ORIGINAL ARTICLE

OCCUPATIONAL ERGONOMICS RISK FACTORS PRIORITIZATION USING INTEGRATED ANALYTICAL HIERARCHY PROCESS (AHP) APPROACH: A STUDY OF A LOCAL AUTOMOTIVE COMPONENT MANUFACTURER.

Fazilah ABDUL AZIZ[1], **Zakri GHAZALLI**[2] and **Nik Mohd Zuki NIK MOHAMED**[3]

[1]*Faculty of Manufacturing and Mechatronic Engineering Technology, University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.*
[1,2,3]*Faculty of Mechanical and Automotive Engineering Technology, University Malaysia Pahang, 26600 Pekan, Pahang Malaysia.*

ABSTRACT

There is a need to support the occupational safety and health (OSH) practitioners defining their priorities action for improving working environment condition and minimizing the risk factors in the early stage of development. This paper aims to identify the critical risk factors of occupational ergonomics among production workers in an automotive component manufacturer. The Analytic Hierarchy Process (AHP) was utilized to prioritize the level of four ergonomics risk main factors and 26 sub-factors. The linear interpolation and a probability value were given by the practitioner to identify the magnitude of risk. In conclusion, physical factors (0.3143) and psychosocial factors (0.2920) were ranked as the two most important risks of occupational ergonomics. The main effective sub-factors initiating occupational ergonomics risk were found that include force exertion in job task (15), carrying and lifting the heavy load (13.91), high workload (13.04) and work stress (11.89). The simple and systematic approach for occupational ergonomics risk factors analysis should help managers of safety and health, as well as production to conduct ergonomics intervention programs that meet workers' needs and enhance productivity. Such prioritization helps organizations to prioritize their ergonomics intervention practices on job task thereby increasing the preventive strategies and proactively reducing the occupational ergonomics risk factors.

Keywords*: Occupational ergonomics, ergonomics risk factors, production workers, analytic hierarchy process (AHP).*

INTRODUCTION

Risk investigation is among the main tasks for an organization to avoid hazards (Badri, Nadeau, & Gbodossou, 2012) and undesired events (Arunraj, Mandal, & Maiti, 2013). The deep knowledge of the working environment and perfect decisions are required to survive in the industry (Aminbakhsh, Gunduz, & Sonmez, 2013). As the production grows, the demand for workforce rises and the occupational well-being of the employees needs to be addressed (J. M. Lu, Twu, & Wang, 2016). However, the readiness of production managers to focus on the concept of employees' well-being and their ability to monitor employees' health-related needs are still poor in occupational safety and health management (OSHM) (Mellor & Webster, 2013). The company management gives more attention to occupational health and safety than employees well-being (Dickson-Swift, Fox, Marshall, Welch, & Willis, 2014).

Occupational safety and health (OSH) risk management has concerned a great deal of consideration from researchers and practitioners (Drakopoulos, Economou, & Grimani, 2012). A substantial OSH risk analysis has been done in various manufacturing industries (Kwon & Kim, 2013; Li & Zhou, 2015; Silvestri, De Felice, & Petrillo, 2012). Problems related to safety, health and workers well-being are produced from any combinations of causes that vary from one industry to another. Risk is defined as a combination of probability and consequences of the occurrence of a specific dangerous event (Card, Ward, & Clarkson, 2012; Routroy & Pradhan, 2012).

Several risk factors for OSH problems can result in bad ergonomics condition at the workplace and poor work organization. Occupational ergonomics efforts are to improve the appropriateness between the employees and the working environment (Dickson-Swift et al., 2014) through the enhanced design of job tasks and working systems. Often times, occupational ergonomics aims to avoid work-related musculoskeletal disorders (WRMSDs) (Bidiawati & Suryani, 2015; Occhipinti & Colombini, 2016; Thetkathuek & Meepradit, 2016). However, there is an inadequate formal system to reduce musculoskeletal disorders (MSD) hazard in developing countries (Maakip, Keegel, & Oakman, 2016).

The industrial ergonomics have an excessive challenge in merging productivity with employees' health, safety and well-being (Cavatorta & DiPardo, 2012) especially in heavy industries including automotive. Mellor and Webster (2013) have suggested that the production managers need to monitor employees' well-being using regular management procedures like work planning, and formal and informal interaction. Thus, the integration of ergonomics to OSHM in the early stage aims to guide industrial engineers and design the job tasks and workplace with optimum productivity without ignoring employees' health, safety and well-being.

Exploratory occupational ergonomics risks factors and developed MSD prevention strategies have become increasingly important. Organization risk management is proposed to reduce MSD hazard and risk factors in the early stage of development (Maakip et al., 2016). However, most MSD diseases are caused by the overlapping of more risk factors (Occhipinti & Colombini, 2016). To ensure that the critical risk factors are firstly eliminated, the OSH practitioners within an organization need a decision mechanism that encompasses a rational, through participatory ergonomics and risk-based approach to identify severe hazards.

Thus, this study developed a systematic approach utilizing the AHP, a decision support system for multi-criteria analysis. AHP is a predominant and influential method for decision making (Saaty, 2008), utilized to encourage resolution on decisions in unsafe or unknown conditions (Melemez, 2015). AHP is capable to measure and synthesize a large number of criteria in an order with the faster and easier application (Huang, Keisler, & Linkov, 2011; Russo & Camanho, 2015) and useful in complex issues (Chang et al., 2016; Das et al., 2017).

AHP method has been successfully applied in the industry of OSH management (Anestis & Kleopatra, 2017; Y. H. Chang et al., 2016; Melemez, 2015; Petruni et al., 2017; Podgorski, 2015; Raviv, Shapira, & Fishbain, 2017). Nevertheless, the AHP is still less frequently applied in the sectors of occupational ergonomics management. Moreover, AHP in occupational ergonomics studies focuses directly on physical ergonomics factors (Badri et al., 2012; Bal, Arslan, & Tavacioglu, 2015; Chinda, 2016; Chinda, Ammarapala, & Suanmali, 2017; Jung, 2001) and some on psychosocial ergonomics factors (Das, Mukhopadhyay, & Koilakuntla, 2015; Das et al., 2017; Jung, 2001). The personal and organizational ergonomics factors are mostly absent in the ergonomics assessment using the AHP method. Therefore, this current study prioritises the occupational ergonomics risk factors of individual, organizational, physical and psychosocial.

The aim of this study is to identify the critical risk factors of occupational ergonomics among production plant workers. In the paper, a framework was presented for evaluating occupational ergonomics risk factors by combining the AHP and linear interpolation method. The framework supports employees in prioritising the occupational ergonomics risk factors as well as estimating the probability and consequences of the occurrence of a specific hazard. The value of this case study is integrated by experienced employees' opinions on relative weighting to identify critical occupational ergonomics risk factors. A case study at an automotive component manufacturer was used to show the relevance of the method.

METHODS

Study framework

This study developed a systematic approach using the AHP, a decision support methodology, for multi-criteria analysis that permits the subjective criteria. The hierarchy structure layout of AHP includes a goal, four ergonomics main factors as criteria and a couple of sub-criteria or sub-factors to be prioritized. AHP is appropriate for results including ranking and prioritising options as well as in measuring views depending on individual experience and knowledge (Chinda, 2016; Chinda et al., 2017; Das et al., 2017).

The goal of developing a scoring model is to estimate the magnitude risks just by and in terms of occupational ergonomics risk factors. Thus, the local weight for each risk sub-factor was used to determine the severity of risks. The severity values of remaining risk sub-factors were determined according to their local weights using linear interpolation equation. Moreover, a probability value was assigned to each risk item by the practitioner considering the possibility of occurrence of each risk. Figure 1 displays the study framework consisting of two main phases.

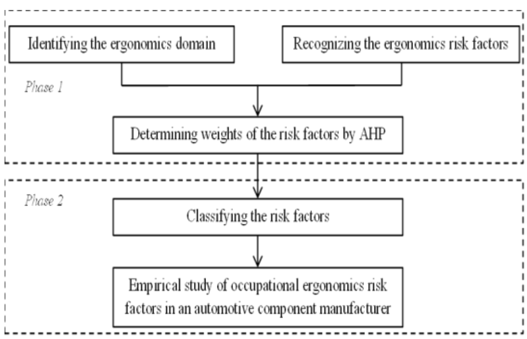

Figure 1. Study framework

Selection of input elements
The occupational ergonomics risk factors affecting employee well-being and productivity were the first to be identified. In the health, safety, environment, and ergonomics (HSEE), ergonomics are described as the environmental, organizational and job factors, human and individual characteristics that influence behaviour at work (Azadeh, Saberi, Rouzbahman, & Valianpour, 2015). Based on literature review and discussions with company management's team, the following four main ergonomics factors were selected to develop the proposed AHP decision model.

i. Individual ergonomics.

Individual ergonomics concerns with individual competence, background, skills, personality, attitude and risk perception. Individual characteristics influence behaviour in complex ways. Individual factors such as age, gender, body weight and being involved in physical activities are meaningfully associated with musculoskeletal symptoms of a different body part (Dianat, Kord, Yahyazade, Karimi, & Stedmon, 2015).

ii. Organizational ergonomics

Organizational ergonomics deal with the optimization of sociotechnical systems including organizational structures, policies and processes. The organizational factors may produce the following ergonomics risks such as shift work, paced work, imbalanced work-rest ratios, demanding work standards and lack of task variety (Pavlovic-Veselinovic, Hedge, & Veselinovic, 2016).

iii. Physical ergonomics

Generally, physical ergonomics is concerned with biomechanical characteristics as they are related to physical activity. Physical ergonomics is required in design intervention (Sanjog, Patnaik, Patel, & Karmakar, 2016) and connected to real and potential quality deviation (Ivarsson & Eek, 2015) in the manufacturing industry.

iv. Psychosocial ergonomics

Psychosocial ergonomics is related to interactions among job content, work organization and management. WMSD was initiated by a combination of many psychosocial risks and high physical demand works (Oakman, Macdonald, & Wells, 2014). A systematic process operating at the organizational level is required to prevent potential psychosocial risks at the workplace (Janetzke & Ertel, 2017).

Developing AHP decision model
This phase involves formulating an appropriate hierarchy of the AHP model consisting goal, factors and sub-factor. The goal of the research study problem is to prioritize occupational ergonomics risk factors. Twenty-six risk factors addressed by each measure were recognized through literature analysis and classified by the viewpoints of the company OSH practitioners. The data acquired were summarized to formulate AHP hierarchy as shown in Figure 2. Once the hierarchy was built, a numerical scale was assigned to each pair of n alternatives (A_i, A_j) by the practitioners (Table 1).

Creating pairwise comparison and obtaining the matrices of factor and sub-factor
A set of questionnaire was designed to determine the importance of each main factor and sub-factor. This questionnaire was prepared using pair-wise comparison. It comprised 78 questions including 1 factor level (6) and 4 sub-factor levels (72). The comparison of any two factors A_i and A_j with respect to the higher level factor was made using questions of the type: "When you are considering occupational ergonomics risk factors in the early phase of a project, how important is the element A_i over the element A_j and how many times more important?".

A matrix of element evaluation denoted as A was formed using the comparisons. Each entry a_{ij} of the matrix in the position (i,j) was obtained comparing the row element A_i with the column element A_j (Equ.1):

$$A=\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2j} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3j} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & a_{i3} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} is the relative importance of the element A_i with respect to the element A_j. The entries a_{ij} were directed by the following rules: $a_{ij}>0$; $a_{ji} = 1/a_{ij}$; $a_{ii} = 1$ for i, j = 1, 2, ., n.

Based on these rules, the pairwise comparison matrix A was positive and reciprocal (Saaty, 1987), which was rewritten in Equ. 2:

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1j} & \cdots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \cdots & a_{2j} & \cdots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3j} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{1j} & 1/a_{2j} & 1/a_{3j} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \cdots & 1/a_{in} & \cdots & 1 \end{bmatrix} \quad (2)$$

Once the overall expert judgments were created and calculated using the geometric mean (Equ. 3), they were inserted into the comparison matrix B (Equ. 4):

Geometric mean,

$$\text{GMi} = \sum_{i=1}^{n} \sqrt[n]{a_{ij}} = \sqrt[n]{a_{ij1} x\, a_{ij2}\, x \ldots x\, a_{ijn}} \quad (3)$$

Where n = number of participants

$$B = \begin{bmatrix} b_{11} & b_{12} & b_{13} & \cdots & b_{1j} & \cdots & b_{1n} \\ b_{21} & b_{22} & b_{23} & \cdots & b_{2j} & \cdots & b_{2n} \\ b_{31} & b_{32} & b_{33} & \cdots & b_{3j} & \cdots & b_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{i1} & b_{i2} & b_{i3} & \cdots & b_{ij} & \cdots & b_{in} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & b_{n3} & \cdots & b_{nj} & \cdots & b_{nn} \end{bmatrix} \quad (4)$$

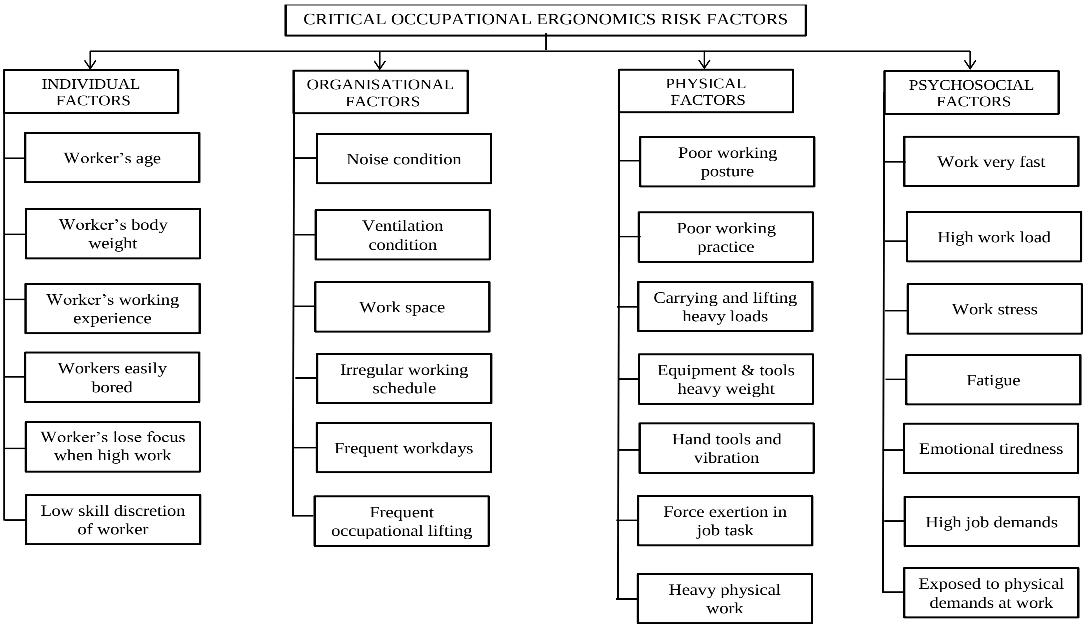

Figure 2. AHP model of occupational ergonomics risk factors

Table 1 Saaty's Ratio scale for pair wise comparison of the importance of weights of criteria (Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favour one over another
5	Essential or strong importance	Experience and judgment strongly favour one over another
7	Very strong importance	An element is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is one of the highest possible orders of affirmation
2,4,6,8	Intermediate values between two adjacent judgements	Comprise is needed between two judgements
Reciprocals	When activity I compared to j assigned one of the above numbers, the activity j compared to I assigned its reciprocal	
Rational	Ratios arising from forcing consistency of judgments	

Table 2 Random index (Saaty, 1994)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.124	1.32	1.41	1.45	1.49

Determining local weight and global weight of elements
The pairwise comparisons produced the matrix of ranking for each level in the hierarchy after all matrices were developed and all pairwise comparisons were obtained. After that, a vector of local weights or priorities of elements in matrix B was calculated. The principal eigenvector *w* of the matrix was calculated using Equ. 5 ;

$$\text{Eigenvector} = w_i = \frac{GM_i}{\sum_{i=1}^{n} GM_i} \quad (5)$$

$$\text{Eigenvalues} = \text{local weight} = \frac{\sum_{i}^{n} w_i}{n} \quad (6)$$

Where n = number of elements

Verifying the consistency of comparisons
After identifying the local priority vector, the consistency of the pairwise comparison matrix was determined. The consistency index was calculated using the maximum eigenvalue λ_{max} (Saaty, 1987) (Equ. 7). The consistency index and consistency ratio were represented in Equ. 8 and Equ. 9;

$$\lambda_{max} = \sum_{i=1}^{n}\left[\left(\sum_{i=1}^{n} GM_i\right)\left(w_j\right)\right] \quad (7)$$

Where, λ_{max} = maximum eigenvalue of matrix B and *n* is the number of elements

$$\text{Consistency index (CI)} = \frac{\lambda_{max}-n}{n-1} \quad (8)$$

Consistency ratio (CR),

$$\text{CR} = \frac{\text{Consistency index (CI)}}{\text{Random index (RI)}} \quad (9)$$

The random index (RI) is shown in Table 2. The CR is acceptable if the value is less than or equal to 0.10 (10%). Otherwise, the results are considered inconsistent and the pairwise comparison has to be repeated again.

Synthesizing the weight of each element
After the local priority, the vector was determined with the consistency ratio evaluated to obtain the synthesized weight. The synthesized weight or global priority vector for elements was represented in Equ. 10;

Global weight, W_i

$$W_i = (Criteria\ local\ weight)(Subcriteria\ local\ weight) = b_i c_{ij} \quad (10)$$

Classifying the risk factors
The local weight for each risk sub-factor was used to determine the severity of risks. The risk sub-factor with the highest local weight was assigned with a severity scale of 5 while the risk sub-factor with the lowest local weight was assigned with a severity scale of 1. The severity values of remaining risk sub-factors were determined according to their local weights using linear interpolation formula as shown in Equ. 11.

$$y_2 = \frac{(x_2-x_1)(y_3-y_1)}{(x_3-x_1)} + y_1 \quad (11)$$

A probability value between 1 and 3 (1 = low, 2 = medium, 3 = high) was assigned to each risk sub-factor by the practitioner considering their possibility of occurrences to the workers. The magnitude of each risk sub-factor was calculated using Equ. 12:

$$= (Severity\ value)(Probability\ value) = \text{S x P} \quad (12)$$

APPLICATION OF PROPOSED AHP MODEL

Subjects
The determination of decision criteria began by forming a panel of experts as decision makers. Ten senior and experienced employees from different departments namely production (4), engineering (3), and safety, health, and environment (3) were invited to participate in this study. The employees or production plant practitioners were selected according to their job tasks, roles and influences on OHSM system practices. They had at least 10 years of working experience.

Hierarchy and factor evaluation
As explained earlier, the pairwise comparison judgment matrices were obtained from 10 evaluators in the measurement. Each matrice was translated into the corresponding largest eigenvalue problem and solved to find the normalized or eigenvector and eigenvalues or high priority weights for each factor. Examples of the result are as shown in Table 3, 4 and 5.

As can be seen in Table 4, the physical risk factor (PYF) was perceived as the most significant occupational ergonomics risk factor followed by psychosocial risk factor (PSF), organizational risk factor (OF) and individual risk factor (IF), respectively. The same procedure was applied to all sub-factors to determine their influence on the main factor. Pairwise comparisons were made to prioritize sub-factors placed beneath each level in the hierarchy.

For the physical risk factor group (Table 5), 'force exertion in job task (PYF6)' was identified to give more effects compared to other factors. In this group, 'carrying & lifting heavy load (PYF3)' was assessed to be the second important factor.

Consistency validation
It is necessary to execute a consistency validation for each hierarchy and framework as a whole for every judgment matrix form. If the

hierarchy does not passed the validation, the experts are required to adjust their forms until they passed. Table 6 presents the percentage of CR for all levels that were less than 10%. Hence, the hierarchy had pass consistency validation.

Table 3 Pairwise comparison matrix of occupational ergonomics risk main factor

	IF	OF	PYF	PSF
Individual factor (IF)	1	1.0254	0.6384	0.5435
Organizational factor (OF)	0.9752	1	0.6279	0.8089
Physical factor (PYF)	1.5664	1.5926	1	1.1161
Psychosocial factor (PSF)	1.8399	1.2362	0.8960	1
Column Sum	5.3815	4.8543	3.1623	3.4686

Table 4 Normalization and calculation for weightages of ergonomics risk main factors

	IF	OF	PYF	PSF		Average	Percentage, %
Individual factors (IF)	0.1858	0.2112	0.2019	0.1567		0.1889	18.89
Organizational factors (OF)	0.1812	0.2060	0.1986	0.2332		0.2047	20.47
Physical factors (PYF)	0.2911	0.3281	0.3162	0.3218		**0.3143**	**31.43**
Psychosocial factors (PSF)	0.3419	0.2547	0.2833	0.2883		0.2920	29.20
					Total	1	100

Table 5 Normalization and calculation for weightages of physical factors

	PYF1	PYF2	PYF3	PYF4	PYF5	PYF6	PYF7	Average	%
PYF1	0.1052	0.1558	0.0981	0.1326	0.0747	0.0922	0.0723	0.1044	10.44
PYF2	0.0920	0.1361	0.2066	0.1830	0.1199	0.1055	0.1066	0.1357	13.57
PYF3	0.2019	0.1240	0.1882	0.1327	0.2261	0.3480	0.1772	**0.1997**	**19.97**
PYF4	0.1279	0.1198	0.2285	0.1610	0.1769	0.1262	0.2030	0.1633	16.33
PYF5	0.0789	0.0635	0.0466	0.0510	0.0560	0.0409	0.0794	0.0595	5.95
PYF6	0.2179	0.2462	0.1033	0.2437	0.2610	0.1909	0.2403	**0.2148**	**21.48**
PYF7	0.1763	0.1546	0.1286	0.0961	0.0854	0.0962	0.1211	0.1226	12.26
							Total	1	100

Table 6 Consistency validation

Judgement matrix	λ_{max}	CI	CR	Consistency validation
Occupational ergonomics risk factors	4.0174	0.0058	0.0064	0.64%
Individual risk factors	6.1770	0.0354	0.0285	2.85%
Organizational risk factors	6.2577	0.0515	0.0416	4.16%
Physical risk factors	7.2639	0.0440	0.0333	3.33%
Psychosocial risk factors	7.1862	0.0310	0.0235	2.35%

Factor scores and final results

The local and global weights for each factor in the hierarchy were calculated according to their perceived contribution to the risk factors affecting the safety, health, well-being and productivity of workers (Table 7). Among the individual factors, 'lose work focus (IF5)' showed the highest value. Meanwhile, the 'frequent occupational lifting (OF6)' is the most critical compared to other factors in the organizational risk factor group. For the psychosocial factor group, 'lose work focus (IF5)' was identified with more effects compared to others.

The global weights discovered that 'force exertion in job task (PYF6)' had an overall weight of 0.0675 (see Table 7) and perceived as the item with the most significant impact. A second significant impact was identified from 'Carrying & lifting heavy loads (PYF3)' with overall weights of 0.0628.

Table 8 illustrates the occupational ergonomics risk factor magnitudes assessed through the risk matrix. The results indicated that with a risk magnitude of 15, the item 'force exertion in job task' required the most significant improvement among the 26 sub-factors. Temporarily, the sub-factor 'carrying & lifting heavy load' has the second-highest risk with a magnitude of 13.91, followed by 'high work load', 'work stress', 'lose work focus', and 'equipment & tools heavy weight'.

Table 7. Composite priority weights for occupational risk factors

Main factor	Local weight	Sub-factor	Local weight	Global weight
Individual Factors (IF)	0.1889	Age (IF1)	0.1525	0.0288
		Body weight (IF2)	0.1073	0.0203
		Working experience (IF3)	0.1506	0.0284
		Easily feel bored (IF4)	0.1847	0.0349
		Lose work focus (IF5)	**0.2724**	0.0514
		Low skill discretion (IF6)	0.1325	0.0250
Organizational Factors (OF)	0.2047	Noise condition (OF1)	0.0749	0.0153
		Ventilation condition (OF2)	0.1921	0.0393
		Work space (OF3)	0.1795	0.0367
		Irregular working schedule (OF4)	0.2094	0.0429
		Frequent workdays (OF5)	0.1230	0.0252
		Frequent occupational lifting (OF6)	**0.2211**	0.0453
Physical Factors (PYF)	**0.3143**	Poor working posture (PYF1)	0.1044	0.0328
		Poor working practice (PYF2)	0.1357	0.0426
		Carrying & lifting heavy load (PYF3)	0.1997	**0.0628**
		Equipment & tools heavy weight (PYF4)	0.1633	0.0513
		Hand tools and vibration (PYF5)	0.0595	0.0187
		Force exertion in job task (PYF6)	**0.2148**	**0.0675**
		Heavy physical work (PYF7)	0.1226	0.0385
Psychosocial Factors (PSF)	0.2920	Work very fast (PSF1)	0.1159	0.0339
		High work load (PSF2)	**0.2020**	0.0590
		Work stress (PSF3)	0.1849	0.0540
		Fatigue (PSF4)	0.1052	0.0307
		Emotional tiredness (PSF5)	0.1181	0.0345
		High job demands (PSF6)	0.1587	0.0463
		Exposure to physical demands at work (PSF7)	0.1151	0.0336
			Total	1

Table 8. Occupational risk factors magnitudes assessed through the risk matrix

Risk factors	Probability of occurrence	Severity of risks	Magnitudes of risks
Force exertion in job task	3	5.00	***15.00***
Carrying & lifting heavy load	3	4.64	***13.91***
High work load	3	4.35	***13.04***
Work stress	3	3.96	***11.89***
Lose work focus	3	3.77	***11.31***
Equipment & tools heavy weight	3	3.76	***11.28***
High job demands	3	3.38	*10.13*
Frequent work lifting	3	3.29	*9.88*
Heavy physical work	3	2.78	*8.34*
Emotional tiredness	3	2.47	*7.40*
Exposure to physical demands at work	3	2.40	*7.21*
Poor working posture	3	2.34	*7.02*
Irregular working schedule	2	3.11	*6.22*
Poor working practice	2	3.09	*6.19*
Ventilation condition	2	2.84	*5.68*
Work space	2	2.64	*5.28*
Easily feel bored	2	2.50	5.00
Work very fast	2	2.42	4.84
Fatigue	2	2.18	4.36
Working experience	2	2.00	4.01
Hand tools and vibration	3	1.26	3.77
Frequent workdays	2	1.75	3.51
Age	1	2.03	2.03
Low skill discretion	1	1.74	1.74
Body weight	1	1.38	1.38
Noise condition	1	1.00	1.00

DISCUSSION

The occupational ergonomics risk factors assessment is an active method to evaluate the conditions of the working environment. Since the decision makers need to prioritize their actions to arrange their implementation, the ergonomics risks factors need to be ranked. For this purpose, the importance weight of the measures is needed. Hence, this study proposed the production plant practitioner-judgment estimations using combined AHP and linear interpolation methods to determine the weights of the measures in this regard.

The benefits of using AHP are that it is capable of checking and reducing the inconsistency of expert judgment as well as reducing bias in the decision-making process since it provides a group's decision (Aminbakhsh et al., 2013). AHP is also flexible and easy to use, apart from being able to provide consistent judgment to the decision makers (Arunraj et al., 2013). Moreover, the AHP is a straightforward and effective instrument (Forman & Gass, 2001; Vaidya & Kumar, 2006).

The proposed framework and method allowed the combination of numerous tools used in practice namely know-how and feedback from experience to fill databases. The strategic knowledge of the employee representatives is significant to activate risk management (Janetzke & Ertel, 2017).The analyst's judgements are self-consistent to determine the rank that can bring the advantage of AHP (Caputo, Pelagagge, & Salini, 2013). The geometric mean of individual judgements has been used through the AHP method in group decision making to minimize bias (Aminbakhsh et al., 2013; Grošelj & Stirn, 2012).

Furthermore, hierarchy provides support for the OSH' practitioners and production managers, regardless of industry and country. Compared to the hierarchies in previous studies done by Das et al. (2017) and Das et al. (2015), the current case study has defined a hierarchy more complete because the set of sub-factor is variety and comprehensive since it covers ergonomics, safety and health, and productivity aspects. If compared with hierarchies produced by Bal et al. (2015), the criteria were almost similar, but the sub-criteria were dissimilar due to different industry.

The AHP results of this study have disclosed the physical risk factor (PYF) as the most significant occupational ergonomics risk factor followed by psychosocial risk factor (PSF) (Table 7). These results were in line with the risk factors for WMSDs in general physicians by Das et al. (2015), which found that physical risk factors are more critical than psychosocial risk factors. Production managers in a manufacturing company are more focused on ergonomics study for reducing the physical risk factors in the workplace (Otto & Battaïa, 2017). Furthermore, physical and psychosocial factors may interact with each other (Vandergrift, Gold, Hanlon, & Punnett, 2012; Widanarko, Legg, Devereux, & Stevenson, 2015). Despite the importance of ergonomics risk factors preventative practices, Gupta et al. (2018) discovered that the participatory physical and psychosocial intervention are still not yet effective for enhancing the working performance of manufacturing workers. Thus, other ergonomics domains including personal and organization interventions need to be implemented.

Referring to the physical sub-factor weights (Table 7), the sub-factors of force exertion in job task (PYF6) was the most serious ergonomics risk factor. This was in agreement with earlier studies revealing that hand force exertion in working process increases the risk of WMSD among workers (Widanarko et al., 2014, 2015; Zare et al., 2015). Hence, Weston et al. (2017) introduced a new preventive strategy for occupational ergonomics risks utilizing the biomechanical model to determine the pushing and pulling risk limits assessed via hand forces and turning torque. Moreover, the humeral angel of worker is more important to be considered for decreasing the potential overexertion injury risk (Cudlip & Dickerson, 2018).

The most significant individual risk factor was the lose of work focus (IF5). This finding indicated that workers are not comfortable in their workplace and find it difficult to focus on their tasks. As reported by Lu et al. (2015), enjoy the work and cooperation in a team will make workers focus more on their jobtask. In addition, the lengthened working day caused worker to become annoyed very easily and not focus on their work (Coulson, McKenna, & Field, 2008).

The frequent work lifting (OF6) was perceived as the most critical for organizational risk factors. This finding was in line with previous studies discovering that frequent work lifting is often associated with a high risk of workplace musculoskeletal injury (Choi and Brings, 2016; Oranye et al., 2016). Antwi-Afari et al. (2017) described that the increment of the danger of falling is related to worker's inbalance control on the unstable supporting surface due to the repetitive lifting of heavy weights. The smallest lifting index is recommended by designing the workplace with tiny twisting and moderate lifting frequency (Singh & Kumar, 2012).

The most important psychosocial risk factor chosen by the practitioners was the high work load (PSF2). Serious stress and physically tired are caused by high workloads and long working hours (Perry, Mulligan, & Smith, 2017). Thus, better design of re-engineering process (Spagnoli & Balducci, 2017) and job control (Ilies, Dimotakis, & De Pater, 2010; Moyer, Aziz, & Wuensch, 2017) can avoid employees from experiencing high work load.

Referring to the high-level risk results (Table 8), the sub-factors of force exertion in job task, carrying and lifting a heavy load, high work load, work stress, lose work focus, and equipment and tools heavy weight were the most important sub-factors and should be given more attention than the others. 'Carrying and lifting heavy load' was ranked as the second most critical ergonomics risk factor by the employees. This finding was supported by Mohammadi et al. (2013) stating that lifting and bringing down task is critical and should be prioritized in conducting restorative activities. In industry, carrying and lifting movement are required for completing the main tasks and it's a common source for ergonomics hazards like WMSD (Dodge, 2012; Peppoloni, Filippeschi, Ruffaldi, & Avizzano, 2016; Roffey, Wai, Bishop, Kwon, & Dagenais, 2010). The manual lifting and treatment of substantial burdens are typically joined by unnatural and awkward body stances that must be redressed (Savino, Mazza, & Battini, 2016).

'Work stress' is a common symptom among automotive industry workers came in next as the fourth most important ergonomics risk factors. This was similar to that of Drakopoulos et al., (2012) who reported that work stress in workplace has attracted many researchers. The effective management of work-related stress in the workplace requires participation from all including senior management, junior management and shop floor workers (McVicar et al., 2013; Mellor et al., 2013). For instance, work stress can be decreased through organization support from the immediate supervisor by enhancing the effectiveness of formal work schedule flexibility (Løkke & Madsen, 2014).

'Equipment and tools heavy weight' was ranked as the sixth most important ergonomics risk factor out of the 26 ergonomics risk factors investigated. This finding has supported the latest study done by Weston et al. (2018) claiming that the effects of using heavy hand tools to perform tasks have received great attention. Authors have designed exoskeletal interventions to support occupational work by diminishing bio-mechanical risks to the shoulders resulting from the use of heavy hand tools. Powered hand tools can increase productivity but intensify the musculoskeletal injuries and diseases due to heavy tool weight and a great tool vibration (C.-H. Chang & Wang, 2000). Thus, WMSD complaints were growing among industry workers who handled and lifted heavy equipment and tools (Abdul Aziz, Ghazalli, Mohamed, & Isfar, 2017; Yassierli, 2017).

The proposed framework decomposed the decision problem into a hierarchy of more easily comprehended sub-problems that enhanced the assignment of weights to the factors and sub-factors. The proposed method provided an effective approach for prioritization of occupational ergonomics risk factors. The results of the present study are supposed to support safety and health practitioners to manage the ergonomics risk factors and plan for ergonomics intervention activities.

CONCLUSION

The study goal was to identify the occupational ergonomics risk factors involving the AHP method in the definition of decision priorities. From the results of the case study, the method seemed helpful in creating the awareness of occupational ergonomics risk factors. The involvement of experienced employees from the different department is essential in establishing a thorough consideration of critical issues and interdependencies in determining a complete risk analysis. Furthermore, an analysis has been made using real-life occupational ergonomics risk factors in an automotive component manufacturer. The value of this case study was integrated by experienced employees' opinions on relative weighting to identify the critical risk factors. Then, OSH practitioners and production managers have produced preventive strategies and proactively reduced the occupational ergonomics risk factors.

The results of this study can contribute to the optimization of organization ergonomics intervention practices, thereby increasing the preventive strategies and proactively reducing the occupational ergonomics risk factors. With these reasons, the determination of occupational ergonomics risk factors in the early stage of development plays an important role in designing and evaluating an existing working environment. Furthermore, this approach can guide the decision makers to create ergonomics workplace for the benefits of employee's safety, health and well-being by determining the critical risk factors at the early phase of development. At the end of the day, presenting a framework for interpreting the proposed scoring manner will be constructive.

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COMPETING INTERESTS

There is no conflict of interest.

REFERENCES

Abdul Aziz, F., Ghazalli, Z., Mohamed, N. M. Z., & Isfar, A. (2017). Investigation on musculoskeletal discomfort and ergonomics risk factors among production team members at an automotive component assembly plant. IOP Conference Series: Materials Science and Engineering, 257(1). https://doi.org/10.1088/1757-899X/257/1/012040

Aminbakhsh, S., Gunduz, M., & Sonmez, R. (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. Journal of Safety Research, 46, 99-105. https://doi.org/10.1016/j.jsr.2013.05.003

Anestis, S., & Kleopatra, P. (2017). Exploring of the consequences of human resources multitasking in industrial automation projects : a tool to mitigate impacts. Procedia Engineering, 196(June), 738–745. https://doi.org/10.1016/j.proeng.2017.08.002

Antwi-Afari, M. F., Li, H., Edwards, D. J., Pärn, E. A., Seo, J., & Wong, A. (2017). Effects of different weights and lifting postures on balance control following repetitive lifting tasks in construction workers. International Journal of Building Pathology and Adaptation, 35(3), 247–263.

Arunraj, N. S., Mandal, S., & Maiti, J. (2013). Modeling uncertainty in risk assessment: An integrated approach with fuzzy set theory and Monte Carlo simulation. Accident Analysis and Prevention, 55, 242-255. https://doi.org/10.1016/j.aap.2013.03.007

Azadeh, A., Saberi, M., Rouzbahman, M., & Valianpour, F. (2015). A neuro-fuzzy algorithm for assessment of health, safety, environment and ergonomics in a large petrochemical plant. Journal of Loss Prevention in the Process Industries, 34, 100–114. https://doi.org/10.1016/j.jlp.2015.01.008

Badri, A., Nadeau, S., & Gbodossou, A. (2012). Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation. Accident Analysis and Prevention, 48, 223-234. https://doi.org/10.1016/j.aap.2011.05.009

Bal, E., Arslan, O., & Tavacioglu, L. (2015). Prioritization of the causal factors of fatigue in seafarers and measurement of fatigue with the application of the Lactate Test. Safety Science, 72, 46–54. https://doi.org/10.1016/j.ssci.2014.08.003

Bidiawati, J. R. A., & Suryani, E. (2015). Improving the Work Position of Worker's Based on Quick Exposure Check Method to Reduce the Risk of Work Related Musculoskeletal Disorders. Procedia Manufacturing, 4, 496–503. https://doi.org/10.1016/j.promfg.2015.11.068

Caputo, A. C., Pelagagge, P. M., & Salini, P. (2013). AHP-based methodology for selecting safety devices of industrial machinery. Safety Science, 53, 202–218. https://doi.org/10.1016/j.ssci.2012.10.006

Card, A. J., Ward, J., & Clarkson, P. J. (2012). Successful risk assessment may not always lead to successful risk control: A systematic literature review of risk control after root cause analysis. Journal of Healthcare Risk Management, 31(3), 6–12. https://doi.org/10.1002/jhrm

Cavatorta, M. P., & DiPardo, M. (2012). Improving the ergonomics of the workplace to enhance productivity and safety. In Workplaces: Safety, Social Implications and Expectations (pp. 53–70).

Chang, C.-H., & Wang, M.-J. J. (2000). Evaluating factors that influence hand-arm stress while operating an electric screwdriver. Applied Ergonomics, 31(3), 283–289.

Chang, Y. H., Yang, H. H., & Hsiao, Y. J. (2016). Human risk factors associated with pilots in runway excursions. Accident Analysis and Prevention, 94, 227–237. https://doi.org/10.1016/j.aap.2016.06.007

Chinda, T. (2016). Investigation of factors affecting a construction waste recycling decision. Civil Engineering and Environmental Systems, 33(3), 214–226.

Chinda, T., Ammarapala, V., & Suanmali, S. (2017). Key factors influencing management decisions concerning safety equipment selection. International Journal of Occupational Safety and Ergonomics (JOSE), 0(0), 1–11. https://doi.org/10.1080/10803548.2017.1337294

Choi, S. D., & Brings, K. (2016). Work-related musculoskeletal risks associated with nurses and nursing assistants handling overweight and obese patients: A literature review. Work, 53(2), 439–448. https://doi.org/10.3233/WOR-152222

Coffey, M., Dugdill, L., & Tattersall, A. (2009). Designing a stress management intervention in social services. International Journal of Workplace Health Management, 2(2), 98–114.

Coulson, J. C., McKenna, J., & Field, M. (2008). Exercising at work and self-reported work performance. International Journal of Workplace Health Management, 1(3), 176–197. https://doi.org/10.1108/17538350810926534

Cudlip, A. C., & Dickerson, C. R. (2018). Female maximal push/pull strength capabilities by humeral abduction angle in bilateral exertions. Applied Ergonomics, 70(September 2017), 136–141. https://doi.org/10.1016/j.apergo.2018.02.023

Das, S. K., Mukhopadhyay, S., & Koilakuntla, M. (2015). Analytic Hierarchy Process to Rate Risk Factors Associated with WMSDs in General Physicians. Journal of Health Management, 17(2), 241–247. https://doi.org/10.1177/0972063415575813

Das, S. K., Patyal, V. S., & Mukhopadhyay, S. (2017). Development and validation of a Re-Modified Work-Style Short Form Questionnaire for assessment of stress in medical practitioners working in Indian hospitals. Theoretical Issues in Ergonomics Science, 18(2), 95–109. https://doi.org/10.1080/1463922X.2016.1154228

Dianat, I., Kord, M., Yahyazade, P., Karimi, M. A., & Stedmon, A. W. (2015). Association of individual and work-related risk factors with musculoskeletal symptoms among Iranian sewing machine operators. Applied Ergonomics, 51, 180–188.

Dickson-Swift, V., Fox, C., Marshall, K., Welch, N., & Willis, J. (2014). What really improves employee health and wellbeing. International Journal of Workplace Health Management, 7(3), 138–155. https://doi.org/10.1108/IJWHM-10-2012-0026

Dodge, R. B. (2012). Patterns of root cause in workplace injury. International Journal of Workplace Health Management, 5(1), 31–43. https://doi.org/10.1108/17538351211215375

Drakopoulos, S., Economou, A., & Grimani, K. (2012). A survey of safety and health at work in Greece. International Journal of Workplace Health Management, 5(1), 56–70. https://doi.org/10.1108/17538351211215393

Forman, E. H., & Gass, S. I. (2001). The analytic hierarchy process—an exposition. Operations Research, 49(4), 469–486.

Grošelj, P., & Stirn, L. Z. (2012). Acceptable consistency of aggregated comparison matrices in analytic hierarchy process, 223, 417–420. https://doi.org/10.1016/j.ejor.2012.06.016

Gupta, N., Wåhlin-Jacobsen, C. D., Abildgaard, J. S., Henriksen, L. N., Nielsen, K., & Holtermann, A. (2018). Effectiveness of a participatory physical and psychosocial intervention to balance the demands and resources of industrial workers: A cluster-randomized controlled trial. Scandinavian Journal of Work, Environment and Health, 44(1), 58–68. https://doi.org/10.5271/sjweh.3689

Halim, I., Abdullah, R., & Ismail, A. R. (2012). A Survey on Work-related Musculoskeletal Disorders (WMSDs) among Construction Workers. Journal of Occupational Safety and Health, 9(1).

Harputlugil, T. · Prins, M. · Tanju Gültekin, A. · Ilker Topçu, Y. (2011). Conceptual Framework for Potential Implementations of Multi Criteria Decision Making (Mcdm) Methods for Design Quality Assessment. Management and Innovation for a Sustainable Built Environment, (June).

Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Science of the Total Environment, 409(19), 3578–3594. https://doi.org/10.1016/j.scitotenv.2011.06.022

Ilies, R., Dimotakis, N., & De Pater, I. E. (2010). Psychological and physiological reactions to high workloads: implications for well-being. Personnel Psychology, 63(2), 407–436.

Ivarsson, A., & Eek, F. (2015). The relationship between physical workload and quality within line-based assembly, 0139(November). https://doi.org/10.1080/00140139.2015.1105303

Janetzke, H., & Ertel, M. (2017). Psychosocial risk management in more and less favourable workplace conditions. International Journal of Workplace Health Management, 10(4), 300–317. https://doi.org/10.1108/IJWHM-09-2016-0063

Jung, H. S. and J. H.-S. (2001). Establishment of Overal workload assessment technique for various task and workplaces. International Journal of Industrial Ergonomics, 1(28), 341-353. https://doi.org/http://dx.doi.org/10.1016/S0169-8141(01)00040-3

Kwon, O. J., & Kim, Y. S. (2013). An analysis of safeness of work environment in Korean manufacturing: The " safety climate" perspective. Safety Science, 53, 233-239. https://doi.org/10.1016/j.ssci.2012.10.009

Li, J. F., & Zhou, Y. F. (2015). Occupational hazards control of hazardous substances in clean room of semiconductor manufacturing plant using CFD analysis. Toxicology and Industrial Health, 31(2), 123-139. https://doi.org/10.1177/0748233712469996

Løkke, A.-K., & Madsen, H. (2014). Public sector managers and work stress. International Journal of Workplace Health Management, 7(2), 105–120.

Lu, J. M., Twu, L. J., & Wang, M. J. J. (2016). Risk assessments of work-related musculoskeletal disorders among the TFT-LCD manufacturing operators. International Journal of Industrial Ergonomics, 52, 40–51. https://doi.org/10.1016/j.ergon.2015.08.004

Lu, L., Lin, H. Y., Lu, C., Siu, O., & Lu, C. (2015). The moderating role of intrinsic work value orientation on the dual-process of job demands and resources among Chinese employees. https://doi.org/10.1108/IJWHM-11-2013-0045

Maakip, I., Keegel, T., & Oakman, J. (2016). Prevalence and predictors for musculoskeletal discomfort in Malaysian office workers: Investigating explanatory factors for a developing country. Applied Ergonomics, 53, 252–257. https://doi.org/10.1016/j.apergo.2015.10.008

McVicar, A., Munn-Giddings, C., & Seebohm, P. (2013). Workplace stress interventions using participatory action research designs. International Journal of Workplace Health Management, 6(1), 18–37. https://doi.org/10.1108/17538351311312303

Md. Fashiar Rahman, Md. Bony Amin, M. P. (2014). Application of AHP in Development of Multi-Criteria Ergonomic Approach for Choosing the Optimal Alternative for Material Handling-A Case Study and Software Development to Facilitate AHP Calculation. International Journal of Engineering Research & Technology, 3(6), 1064–1074.

Melemez, K. (2015). Risk factor analysis of fatal forest harvesting accidents: A case study in Turkey. Safety Science, 79, 369–378. https://doi.org/10.1016/j.ssci.2015.07.004

Mellor, N., Smith, P., Mackay, C., & Palferman, D. (2013). The "Management Standards" for stress in large organizations. International

Journal of Workplace Health Management, 6(1), 4–17.

Mellor, N., & Webster, J. (2013). Enablers and challenges in implementing a comprehensive workplace health and well-being approach. International Journal of Workplace Health Management, 6(2), 129–142. https://doi.org/10.1108/IJWHM-08-2011-0018

Mohammadi, H., Motamedzade, M., Faghih, M. A., Bayat, H., Mohraz, M. H., & Musavi, S. (2013). Manual Material Handling Assessment Among Workers of Iranian Casting Workshops. International Journal of Occupational Safety and Ergonomics, 19(4), 675–681. https://doi.org/10.1080/10803548.2013.11077021

Moyer, F., Aziz, S., & Wuensch, K. (2017). From workaholism to burnout: psychological capital as a mediator. International Journal of Workplace Health Management, 10(3), 213–227. https://doi.org/10.1108/IJWHM-10-2016-0074

Oakman, J., Macdonald, W., & Wells, Y. (2014). Developing a comprehensive approach to risk management of musculoskeletal disorders in non-nursing health care sector employees. Applied Ergonomics, 45(6), 1634–1640. https://doi.org/10.1016/j.apergo.2014.05.016

Occhipinti, E., & Colombini, D. (2016). A toolkit for the analysis of biomechanical overload and prevention of WMSDs: Criteria, procedures and tool selection in a step-by-step approach. International Journal of Industrial Ergonomics, 52, 18–28. https://doi.org/10.1016/j.ergon.2015.08.001

Oranye, N. O., Wallis, B., Roer, K., Archer-Heese, G., & Aguilar, Z. (2016). Do personal factors or types of physical tasks predict workplace injury? Workplace Health and Safety, 64(4), 141–151. https://doi.org/10.1177/2165079916630552

Otto, A., & Battaïa, O. (2017). Reducing physical ergonomic risks at assembly lines by line balancing and job rotation: A survey. Computers and Industrial Engineering, 111, 467–480. https://doi.org/10.1016/j.cie.2017.04.011

Pavlovic-Veselinovic, S., Hedge, A., & Veselinovic, M. (2016). An ergonomic expert system for risk assessment of work-related musculo-skeletal disorders. International Journal of Industrial Ergonomics, 53, 130–139. https://doi.org/10.1016/j.ergon.2015.11.008

Peppoloni, L., Filippeschi, A., Ruffaldi, E., & Avizzano, C. A. (2016). (WMSDs issue) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts *. International Journal of Industrial Ergonomics, 52, 1-11. https://doi.org/10.1016/j.ergon.2015.07.002

Perry, M. A., Mulligan, H., & Smith, C. (2017). How do professional caregivers perceive their health and well-being? International Journal of Workplace Health Management, 10(6), 434–449. https://doi.org/10.1108/IJWHM-05-2017-0029

Petruni, A., Giagloglou, E., Douglas, E., Geng, J., Chiara, M., & Demichela, M. (2017). Applying Analytic Hierarchy Process (AHP) to choose a human factors technique : Choosing the suitable Human Reliability Analysis technique for the automotive industry. Safety Science. https://doi.org/10.1016/j.ssci.2017.05.007

Podgorski, D. (2015). Measuring operational performance of OSH management system ? A demonstration of AHP-based selection of leading key performance indicators. Safety Science, 73, 146–166. https://doi.org/10.1016/j.ssci.2014.11.018

Raviv, G., Shapira, A., & Fishbain, B. (2017). AHP-based analysis of the risk potential of safety incidents : Case study of cranes in the construction industry. Safety Science, 91, 298–309. https://doi.org/10.1016/j.ssci.2016.08.027

Roffey, D. M., Wai, E. K., Bishop, P., Kwon, B. K., & Dagenais, S. (2010). Causal assessment of workplace manual handling or assisting patients and low back pain : results of a systematic review. The Spine Journal, 10(7), 639–651. https://doi.org/10.1016/j.spinee.2010.04.028

Routroy, S., & Pradhan, S. K. (2012). Framework for green procurement: a case study. International Journal of Procurement Management, 5(3), 316–336.

Russo, R. D. F. S. M., & Camanho, R. (2015). Criteria in AHP: A systematic review of literature. Procedia Computer Science, 55(Itqm), 1123–1132. https://doi.org/10.1016/j.procs.2015.07.081

Saaty, R. W. (1987). The analytic hierarchy process-what it is and how it is used. Mathematical Modelling, 9(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty, T. L. (1980). The Analytic Hierarchy Process. Decision Analysis, 1–17.

Saaty, T. L. (1994). How to Make a Decision: The Analytic Hierarchy Process. Interfaces, 24(6), 19–43. https://doi.org/10.1287/inte.24.6.19

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), 83. https://doi.org/10.1504/IJSSCI.2008.017590

Sanjog, J., Patnaik, B., Patel, T., & Karmakar, S. (2016). Context-specific design interventions in blending workstation: An ergonomics perspective. Journal of Industrial and Production Engineering, 33(1), 32–50. https://doi.org/10.1080/21681015.2015.1099057

Savino, M., Mazza, A., & Battini, D. (2016). International Journal of Industrial Ergonomics New easy to use postural assessment method through visual management. International Journal of Industrial Ergonomics, 53, 48–58. https://doi.org/10.1016/j.ergon.2015.09.014

Silvestri, A., De Felice, F., & Petrillo, A. (2012). Multi-criteria risk analysis to improve safety in manufacturing systems. International Journal of Production Research, 50(17), 4806–4821. https://doi.org/10.1080/00207543.2012.657968

Singh, S., & Kumar, S. (2012). Factorial analysis of lifting task to determine the effect of different parameters and interactions. Journal of Manufacturing Technology Management, 23(7), 947–953. https://doi.org/10.1108/17410381211267754

Spagnoli, P., & Balducci, C. (2017). Do high workload and job insecurity predict workplace bullying after organizational change? International Journal of Workplace Health Management, 10(1), 2–12. https://doi.org/10.1108/IJWHM-05-2016-0038

Thetkathuek, A., & Meepradit, P. (2016). Work-related musculoskeletal disorders among workers in an MDF furniture factory in eastern Thailand. International Journal of Occupational Safety and Ergonomics (JOSE), 0(0), 1–11. https://doi.org/10.1080/10803548.2016.1257765

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process : An overview of applications, 169, 1–29. https://doi.org/10.1016/j.ejor.2004.04.028

Vandergrift, J. L., Gold, J. E., Hanlon, A., & Punnett, L. (2012). Physical and psychosocial ergonomic risk factors for low back pain in automobile manufacturing workers. Occupational and Environmental Medicine, 69(1), 29–34.

Weston, E. B., Alizadeh, M., Knapik, G. G., Wang, X., & Marras, W. S. (2018). Biomechanical evaluation of exoskeleton use on loading of the lumbar spine. Applied Ergonomics, 68(November 2017), 101–108. https://doi.org/10.1016/j.apergo.2017.11.006

Weston, E. B., Aurand, A., Dufour, J. S., Knapik, G. G., & Marras, W. S. (2017). Biomechanically-determined hand force limits protecting the low back during occupational pushing and pulling tasks. Ergonomics, (just-accepted), 1–32.

Widanarko, B., Legg, S., Devereux, J., & Stevenson, M. (2014). The combined effect of physical, psychosocial/organisational and/or environmental risk factors on the presence of work-related musculoskeletal symptoms and its consequences. Applied Ergonomics, 45(6), 1610–1621. https://doi.org/10.1016/j.apergo.2014.05.018

Widanarko, B., Legg, S., Devereux, J., & Stevenson, M. (2015). Interaction between physical and psychosocial work risk factors for low back symptoms and its consequences amongst Indonesian coal mining workers. Applied Ergonomics, 46(Part A), 158–167. https://doi.org/10.1016/j.apergo.2014.07.016

Yassierli. (2017). Implementation of ergonomic programs to reduce sick leave due to low back pain among nickel mining operators. International Journal of Industrial Ergonomics, 61, 81–87. https://doi.org/10.1016/j.ergon.2017.05.013

Zare, M., Bodin, J., Cercier, E., Brunet, R., & Roquelaure, Y. (2015). Evaluation of ergonomic approach and musculoskeletal disorders in two different organizations in a truck assembly plant. International Journal of Industrial Ergonomics, 50, 34-42. https://doi.org/10.1016/j.ergon.2015.09.009