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A web-based ergonomics assessment system for prioritizing critical work-related musculoskeletal disorders risk factor

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Abstract. Work-related musculoskeletal disorder (WMSD) is one of critical health disease, and large numbers of industry workers are not even aware they have it due to a lack of ergonomics knowledge. This paper seeks to describe the development of a web-based ergonomics assessment system (W-BEAS) for risk factors that lead to WMSD growth. There are four main ergonomics risk factors, and 26 sub-factors have selected based on literature review, discussions with experts and questionnaire survey among automotive production workers. These factors employed in the analytic hierarchy structure (AHP) model for analysis purpose. The integration of AHP and the web-based expert system (WBES) were developed to support the W-BEAS. W-BEAS had pre-tested and evaluated by ten experienced workers of an automotive component manufacturer. The inconsistency ratio for all comparison module ranged from 0 to 0.045, shows that the judgment is consistent because of value less than 0.1. Respondents considered organizational risk factor (OF=0.544) is the most critical to lead the WMSD growth. The respondents achieve an average of 3.95 for both content satisfaction and system satisfaction. Respondents were satisfied with W-BEAS content and system performance. The preliminary results confirmed that the W-BEAS effectively helped workers to identify the critical ergonomics risk factors. The existence of the W-BEAS application that has designed is expected to be an ergonomics assessment tool to guide workers in decision-making, and provide the best solution that meets employer needs, so WMSD critical risk resolved effectively and efficiently.

Keywords. Web-based assessment system; ergonomic risk factors; Expert system; analytical hierarchy process (AHP); knowledge-based system (KBS).

1. Introduction

Industry workers performing manual operations subjected to WMSD [1,2]. The high prevalence of WMSD 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.



The OHSMS focus should not be on the development of healthy and safe working conditions only, but also equally to the workplace comfort and wellness, and employee's well-being. Most of the companies had no information with regards to the ergonomics performance [8]. The MSDs consistently continues as one of the OSH related problems due to OSH, and ergonomic intervention has not wholly implemented [9]. A significant research statement that arises here then is that workplace ergonomics risk assessment in the industry done minimally and ineffectively. The primary cause of this situation is the lack of knowledge for its realization among the workers. That is, the research statement is that knowledge is a critical factor in realizing and improving workplace ergonomics assessment.

For this reason, this paper intends to address the problems of ergonomics risk assessment from a knowledge-based (KB) approach and through a system perspective. Thus, a research effort whose ultimate purpose is to develop an ergonomics assessment system based on knowledge, to support workplace ergonomics management in an automotive manufacturer. The current study employs artificial intelligence to develop computer software programs that are designed to reproduce the critical thinking capacities of human experts in a knowledge-based system (KBS). KBSs are computer-based information systems that constitute knowledge of experts and able to resolve problems at an expert's level of performance [10]. Furthermore, integration with the multiple criteria decision making (MCDM) is necessary for prioritizing the ergonomics risks factors.

The developed algorithm of the system based on the analytic hierarchy process (AHP) technique [11], for the rules and inference engine. The AHP was used for MCDM process and provides reasonable support [12], flexible approach to risk analysis [13] and offers a quantitative method for analysing subjective information [15]. The ergonomics assessment system aimed is to identify the priority risk factors for workplace ergonomics, easier application [16,17] and less complicated MCDM strategies like AHP ought to be adequate [18]. In this circumstance, choosing more complicated procedures like Fuzzy AHP won't create distinctive results [19–21].

Within this work, a web-based expert system (WBES) for ergonomics assessment of risk factors related to WMSD developed. WBES is the integration of KBS technology with web technology and accessing the expert system via the website [22]. WBES can provide the benefits of KBS and Internet technology or internet of things (IoT) [23]. The unique advantages of utilizing WBES in decision making is the possibility to beat limited resources in terms of time, data and communication [24]. IoT is one of the nine pillars of Industry 4.0 which are increasingly applicable [25]. The current study supports the Industry 4.0 attention with the integration of human in the industry to achieve constant improvement and concentrate value-adding activities [26]. Besides, WBES can be used by any platform, any time and any place within internet connection areas [27] and likewise produce the collaborative work [28].

Many researchers have presented their works on the ESs to assess the WSMD [29–33]. However, these ESs showed limited ability to tackle the ergonomics risk of physical and organizational factors. Thus, compared to previous studies the W-BEAS applied the macro-ergonomics factors including ergonomics risk of the individual, organizational, physical and psychosocial. Furthermore, the W-BEAS combined with deployment on the internet to make it accessible anywhere and anytime are the factors that distinguish W-BEAS from all previous expert systems (ESs) of risk assessment of WMSD reported in the open literature [34–37].

This paper objective to develop a web-based ergonomics assessment system (W-BEAS) for prioritizing the critical ergonomics risk factors related to WMSD using the AHP technique by estimating the weights. The W-BEAS employs KB and AHP as decision algorithms to prioritize the essential risk factors. KB and AHP as an inference engine (IE) integrated into a web server through which it can access from any device with an Internet connection. The significance of this study is to produce fast and straightforward ergonomics assessment tools accessible via web browsers as well as mobile devices. Furthermore, provide an expert-based decision making available to any level of expertise. This paper is structured as follows: Section 2 gives work-related musculoskeletal disorders risk factors. In Section 3 is W-BEAS development. Section 4 is pre-testing and evaluation of W-BEAS. Section 5 concludes the work and future directions of the study.

2. WMSD risk factors

There was a general consensus among scholars in relation to the multifactorial idea of WMSDs[38]. Among the various factors associated, it was learned that the WMSD development is influenced by the physical demand of tasks[39,40], work organizational hazards[41,42] and psychosocial contexts[43,44]. Besides, personal factors such as individual perceptions and other related characteristics are equally important in dealing with risk management[38,45]. Maakip et al., has suggested to fully explore the role of the work environment in developing countries on the development of WMSD [46]. Correspondingly, an accurate set of risk factors are required to implement effective ergonomics programmes[47]. Therefore, several ergonomics risk factors including individual, organizational, physical and psychosocial have been explored in this study.

2.1. Individual ergonomics

Individual ergonomics is concerned with personal competence, background, skills, personality, attitude, and risk perception. Individual characteristics influence behavior in complex ways. Individual factors such as age, gender, body weight, and being involved in physical activities associated with musculoskeletal symptoms of a different body part [48].

2.2. Organizational ergonomics

Organizational ergonomics is concerned with optimizing sociotechnical systems including their organizational structures, policies, and processes. The organizational factors may produce the following ergonomics risks including shift work, paced work, imbalanced work-rest ratios, demanding work standards, and lack of task variety [35].

2.3. Physical ergonomics

Generally physical ergonomics is concerned with biomechanical characteristics as they are related to physical activity. Physical ergonomics is required in design intervention [49] and connected to real and potential quality deviation [50] in the manufacturing industry.

2.4. Psychosocial ergonomics

Psychosocial ergonomics is concerned with interactions among job content, work organization and management. WMSD was initiated by a combination of many psychosocial risks and high physical demand works [43]. A systematic process operating at the organizational level is required in preventing potential psychosocial risks at the workplace [51].

Based on literature review, discussions with experts and questionnaire survey among automotive production workers, the twenty-six risk sub-factors were selected to develop the proposed AHP decision model. Fig. 1 depicts a hierarchy structure of the AHP decision model for WMSD critical risk factors.

3. W-BEAS development

W-BEAS was designed and developed by the authors to assist the evaluation of ergonomics risk factors that lead to WMSD development. W-BEAS has consolidated the power of knowledge-based system, AHP techniques, and empirical data. The W-BEAS was designed as web based expert system since it was planned to accessible anytime and anyplace inside the organization. Effective AHP-based expert system requires an appropriate model construction that considers all essential attributes of the ergonomics risk factors and approaches their particular significance (weights) from the user. This study follows the AHP procedures to acquire critical risk factors through a pairwise comparison process and create prioritization.

3.1. AHP analysis

The variety of risk factors within each identified category may have tremendous variability from worker to worker, a viable means for evaluating and getting some degree of significance of the risk factors are necessary. AHP analysis does this in WMSD. AHP has been successfully applied to a wide range of

problems in occupational safety, health and ergonomics [52–56]. AHP approach can measure the decision maker's experiential judgments, mainly when the aims lacked quantifiable data. AHP with hierarchy structure helps the decision makers to understand the priorities of their selection [57] and applied to manage the importance weight of each critical factor [15].

When the knowledge data based is completed each expert has been asked to make pair-wise comparisons involving all pairings of the risk factors within each of the four modules or main elements including individual, organizational, physical and psychosocial ergonomics risk factors. The primary task of the AHP is to determine the relative importance of the risk factors through the pair-wise comparisons process. The overall importance of one risk factor over others is calculated using a rating scale proposed by [58]. The AHP-based approach involves the following main steps:

- *Step 1:* Develop a hierarchy of factors influencing the last decision (refer figure 1).

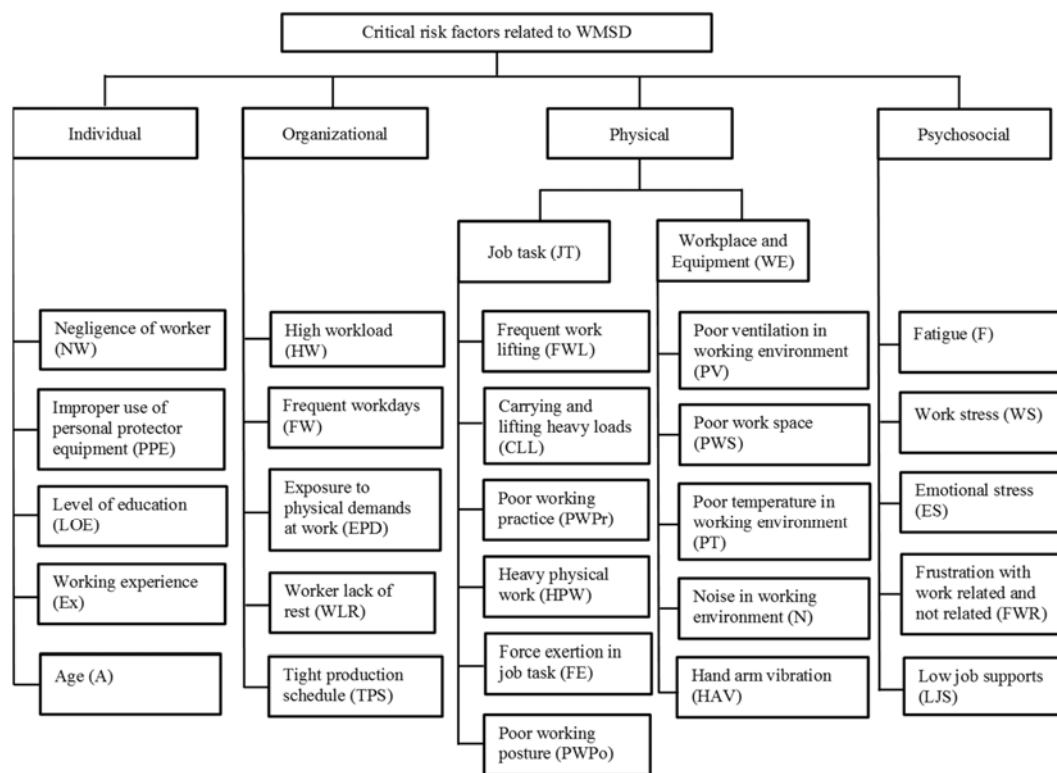


Figure 1. Hierarchical structure of the AHP model for WMSD critical risk factor.

- *Step 2:* Make pair-wise comparisons: Area experts are asked to evaluate the relative critical of risk factors within and among the significant levels and construct a pair-wise comparison matrix. Weights corresponding to the relative importance of all factors in each hierarchy can then calculated. For n factor, $n(n-1)/2$ comparisons are made.
- *Step 3:* The process of calculating the priority of each risk factor in terms of its contribution to the overall goal. It involves the following steps.
- *Step 3.1:* Once the overall expert judgments are created and calculated using the geometric mean (GM_i), refer equation (1).

$$GM_i = \sum_{i=1}^n \sqrt[n]{a_{ij}} = \sqrt[n]{a_{i1} \times a_{i2} \times \dots \times a_{in}} \quad (1)$$

Where n = number of participants

- *Step 3.2:* The next step is to calculate a vector of local priority weights of elements, refer equation (3). The first eigenvector w of the matrix can be calculated using the equation (2).

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

$$\text{Eigenvalues} = \text{local priority weight} = \frac{\sum_{i=1}^n w_i}{n} \quad (3)$$

Where n = number of elements

- *Step 3.3:* The synthesized weight or global priority weight for elements presented as in the equation (4):

$$\text{Global priority vector, } W_i = CLW \times SCLW \quad (4)$$

Where CLW is criteria local weight and SCLW is sub-criteria local weight

- *Step 4:* 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 (CR) can be seen in the equation (5) and (7).

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

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

where, λ_{\max} = maximum eigenvalue and n is the number of elements

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

If the value of CR is smaller or equal to 10% the difference is acceptable. If the CR is higher than 10%, then the subjective judgment need to be revised. In the closing part of the risk factor analysis, the AHP method assesses priority weights for different factors that are useful in evaluating the overall risk level of the system.

3.2. Architecture design of W-BEAS

3.2.1. System architecture. The basic structure of W-BEAS includes the user interface, a knowledge based and an AHP inference engine. The system was implemented using XAMPP for AHP inference engine and MySQL server is used as a database. XAMPP consists mainly of the Apache HTTP Server, Maria DB database, and interpreters for scripts written in the PHP and Perl programming languages. The W-BEAS structure illustrated in figure 2.

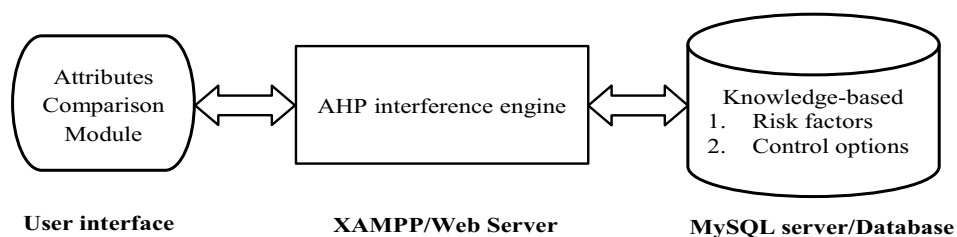


Figure 2. Architecture of W-BEAS.

The W-BEAS has five major components. Figure 3 shows the system components and their corresponding functions.

- 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 technique to calculate each factor and sub-factor weights. The consistency test for data input also performed. This component can retrieve the corresponding numerical values regarding the submitted specific condition about those factor and sub-factor mentioned previously.
- The fourth component is data output part. This component is to prioritize for main factor and sub-factor of ergonomics risk related to WMSD.
- The fifth component is assessment results in table and graph form.

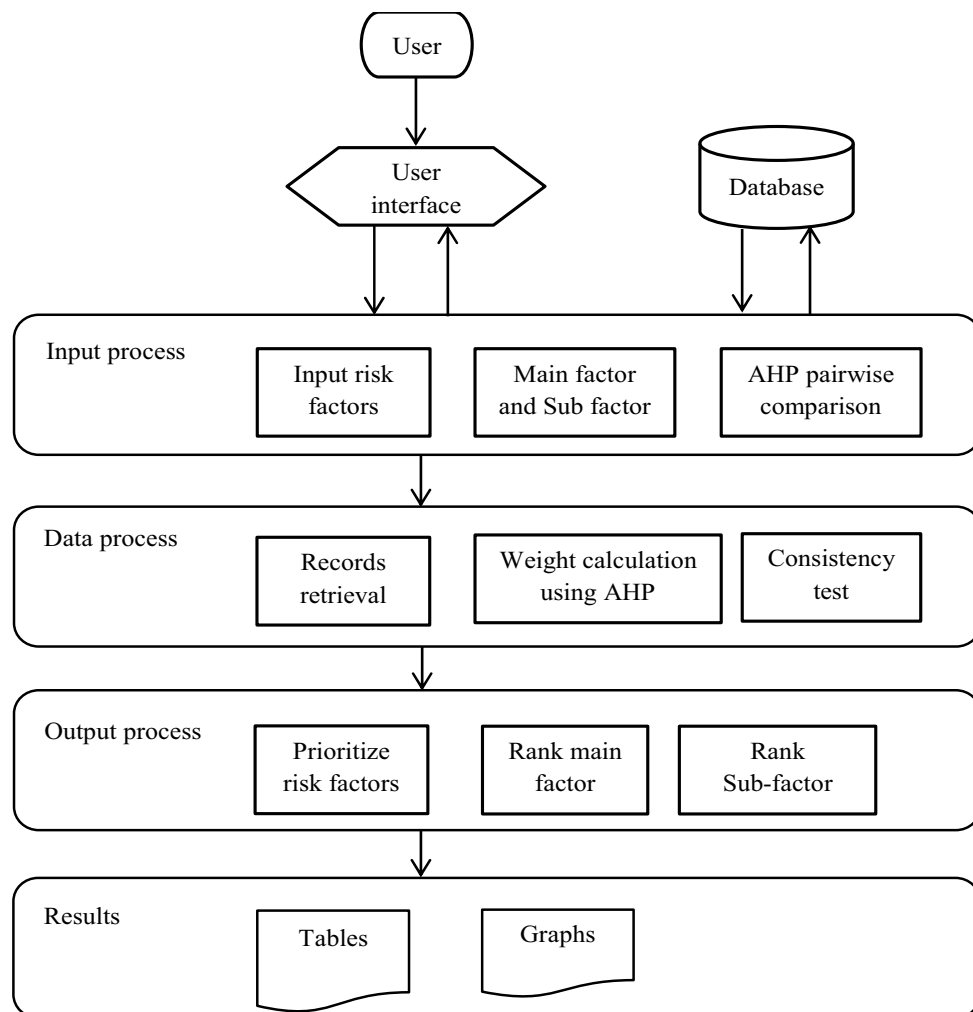


Figure 3. Components of the W-BEAS and their corresponding functions.

In total, W-BEAS contains sixty-two questions inscribe the assessment criteria including main factors and sub-factors of ergonomics risk related to WMSD. Figure 4 displays a screenshot for the W-BEAS interface of the home page. Figure 5 depicts one out of seven pages containing system interface of comparison modules. Other screenshots copies are given in figure 6 and figure 7.

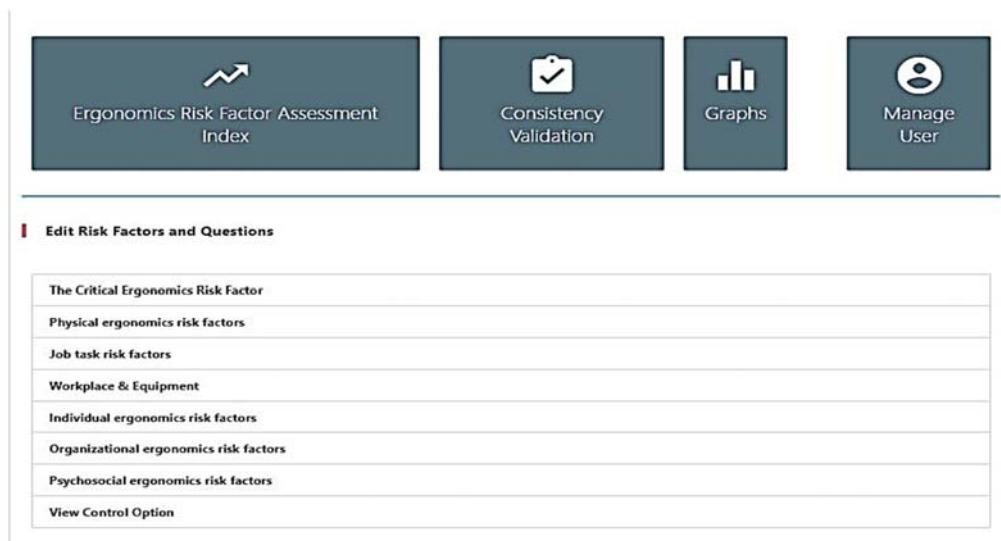


Figure 4. User interface: Home page of W-BEAS.

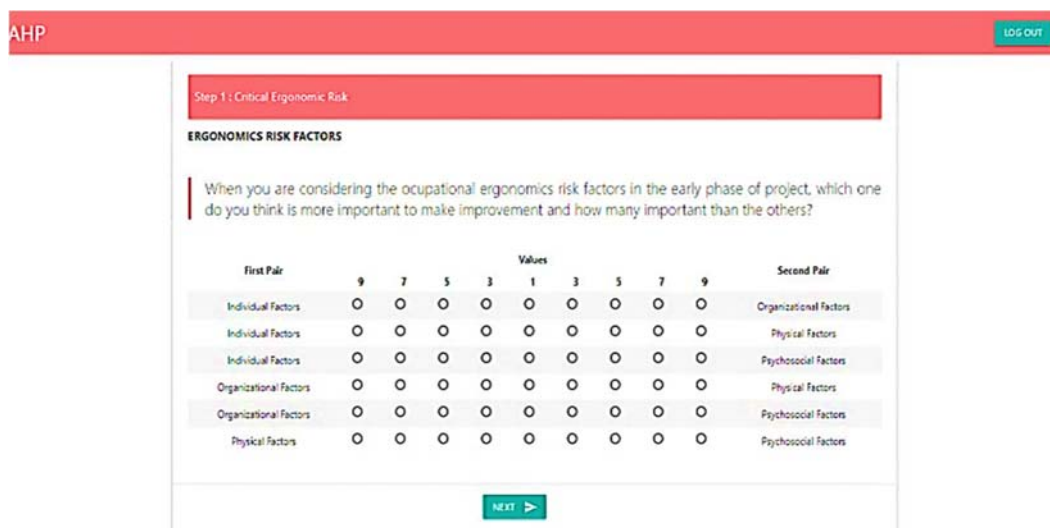


Figure 5. User interface: Comparison Module for ergonomics risk factors.

The priority weight of assessment factors and sub-factors serve as the critical indicators of risk factors lead to WMSD growth. The W-BEAS first collects preference data from each pairwise comparison and then converts them into a normalized scale, using the described normalization process. After that, the aggregated preference score indicates the most critical risk factor (refer figure 6 and 7). The control options for each risk factors are available in W-BEAS for worker guideline. In turn, the consistency results display for each comparison modules (see figure 8).

AHP Home Assessment Index Consistency Validation Graphs Manage User LOG OUT

Click the criteria for more info

Criteria (1st level)	Local priority	Group Rank	Sub criteria (2nd level)	Local priority	Group Rank	Sub criteria (3rd level)	Local priority	Group Rank	Global priority	%	Global Rank
Individual ergonomics risk factors	0.0714	4				Negligence of workers (NW)	0.2173	2	0.0155	1.5518	15
						Improper use of personal protector equipment (PPE)	0.1296	4	0.0093	0.9252	21
						Level of education (LE)	0.4427	1	0.0316	3.1608	10
						Working experience (WE)	0.1676	3	0.012	1.1963	18
						Worker age (A)	0.0428	5	0.0031	0.3055	25
Organizational ergonomics risk factors	0.5694	1				High work load (HWL)	0.222	2	0.1264	12.6424	2
						Exposure to physical demands at work (EPD)	0.4971	1	0.2831	28.3055	1
						Tight production schedule (TPS)	0.1149	3	0.0654	6.5445	3
						Frequent work days (FWD)	0.0941	4	0.0536	5.3604	6
						Lack of rest (LR)	0.0718	5	0.0409	4.086	7

Figure 6. Result interface: Example of ergonomics assessment results in table form.

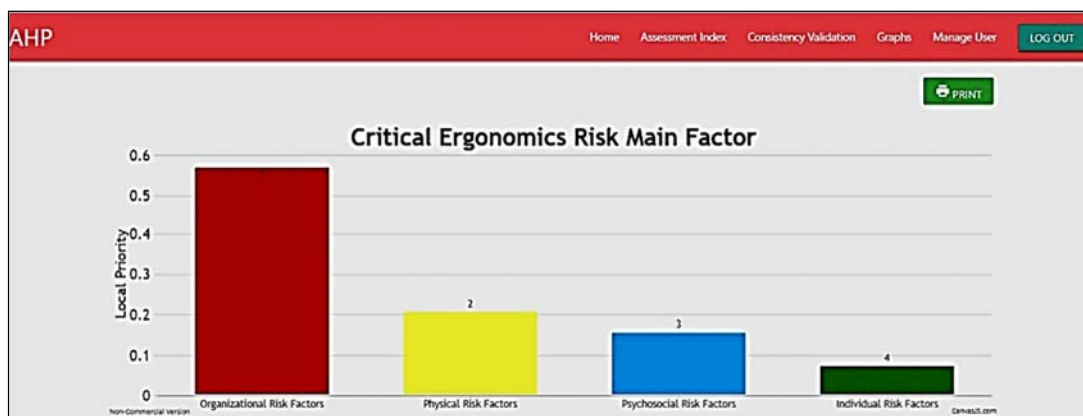


Figure 7. Result interface: Example of priority local weight results in graph form.

AHP Home Assessment Index Consistency Validation Graphs Manage User LOG OUT

Comparison Module	Level	λ_{max}	CI	CR*	Consistency validation (%)
Criteria - ergonomics risk factors	Level 1	4.13625	0.04542	0.05046	5.05 < 10%
Sub-criteria - Individual ergonomics risk factors	Level 2	5.39458	0.09865	0.08808	8.81 < 10%
Sub-criteria - Organizational ergonomics risk factors	Level 2	5.30221	0.07555	0.06746	6.75 < 10%
Sub-criteria - Physical ergonomics risk factors	Level 2	2	0	0	0 < 10%
Sub-criteria - Jobtask (JT)	Level 3	6.53842	0.10768	0.08684	8.68 < 10%
Sub-criteria - Workplace and equipment (WE)	Level 3	5.3424	0.0856	0.07643	7.64 < 10%
Sub-criteria - Psychosocial ergonomics risk factors	Level 2	5.29239	0.0731	0.06527	6.53 < 10%

*Note: If the value of CR is smaller or equal to 0.1, the inconsistency is acceptable. If the CR is greater than 0.1, the subjective judgment need to be revised.

Figure 8. User interface: Example of comparison module consistency results.

4. Preliminary test and evaluation of W-BEAS

4.1. Preliminary test of W-BEAS

The W-BEAS tentatively tested with experienced workers in a vehicle component manufacturer. Ten senior employees were selected based on their knowledge, working experiences, and expertise. Employee's know-how applied to judge and evaluates the ergonomics risk factor used in all levels of the hierarchy and to provide the corresponding pair-wise comparison judgments using the five-point scale. They have had more than ten years working experience in the automotive production plant, attach in the related department and holding variety position titles. They are knowledgeable and can present well the general practices and opinions of workplace ergonomics in evaluating the risk and assigning the relative scales to determine the relative rank of factor or sub-factor of the formulated AHP model.

W-BEAS had temporarily installed in company server for testing purpose. Then, the W-BEAS database link has shared with selected workers for them to browse through the internet connection to perform the ergonomics risk assessment. Each worker was then allowed to use the W-BEAS, and within 20 minutes each worker had completed this, and the system had identified the critical ergonomics risk factors that can contribute to the development of a WMSD.

As summarized in table 1, observed that it has significant between-group differences in age, education level, and working experience. The users involved in the W-BEAS application also have a comparable working department and working position. All respondents are male and working in normal shift.

Table 1. Demographic information of respondents.

Demographic dimension		Freq.	%
Age (years)	35 ~ 44	7	70
	45 ~ 55	3	30
Gender	Male	10	100
	Female	0	0
Education level	Certificate	3	30
	Diploma	4	40
	Degree	3	30
Working experience (years)	11 ~ 15	6	60
	16 ~ 20	4	40
Working Department	Production Assembly	3	30
	Production Stamping	2	20
	Engineering	2	20
	Safety, health and environment	3	30
Working Position	Executive	2	20
	Engineer	2	20
	Assistant Manager	4	40
	Manager	2	20
Working time	Normal	10	100
	Shift	17	0

A combined matrix or comparison module of the normalized priority weights of assessment risk factor was generated by calculating the geometric mean of the entries from respondents. The computations of the inconsistency indices for these comparison module ranged from 0 to 0.045 (see figure 9 to 15), the judgment is consistent since the inconsistency ratio is lower than 0.1 as suggested by [59]. The pair wise comparison is also used to rank the sets of sub-factor with respect to their associated main factor. The results are shown in figure 9 to 15. As shown in figure 9 respondents considered organizational risk factor (OF=0.544) is the most critical for and followed by physical risk factor (PhyF=0.216) and two others.



Figure 9. Ranking of main ergonomics risk factor.

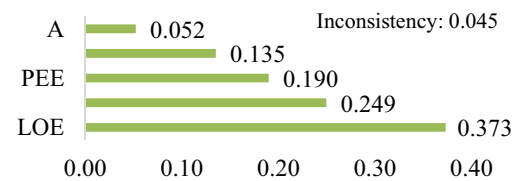


Figure 10. Ranking of sub factor with respect to main factor "individual".

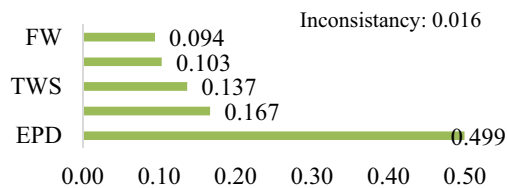


Figure 11. Ranking of sub factor with respect to main factor "organizational".

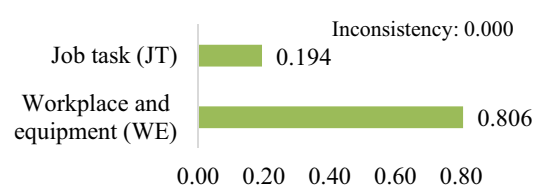


Figure 12. Ranking of sub factor with respect to main factor "physical".



Figure 13. Ranking of sub factor with respect to main factor "physical-job task".

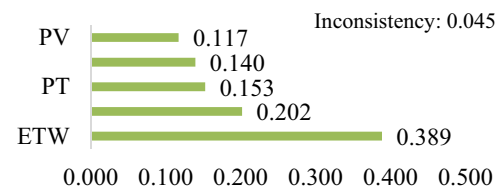


Figure 14. Ranking of sub factor with respect to main factor "physical-workplace and equipment".

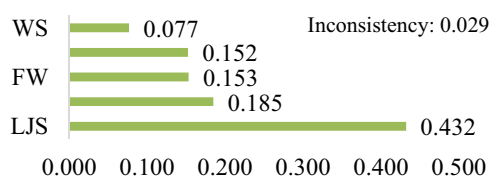


Figure 15. Ranking of sub factor with respect to main factor "psychosocial".

4.2. Initial evaluation of W-BEAS

W-BEAS performance evaluation is required so that this kind of expert system is legally or officially acceptable by the users. User's recognition or affirmation to the system is important and valid. To evaluate the W-BEAS, current study measured the user's satisfaction with the content and system application in general. Content satisfaction thus refers to the extent to which an assessor is satisfied with the ergonomics risk factors that a system evaluates. System satisfaction, in contrast, denotes the degree to which an assessor is satisfied with his or her use of and interaction with a recommendation system. We adapt question items from the previous study to measure content and system satisfaction, with some adjustments to appropriate this study context [60].

A post-evaluation survey was conducted to evaluate the efficacy of W-BEAS. An evaluation instrument contains eight items addressing the self-assessment mechanism of the system. A five-point Likert scale was used with 1 = strongly disagree, and 5 = strongly agree. The respondents are same who had used the W-BEAS during the system testing purposed.

To measure the reliability of measurements instruments examines their internal consistency based on Cronbach's alpha [61]. Table 2 and table 3 summarizes descriptive data for the items used to measure W-BEAS satisfaction. The alpha values range between 0.737 and 0.866, considerably higher than the standard threshold of 0.70. Thus, the measurement instrument shows satisfactory reliability.

As table 5 and table 6 displays, the respondents achieve an average of 3.95 in content satisfaction and 3.95 in system satisfaction. This finding suggests the respondents were satisfied for W-BEAS content in producing critical ergonomics risk factors and the overall system performance.

Table 2. Analysis of content satisfaction and reliability scores.

Measurement item	Mean	SD	Cronbach's Alpha
Content satisfaction			
1. Evaluation factor used in this system are enough to evaluate and rank the ergonomics risk factors	4.10	0.738	0.737
2. This system effectively helped me in prioritizing criteria for evaluation of the ergonomics risk factors	3.80	0.789	
3. This system effectively helped me to specify the ergonomics risk factors	4.00	0.667	
4. I can effectively complete task of evaluation of the ergonomics risk factors using this system	3.90	0.568	
Average	3.95	0.691	

Table 3. Analysis of system satisfaction and reliability scores.

Measurement item	Mean	SD	Cronbach's Alpha
System satisfaction			
5. This system is easy to learn and to use	4.30	0.483	0.866
6. I am satisfied with the tool in term of workplace ergonomics assessment procedure	3.70	0.675	
7. This system has all the functions and capabilities i expected it to have	3.90	0.876	
8. Overall I am satisfied with this system	3.90	0.738	
Average	3.95	0.693	

Current study examines the convergent and discriminant validity of the measurement instrument through principle components factor analysis [61]. As revealed in table 4, the Kaiser Meyer-Olkin value was 0.611, exceeding the recommended value of 0.6 and Bartlett's Test of Sphericity, $p < 0.05$ reached statistical significance, supporting the factorability of the correlation matrix [62]. Therefore, our instrument shows adequate convergent and discriminant validity. Overall, current study findings express the practicality and value of using the AHP technique to construct effective W-BEAS for critical risk factors prioritization. As emphasized by our experimental results, users are satisfied with the risk factors prioritization offered by the W-BEAS but need to provide more talks and training to the users for better system application.

Table 4. Analysis of convergent and discriminant validity.

Measurement items	Factor loading
1. This system is easy to learn and to use	0.761
2. Evaluation factor used in this system are enough to evaluate and rank the ergonomics risk factors	0.777
3. This system effectively helped me in prioritizing criteria for evaluation of the ergonomics risk factors	0.741
4. This system effectively helped me to specify the ergonomics risk factors	0.796
5. I can effectively complete task of evaluation of the ergonomics risk factors using this system	0.845
6. I am satisfied with the tool in term of workplace ergonomics assessment procedure	0.717
7. This system has all the functions and capabilities i expected it to have	0.593
8. Overall i am satisfied with this system	0.817
Kaiser –Meyer-Olkin Measure of Sampling Adequacy	0.611
Bartlett's Test of Sphericity	0.009

5. Conclusions

Managing ergonomics risk factor is a proactive approach to reduce and eliminate the WMSD among the workers. Also, pursue continuous workplace improvement and enhance employees working performance. The ergonomics risk factors directly impact an employee's productivity and efficiency. Thus, this paper developed a web-based system that would assist the workers in assessing the workplace ergonomics risks factors at any platform, time and place within internet connection areas in the vehicle component manufacturer.

The preliminary results confirmed that the W-BEAS would help workers to identify the critical ergonomics risk factors. W-BEAS may serve for guiding the implementation of the holistic mechanism to enhance assessing workplace ergonomics risk performance. The development of W-BEAS would enable safety and health practitioners, and production managers to build their self-assessment platform for preventive strategies, plans, and actions of workplace ergonomics.

The W-BEAS contained a list of assessment risk factors and developed a scoring guideline for ergonomics risk factors self-assessment. The initial findings of the evaluation surveys verified the potential applicability of the W-BEAS. Despite the relatively small sample, many respondents satisfied and agreed that the W-BEAS effectively helped them in prioritizing the critical ergonomics risk factors. In addition, using the W-BEAS would facilitate information sharing of best practices to any level of expertise.

Future research would validate the W-BEAS identified for different automotive component manufacturers with same operations nature, separately and collectively. In order to disclose automotive-specific characteristics, comparative evaluations of critical ergonomics risk factors should be conducted in more automotive manufacturers.

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