A Knowledge-Based Ergonomics Assessment System for WMSD Prevention Using AHP Methodology

Fazilah Abdul Aziz, Zakri Ghazalli, Mohd Jawad Mohd Jamil, Awanis Romli and Nik Mohd Zuki Nik Mohamed

Abstract This research develops a knowledge-based ergonomics assessment system (KBEAS) that measure and predicts the degree of criticality of risk factors related to work-related musculoskeletal disorders (WMSD). Predicting WMSD individual risk level provides critical decision support information to occupational safety and health (OSH) practitioners in the ergonomic analysis. The KBEAS is based on the analytic hierarchy process (AHP) methodology. The current study integrates AHP method with real workplace ergonomics risk data and design web-based system assisting a sensible multi-criteria WMSD related risk factors. The objectives involve knowledge acquisition performed through preliminary study, MSD symptom study, literature analysis, and tacit knowledge analysis and practitioner survey to identify the ergonomics risk factors that include individual, organizational, physical and psychosocial. The application of this system shows that the design of the proposed KBEAS for WMSD risk factors has been validated and gets each risk factors weight easily by using AHP. The study findings showed that 'organizational ergonomics risk factors' is more critical than other factors. The overall prioritization revealed that 'exposure to physical demands' had a priority vector of 26.33%, and it was perceived as the item with the most critical factor. The KBEAS could help the user to make an objective judgement on the subjective description and get the correct result of the ergonomics risk factors.

Keywords Knowledge-based ergonomics assessment system · WMSD
AHP · Web-based system

F. Abdul Aziz (✉) · Z. Ghazalli · N. M. Z. Nik Mohamed
Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia
e-mail: fazilahaa@ump.edu.my

M. J. Mohd Jamil · A. Romli
Faculty of Computer Systems and Software Engineering,
Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

F. Abdul Aziz
Faculty of Manufacturing Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia

M. H. A. Hassan (ed.), *Intelligent Manufacturing & Mechatronics*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-10-8788-2_16

1 Introduction

Industry workers performing manual operations are subjected to musculoskeletal disorders (MSD) [1, 2]. The high prevalence of MSD symptoms as a significant problem among Malaysia automotive workers [3–5]. The occupational health and safety management system (OHSMS) has been known to play an essential role in controlling the safety conditions of workplaces and health of the employees in the companies [6, 7]. However, occupational safety and health (OSH) practitioners appear to focus on checking the safety and health aspects rather than zooming in on getting to the human factors or ergonomics issues.

Most of the companies had no information with regards to the health, safety and ergonomics performance [8]. Thus, WMSDs consistently continues as one of the occupational safety and health (OSH) related problems due to OSH and ergonomic intervention have not been wholly implemented [9]. In particular, with regards to the OHSMS, the focus should not be only on the development of healthy and safe working conditions, but also equally to the workplace comfort and wellness, and employee's well-being. Thus, a practical approach to predict workplace ergonomics risk exposure can be beneficial to occupational health and safety practitioners and production managers to prevent WMSD symptom among production workers. Therefore, this research is an effort to develop a knowledge-based ergonomics assessment system (KBEAS) that assists in evaluating the potential of WMSD risk factors at an automotive component manufacturer.

The proposed algorithm of the system is based on AHP method (T. L. Saaty 1980) for the rules and inference system. The AHP was used for multi-criteria decision-making process and provides reasonable support [10] and flexible approach to risk analysis [11]. Since decision maker can unbiasedly get numerical pair-wise comparisons by choosing proper numerical scale to quantify linguistic pair-wise comparisons [12]. The web-based system was set up as ergonomics assessment tool since it was fundamental for such a medium to be open efficiently and auspicious [13]. Web-based system application has upgraded the effect of a decision support system when the choice available is considered by an expansion in the quantity of other options to assess [14].

The final experiment results show that KBEAS could use to predict a particular risk factors level to obtain several appropriate measures proposed by OSH practitioners in engineering and administration controls. Consequently, a smart and practical tool can be developed to identify WMSD risk related to a variety of factors.

2 Knowledge Acquisition Process

The required information and knowledge to construct the knowledge base are obtained through knowledge acquisition process (KAP). KAP consists of a mixture of knowledge acquisition methods. The preliminary knowledge acquisition gains an overview of the workplace ergonomics problem. The WMSD symptom knowledge acquisition finds about the body pain complaint among production workers.

Initially, the potential risk factors are obtained from literature associated to back, neck, shoulder, and arm pain. The literatures contain a wealth of information about the possible causes of MSD [15–18]. Based upon the expertise, experience, and accessibility the group of subject matter experts (SME) consists of a managing director and general manager, as well as department managers from production, engineering, and safety health and environment are selected for tacit knowledge analysis. The recognized risk factors and common characteristics are acquired from the literature that represents the categories individual-related, organizational-related, physical-related and psychosocial-related risk factors.

To validate the risk factors related to WMSDs, the survey is considered useful in identifying the dominant risk factors. The questionnaire was distributed to practitioners at three automotive production plants. The consequences of the knowledge acquisition lead to the generation of various risk factors. The final risk factors thus acquired are summarised to formulate the AHP hierarchy, as shown in Fig. 1.

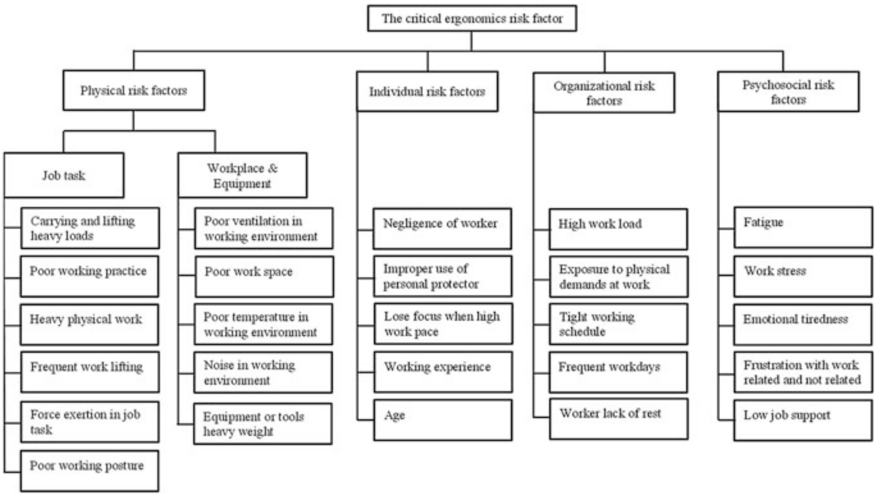


Fig. 1 AHP hierarchy structure of ergonomics risks factors

3 AHP Methodologies

The risk factors related to WMSD are diversity, various, and dynamic. Based on that, to achieve intelligence and dynamic in early detection and meantime facilitate employees to make an objective descriptive of subjective judgments, the current study applies AHP methodology. The pair-wise comparison is the relative importance of one criterion over another in meeting a specific goal [13, 19]. Given those, current study set up ergonomics assessment model of WMSD risk factors to do the quantitative analysis. The AHP-based method involves the following significant steps:

1st Step: Develop a hierarchy of factors based on KAP results (refer Fig. 1).

2nd Step: Construct judgement matrix and make pair-wise comparisons: Practitioners are asked to evaluate the relative importance of risk factors within and among the leading ergonomics factors. A matrix of element evaluation, denoted as A, will be formed using the comparisons. Each entry a_{ij} of the matrix, in the position (i, j) is obtained comparing the row element A_i with the column element A_j: Means of pair-wise comparison administered the survey questionnaire. A numerical scale is then assigned to each pair of alternatives (A_i, A_j) by the experts (refer Table 1).

3rd Step: Synthesize judgments: The process is to calculate a vector of local weights or priorities of each risk factor in term of its contribution to the overall goal. It includes the following steps.

Step 3.1 Once the overall expert judgments are created and calculated using the geometric mean [refer Eq. (1)],

Table 1 Pair-wise comparison scale used with AHP adapted from [3]

Intensity of importance	Score	Definition	Explanation
1	1	Equal importance	Two elements contribute equally to the property
2	3	Moderate importance of one over another	Experience and judgment slightly favor one over the other
3	5	Essential or strong importance	Experience and judgment strongly favor one over another
4	7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice
5	9	Extreme importance	The evidence favoring one element over another is one of the highest possible orders of affirmation
Reciprocals	When activity I compared to j assigned one of the above numbers, the activity j compared to i is assigned its reciprocal		
Rational	Ratios arising from forcing consistency of judgments		

$$\text{Geometric mean, GM}_\text{i} = \sum_{i=1}^{n} n\sqrt{a_{ij}} = \sqrt[n]{a_{ij\,1} x\, a_{ij2} x \ldots x\, a_{ijn}} \quad (1)$$

where n = number of participants

Step 3.2 The next step is to calculate a vector of local weights or priorities of elements [refer Eq. (3)]. The principal eigenvector w of the matrix can be calculated using the Eq. (2).

$$\text{Eigenvector } = \text{w}_\text{i} \frac{GM_i}{\sum_{i=1}^{n} GM_i} \quad (2)$$

$$\text{Eigenvalues } = \text{local weight } = \frac{\sum_\text{i}^{n} w_\text{i}}{n} \quad (3)$$

where n = number of elements

Step 3.3 The synthesized weight or global priority vector for elements can be presented as in the Eq. (4):
Global priority vector, $\text{W}_{\text{i};}$

$$\text{W}_\text{i} = (\text{Criteria local weight})(\text{Sub } - \text{criteria local weight}) \quad (4)$$

4th Step: Upon having the local priority vector determined, it is then necessary to evaluate the consistency of the pairwise comparison matrix. The consistency index and consistency ratio can be seen in the Eqs. (5) and (7).

$$\text{Consistency index (CI)} = \frac{\lambda_\text{max} - n}{n - 1} \quad (5)$$

$$\lambda_\text{max} = \sum_{i=1}^{n} \left[\left(\sum_{i=1}^{n} GM_i \right) (w_j) \right] \quad (6)$$

where, λ_max = maximum eigenvalue and n is the number of elements

$$\text{Consistency ratio (CR)} = \frac{\text{Consistency index (CI)}}{\text{Random index (RI)}} \leq 0.10 \quad (7)$$

If the value of consistency ratio (CR) is smaller or equal to 0.1 the inconsistency is acceptable. If the CR is greater than 0.1 then the subjective judgment need to be revised.

4 KBEAS Development

In the present convenience working environment, it is fundamental to propose and set up a reasonable system which will consolidate the power of web-based systems, AHP analysis, and empirical data and therefore advance the efficiency of prioritizing processes. The KBEAS was designed as a web-based system since it was planned to accessible anytime and anyplace inside the organization.

4.1 Structure of System

The basic structure of the web-based system includes the user interface, a knowledge base, and an AHP inference engine. The proposed system is implemented by using XAMPP and MySQL server is used as a database. XAMPP is a free and open source cross-platform web server solution stake package. XAMPP consists mainly of the Apache HTTP Server, Maria DB database, and interpreters for scripts written in the PHP and Perl programming languages. The structure of the developed web-based system for ergonomics assessment purpose is given in Fig. 2.

Component of the system. Figure 3 demonstrates the system components and their corresponding functions. The system has four major components. First one is a database component in which all factors information are stored. Users would retrieval be able to the risk factors record by time and embed new record.

The second component is data input part. Concerning user's determination comparing data is recovered from the database. The third component is a data processing part which allows the server to use AHP method to calculate each criterion and sub-criteria weights. The consistency test for data input also performed. This component can retrieve the corresponding numerical values regarding the submitted specific condition about those criteria and sub-criteria mentioned previously. The fourth component is data output part. This component is to prioritize for criteria and sub-criteria of risk factors. Also, rank all the criteria and sub-criteria within the group and all groups of factor.

Section of a web-based system. The system is divided into two sections. One of them is administrator side and the other one is user side. Administrator or user can

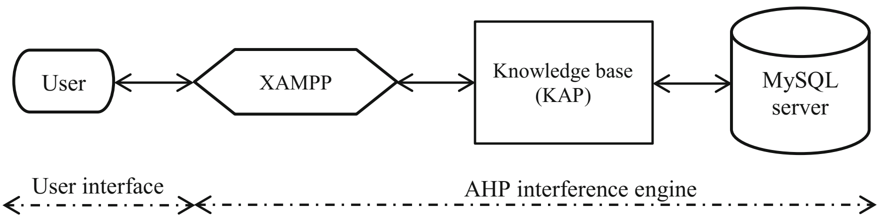


Fig. 2 Web-based of knowledge-based ergonomics assessment system structure

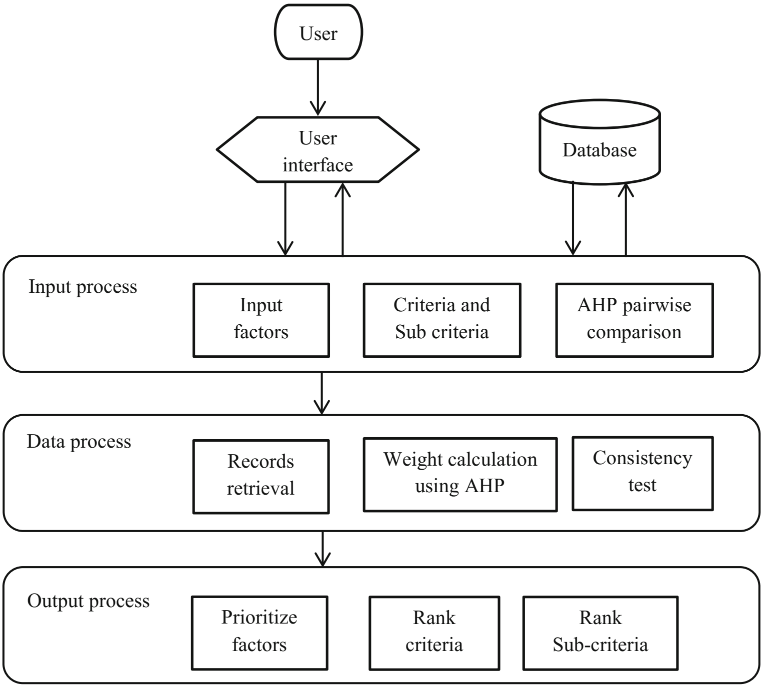


Fig. 3 Components of the KBEAS and their corresponding functions

access the system wherever he/she needs. The flow diagram of the system is illustrated in Fig. 4. Under administrator section, administrator of the system makes some definitions on the purpose of use. These definitions are as follows: remove a record, remove a user, modify risk factors, modify questions, and adding a legend.

Company's Safety Health Officer (SHO) User: Safety Health Officer User has primary responsibility for ergonomics risk report for the production plant. Safety Health Officer can login both administrator and user. Other Users: system's other defined users, registered user who is employee representative from the related department and had authority over the ergonomics assessment.

4.2 System Application

To validate the proposed KBEAS, an application in a local automotive component manufacturer has been done. The evaluation group was made up of fifteen practitioners from several departments under production plant, whose expertise was different. All practitioners that participated had at least 5 years of working experience in the company. The practitioners were selected according to their job tasks, roles and influences on OHSM system practices.

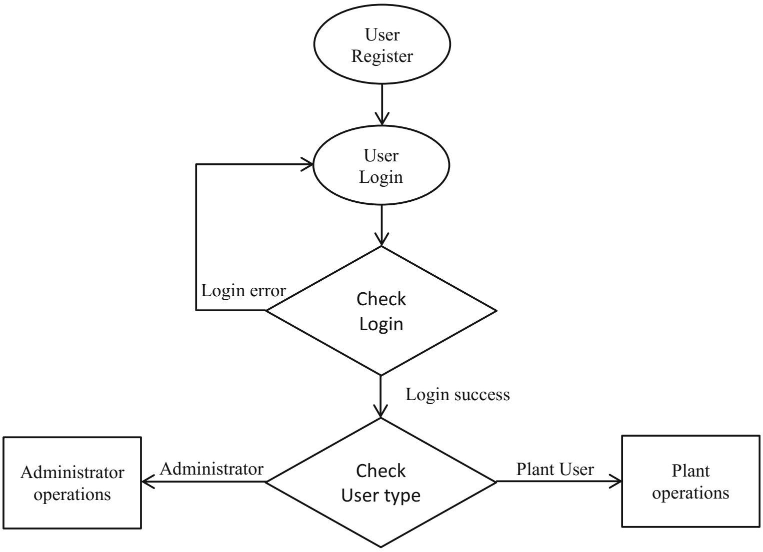
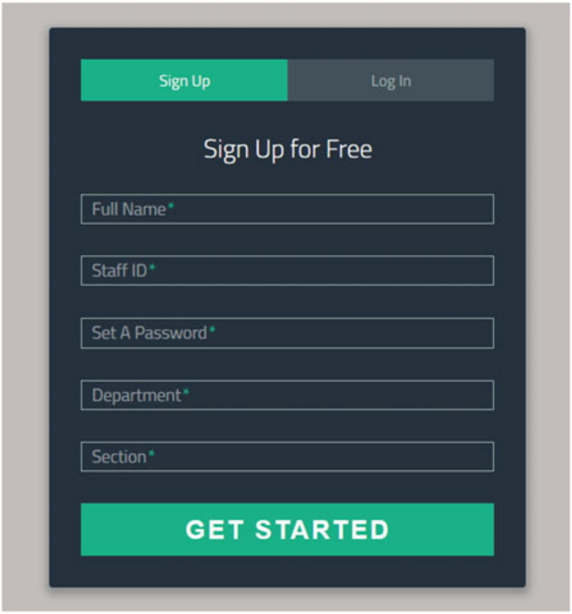


Fig. 4 Flow diagram of the system

The system works as follows, after registering to the system (refer Fig. 5), the user can log into the system for data input purpose.

Then, once the user logs into the system the comparison module page of the system appears. Figure 6 displays one out of seven comparison modules. Each question defined under different potential risks is answered and scale is selected. After the comparison module is completed, user click button "Next questions" and

Fig. 5 User interface: registration page of the web-based system



When you are considering the ergonomics job task risk factors in the early phase of project, which one do you think is more important to make improvemnet and how amny times more important than others?

No.	First Pair	Values									Second Pair
		5	4	3	2	1	2	3	4	5	
1.	Carrying and lifting heavy loads	○	○	○	○	○	○	○	○	○	Poor working practice
2.	Carrying and lifting heavy loads	○	○	○	○	○	○	○	○	○	Heavy physical work
3.	Carrying and lifting heavy loads	○	○	○	○	○	○	○	○	○	Frequent work lifting
4.	Carrying and lifting heavy loads	○	○	○	○	○	○	○	○	○	Force exertion in job task
5.	Carrying and lifting heavy loads	○	○	○	○	○	○	○	○	○	Poor working posture
6.	Poor working practice	○	○	○	○	○	○	○	○	○	Heavy physical work
7.	Poor working practice	○	○	○	○	○	○	○	○	○	Frequent work lifting
8.	Poor working practice	○	○	○	○	○	○	○	○	○	Force exertion in job task
9.	Poor working practice	○	○	○	○	○	○	○	○	○	Poor working posture
10.	Heavy physical work	○	○	○	○	○	○	○	○	○	Frequent work lifting
11.	Heavy physical work	○	○	○	○	○	○	○	○	○	Force exertion in job task
12.	Heavy physical work	○	○	○	○	○	○	○	○	○	Poor working posture
13.	Frequent work lifting	○	○	○	○	○	○	○	○	○	Force exertion in job task
14.	Frequent work lifting	○	○	○	○	○	○	○	○	○	Poor working posture
15.	Force exertion in job task	○	○	○	○	○	○	○	○	○	Poor working posture

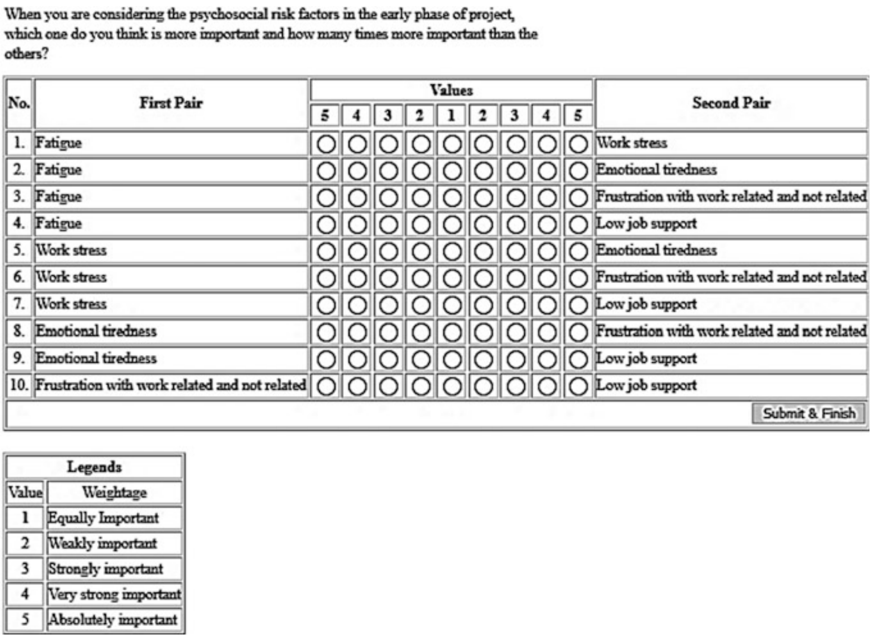
Next Question >

Legends	
Value	Weightage
1	Equally Important
2	Weakly important
3	Strongly important
4	Very strong important
5	Absolutely important

Fig. 6 User interface: comparison module for job task risk factors

system allows the user to pass on to the next page. Afterward, the user clicks the button "submit and finish" (see Fig. 7), the end of questions and data input process.

The registration page (refer Fig. 5) will appear for next data input. Once completing the comparison modules, the system calculates the risk factors weight. After the prioritization process, the system provides the user with intermediate results consisting of the priority factors and the consistency of the pairwise comparison module.



When you are considering the psychosocial risk factors in the early phase of project, which one do you think is more important and how many times more important than the others?

No.	First Pair	Values									Second Pair
		5	4	3	2	1	2	3	4	5	
1.	Fatigue	○	○	○	○	○	○	○	○	○	Work stress
2.	Fatigue	○	○	○	○	○	○	○	○	○	Emotional tiredness
3.	Fatigue	○	○	○	○	○	○	○	○	○	Frustration with work related and not related
4.	Fatigue	○	○	○	○	○	○	○	○	○	Low job support
5.	Work stress	○	○	○	○	○	○	○	○	○	Emotional tiredness
6.	Work stress	○	○	○	○	○	○	○	○	○	Frustration with work related and not related
7.	Work stress	○	○	○	○	○	○	○	○	○	Low job support
8.	Emotional tiredness	○	○	○	○	○	○	○	○	○	Frustration with work related and not related
9.	Emotional tiredness	○	○	○	○	○	○	○	○	○	Low job support
10.	Frustration with work related and not related	○	○	○	○	○	○	○	○	○	Low job support

Submit & Finish

Legends	
Value	Weightage
1	Equally Important
2	Weakly important
3	Strongly important
4	Very strong important
5	Absolutely important

Fig. 7 User interface: comparison module for psychosocial risk factors

4.3 Results

In this study, the experience with the system and ergonomics risk factors data obtained from the company resulted in a priority vector as illustrated in Table 2.

Based on the results acquired in the AHP analysis, the following statements can, therefore, be made:

i. Organizational risk factors are more critical than physical risk factors.
ii. Physical risk factors are more critical than psychosocial risk factors.
iii. Psychosocial risk factors are more critical than individual risk factors.
iv. Individual risk factors are less significant than organizational risk factors.

The weights for each of the factors in the hierarchy were calculated in line with their perceived contribution to the risky situation to the workers in automotive component production plant (refer Table 3).

Table 2 Priority results for ergonomics risk factors related to WMSD

Criteria	Priority
Individual ergonomics risk factors	0.0845
Organizational ergonomics risk factors	0.5440
Physical ergonomics risk factors	0.2036
Psychosocial risk factors	0.1679

Table 3 Ranking of risk factors associated with WMSD

Ergonomics risk factors	Global priority (%)	Rank
Exposure to physical demands	*26.33*	*1st*
Higher work load	*10.29*	*2nd*
Tight working schedules	6.41	3rd
Equipment or tools heavy weight	*6.10*	4th
Frequent work days	*5.99*	5th
Low job support	5.79	6th
Lack of rest	5.38	7th
Poor work space	4.26	8th
Fatigue	3.51	9th
Frustration with work related and not related	3.48	10th
Lose focus when higher work load	3.46	11th
Emotional tiredness	2.39	12th
Noise in working environment	2.20	13th
Poor temperature in working environment	2.12	14th
Poor ventilation in working environment	1.72	15th
Work stress	1.62	16th
Working experience	1.60	17th
Negligence of worker	1.60	17th
Improper use of personal protector equipment	1.34	19th
Force exertion in job task	1.06	20th
Poor working posture	1.01	21st
Poor working practice	*0.53*	*22nd*
Heavy physical work	*0.51*	*23rd*
Carrying and lifting heavy loads	*0.47*	*24th*
Age	*0.44*	*25th*
Frequent work lifting	*0.37*	*26th*

The overall prioritization revealed that 'exposure to physical demands' had a priority vector of 26.33%, and it was perceived as the item with the most critical factor. It is compulsory to execute a consistency validation for each hierarchy and the model as a whole for every comparison module form. In this regard, Table 4

Table 4 Consistency validation

Comparison modules	CR
Criteria of occupational ergonomics risk factors	0.0517
Sub-criteria of Individual risk factors	0.0923
Sub-criteria of organizational risk factors	0.0295
Sub-criteria of physical risk factors	0.0000
Sub-criteria of physical (job task) risk factors	0.0712
Sub-criteria of physical (workplace and equipment) risk factors	0.0596
Sub-criteria of psychosocial risk factors	0.0074

shows consistency ratio (CR) value consistency check. Since the CR for all comparison modules is less than 0.1, the hierarchy has therefore passed consistency validation.

Acknowledgements We thank University Malaysia Pahang (UMP) for grant support RDU160390, the Ministry of Higher Education Malaysia (MoHE) of the scholarship SLAI (Sijil latihan akademik IPTA).

References

1. Sylla, N., Bonnet, V., Colledani, F., Fraisse, P.: Ergonomic contribution of ABLE exoskeleton in automotive industry. Int. J. Ind. Ergon. **44**, 475–481 (2014). https://doi.org/10.1016/j.ergon.2014.03.008
2. Yoon, S.-Y., Ko, J., Jung, M.-C.: A model for developing job rotation schedules that eliminate sequential high workloads and minimize between-worker variability in cumulative daily workloads: application to automotive assembly lines. Appl. Ergon. **55**, 8–15 (2016). https://doi.org/10.1016/j.apergo.2016.01.011
3. Anita, A.R., Yazdani, A., Hayati, K.S., Adon, M.Y.: Association between Awkward posture and Musculoskeletal disorders (MSD) among assembly line workers in an automotive industry. Malays. J. Med. Heal. Sci. **10**, 23–28 (2014)
4. Aziz, F.A., Ghazalli, Z., Mohamed, N.M.Z., Isfar, A.: Investigation on musculoskeletal discomfort and ergonomics risk factors among production team members at an automotive component assembly plant. In: IOP Conference Series: Materials Science and Engineering, p. 12040. IOP Publishing (2017)
5. Nur, N.M., Dawal, S.Z., Dahari, M.: The prevalence of work related musculoskeletal disorders among workers performing industrial repetitive tasks in the automotive manufacturing companies, pp. 1–8. Int. Conf. Ind. Eng. Oper. Manag. Bali, Indones (2014)
6. İnan, U.H., Gül, S., Yılmaz, H.: A multiple attribute decision model to compare the firms' occupational health and safety management perspectives. Saf. Sci. **91**, 221–231 (2017). https://doi.org/10.1016/j.ssci.2016.08.018
7. Mohammadfam, I., Kamalinia, M., Momeni, M., Golmohammadi, R., Hamidi, Y., Soltanian, A.: Evaluation of the quality of occupational health and safety management systems based on key performance indicators in certified organizations. Saf. Health Work. **8**, 156–161 (2017). https://doi.org/10.1016/j.shaw.2016.09.001
8. Khandan, M., Aligol, M.H., Shamsi, M., Poursadeghiyan, M., Biglari, H., Koohpaei, A.: Occupational health, safety, and ergonomics challenges and opportunities based on the organizational structure analysis: a case study in the selected manufacturing industries in Qom Province, Iran, 2015. Ann. Trop. Med. Public Heal. **10**, 606–611 (2017). https://doi.org/10.4103/ATMPH.ATMPH_110_17
9. Oakman, J., Rothmore, P., Tappin, D.: Intervention development to reduce musculoskeletal disorders: Is the process on target? Appl. Ergon. **56**, 179–186 (2016). https://doi.org/10.1016/j.apergo.2016.03.019
10. Karaca, F.: An AHP-based indoor air pollution risk index method for cultural heritage collections. J. Cult. Herit. **16**, 352–360 (2015). https://doi.org/10.1016/j.culher.2014.06.012
11. Lam, H.Y., Choy, K.L., Ho, G.T.S., Cheng, S.W.Y., Lee, C.K.M.: A knowledge-based logistics operations planning system for mitigating risk in warehouse order fulfillment. Int. J. Prod. Econ. 1–17 (2015). https://doi.org/10.1016/j.ijpe.2015.01.005
12. Saaty, T.L.: Decision making with the analytic hierarchy process. Int. J. Serv. Sci. **1**, 83 (2008). https://doi.org/10.1504/IJSSCI.2008.017590

13. Xiong, D., Chen, J.: A web-based automatic warning system for citrus bacteria canker disease using AHP methodology. In: Proceedings of the 2011 International Conferences Information Technology Computer Engineering and Management Sciences ICM 2011 vol. 1, pp. 324–327 (2011). https://doi.org/10.1109/icm.2011.200
14. Sundarraj, R.P.: A web-based AHP approach to standardize the process of managing service-contracts. Decis. Support Syst. **37**, 343–365 (2004). https://doi.org/10.1016/S0167-9236(03)00033-2
15. Rafeemanesh, E., Kashani, F.O., Parvaneh, R., Ahmadi, F.: A Survey on low back pain risk factors in steel industry workers in 2015. Asian Spine J. **11**, 44–49 (2017)
16. Biswas, G., Bhattacharya, A., Bhattacharya, R.: Occupational health status of construction workers: a review. Int. J. Med. Sci. Public Heal. **6**, 1 (2017). https://doi.org/10.5455/ijmsph.2017.0745302112016
17. de Cássia Pereira Fernandes, R., da Silva Pataro, S.M., de Carvalho, R.B., Burdorf, A.: The concurrence of musculoskeletal pain and associated work-related factors: a cross sectional study. BMC Public Health **16**, 628 (2016). https://doi.org/10.1186/s12889-016-3306-4
18. Bodin, J., Garlantézec, R., Costet, N., Descatha, A., Fouquet, N., Caroly, S., Roquelaure, Y.: Forms of work organization and associations with shoulder disorders: results from a French working population. Appl. Ergon. **59**, 1–10 (2017). https://doi.org/10.1016/j.apergo.2016.07.019
19. Cakir, O., Canbolat, M.S.: A web-based decision support system for multi-criteria inventory classification using fuzzy AHP methodology. Expert Syst. Appl. **35**, 1367–1378 (2008). https://doi.org/10.1016/j.eswa.2007.08.041
20. Saaty, T.L.: The analytic hierarchy process. Decis. Anal. 1–17 (1980)
21. Saaty, R.W.: The analytic hierarchy process-what it is and how it is used. Math. Model. **9**, 161–176 (1987). https://doi.org/10.1016/0270-0255(87)90473-8
22. Saaty, T.L.: How to make a decision: the analytic hierarchy process. Interfaces (Providence). **24**, 19–43 (1994). https://doi.org/10.1287/inte.24.6.19