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Decision making models and human factors: TOPSIS and Ergonomic Behaviors (TOPSIS-EB)

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A B S T R A C T

An effective safety management requires attention to human factors as well as system components which make risky or safe situations at technical components. This study evaluates and analyze ergonomic behaviors in order to select the best work shift group in an Iranian process industry, in 2010.The methodology was based on the Ergonomic Behavior Sampling (EBS), and TOPSIS method. After specifying the unergonomic behaviors and with reference to the results of a pilot study, a sample of 1755 was determined, with a sampling accuracy of 5% and confidence level of 95%. However, in order to gain more confidence, 2631 observations were collected. The results indicate that 43.6% of workers' behaviors were unergonomic. The most frequent unergonomic behavior was amusing of legs while load lifting with 83.01% of total unergonomic behaviors observations. Using TOPSIS method, the most effective shift group and the least attractive alternatives for intervention were selected in this company. Findings declare high number of unergonomic behaviors. Catastrophic consequences of accidents in petrochemical industry necessitate attention to workers' ergonomic behaviors in the workplace and promotion of them.

1. Introduction

An effective safety management requires attention to human factors, as system components, with the potential to make risky or safe states in technical components. When we consider human factors, organizations with high reliability can recognize hazards before happening. Human factors include procedures comprising: 1) facilities, equipment and environment, 2) management systems and 3) people (Attwood et al., 2004).

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1.1. Ergonomic behavior

There is no specific definition in the literature for ergonomic behavior. However, one can adopt safety behavior definition that has been presented in a practical guide for behavioral change in the UK oil and gas industry (Khandan & Maghsoudipour, 2012; Khandan et al., 2013) for ergonomic behavior. This definition is: "A behavior that is directly related to Ergonomics, such as manual handling correctly, have correct posture or talking to colleagues about ergonomics". In fact, ergonomic behavior is the application of the ergonomic principles that prevent musculoskeletal disorders or cumulative trauma disorders. For example, lifting with correct weight and closing objects to the body while lifting are examples of these principles. Findings of McSween (2003) suggest that in most organizations at behavioral risks include from 86 to 96 percent of all injuries. These data suggest that employees are guilty of 96% of their injuries. In terms of behavioral psychology, behavior is a function of environment in which it occurs. Unsafe work behavior is accordingly the result of (1) the physical environment, (2) the social environment, and (3) the workers' experience (McSween, 2003 ; Rahmani et al., 2013). Relationship between workload and job satisfaction is proven is some study (Khandan & Maghsoudipour, 2012).

The expenses of the musculoskeletal disorders are estimated to be $\frac{1}{13}$% of the government budget in 2000 in Iran (Nouri et al, 2008), which makes it as an important research topic. First, we showed that our objective behaviors are accepted as behavior in the literature. Manual handling (Attwood et al., 2004; Poornajaf A et al, 2016) and manual lifting (Attwood et al., 2004; Nouri et al., 2008; Geller, 2016; Mohammad Fam et al., 2008) are recognized as behavior. Moreover, manual lifting components as closing load to body, correct weight for lifting and schedule of lifting and appropriate grip were considered as behavior (Attwood et al., 2004; McSween, 2003). Posture of workers is one of the most important factors at the workplaces that are known as behavior (Attwood et al., 2004; Khandan et al., 2012; Mohammad Fam et al., 2008; Lueder, 2005; Chung, 2006) and the elements of posture such as elbow bending and trunk twisting are also posed as behavior (McSween, 2003; Bridger & Pisula, 2014; Habibi et al., 2012).

2. Material and Methods

This cross-sectional study was conducted by using Ergonomic Behavior Sampling (EBS) technique based on Safety Behavior Sampling (SBS), and TOPSIS method. Furthermore, the relationship between Ergonomic Behavior and employees' demographic characteristics such as age, education, job, experience, number of training courses and marriage status was examined. In addition, statistical analysis tests of t-test, ANOVA and Pearson correlation were used. A demographic questionnaire was used to gather general data around workers. All of the workers of the functional units of the company were participated in the study. Total number of observed workers was within 5 shift work groups. Working day group works all of weekdays between 8-17 o'clock but shift work groups (A, B, C, D) work three times in week (from 6 until 14, 14-22, and 22-6) rotationally. Their jobs are identical.

2.1. Procedure for Safety Behavior Sampling

2.1.1 Work Station Definition

It means identification of the department in an organization where ergonomic behavior sampling is going to be conducted. In this study, a workstation is considered as functional units of the company in Iran.

2.1.2 Preparing a List of unergonomic Acts

After specifying the unergonomic behaviors as any action that could have harmful consequences, a list of unergonomic acts was prepared. The obtained list was adjusted based on literature review and present conditions such as the type and nature of work, the reviews of accidents reports, and the present cultural conditions. Table 1shows a specimen worksheet.

Table 1
Ergonomic Behavior Checklist

Behavior	Ergonomic	Unergonomic	Notices
Carrying load weight			
load closed to body during carrying			
grip of load during carrying			
path of carrying			
symmetric carrying			
distance of carrying			
lifting load weight			
feet movement-not twisting			
grip of load during lifting			
load closed to body during lifting			
use of legs during lifting			
upper armposture			
leg posture			
trunk posture			
lower armposture			
wrist posture			
neck posture			

2.1.3. Conduct a Pilot Study

After specifying the unergonomic behaviors, a number of necessary observations of workers' behaviors was carried out in order to determine the proportion of their unergonomic behaviors. The number of required observations was based on the data collected during the pilot study, the accuracy required, and the given level of confidence. Two terms were recorded during the pilot study:

1. Total number of observations made (N1)
2. Number of observations in which unergonomic behavior was observed (N2)

Thus, the proportion of unsafe behavior is (McSween, 2003; Perdue, 1999; Mohammad Fam et al., 2008):

$$p = \frac{N_2}{N_1} \tag{1}$$

Let *e* be the desired accuracy, N be the total number of observations required, $Z_{0.95}$ be the value obtained from standardized normal tables for a given level of confidence, then the total number of required ergonomic behavior observations is derived as follows,

$$N = \frac{[Z_{1-\alpha}^2 P(1-P)]}{e^2}, \tag{2}$$

Accuracy may be interpreted as the tolerance limit of the observations that falls within a desired confidence level. 5% accuracy with 95% confidence level is the combination often used in ergonomic behavior sampling. This means that 95% of the time within 5% accuracy limit, the conclusion drawn based on ergonomic behavior sampling will be representative of the actual population.

2.1.4. Calculation of the required number of observations

Performing pilot study, the proportion of unergonomic acts was estimated to be about 47.7%. With 5% accuracy and 95% confidence level, the total number of observations was estimated as 1755.

Ergonomic behavior sampling needs to be executed, randomly. It is accomplished when each period of observation during the workday is selected by the same chance. So in the next step the observations are performed randomly. It means that both observed workers (134 workers of functional units) and frequency of observations (in the period of 8 hours from 8AM to 17PM) were selected, randomly. Since the behavior of human being might change from time to time, the observation duration has a critical role in the accuracy of the results. This duration should be as short as possible. In this research, the average time of each observation duration was 3 seconds. So, unergonomic behaviors were carefully recorded in a limited time of 3 seconds. The researchers carried out the observations randomly while the subjects were not aware of the fact that they were being observed. In order to recognize the relationship between the employees' demographic characteristics and unergonomic behaviors, previously mentioned variables such as age, work experience, education, work shift group and marriage status were registered through interviews and a special questionnaire.

2.2. The TOPSIS method

Technique for Order-Preference by Similarity to Ideal Solution (TOPSIS) method is a technique for order preference by similarity to ideal solution and is proposed by Hwang and Yoon (1981).The ideal solution (also called positive ideal solution) is a solution that maximizes the benefit criteria/attributes and minimizes the cost criteria/attributes, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. The so-called benefit criteria are those for maximization, while the cost criteria are those for minimization. The best alternative is the one, which is closest to the ideal solution and farthest from the negative ideal solution. Suppose an multi criteria decision making (MCDM) problem has *n* alternatives, A_1,..., A_m, and *m* decision criteria, X_1,…,X_n.

Each alternative is evaluated with respect to the *m* criteria. All the values/ratings are assigned to the alternatives with respect to each criterion form a decision matrix denoted by DM. Let $W= (w_1,\ldots,w_m)$ be the relative weight vector about the criteria. Then the TOPSIS method can be summarized as follows,

Normalize the decision matrix using the equation below:

$$n_{\mathrm{ij}} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r^2{}_{ij}}},$$

where r_{ij} is the normalized criteria/attribute value/rating.

1) Calculate the weighted normalized decision matrix. Make use of the known weights vector and normalized decision matrix.

$$W = \{w_1, w_2, \ldots, w_n\} \approx (considerasadutyofDecisionMaker)$$

$$\text{weighted normalized decision matrix} = V = N_D.W_{n\times n} = \begin{vmatrix} V_{11,\ldots} & V_{1j,\ldots} & V_{1n} \\ \vdots & \vdots & \vdots \\ V_{m1,\ldots} & V_{mj,\ldots} & V_{mn} \end{vmatrix}$$

2) Determine the ideal and negative-ideal solutions:

$$\text{Ideal Solutions} = A^+ = \{(\max V_{ij} \mid j \in J), (\min V_{ij} \mid j \in J') \mid i = 1,2,\ldots,m\} = \{V_1{}^+, V_2{}^+, \ldots, V_j{}^+, \ldots, V_n{}^+,\}$$

$$\text{Negative} - \text{Ideal Solutions} = A^- = \{(min\, V_{ij} \mid j \in J), (\max V_{ij} \mid j \in J') \mid i = 1,2,\ldots,m\} = \{V_1{}^-, V_2{}^-, \ldots, V_j{}^-, \ldots, V_n{}^-,\}$$

where$J$ and $J'$are the sets of benefit criteria and cost criteria, respectively.

3) Calculate the Euclidean distances of each alternative from the ideal solution and the negative-ideal solution, respectively:

$$d_{i^+} = \left\{\sum_{j=1}^{n}\left(V_{ij} - V_j^{+}\right)^2\right\}^{0.5} \quad ; \quad i = 1,2,\dots,m \text{(Eq. 1)}$$

$$d_{i^-} = \left\{\sum_{j=1}^{n}\left(V_{ij} - V_j^{-}\right)^2\right\}^{0.5} \quad ; \quad i = 1,2,\dots,m \text{(Eq. 2)}$$

4) Calculate the relative closeness of each alternative to the ideal solution. The relative closeness of the alternative A_i with respect to A is defined as:

$$Cl_{i^+} = \frac{d_{i^-}}{(d_{i^+} + d_{i^-})} \; ; 0 \leq cl_{i^+} \leq 1 \; ; \; i = 1,2,\dots,m \quad (3)$$

5) Rank the alternatives according to the relative closeness to the ideal solution. The bigger the Cl_{i^+}, the better the alternative A_i. The best alternative is the one with the greatest relative closeness to the ideal solution.

3. Results

In our survey, all workers were male. Average employees' age was (30.95 ± 5.298) years old. In terms of marital status, 63.6% of the employees were married and the rest of them were single. In terms of educational background, the employees with diploma or lower education had the largest proportion with 38.8% of all employees. The employees with M.Sc. or higher levels of education were the least proportion with 3.7%. The results of these demographic characteristics are shown in table 2.

Table 2
Frequencies of individual according to job unit, Education level and shift work group

Variable	alternatives	percentage
Job unit	Operation	73.1
	maintenance	11.2
	Technical services	9.7
	storage	0.6
Education level	Diploma or lower	38.8
	Junior college diploma	20.9
	Bachelor	36.6
	Master or higher	3.7
Shift work Group	A	15.7
	B	16.4
	C	20.1
	D	17.9
	Working day	29.9

The results also signified that the average work experience was (6.57 ± 4.44) years. In average, every worker attended five safety training courses but the range varied from 1 to 20 courses.

3.2. Reliabilities of the ergonomic target behaviors checklist (ETBC)

Checklist's reliability was 87%, assessed by comparing six different persons' responses who completed ETBC for similar situations and calculating percentage of similar responses, so its reliability was desirable (Geller, 2001).

3.3. Ergonomic behaviors results

The results indicated that 43.6% of workers' behaviors were unergonomic within total number of 1147. Among unergonomic acts, the most frequent unergonomic behaviors were amusing of legs while load lifting had 87% of total unergonomic behaviors observations. On the other hand, carrying load with correct weight with only about 0.042% of unergonomic behaviors, among total observations, had the best condition. Results did not declare any significant relationship between ergonomic behavior percentage and demographic characteristics ($p>0.05$).

3.4. Results based on applying TOPSIS method

In this study, 17ergonomic behaviors (n=17) in five shift work groups (n=5) were recognized. Table 3 shows decision making matrix which contains ergonomic behaviors frequencies for each work shift groups.

Table 3
Decision making matrix (Frequencies of each unergonomic behavior as a function of shift work groups)

	E.B.																
Shift-Group	carrying Load weight	load closed to body during carrying	use of legs during lifting	move feet - don't twist during lifting (foot movement-not twisting during	grip of load during lifting	neck pos.	upper arm posture	lower arm pos.	wrist pos.	trunk pos.	leg pos.	Lifting load weight	load closed to body during lifting	distance of carrying	grip of load during carrying	path of carrying	symmetric carrying
A	0	2	5	0	0	22	28	26	28	24	14	1	3	4	0	2	3
B	1	6	8	2	2	24	32	37	24	38	22	0	1	3	2	3	2
C	6	6	10	5	5	30	36	30	31	32	25	0	0	1	1	0	1
D	4	7	10	6	7	34	31	33	33	33	27	0	0	3	3	2	2
NO	1	8	11	2	7	40	59	50	46	52	34	0	2	3	2	3	4

For conducting TOPSIS method, we need to weight each safety climate factor as an input to this method algorithm. According to using Entropy method, weights are as following: carrying load weight: 0.370, load closed to body during carrying: 0.138, Lifting load weight: 0.1113, moving feet - not twisting during lifting: 0.0784, grip of load during lifting: 0.0720, grip of load during carrying: 0.0662, carrying path: 0.056, symmetric carrying: 0.0211, distance of carrying: 0.017, load closed to body during lifting: 0.016, use of legs during lifting: 0.013, upper arm posture: 0.0096, leg posture: 0.0085, trunk posture: 0.0074, lower arm posture: 0,0059, wrist posture: 0.0055, and neck posture: 0.0052.

Then, normalized matrix was developed. Also, weighted normalized decision matrix was calculated in the next step. In next stage, ideal positive alternative and ideal negative alternative were evaluated. According to the acquired data, maximum and minimum values are selected.

$$A^{+} = \left\{ \begin{array}{c} 0 , 0.002 , 0.003 , 0 , 0 , 0.0017 , 0.0031 , \\ 0.0019 , 0.0018 , 0.0021 , 0.0021 , 0 , 0 , \\ 0.0026 , 0 , 0 , 0.0036 \end{array} \right\} \qquad A^{-} = \left\{ \begin{array}{c} 0.091 , 0.009 , 0.0071 , 0.0566 , 0.045, 0.003 , \\ 0.0065 , 0.0036 , 0.0034 , 0.003 , 0.0051 , \\ 0.370 , 0.111, ,0.01 , 0.047 , 0.033 , 0.014 \end{array} \right\}$$

Next, we calculated the aggregate dominance matrix. Finally, relative similarity to ideal amounts of the compared alternatives is determined as Table 4.

Table 4
Relative similarity to ideal amounts of the compared alternatives

working shift group	Cl^{+}_{i}
A	0.247
B	0.841
C	0.781
D	0.782
NO	0.789

Priority queue is determined according to Cl^{+}_{i}values. By doing this step we can realize that working shift group of B is the most effective and shift groups of A is the least attractive alternative for selection. So, B, working day (No), D, C and A groups are ranked as first, second, third, fourth and fifth ranked of degree of importance, respectively.

4. Discussion and Conclusion

When we consider catastrophic consequences of accidents in petrochemical industry, we realize the importance of paying attention to preventive principles and decrease employees' unergonomic behaviors. This action results in reduced injuries and accidents costs. In order to obtain that, we can focus on these behaviors: carrying load with correct weight, closing load to body during carrying, and lifting load with correct weight, since these factors are located at first, second and third priorities according to Entropy method result, respectively. Better and sustainable improvement in ergonomic behaviors in a company will be achieved by paying more attention to correcting these behaviors. Moreover, TOPSIS method results have revealed that priority for correcting actions must be accomplished on groups with lower importance. Hence, A, C and D groups must be considered as high priorities. On the other hand, we cannot neglect physical, social conditions and management's behavior effects on workers' behavior forming at the workplace. Also, some effectiveness components have been proved for improving safety in process industries as following (McSween, 2003):

- A behavioral observation and feedback process
- Formal review of observation data
- Improvement goals
- Reinforcement for improvement and goal attainment

These elements show the importance of considering workers' behaviors at workplace for optimizing comfort, safety and productivity in organization. Thus, behavior observation and feedback must be performed through surveys on timely and scheduled basis. Finally, ABC (Activators-Behaviors-Consequences) model. Application can contribute to improve ergonomic behaviors. By means of Activators such as ergonomics meetings, goal setting, rules and regulations, we can improve behaviors directly. However, the consequences such as self-approval, reprimand, peer approval, penalty, feedback and injury can improve behaviors by increasing motivation. Recommended Use of the Finnish method to quantify the ergonomic properties in workplaces can be useful as an environmental evaluation in this view point.

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