k,l} < \overline{I}$$

The discussed step in this research would better help to find preference of saloon k to saloon l.

3.1.7. Step 7

This step determines the discordance dominance matrix. This matrix can be established by discordance index and a paramete$(\overline{N}I)(\overline{N}I)$can be calculated by Equation 6:

$$\overline{NI} = \sum\nolimits_{k=l}^{m} \sum\nolimits_{l=1}^{m} \frac{I_{kl}}{m\,(m-1)} \quad (6)$$

Through comparing all the elements in the discordance matrix and the value of $(\overline{N}I)$ the discordance dominance matrix can be established, the elements of which are defined as:

$g_{k,l}$ [illegible] $NI_{k,l}$ [illegible] $\overline{NI}$

Table 1. Frequencies of Participants in Different Halls and Education Levels[a]

Variable	Options	Frequency	Percentage
Hall	Pars Pac	[illegible]	19.6
	Pars Nag[illegible]	[illegible]	10.8
	Packaging	3	1.2
	Leher	28	11.7
	Tempering	19	7.9
	Gradation	33	13.8
	Decoration	84	35
Education level	Lower than diploma	58	24.2
	Diploma	137	57.1
	Associate's degree	21	8.7
	Bachelor and higher	24	10

[a] N = 240.

$g_{k,l} \ = 0 if NI_{k,l} < \overline{NI}$

This step is important to make judgment around comparing the saloons.

3.1.8. Step 8

This step is to determine the aggregate dominance matrix.

$h_{k,l} = f_{k,l}.g_{k,l}$

3.1.9. Step 9

This step is to eliminate the inferior alternatives. While the outranking relationship has been constructed, the less favorable alternatives can be eliminated, and then we get a non-inferior solution(s). The dominated alternatives can be easily identified in the H matrix, and we simply eliminate any column(s) which have an element of 1.

The two last steps are essential to abolish less attractive halls. In other words, they would help to distinguish between more and less ergonomically halls and then find out which saloons need more attention to corrective actions in the field of ergonomics.

4. Results

Analyzes conducted in this study revealed that [illegible].67% (n = 124) of the staff were female. The average age of subjects was 28.02 years with a standard deviation of [illegible]53 and its range was 57 - 18 years. The mean work experience of participants was 3.72 ± 4.54 years. Employees participated in 0.64 ± 0.71 of courses about occupational health and safety training or standard operations procedures. According to the staff report, the majority worked with right hand (225 employees (93.8%) and others with left hand. Data belonging to work halls and the participants' status in terms of education level can be seen in Table 1.

In addition, he range of the ART method was 6 to 39 and the average score between all samples was 30.07 ± 12.43.

4.1. Elimination et Choice Translating Reality Results

The aim of this section was designed as the analysis of the ergonomic risk factors using ELECTRE to select the best work hall. In this study, 12 factors/ergonomics risk factors in seven working halls (m = 7) were assessed. For the implementation of the ELECTRE method, it is needed to weigh each safety climate factor. Decision matrix, as revealed in Table 2, shows the obtained results.

After various matrix calculations and creations, two key matrices were obtained: first, the concordance dominance matrix that any single element in matrix F was the effective and efficient option and dominant over the other; second, the discordance dominance matrix that element of matrix G was also indicative of dominance among the options. According to these matrices, the aggregate dominance matrix for Ergonomic Risk Factors was obtained as follows:

$$H = \begin{vmatrix} - & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & - & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & - & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & - & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & - & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & - \end{vmatrix}$$

According to the elimination of the inferior alternatives step, based on matrix H, it could be concluded that calibration and Pars Naghsh halls were the most effective options for selection (it means that these two halls had the best ergonomic conditions amongst all). On the other hand, the Decoration hall had less attractive status among them. Based on the obtained data Decoration hall must be at the forefront of implementing the necessary reforms and control procedures. Table 3 shows the importance of production units in terms of variable levels. In addition, the impact and effectiveness of product units based on the ELECTRE method output is shown in Figure 1.

As mentioned, the 13th ART factor is psychosocial factor. This factor has a subjective nature and hence was

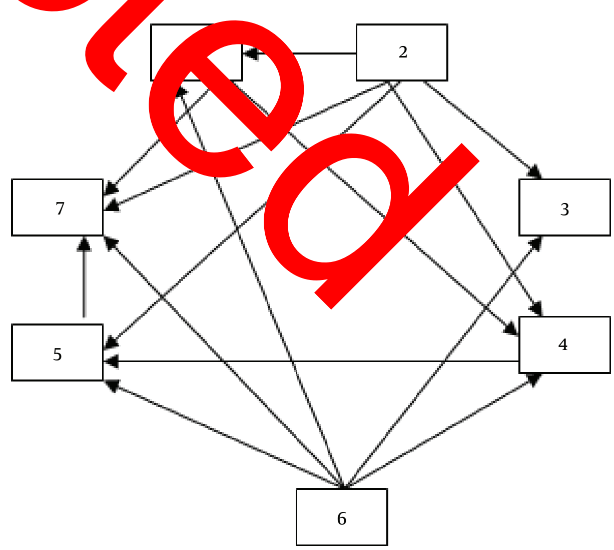

Figure 1. The Interaction Pattern of Working Halls on Each Other Using Elimination et Choice Translating Reality

Table 2. Decision Matrix for Ergonomic Risk Factors[a]

Criteria Alternatives	A_1	A_2	B	C_1	C_2	C_3	C_4	C_5	D_1	D_2	D_3	D_4
Pars pack	6	6	5	2	2	0	2	0	8	2	2	1
Pars Naghsh	0	3	0	1	1	0	1	0	4	1	1	0.5
Packaging	6	6	8	2	1	2	2	1	8	2	1	1
Leher	3	6	0	2	2	4	2	2	0	1	0	1
Tempering	6	6	5	2	2	4	2	0	0	1	2	1
Gradation	3	3	0	2	0	0	2	0	0	1	2	1
Decoration	6	6	8	2	0	2	2	1	8	2	2	1
Weight	0.[illegible]	0.054	0.017	0.163	0.249	0.006	0.169	0.106	0.006	0.160	0.011	0.054

[a] A_1, arm movements; A_2, repetition; B, forc[illegible]eck/[illegible]osture; C_2, back posture; C_3, arm posture; C_4, wrist posture; C_3, hand/finger grip; D_1, breaks; D_2, work pace; D_3, other factors such as vibration poor illumination; etc. D_4, duration.

Table 3. Significance [illegible]rk Halls [illegible] View P[illegible] of Ergonomic Risk Factors

Significance	Work H[illegible]	Specification
1	Gradi[illegible]	[illegible] on troubleshooting containers High risk for musculoskeletal disorders in the neck Repetitive motion in [illegible]rist App[illegible]ation of improper chairs
2	Pars Naghsh	Re[illegible]otion in [illegible], hand and shoulder Standing position at all times of production High risk for musc[illegible]eletal [illegible]ers in the lower back
3	Pars Pack	[illegible]g positi[illegible] workers accompanied with repetitive motion and high risk for knee, neck and shoulder
4	Leher	Collecti[illegible]ntainers f[illegible] conveyor Transferring of sound dishes to the grading section as well as defective broken items i[illegible] the crush[illegible]tion
	Tempering	Repetitive moti[illegible] picking up di[illegible]es on the belt conveyor in standing posture Removing dishes from the conveyor at the end in sit[illegible] posture High ris[illegible]ulder and arm, neck and back
5	Packaging	Introducing the greatest[illegible]n shoul[illegible] and hand Handling with the heavy Pallet loaded with dishes The high risk of musculoskeletal [illegible]orders [illegible] lu[illegible]r Application of inappropriate tables and chairs
6	Decoration	High frequency of repetit[illegible]otion [illegible] risk for [illegible] neck, shoulder and arm Heavy load of work and lack of adequate work breaks Continu[illegible]ng on i[illegible]rs High risk of lower back disorders

eliminated from ELECTRE. However, the most important psychosocial factors in the investigated environment were tendency to rest, uniform work, high levels of attention and concentration, and repeated work deadlines.

5. Discussion

Naturally, decision-making problem-solving including multi-criteria options is complex and is not easily possible, especially in the situation of various variables, lack of detailed information and different sizes (16). For this reason, methods such as MCDM and in particular the multiple attribute decision-making (MADM) have been developed for solving these problems (27). Multi-attribute methods have different techniques at different stages of decision-making. In these techniques, several options are compared on the basis of several criteria and the best option or the appropriate option list is selected. Decision-making methods based on mathematics reasoning determine the best option among the available options and their priorities (28).

[illegible]n this study, [illegible] of the methods of MADM named ELEC[illegible] was u[illegible]. In this method, instead of rankings options, a new[illegible]ncept [illegible]d, known as outranking concept. In this [illegible]ncep[illegible]hough[illegible]he options do not have any mathematical adv[illegible]ntage[illegible]ea[illegible] other, risk analyst accepts and selects one op[illegible]on over[illegible]e others based on the resulting graph (22). Acc[illegible]to th[illegible]btain[illegible]d d[illegible], the decoration unit was determined a[illegible]he best u[illegible]mong others. Despite the application of de[illegible]sion-ma[illegible]g procedures in different fields of science, in th[illegible]field[illegible]ergonomics, safety, and occupational health (OHSE)[illegible]has rarely been used. However, it can be found in some parts of the safety literatures (20, 29-31) and ergonomics (32). Evaluation of the significance of ergonomic behavior (33) and the best group shifts selection in the view of proper behaviors (32) are examples of these studies. However, the total number of OHSE-MCDM researches compared with other fields in science is minimal. On the other hand, ART as a novel method is being used less. However, the few study found in this field have provided the possibility to compare the result.

In the present study, based the obtained weight factors, back posture had the higher weight, and thus increases the risk of musculoskeletal disorders. Previous studies confirm our results (30-32). On the other hand, Sarsangi et al. (15) using the QEC method in a similar industry indicated that the majority of workers had pain in the back (53%), shoulder and arm (58%), and neck (79%) and wrist (81%); hence, they were indicated as high and very high risk areas. Their results are in line with our findings except for the arm. The other three upper limbs were also of high importance in the present study; only arm was the least important. In addition, in a study by Tint and colleagues with the aim of improving the ergonomic conditions of computer users (experts/business employees), wrist situation and posture was reported as a high-weight and important point. They used the [illegible]T method (N = 106) and results showed that uniform activity led to causing problems such as musculoskeletal disorders (34).

The grip has received considerable weight, which is in line with other researches although in the present study, opposite to their results, resting had the [illegible]st weight (35). The reason can be found in the agenda and organization of work of the two companies. According to the characteristics and the implementation of the candidate tasks in working halls to control and redesign, it was revealed that these tasks required repetitive movements and using of hand and ankle. In the previous study performed to investigate the risk of upper limbs disorders (ULD) using ART, it was reported that manual work had higher score of exposure than automatic tasks (36).

5.1. Conclusion

With regard to the unsuitable consequences related to lack of attention to occupational ergonomic risk factors, through incidence and prevalence of musculoskeletal disorders in both individual and organizational variables, having assess and controlling them in the form of ergonomics risk management is very important. Managing these risks requires prioritization of work units. In this situation, time and budget are two main elements to take the best advantage. The application of MCDM models, in particular ELECTRE, revealed that the use of these methods in selection processes and decision-making procedures could be designed, especially accompanied with the ART method. Based on the research findings and the results of ELECTRE, two halls named Grading and Pars Naghsh should be the priority of corrective action. Furthermore, packaging and decoration halls with low levels of risk are located in the end of implementation of corrective actions list. Replacing equipment with ergonomic ones such as proper chairs, transforming the implementation of activities from standing to sitting posture, and job rotation programs can be applied as control solutions and for reducing the workplace risks. In addition, it is suggested that the psychosocial factors be examined separately and more accurately.

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