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Parameters of effects in decision making of automotive assembly line using the Analytical Hierarchy Process method

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ABSTRACT

The automotive industry contributes high income to most of the countries. The assembly line is an essential part of the automotive industry because it combines all the components into a complete body unit. Assembly lines often experience delays in meeting production targets, requiring overtime to complete. Musculoskeletal Disorder (MSD) complaints among assembly workers predominantly lie in trimming, chassis, and finishing processes. Improvements are needed to reduce complaints according to the priority process. This study aims to prioritize the process on the assembly line with the parameters of work position, workload, work layout and equipment. This study implements the Analytical Hierarchy Process (AHP) method to achieve the objectives of the decision-making process. Preliminary weighting priorities for chassis, finishing and trimming are 0.6153, 0.2313 and 0.1533; respectively highest weight is in the chassis process and will be a priority for this study in optimizing solutions.

Introduction

The automotive industry is one of the most strategic, most important, that significantly impacted the manufacturing environment [1]. This industry makes a substantial contribution to the development and economic growth of the country [2,3]. Economic, environmental, marketing and national policy improvements are also expected from the automotive industry [4,5].

The car manufacturing industry produces various models with different prize levels [6]. Therefore, the automotive companies of various brands manufacture cars with increasing capacity every year. The automotive production process is complicated, especially at the assembly line, which assembles the components into new units [7]. Hence, a balance of man-machine cooperation is required in all assembly line processes to optimize the assembly process [8]. The primary source that influences the smoothness of the manual assembly process is humans [9–11]. Almost 95% of the workforce masters the assembly process that enables them to do multiple job tasks manually [6].

The manual assembly process requires comfort and safety to work comfortably during the production shifts. During unavoidable circumstances, the production team needs to do overtime to cater to the customer's demand. Longer working hours will affect the workers' performance; however, the processes that apply ergonomics principles will achieve better performance [12]. Therefore, decision-making is required to maintain the production process's smoothness to assemble automotive product units. AHP is one of the methods used in the decision-making process [13,14]. It is a multi-criteria decision-making method, first developed by Saaty [15–17].

In the automotive industry, decision-making is vital to select materials [18], line scheduling [19], supply chains [20–22], manual assembly process [23], design criteria [24–26] and identifying occupational health risk factors [27]. Mistreatments of MSD are significant issues in the automotive industry. Thus, it requires strategies to overcome the problems related to MSD [28,29]. MSD complaints affect the normal functioning of the musculoskeletal system due to repeated exposure to various risk factors in the workplace [30,31]. The musculoskeletal system includes tendons, tendon sheaths, ligaments, bursa, blood vessels, joints, bones, muscles and nerves [32].

This study aims to decide which process in the assembly line causes the production delay and why it requires overtime to

Abbreviations: AHP, Analytical Hierarchy Process; α- D MCDM, Alpha- Discounting Multi Criteria Decision Making; ED, Electro Deposition; MCDM, Multi Criteria Decision Making; MSD, Musculoskeletal Disorder; PCM, paired Comparative Matrix

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Nomenclature

CR	Consistency Ratio
CI	Consistency Index
RI	Radom Index

complete the production target caused by MSD complaints during working hours. The process in the assembly line consists of Trimming, Chassis and Final. This study focuses on humans as objects in selecting alternative approaches on the assembly line with criteria such as work position, workload, work layout, and equipment to minimize production delays.

Methodology

Fig. 1 describes the steps taken in the decision-making process for the assembly line in the automotive industry in minimising the impact of overtime on workers' MSD complaints.

As shown in Fig. 1, the stages in this study begin by observing the situation in the assembly line associated with workers as the primary source of the workforce in the smooth production and end with selecting one of the processes as a priority using the AHP approach.

Automotive assembly line

Fig. 2. describes the standard automotive production lines: Body Shop, Paint Shop, Assembly and Final Shop [33,34]. The body shop is the process line that assembles individual car parts according to tight specifications to become the body frame or body in white. Next, the Paint Shop is where the car painting procedure consists of the electro-deposition (ED) process of dipping the car body into the chemical tank by conducting electricity to prevent rust outside the car body panels. Next, the ED sanding process improves the body panel surfaces in appearance and sealing quality. Sealing quality is vital to prevent leakage, rust, dampers, dust, and vibration resistance. All chemicals used in the painting process are according to safety and health standards and their impact on the environment [35].

Fig. 3 describes the stages of the automotive assembly process performed by combining components to become a complete body unit. The Assembly Line generally consists of three main processes: Trimming, Chassis, and Finishing. Trimming is the process of assembling electrical harnesses and accessories. Chassis is the process

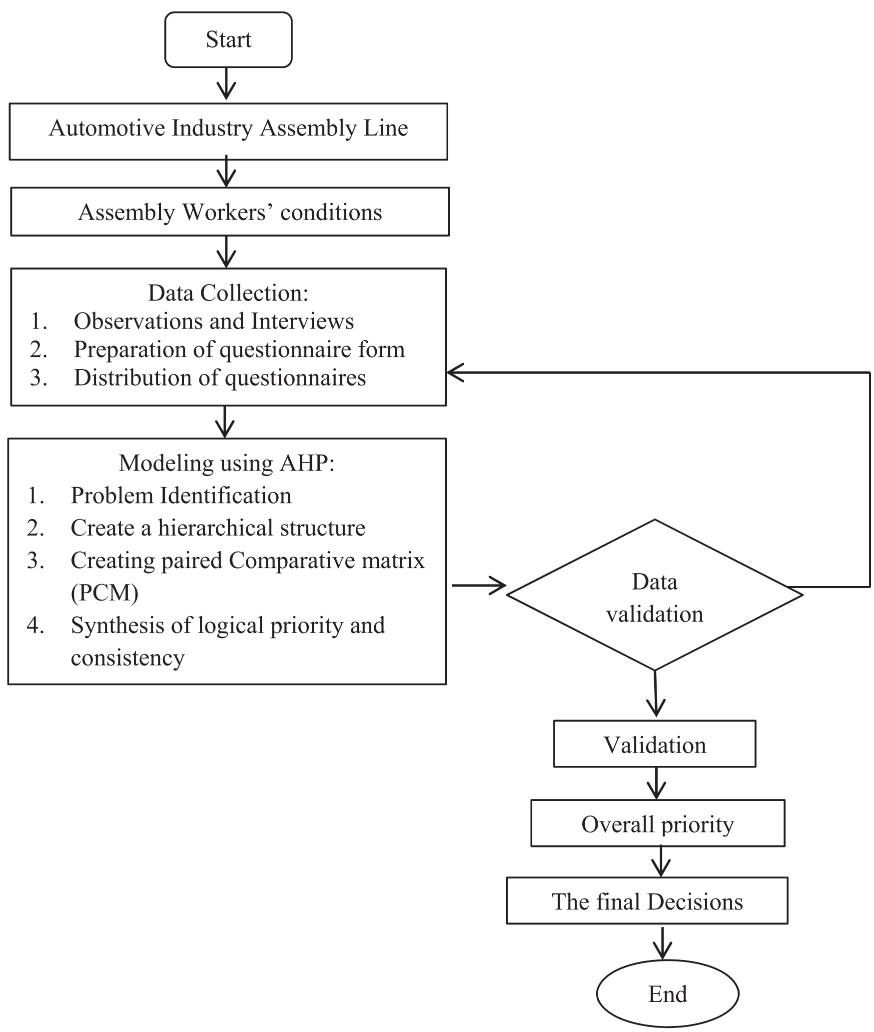

Fig. 1. Automotive assembly decision-making process.

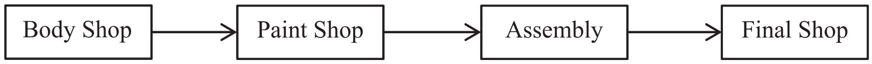

Fig. 2. Production process of the automotive industry.

of accommodating various systems, such as installing under the body and other essential components. Next, Finishing is the process of installing all the fittings.

Assembly workers' conditions

Assembly lines for low-to-medium production depend on the workforce to assemble parts and components. For this type of production set-up, MSD complaints are high due to interruptions faced by the employees at almost every workstation along the Assembly line [6]. The leading cause of MSD complaints is an improper working environment, which influences the workers' efficiency in carrying out tasks [36]. The work done by lifting components, bending, twisting limbs, squats, and necks bend backwards has become a routine during working hours. Automotive manufacturing is in the heavy industry category; therefore, a proper ergonomic work environment is crucial in the assembly process [37].

Based on many studies, many MSD complaints by the workers are located in the neck, shoulders, arms, hands, back, legs and ankles [38]. The MSD complaints resulted in low assembly line productivity as the company could not meet the daily output target and required overtime to cover the output losses.

[39]. The extra working hours required at the assembly process affect the industry's costs, thus reducing the customers' performance rating. Overtime adversely affects the automotive industry in terms of company performance and revenue. Therefore, corrective action is needed to minimise excessive MSD complaints made by the workers at the Assembly line. It requires a decision-making process in prioritising the strategies (Trimming, Chassis, and Final) in the Assembly line. One of the methods used in the decision-making process is AHP with a multi-criteria approach [40]. The criteria focus only on the workers in the Assembly process workstations.

Data Collection

Observations and interviews

This case study involved direct observations on the assembly lines of the selected automotive industries in Indonesia. These observations were to understand how employees work at the assembly line during working hours. These include positioning tools and components used in the process and the distance required to carry them. These processes involved workers' workload and the time needed for the assembly activities. The study uses the Work-Related MSD's observation method to assess ergonomic conditions [41]. In addition to observations, interviews with workers involved to discover their complaints were also conducted [2]. Interviews affected employees and supervisors from the upstream to the downstream assembly process. These interviews aimed to obtain information on the implementation of assembly processes and utilisation of tools used in the workstation [42].

Preparation of questionnaires form

The information obtained during the case study interviews is critical in planning decision-making questionnaires. The questionnaires designed in this study need to follow the AHP as a decision-making model [43]. The AHP questionnaire model consists of three primary levels in a hierarchical decision-making structure. The first level is in the hierarchical structure consisting of the goal, level 2 is the criteria used for decision making, and level three are alternatives to attain the desired goal.

AHP method requires information on the evaluation scale that experts must fill out the paired questionnaire matrix. The final stage of the AHP method is to create a paired matrix between criteria and alternatives [44]. From the results of the matrix calculation performed, the highest final value will be used in making alternative decisions of the selected process.

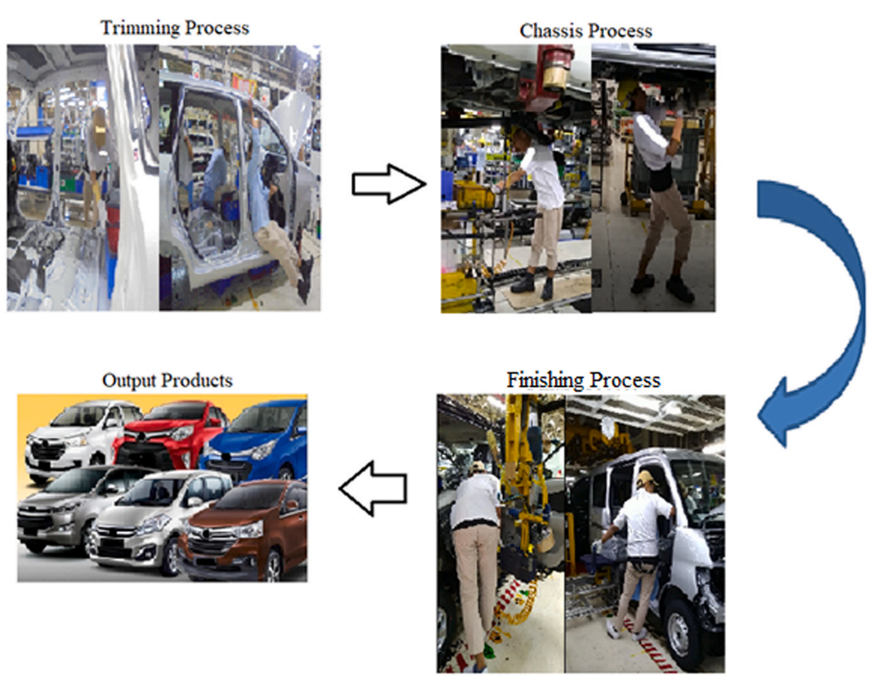

Fig. 3. The manual assembly process in automotive manufacturing.

Table 1
The matrix form used in the AHP questionnaire is made based on the level of importance of the elements that influence it.

Element A	Element B			
	A	B	C	D
A	1	.3.[(a)]	.1/3.[(b)]	.2.
B		1	.4.	.7.
C			1	.1/2.
D				1

Description
Value in [(a)]: Factor C is slightly more important than D
Value in [(b)]: Factor E is slightly more important than C
Note: Consistency of assessment is very important to note

Table 1 explains that the elements in section A are the same as the elements B that experts will evaluate based on paired relationships.

Distribution of questionnaires

The questionnaires used in this study should be answered by experts or someone familiar with all the assembly processes. In this study, supervisors and foremen at the assembly line prioritise criteria and evaluate each AHP measuring criterion [16]. They are the ones who control the production of automotive products in the assembly line from upstream to downstream in terms of available facilities and infrastructure, as well as incidents that occur during the production process. Questionnaires that experts have completed will be processed following AHP procedures to obtain the final result of decision-making in choosing alternatives [45].

Modelling using AHP

The working principle of AHP is to simplify a complex and unstructured, dynamic and strategic problem into hierarchical order. There are four hypotheses in the AHP model: Reciprocal Comparison, Homogeneity, Independence, and Expectation. AHP compares elements at each level, which is part of the alternative α-Discounting Method for Multi-Criteria Decision Making (α-D MCDM) ([46,47]. α-D MCDM realizes a set of options that can change over a homogeneous linear or non-linear in the AHP system [48]. Many researchers apply AHP MCDM in decision-making analysis to solve their problems [49]. The basic concept of AHP is the use of a pairwise comparison matrix to generate alternative weights between criteria and alternatives to achieve the goal. Process consistency determines whether the data obtained are valid by calculating the ratio value with the available benchmark, $CR \le 10\%$. If more than 10%, it is necessary to repeat the evaluation process given by the specialist [50,51].

Problem identification

Specific and clear identification is required to address the automotive assembly line problems. It is crucial to clarify all the assumptions and perspectives that underlie this decision-making in identifying and prioritizing the process [13]. The focus of the study is to identify problems in the automotive assembly line in terms of MSD complaints felt by workers in their respective workstations. These MSD problems exist due to the extensive use of manual assembly processes [6]. MSD complaints delay the production output and cause overtime to meet the production target. Inappropriate working environments also impact MSD complaints on assembly workers [10]. Thus, improvements are needed to reduce delays and extra working hours for the workers. Therefore, it is necessary to choose one of the three processes: Trimming, Chassis, and Finishing, which will be the company's main priority.

Create a hierarchical structure

AHP organizes problems and decision-making hierarchically. Indications of the decision-making element are a criterion used to evaluate selected decisions [45]. The primary step of the AHP method is to describe decision issues into a progression comprising of the foremost vital components of problems [17]. The hierarchical structure in decision making consists of three levels:

- The top-level is the goal to be achieved from this AHP model.
- The intermediate level contains criteria that influence the achievement of goals.
- The lower level is the alternatives selected to achieve the objectives.

Experts determined the criteria based on the results of observations and interviews. They determine the suitability of criteria considering the level of importance caused by MSD complaints at every workstation. The experts decided that the decision making in this study consisted of three main criteria. Firstly, a job position is a posture formed naturally by workers who interact with work procedures and facilities while performing tasks. Secondly, the workload is the capability of workers to perform the tasks. Thirdly, the layout is the arrangement of production facilities and equipment in facilitating an effective working environment. Finally, equipment is the tools used during the production process. These four criteria are the most problematic MSD conditions that impact the productivity of the production process.

Creating Paired Comparative Matrix (PCM)

The designed questionnaires were distributed to assembly line experts for evaluation in creating PCM. All the assessments from the experts were transformed into a group assessment by summing the scores for the matrix [45]. The rating scales used ranged from 1 to 9 and vice versa, which means that these two elements have a relationship and a level of importance corresponding to the meaning of each scale value used. Table 2 illustrates the paired assessment scales that experts must use in filling out questionnaires. The evaluation matrix obtained from the experts was developed and resolved using the eigenvector method.

A paired comparison matrix for all criterion factors is compared with each other to determine the relative importance of each element in achieving the goal. Eqs. (1) – (4) is a formula used in a repetitive process in which all criteria are compared [52]. Matrix A is mathematically consistent if:

Table 2
Pair Comparative Evaluation Scale.

Description of intensity	Description
1	Both elements are equally important
3	Elements that are slightly more important than other elements
5	Elements that are more important than other elements
7	An element that is clearly more absolute is essential to another element
9	An absolute element is more important than any other element
2,4,6,8	Values between two close value considerations
the opposite	Inverse if for my activity I get one figure compared to activity j, the number j value of the inverse value is compared.

Table 3
Scale of the random Index Value (*RI*).

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.24	1.24	1.34	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

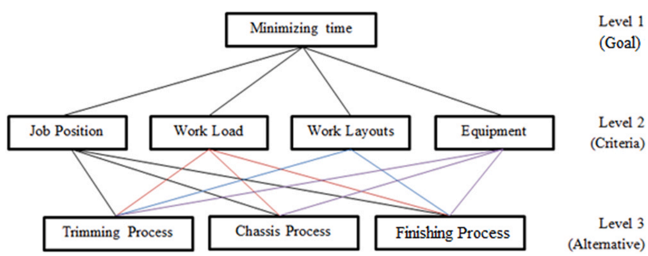

Fig. 4. The structure of the decision-making hierarchy.

$$a_{ij}a_{jk} = a_{ik} \text{ for all } i,\ j \text{ and } k\text{, selected method eigenvector} \tag{1}$$

Table 4
The comparison matrix pairs criteria with criteria based on a combination of expert values.

Element criteria A	Element criteria B			
	Job position	Work-load	Work layout	Equipment
Job position	1.0000	0.2811	1.4422	0.5228
Workload	3.5569	1.0000	5.5934	7.0000
Layout	0.3333	0.1788	1.0000	0.2120
Equipment	1.9129	0.1429	4.7177	1.0000
Amount	6.8031	1.6028	12.7533	8.7348

Paired comparison matrices cannot be used to normalize columns for *Wi* if the matrix is incompatible and in terms of incomplete consistency [45,52,46].

Matrix *N* is produced from a normalized consistency that can be quantified:

$$N = \begin{pmatrix} w_1 & w_1 \,\dots\dots\dots & w_1 \\ w_2 & w_2 \,\dots\dots\dots & w_2 \\ \vdots & \vdots \,\dots\dots\dots & \vdots \\ w_n & w_n \,\dots\dots\dots & w_n \end{pmatrix} \tag{2}$$

N with the opposite process can determine the comparison matrix *A*:

$$A = \begin{pmatrix} 1 & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \dots & \frac{w_2}{w_n} \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & 1 \end{pmatrix} \tag{3}$$

With description:
A = comparison pairwise matrix.
w_1 = weight of element 1,
w_2 = weight of element 2,
w_n = weight of element n.
n is the number of criteria compared, the weight of w_i for criteria i and a_{ij} is a comparison of the weight of criteria i and j.

Synthesis of Logical priority and consistency

In order to obtain the relative weight of the elements in decision making, priority synthesis was performed using vector eigenvalues. Paired comparison matrices were calculated at every level. The determination of eigenvector value at the AHP stage is almost the same as the α –D stage of MCDM by using matrix calculation [48]. Logical consistency can be achieved by arranging all eigenvectors obtained from each element in the hierarchical structure. Eqs. (4) – (7) are used in determining the consistency ratio [52,53]. To calculate the consistency ratio:

Table 7
The ratio consistency value of the comparison ratio between criteria and alternatives.

Comparison element	*λmax*	*CI*	*RI*	*CR*	Validation
Criteria minimize time	4.1317	0.0439	0.9000	0.0487	0.1
Criteria – Job position	3.0511	0.0256	0.5800	0.044	0.1
Criteria – Workload	3.0647	0.0323	0.5800	0.0557	0.1
Criteria – Layout	2.9258	-0.0371	0.5800	-0.0640	0.1
Criteria – Equipment	2.9992	-0.0004	0.5800	-0.0007	0.1

Table 5
Calculation of normalization value from criterion-paired comparison matrix.

Element criteria A	Element criteria B				*∑line*	Priority Vector
	Job position	Work-load	Work layout	Equipment		
Job position	1.0000	0.2811	1.4422	0.5228	0.4953	0.1238
Workload	3.5569	1.0000	5.5934	7.0000	2.3867	0.5967
Layout	0.3333	0.1788	1.0000	0.2120	0.2632	0.0658
Equipment	1.9129	0.1429	4.7177	1.0000	0.8547	0.2137

Table 6
Calculation of vector consistency values from a criterion-paired comparison matrix.

Element criteria A	Element criteria B				*∑line*	Eigent Vector
	Job position	Work-load	Work layout	Equipment		
Job position	0.1238	0.1677	0.0949	0.1117	0.4982	0.1238
Workload	0.4404	0.5967	0.3681	1.4958	2.9010	0.5967
Layout	0.0413	0.1067	0.0658	0.0453	0.2591	0.0658
Equipment	0.2369	0.0305	0.3105	0.2137	0.7915	0.2137

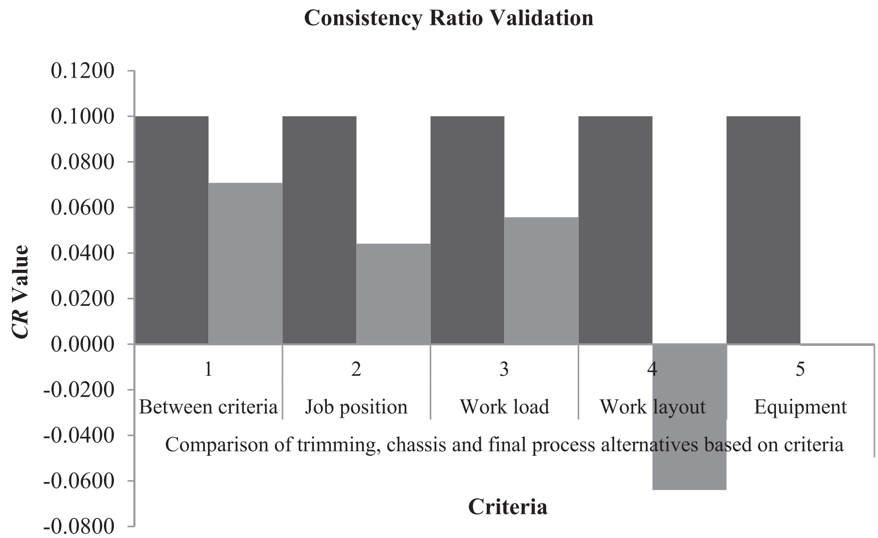

Fig. 5. The consistency value of the comparison ratio between criteria and alternatives.

$$CR = \frac{CI}{RI} \tag{4}$$

For, CI = Consistency index of A, RI = Random consistency of A, λmax = maximum Eigenvalue of matrix A, a_{ij} = numerical comparison between values i and j.

In achieving convergence, some calculations are needed to make a decision when involving an inappropriate matrix. Eq. (5) is used in converting raw data into absolute mean value and normalized weight $W = (W_1, W_2, W_3, \ldots W_n)$.

$$AW = \lambda max\ W,\ \ \lambda max\ \geq\ n \tag{5}$$

$$\lambda_{\max} = \frac{\sum ajwj - n}{w1} \tag{6}$$

$$CI = \frac{\lambda max - n}{n - 1} \tag{7}$$

Random index (RI) values were obtained using n (number of experts) seen directly in the RI table. The scale of the random index value used is listed in Table 3. The random index value is used to obtain the consistency ratio value in validation [54].

Evaluation results are acceptable when the CR value (consistency ratio) is < = 10% (0.1). If the CR value > 10%, then it is inconsistent, and comparisons must be studied [55]. The compatibility level of paired comparisons considers algorithms related to the compatibility of hierarchical analysis indicators. [53].

Overall priority

The overall priority is final for each alternative. The weight of each criterion shows the level of importance and differs from each other [56]. The weighted assessment uses the eigenvalues obtained during the validation for the consistency ratio.

The final decision

The final result considers the overall goals and sensitivity analysis comparison. Priority weight is rated based on the received value sort by highest to lowest priority of weight values. Hence, the final results help the company decide on the selected process to be prioritized for improvement.

Table 8
The overall priority of each alternative.

Alternative	Criteria				Total
	Job Position	Workload	Work Layout	Equipment	
	0.1238	0.5967	0.0658	0.2137	
Trimming	0.2073	0.1414	0.1723	0.1551	0.1545
Chassis	0.6406	0.7251	0.3711	0.3007	0.6006
Finishing	0.1521	0.1335	0.4567	0.5442	0.2448
					1.0000

Result and Discussion

The structure of the hierarchy in decision making

Fig. 4 shows the structure of the AHP decision-making hierarchy. The structure consists of three stages. The first level aims to minimise the impact of MSD complaints by workers. Meanwhile, level two contains the criteria used in achieving the goal. The criteria used were job position, workload, work layout and equipment. The third level consists of alternatives that will be selected based on the comparative relationship with the criteria. The alternative consists of three main assembly line processes: trimming, chassis, and finishing.

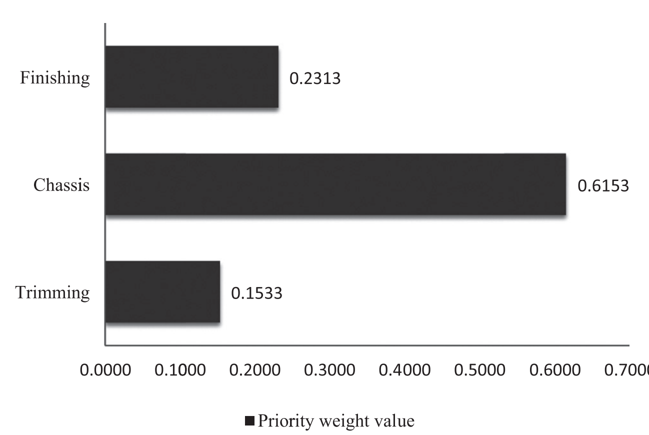

Fig. 6. The overall value of the alternative priority weight.

The parameters used in this study shown in Fig. 4 intended to minimize overtime from the condition of MSD workers' complaints that they felt. Previous researchers used parameters to reduce waste from the floor conditions of its production [56]. The individual, organizational, physical and psychosocial aspects are widely studied the risk factors related to MSD impacts [27].

Paired Comparison Matrix Results (PCM)

The paired comparison matrix was obtained from the designed questionnaires distributed to the experts. Eqs. (2–3) were used to determine the paired comparison matrix of existing problems based on the relationship of criteria with criteria; and the relationship of each criterion with alternatives. Table 4 shows an example of applying a criterion-paired comparison matrix with the criteria used based on a combination of assessments provided by experts.

Table 4 provides information on the combined assessments given by all experts on the relationship of criteria against criteria consisting of job position, workload, work layout and equipment. The same method is used to compare each criterion's matrix comparison against alternatives.

Once the paired comparison matrix is obtained, the next step is to divide the value in each cell by the number in the relevant column, which aims to generate a normalized matrix. Table 5 Normalizes values of paired comparison matrices for criteria against criteria.

Table 5 shows the paired comparison matrix, and the priority vector criteria for the job position, workload, layout, and equipment are 0.1238, 0.5967, 0.0658, and 0.2137, respectively. Based on the priority vector results, the workload is the selected criterion that significantly impacts the MSD complaints of assembly workers**.**

Synthesis of logical priority and consistency

The next step is to determine the priority vector for each criterion by calculating the consistency ratio using Eqs. (4–6). The first step is to multiply the matrix obtained in Table 4 with the priority vector value of each criterion found in Table 5. The consistency vector value for each criterion is used to determine “eigen λmax’s”.

Table 6 shows the calculation of the vector consistency value for the comparison matrix. The results show values for the Job position; 4.0240, Workload; 4,8617, Layout; 3.9372 and Equipment; 3.7040. The eigenvalue of λmaxs for the criterion is obtained by using Eq. (6):

$$\lambda maxs = \frac{4.0240 + 4.8617 + 3.9372 + 3.7040}{4} = 4.1317$$

The value of the consistency of the index is obtained by using Eq. (7).

$$CI = \frac{4.1317 - 4}{3} = 0.0439$$

Once the results of the consistency index are obtained, the consistency ratio can be calculated using Eq. (4):

$$CR = \frac{0.0439}{0.90} = 0.0488$$

Since the result of the CR value was > 0.1, which means consistent and valid, no repetition is required and can be used for the decision-making process. The same procedures were also used for the paired comparison matrix of each criterion with alternatives to obtain the value of CR. Table 7 and Fig. 5 recap the results of the paired comparison matrices for the criteria with criteria and each criterion with alternate variables.

Table 7 and Fig. 5 show the ratio of the consistency between criteria and alternatives. They describe the validation results based on the CR values of λmax, CI and RI values for each parameter to achieve the goal. All parameters are valid because of the value of CR ≤ 0.1. The parameters used in this study describe the overall condition of the assembly path in achieving the optimum time.

The priority of overall results

Table 8 explains the overall priority weight of this study obtained by summing the eigenvalues of the product of alternatives.

The values are then multiplied with each criterion so that each alternative has an individual priority weight. The final results show that the priority weight of each alternative is 0.1545 for trimming, 0.6006 for chassis, and 0.448 for final. As this is the last stage of the AHP model simulation, the overall values obtained for each alternative will be sorted based on the highest to lowest values.

The final decision

Fig. 6 provides information on the priority weights of each alternative obtained. This priority weight is obtained from the total calculation result which is the overall weight of the alternatives used. The Chassis has the highest priority weight (0.6006) compared to Finishing (0.2448) and Trimming (0.1545).

The AHP method concluded that the Chassis process has the highest MSD issues at the assembly line. To validate the results, the experts confirmed that Chassis is the process that requires the most remarkable improvement in minimizing overtime work for the Job position, Workload, Layout and Equipment.

The nature of the Chassis process involves a high level of process complexity that require precision, focus, and energy. Most of the components at the Chassis process are large and primarily heavy, which requires endurance and limb strength. Therefore, a detailed study will be conducted to analyze workers' MSD complaints in the Chassis process. Then, provide what solutions can be delivered to minimize such complaints in the assembly line.

Conclusion

MSD's complaints felt by assembly workers in the automotive industry impacted the non-smooth running of the production process. An improvement process is needed to overcome the MSD complaints, which is the main issue at the manual assembly line. The decision-making process using the AHP approach is necessary to prioritise problems to be improved. In terms of ranking, the Chassis process is the first to be prioritised, followed by Finishing and Trimming.

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