Original Article

Determination and Prioritizing of the Factors Affecting the Tolerance to Shift Work Using Techniques of the Delphi and Fuzzy Analytical Hierarchical Process

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Abstract

Aim: This study aimed to identify, classify, and prioritize the factors affecting tolerance to shift work using Delphi and fuzzy analytical hierarchy process (FAHP) techniques. **Methods:** This descriptive analytical study was conducted in 2023. First, the literature review and Delphi technique identified the factors affecting tolerance to shift work. Then, these factors were grouped into five categories. The FAHP was used to prioritize the factors. Finally, the data were analyzed using MATLAB software (version 2019a). **Results:** Thirty-two factors were identified and grouped into five categories. Based on the results of FAHP, the relative weights of individual factors, working conditions, working hours, family and living conditions, and social conditions were computed as 0.231, 0.211, 0.187, 0.186, and 0.182, respectively. **Conclusion:** These results highlight the significance of factors influencing tolerance to shift work and can aid in planning preventive measures for the decrease of shiftwork disorders.

Keywords: Delphi method, fuzzy analytical hierarchy process, risk factors, shift work

Introduction

Shift work is a work schedule outside the regular work hours.[1] Some industrialized countries have adopted it to maximize productivity and ensure the continuity of industrial activity.[2] As a result, shift workers have rapidly grown in recent decades.[3] According to the International Labor Organization, nearly 15% of workers in developed countries and 25%–92% of them in developing countries have shiftwork.[4] Shift work can significantly affect human health by disrupting natural biological rhythms.[5] Studies have shown that shift work is linked to higher risks of sleep disorders, cardiovascular problems, psychological discomfort, and digestive issues.[6] To obtain a deeper understanding of this phenomenon, it is important to identify the factors affecting the tolerance to shift work.[7] The use of the Delphi method is advised for qualitative research. This method has been employed in studies across various fields such as medicine, civil engineering, environment, ergonomics, and occupational health.[8] Mousavi *et al*. utilized this technique to recognize the factors influencing the incidence of needle stick injury.[9] Similarly, Haghighat *et al*. employed this method to determine the criteria for the selection of noise control solutions in the industry.[10] Moreover, determining the weight and importance of risk factors by a certain method are crucial. Multicriteria decision-making methods can be applied for this purpose.[11] Among these methods, the AHP is a popular and well-known technique. Saati originally developed it. This method relies on expert opinions and paired comparisons.[12] However, it has been observed that, in most cases, experts have

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difficulty in expressing their exact opinions. Fuzzy logic has been proposed to deal with this issue.[13] Tatar employed this approach to prioritize the risk factors causing musculoskeletal disorders.[14] Yazdanirad *et al*. also utilized this technique to prioritize the most important risk factors affecting thermal strain.[15] This study aimed to identify, classify, and prioritize the factors affecting tolerance to shift work using Delphi and fuzzy analytical hierarchy process (FAHP) techniques.

Materials and Methods

The present cross-sectional study was conducted in 2023 at an oil refinery in Iran. The steps of the study are as follows:

Identifying the factors affecting the tolerance to shift work

A nonsystematic literature review was conducted in databases of ISI, PubMed, and Scopus. Keywords were divided into two groups. The first group included impact, effect, factor, risk factor, item, relationship, prediction, and association. The second group included shift work, schedule, night shift, and rotating shift work. Cohort, case–control, retrospective, and cross-sectional studies without time restrictions were included in the study. Irrelevant studies and articles that did not meet the inclusion criteria were removed.

Delphi Technique

In this study, the Delphi technique was used with 25 experts to identify factors related to shift work in industries. Experts reviewed a list of factors and introduced other important factors. The answers were analyzed, and the proposed factors were added to the list. The revised list was then sent back to the experts for receiving their feedback, and the list was revised based on their opinions.[11]

Prioritizing the identified factors using the fuzzy analytical hierarchy process technique

Chang proposed a method to extend the fuzzy hierarchical analysis process. This study applied this method to calculate the final weight of the indicators, the steps of which were as follows.[16]

- Step 1: Definition of fuzzy numbers

Linguistic terms were transformed into fuzzy numbers using Table 1. These numbers were then applied to the fuzzy analytical hierarchical process.[16]

Table 1: Linguistic scale and its synonymous triangular fuzzy numbers

Linguistic terms	Fuzzy numbers
Equally importance	1,1,1
Equal importance to slightly more	1,2,3
A little more importance	2,3,4
A little more importance to more importance	3,4,5
More important	4,5,6
More important to much more important	5,6,7
Much more important	6,7,8
Much more important, absolutely important	7,8,9
Complete important	8,9,10

- Step 2: Formation of paired comparison matrix (A) using fuzzy numbers

The decision matrix involved a paired comparison, as represented in Equation 1.

$$\tilde{A}=\begin{bmatrix} 1 & M_{12} \ldots & M_{1n} \\ M_{21} & 1 \quad \ldots & M_{2n} \\ \vdots & \vdots \quad \ddots & \vdots \\ M_{n1} & M_{n2} \ldots & 1 \end{bmatrix} \tag{1}$$

- Step 3: Calculation of Si

Si represents a triangular fuzzy number that determines the relative weight for each criterion or solution using Equation 2.

$$S_i=\sum_{j=1}^{m} M_{gi}^{J} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{J}\right]^{-1} \tag{2}$$

In this equation, i, j, and M_{gi}^{j} show the column number, row number, and fuzzy numbers of the paired matrix, respectively. $\sum_{j=1}^{m} M_{gi}^{J}$, $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{i}$ and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{i}\right]^{-1}$ are computed using Equations 3–5 as follows.

$$\sum_{j=1}^{m} M_{gi}^{j}=\left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}=\left(\sum_{i=1}^{m} l_i, \sum_{i=1}^{m} m_i, \sum_{i=1}^{m} u_i\right) \tag{4}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}=\left(\frac{1}{\sum_{i=1}^{m} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{m} l_i}\right) \tag{5}$$

- Step 4: calculation of the degree of possibilities

If $S_1=(l_1, m_1, u_1)$ and $S_2=(l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $S_2 \geq S_1$ is computed by the Equation 6.

$$V(S_2 \geq S_1)=hgt(S_2 \cap S_1)=$$

$$\mu_{S_1}(d)=\begin{cases} 1 \; if \; m_2 \geq m_1 \\ 0 \; if \; l_1 \geq u_2 \\ \dfrac{l_1-u_1}{(m_2-u_2)-(m_1-l_1)} \; otherwise \end{cases} \tag{6}$$

Equation 7 shows the degree of possibility of S2 greater than or equal to S1, where S1 and S2 are two triangular fuzzy numbers with values (l1, m1, u1) and (l2, m2, u2), respectively.

$$\begin{aligned} &V(S_2 \geq S_1, S_2, \ldots, S_K)= \\ &V\left[(S \geq S_1) \; and \; (S \geq S_2) \; and \ldots and \; (S \geq S_k)\right] \\ &= Min \; V(S \geq S_i).\; i=1.2.3.\ldots.\; k \end{aligned} \tag{7}$$

- Step 5: calculation of the weight of criteria

Equation 8 was used for the computation of the weight vector of criteria in the paired matrix.

$$d'\left(A_i\right) = Min\ V\left(S_i \geq S_k\right)\ k = 1.2\ldots.\ n.\ k \neq i \qquad (8)$$

Therefore, the nonnormal weight vector was also estimated by Equation 9.

$$W' = \left(d'\left(A_1\right).\ d'\left(A_2\right)\ldots.d'\left(A_n\right)\right)^T\ A_i\left(i = 1.2\ldots.\ n\right) \qquad (9)$$

- Step 6: Calculation of normal weight

The nonnormal weight vector from the previous step was normalized to calculate the normal weight using Equation 10.

$$W = \left(d\left(A_1\right).\ d\left(A_2\right)\ldots.d\left(A_n\right)\right)^T \qquad (10)$$

The geometric mean was also used to combine the N comments of experts, as shown in Equation 11. The output is a comparison matrix obtained from the judgment of experts.

$$a_{ij} = \left(\prod_{K=1}^{K} A_{ijk}\right)^{1/K}\ K = 1.2\ldots.\ K \qquad (11)$$

- Step 7: Calculation of consistency index.

The Gogus and Boucher method was used to calculate the consistency index. The results showed that the consistency index for all matrices was <0.1. Therefore, the findings were deemed to be trustworthy.[17]

Data analysis

Data were descriptively analyzed using Statistical Package for Social Sciences (SPSS), version 25 (IBM, Chicago, Illinois, USA). Matlab 2019a (The MathWorks, Natick, MA, USA) was also used to calculate the consistency index and prioritize factors.

Results

During the literature review process, 105 articles were identified. After removing 37 duplicates, 211 studies were analyzed and 80 factors were extracted. After eliminating 39 duplicate and irrelevant factors, 26 factors were remained. In addition, 6 factors were identified using the Delphi method. The Delphi survey was sent to 25 experts in the first round, with a response rate of 92.00%. In the second round, the Delphi survey was sent to 21 experts with a response rate of 76.33%. In total, 32 factors were identified that were classified into five groups. The hierarchical structure of these factors is shown in Figure 1.

Table 2 displays the comparative importance of the groups. Based on the findings, individual factors obtained the greatest relative weight among the groups (0.231). The other groups consisted of working condition factors (0.211), working hours factors (0.187), family and living conditions factors (0.186), and social condition factors (0.182), in that order.

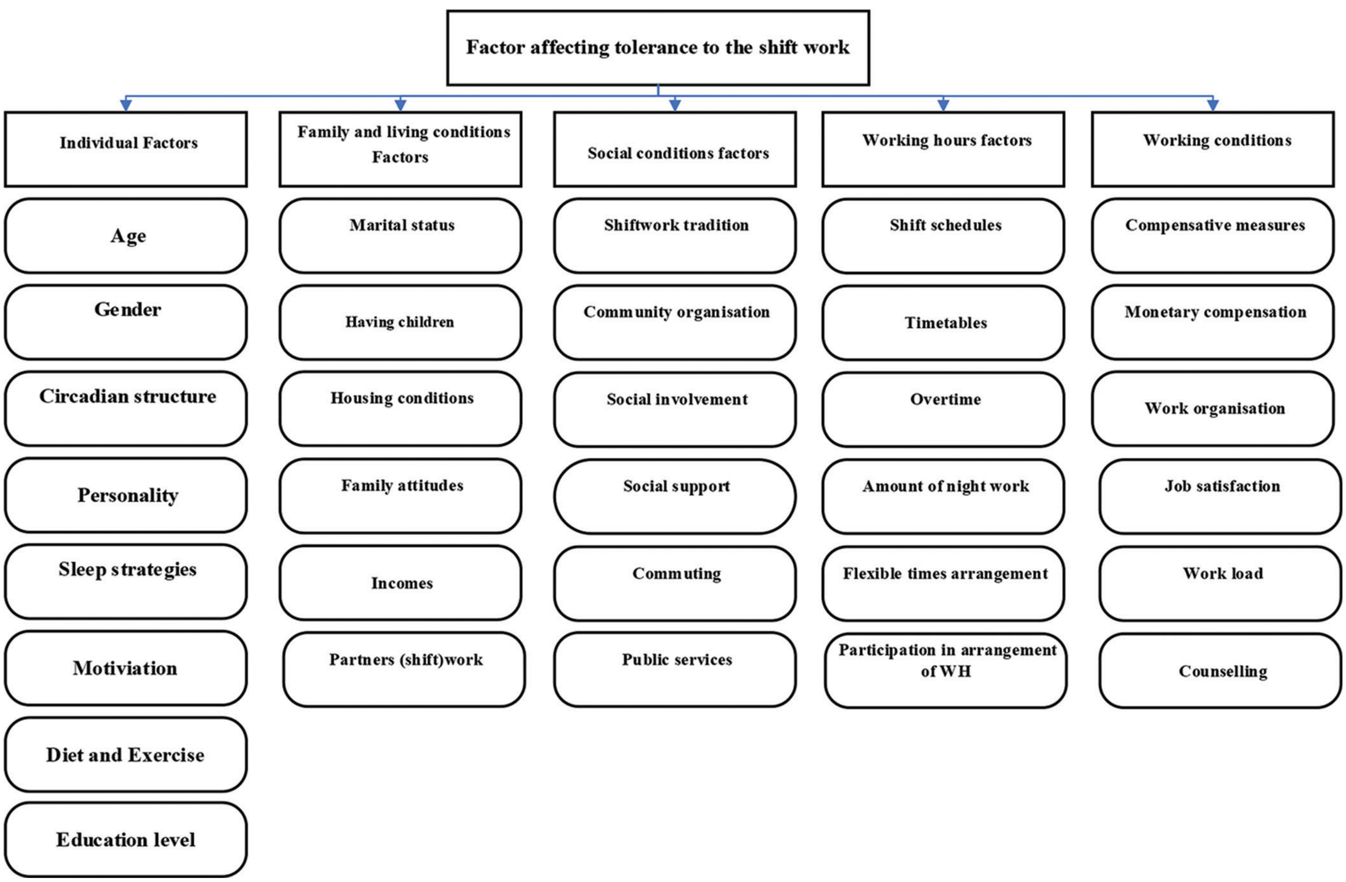

Figure 1: The hierarchical structure of the identified factors

In Table 3, the factors are ranked by their relative weights. The highest relative weight among individual factors was the circadian structure (0.146), whereas the workload had the highest relative weight among working conditions (0.204). The highest relative weight among working hours factors was related to the amount of shift work (0.209), and incomes had the highest relative weight among family and living conditions (0.192). Finally, public services had the highest relative weight among social condition factors (0.198).

Table 2: The final weight of the main groups

Groups	Fuzzy weight			Final weight
	L	M	U	
Individual factors	0.061	0.631	2.117	0.231
Family and living conditions factors	0.088	0.523	1.698	0.186
Social condition factors	0.095	0.661	1.523	0.182
WH factors	0.078	0.451	1.787	0.187
Working condition factors	0.069	0.631	1.881	0.211

WH: Working hours

Discussion

This study identified and grouped 32 factors affecting tolerance to shift work into five categories. These categories include individual factors, family and living conditions, social conditions, working hours, and working conditions factors [Figure 1]. The results showed that individual factors obtained the first priority [Table 2].

Individual characteristics determine psychological and physiological factors, which are more strongly associated with either negative health effects or, conversely, better tolerance. This has significant practical implications in adopting appropriate coping strategies and selecting individuals for shift work to detect early signs of intolerance. Of individual factors, circadian structure, age, and sleep strategies were assigned the highest priorities [Table 3]. Circadian rhythms

Table 3: The final weight of the factors

Groups	Factors	Fuzzy weight			Final weight
		L	M	U	
Individual factors	Sleep strategies	0.131	0.522	1.525	0.131
	Personality	0.055	0.422	1.421	0.119
	Circadian structure	0.045	0.235	2.021	0.146
	Age	0.063	0.328	1.782	0.136
	Gender	0.079	0.416	1.468	0.121
	Motivation	0.051	0.62	1.119	0.112
	Education level	0.078	0.174	1.512	0.108
	Diet and exercise	0.069	0.582	1.286	0.120
Family and living conditions factors	Family attitudes	0.145	0.522	1.231	0.139
	Housing conditions	0.086	0.432	1.116	0.124
	Having children	0.059	0.248	1.963	0.178
	Partners (shift) works	0.047	0.421	1.862	0.184
	Marital status	0.087	0.512	1.762	0.183
	Incomes	0.077	0.761	1.632	0.192
Social condition factors	Social involvement	0.263	0.486	1.321	0.151
	Community organizations	0.096	0.621	1.213	0.157
	Communing	0.076	0.187	1.119	0.112
	Social support	0.086	0.362	1.823	0.187
	Shift works traditions	0.083	0.496	1.775	0.195
	Public services	0.021	0.698	1.596	0.198
WH factors	Timetables	0.229	0.4628	1.321	0.146
	Amount of shift work	0.062	0.5978	1.893	0.209
	Shift schedules	0.042	0.1638	1.799	0.165
	Participation in the arrangement of WH	0.052	0.3388	1.503	0.154
	Flexible times in the arrangement	0.049	0.4728	1.455	0.162
	Overtimes	0.032	0.6748	1.276	0.164
Working condition factors	Monetary compensation	0.252	0.4758	1.561	0.148
	Workload	0.085	0.6108	2.133	0.204
	Work organization	0.065	0.1768	2.039	0.165
	Compensative measures	0.075	0.3518	1.743	0.156
	Counseling	0.072	0.4858	1.695	0.162
	Job satisfaction	0.055	0.6878	1.516	0.164

WH: Working hours

encompass the physical, mental, and behavioral changes that occur within a 24-h cycle for an organism.[18] The influence of light and darkness on circadian rhythms is well-documented. Factors such as food intake, stress, physical activity, social environment, and temperature also play an important role. Important functions, including sleep patterns, hormone release, appetite, and digestion, are impacted by circadian rhythms.[19] The desynchronization of circadian rhythms is considered one of the major causes of disruption to human homeostasis.[20] Previous research findings indicated that individuals with a higher daily variation in oral temperature were better able to tolerate long-term shift work and experience fewer complaints related to digestive, nervous (chronic fatigue), and sleep disorders.[21] The individuals with a larger temperature fluctuation adapt more slowly, thereby maintaining a more consistent temporal structure during night shifts.[22] In addition, Reinberg and Ashkenazi demonstrated that shift workers with low tolerance also exhibited persistent internal desynchronization among various daily rhythms (temperature, heart rate, and hand grip) and activity–rest cycles, and their oral temperature cycle lasted longer than 24 h.[23] Other studies did not find such correlations, but their investigation had a shorter duration.[24] Nevertheless, Costa *et al*. observed a greater shift in phase and a decrease in fluctuation when transitioning to night work in individuals with digestive disorders. In contrast, Knauth observed a slower adjustment to night work in individuals with poor tolerance.[21,25] Furthermore, Roden *et al*. discovered that permanent night workers with high satisfaction display any noticeable shift in their hormonal rhythms from the diurnal orientation, nor did they exhibit any change in cortisol fluctuation compared to daytime workers.[26] Based on the limited number of studies, it seems reasonable to believe that an individual's chronobiological structure plays a crucial role in their ability to tolerate shift work.[27] The aging process is associated with more irregular heart rhythms, sleep problems, mental health issues, reduced physical fitness, and a higher risk of health problems. From a chronobiological perspective, age-related changes involve a decrease in the strength of daily biological rhythms and the earlier timing of these rhythms concerning mental and physical functions.[28] The decline in health with age is more pronounced in shift workers, especially for older individuals (over 45).[29] Establishing healthy sleep habits are essential for workers with nontraditional shifts. It involves the creation of optimal sleep–wake patterns, management of shift schedules, and prioritization of extended main sleep. Consistent sleep routines and minimum disruptions are key for coping with irregular working hours.[30] Napping is particularly beneficial for shift workers, as it can help counteract sleep deprivation, especially during night and early morning shifts. It can lead to increased alertness and reduced fatigue. The timing of a nap regarding the work shift and task type may be more important than its duration. While some studies indicate regular napping improves tolerance in shift workers, other studies show different effects based on individual strategies and cultural, environmental, and working conditions.[31]

The study's limitation is the lack of consideration of the internal relationship between the factors. Future studies should use DEMATEL and ANP methods to investigate the internal relationship between the factors and compare the results with the current study. This study presents a mathematical model to determine the relative importance of the factors.

Conclusion

The findings suggested that personal factors are crucial in determining tolerance to shift work. Other important categories included working conditions, hours, family and living arrangements, and social circumstances. Prioritization of these factors can reduce the likelihood of shift work-related disorders and complications among employees and serve as a scientific reference for recruiting shift workers. The findings of this study can be useful for other industries with shiftwork planning.

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Ethics code

The Medical Ethics Committee of Isfahan University of Medical Sciences approved the study protocol, which was assigned the ethical code IR.MUI.RESEARCH.REC.1402.158.

Conflicts of interest

There are no conflicts of interest.

Authors' contribution statement

Mahnaz Shakerian: Conceptualization, Data collection, Writing-review and editing; Saeid Yazdani Rad: Study design, Methodology, Writing-review and editing; Amir Hossein Khoshakhlagh: Data collection, Writing-review and editing; Seyed Mahdi Mousavi: Data analysis, Writing-original draft.

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