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# Comparison of Fuzzy Analytic Hierarchy Process and Analytic Hierarchy Process Based Decision Support for a Lean Performance Measurement System

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## ABSTRACT

A performance measurement framework for a company that adopted lean manufacturing is needed to measure their achievement in the implementation of lean manufacturing system. A comprehensive design of the performance measurement framework requires an understanding of all the elements including performance of perspectives and key indicators of measurements, and decision support methods such as Fuzzy Analytic Hierarchy Process (FAHP) and Analytic Hierarchy Process (AHP). The comparison of original AHP and FAHP methods in term of decision making for lean manufacturing performance measurement system was performed in this paper. A benchmarking to compute performance based on weight between FAHP and AHP was done as a case study in automotive company. The result of the weight values of AHP and FAHP methods indicated almost similar among performances of lean perspectives and indicators for the company's case study.

**KEY WORDS:** *Lean manufacturing PMS, AHP, FAHP.*

## 1.0 LEAN MANUFACTURING PERFORMANCE MEASUREMENT FRAMEWORK

Companies use frameworks to identify an appropriate set of performance measures to assess their performance. According to Neely et al. [1], the reasons for implementing performance measurement systems usually fall into five general categories: monitoring of performance, identification of areas that are in need of attention, enhancing motivation, improving communications and strengthening accountability. Several authors have conducted research on performance measurement systems for lean manufacturing, including Anand and Kodali [2] and [3], Wong and Wong [4], and Agus and Iteng [5].

Agus and Iteng [5] developed a framework for lean manufacturing, which is linked to business performance. Their framework consists of two Lean production dimensions, namely: Just-In-Time (JIT), and Technology and Innovation (T&I). The framework also has two indicators of business performance i.e. Return On Sales (ROS) and Return On Investment (ROI). Anand and Kodali [2] developed a conceptual lean manufacturing framework for small and medium-sized companies. Their framework has 4 pillars/perspectives i.e. customer focused, respect to humanity, elimination of waste, and continuous improvement. Anand and Kodali [3]also developed lean manufacturing framework used 5 pillars/perspectives with adding supplier perspective to their previous framework in [2]. Wong and Wong [4] developed a lean manufacturing framework for the Malaysian Electrical and Electronics Industry. Their framework consists of three parts, namely: (a) the foundation, which serves as a basic condition for improvement to be carried out, (b) the improvement practices which start with the current state to the defined ideal state, and (c) the indicators for continuous improvement in the 13 key areas of lean manufacturing. However, there is limitation of the lean performance measurements as discussed, such as only a measure of non-financial dimensions. In contrast, Kennerley and Neely [6] suggested that a framework has to be multi-dimensional and have the balance between financial and non-financial measures. The performance framework shown does not reflect the company process and specific goals (targets) which are strongly suggested by Lynch and Cross [7], and Fortuin [8].

A comprehensive design of the Performance Measurement System (PMS) framework requires an understanding of all the elements that can affect performance measurement, as well as potential subsequent actions, including the dimensions and levels of measurement. According to several authors on the subject [9-13], the development of a PMS framework should: - be derived from strategy, - be simple to understand, - provide timely and accurate feedback, - reflect the business process and relate to specific goals, - establish more specific performance criteria at each level, and - periodically re-evaluate the appropriateness of the established performance measurement system in view of the current competitive environment.

The development and the characteristics of a lean manufacturing PMS framework suggest the need for appropriate Key Performance Indicators (KPIs) [8]. The lean KPIs can measure progress toward specific goals and help in making the most appropriate decisions for lean manufacturing activities. Lea and Parker [14] suggested that performance indicators must: be easy to understand, have visual impact, focus on improvements more than on variance and be visible to everybody. Fortuin [8] suggested that indicators must: provide quick feedback, provide information, precisely represent what is being measured and be objective not based on opinions. Therefore KPIs in lean manufacturing PMS framework can used to measure, monitor, evaluate and control status i.e. actual and target and drive improvement by fact/not based on guesswork. They can help to prioritise decision making in improvement activities and continue health checks for the company.

A number of perspectives and KPIs are to be considered in order to make decision making in the Lean PMS. Since many perspectives and indicators are to be analysed, Multi Criteria Decision Making (MCDM) models present the best alternatives in the multiple, usually conflicting, decision criteria. The most popular methods in crisp-based decision making are: Weight Sum Model (WSM), Weight Product Model (WPM), Analytic Hierarchy Process (AHP), and ANP (Analytical Network Process). Fuzzy-based decision making is based on AHP methods known as Fuzzy Analytic Hierarchy Process (FAHP).

Furthermore, in this paper conducted study of comparison between Fuzzy Analytic Hierarchy Process (FAHP) and Analytic Hierarchy Process (AHP) based decision support for a lean performance measurement system in the company.

## 2.0 ANALYTIC HIERARCHY PROCESS (AHP) AND FUZZY ANALYTIC HIERARCHY PROCESS (FAHP)

The AHP is one of the Multi-Criteria Decision Making (MCDM) methods. Saaty [15] introduced the AHP method for analysing a complex problem and coping with both the qualitative and quantitative aspects of decision-making indicators by organising them into a hierarchical model. The AHP can support the identification and weighting of selection indicators for decision-making process, which uses experts‟ judgments to derive the priority scales. In terms of decision circumstances, Saaty et al. [16] and Forman and Saul [17] stated that AHP can be used for applications such as choice, ranking, resource prioritization, allocation, quality management, conflict resolution and performance measurement. The AHP has a consistent preference structure, namely consistency ratios, which are used to measure the consistency of the decision-making process. If pairwise comparison is inconsistent, the pairwise comparisons can be repeated.

The main steps of AHP are [18]: (a) construct a hierarchical model according to the problem, (b) make pairwise comparisons of indicators based on the AHP scale, and (c) compute the result by calculating the weighted priorities for each of the decision elements, checking the consistency and aggregating the priorities elements to get a final priority ranking.

An example of a hierarchical model can be seen in Figure 1. It consists of the goal on level one, several perspectives (indicators) on level two and the alternative choices on level three. The linking lines indicate correspondence between the goal, perspectives and alternatives. Level one line linking consists of the goal and pairwise comparisons between the four perspectives and resulted in four comparison matrices at level 2. The alternatives for decision making are shown on the bottom linking lines between perspectives and alternatives. Finally, the result is computed to obtain the priority alternatives at level three. The steps to calculate weights priorities are explained in section result and discussion.

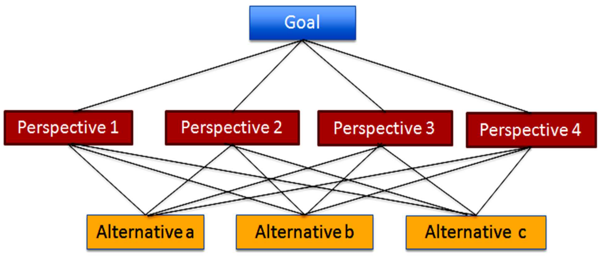


Figure 1: An example of the hierarchical structure.

The AHP can be applied to many fields such as engineering, science, medicine, military [19], social, political, economic, finance, managements and performance measurement. Some examples of the AHP application include its use in decision making, e.g. the evaluation of technology investment decisions [20] and prioritization of key indicators for improving company performance [21]. In addition, Vinodh et al. [22] applied AHP to the choice of the best implementation of lean philosophy to increasing business success.

The primary strength of AHP in decision making lies in its ability to rank choices in order of their effectiveness and efficiency. However, the original AHP uses crisp numbers in comparing one alternative with another. Comparison judgment depends on human perception, which always contain vagueness and imprecision. The crisp numbers often fail to capture this vagueness [23]. Moreover, Kabir and Hasin [24] described the disadvantages of the AHP application to include: its use of an unbalanced scale of judgment, its failure to capture the uncertainty associated with the mapping of one's judgment to a number, its ranking's relative inaccuracy, and its results containing subjective judgment in terms of selection and preference of decision-makers.

Meanwhile, In terms of measurement, evaluation and improvement of company performance, the FAHP method can accommodate a wide range of qualitative and quantitative measures. These would be based on an established set of evaluation performance indicators and decision alternatives. The set of indicators and alternatives are constructed in hierarchy corresponding to decision maker values. The FAHP method can calculate the weighting and rank priorities for each of the decision indicators/alternatives in precise human judgment. Hence, the vagueness in human judgment for decision making in measurement, evaluation and improvement of the company performance could be avoided. The comparison of AHP and FAHP in term of performance measurement is shown in Table 1.

Table 1: The comparison of original AHP and FAHP methods by several authors

| Authors | Original AHP | FAHP |
|---|---|---|
| Kabir and Hasin [24] | Using an unbalanced scale of judgment; AHP ranking's relative inaccuracy; and AHP results containing subjective judgment in terms of selection and preference of decision-makers. | More balance scale of judgment; FAHP ranking's relative accuracy; and FAHP results not containing subjective judgment in terms of selection and preference of decision-makers. |
| Jaskowski et al. [25] | Cannot improve quality of criteria prioritization. | Improve quality of criteria prioritization. |
| Tang and Beynon [26] | Based on individual decision-making to derive priorities on pairwise comparisons. | It allows group decision-making to derive priorities on pairwise comparisons. |
| Lee et al. [27] | Lack of practice in real measurement when an uncertain pairwise comparison environment exists. | Can obtain the relative importance in real practice where an uncertain pairwise comparison environment exists and provide performance evaluation suggestion. |
| Tan et al. [28] | Cannot be used to account for variations in degrees of confidence; such as nuances/traces. | Can be used to account for variations in degrees of confidence, such as nuances/traces. |
| Gupta and Nukala [23] | Decision makers to present their references using crisp numbers that often fail to capture vagueness. | Decision makers to present their references using fuzzy numbers that allow within a reasonable interval. |

## 3.0 METHODOLOGY

In order to develop a lean manufacturing PMS framework, it is better to have multi-dimensional perspectives and performance indicators that can accurately represent the dynamic nature of a company and its specific environment. A clearer definition of lean principles was identified from various relevant industrial work activities that support the lean implementation (practices). Then, the key performance indicators (KPIs) of lean activities that would have a significant influence on company performance were identified. Furthermore, the proposed method was employed the hierarchy that consist of goal at first level, perspectives at second level and indicators/alternatives at third level. There are two methods was performed to determine the degree of importance of the perspectives and indicators or alternatives in the PMS proposed framework. Sub-sequences, a lean manufacturing PMS framework based the PMS structure and process methods such as the AHP and FAHP were developed in this paper.

### 3.1 Original AHP method

In the original AHP demonstrated by Saaty [15], a decision maker expresses judgment about the importance of one alternative over another by using a crisp number. Steps to calculate weights priorities in the AHP method are following [15]:

1. *Construct hierarchy of the problem*
2. *Pairwise comparison matrix*

The matrix C contains pairwise comparison value $c_{ij}$ for all i, j □ {1, 2, …, n}. Let n be the number of criterion and A1, A2, …, An be their corresponding relative priority given by one decision maker.

$$C=\begin{bmatrix} c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \\ c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \end{bmatrix}=\begin{bmatrix} 1 & A1 & \cdots & An \\ 1/A1 & 1 & \cdots & Ann \\ \cdots & \cdots & \cdots & \cdots \\ 1/An & 1/Ann & \cdots & 1 \end{bmatrix} \quad (1)$$

For multiple decision makers: It is used aritmethic mean to defind a new judgment matrix by each decision maker. The number of decision maker is denoted as h and cijk is the pairwise comparison value of criteria i and j given by decision maker k, where k = 1, 2, …, h.

$$\overline{C_{ij}} = \frac{c_{ij}k1 + c_{ij}k2 + \ldots + c_{ij}kn}{h}$$

$$\overline{C}_{ij} = \frac{1}{h}\sum_{k=1}^{n} c_{ij} \quad (2)$$

3. *Calculate eigenvector and eigen value for getting the weights and* $\lambda_{\max}$

The calculating of eigenvector for matrix C: multiply each member of the matrix row and power of 1/n where n is the number of columns, then divided by Sum c.

$$\text{Eigenvctor C (Weights)}=\begin{Bmatrix} \dfrac{\left(c_{11}{*}c_{12}{*}c_{1n}\right)^{1/n}}{Sum\ c} \\ \dfrac{\left(c_{21}{*}c_{22}{*}c_{2n}\right)^{1/n}}{Sum\ c} \\ \dfrac{\left(c_{31}{*}c_{32}{*}c_{3n}\right)^{1/n}}{Sum\ c} \end{Bmatrix} \quad (3)$$

Where Sum c is:

$$Sum\,c=\left(c_{11}{}^{*}c_{12}{}^{*}N_{1n}\right)^{1/n}+\left(c_{21}{}^{*}c_{22}{}^{*}c_{2n}\right)^{1/n}+\left(c_{31}{}^{*}c_{31}{}^{*}c_{3n}\right)^{1/n} \tag{4}$$

Calculate largest eigenvalue ( $\lambda_{max}$ ) of matrix C:

$$\lambda_{max}=\left[(c_{11}+c_{21}+c_{n1}) \quad (c_{12}+c_{22}+c_{n2}) \quad (c_{13}+c_{23}+c_{n3})\ldots\right]\left\{\begin{matrix}\frac{\left(c_{11}{}^{*}c_{12}{}^{*}c_{1n}\right)^{1/n}}{Sum\,c}\\ \frac{\left(c_{21}{}^{*}c_{22}{}^{*}c_{2n}\right)^{1/n}}{Sum\,c}\\ \frac{\left(c_{31}{}^{*}c_{32}{}^{*}c_{3n}\right)^{1/n}}{Sum\,c}\\ \ldots\end{matrix}\right\} \tag{5}$$

*4. The calculating of consistency*

The consistency index (*CI*) and consistency ratio (*CR*) to verify the consistency of the comparison matrix. *n* is the matrix size and RI is random index (see table). *CI* and *CR* are defined as follow:

$$CI=\left(\lambda_{max}-n\right)/(n-1) \tag{6}$$

$$CR=CI\,/\,RI \tag{7}$$

Table 2: RI index table [15].

| Size (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.58 |

The proposed framework of PMS using the original AHP for lean activities is composed of the following steps:

Step 1: Identify the perspectives and indicators/alternatives to be used in the PMS framework model that could have a significant influence on company performance.

Step 2: Construct the AHP model hierarchically based on the perspectives and indicators/alternatives identified at Step (1).

Step 3: Determine the degree of importance, also known as weights of the perspectives and indicators/alternatives by using the AHP method.

Step 4: Collect the information of achievement in the performance indicators of lean manufacturing activities in the step one (1).

Step 5: Calculate lean performance based on weight in step (3) and scoring of lean practices in step (4), and then it is ranked to decide the priority.

Step 6: Analyse and established target improvement based lean performance priority ranking in step (5).

### 3.2 The FAHP Method

The FAHP is more precise than the original AHP to capture vagueness in human decision making. The proposed FAHP deals with the vagueness of the judgment by translating this to a fuzzy number with a triangular membership function with a central value for the fuzzy number. This corresponds to the crisp number given by the decision maker. The judgment from several decision makers is then aggregated and the arithmetic mean operation of the fuzzy number is then used within a procedure to calculate the weight vector.

The FAHP method was proposed to tackle the vagueness and uncertainty existing in the perspectives and the indicators, in the judgment of the decision-makers in evaluating the lean manufacturing activities alternatives. The steps for FAHP used in this proposed method are as follows:

- Establish a decision group,
- Members of the decision groups make a judgment on the importance of the lean manufacturing activities,
- Aggregate judgments of the decision maker,
- Check consistence,
- Calculate the weight.

For detail calculation or formula and procedure to compute weight values using the FAHP method that available on Susilawati et al. [29].

The proposed framework of PMS using the FAHP for lean activities is composed of the following steps:

Step 1: Identify the perspectives and indicators/alternatives to be used in the PMS framework model that could have a significant influence on company performance.

Step 2: Construct the AHP model hierarchically based on the perspectives and indicators/alternatives identified at Step (1).

Step 3: Determine the degree of importance, also known as weights of the perspectives and indicators/alternatives by using FAHP method.

Step 4: Collect the information of achievement in the performance indicators of lean manufacturing activities in the step one (1).

Step 5: Calculate lean performance based on weight in step (3) and scoring of lean practices in step (4), and then it is ranked to decide the priority.

Step 6: Analyse and established target improvement based lean performance priority ranking in step (5).

## 4.0 RESULT AND DISCUSSION

In this section, the application of the lean PMS model based the FAHP or the original AHP is presented as a case study at the discrete manufacturing industry (automotive company) in the Indonesian manufacturing industry. The application of lean manufacturing PMS that consists of identifying the perspectives and performance indicators; construction of the structure hierarchy; conducted a pairwise comparison and data collection. Furthermore, this section explains the analysis and recommendations for the case study undertaken at the companies.

### 4.1 Application of the Lean Manufacturing PMS in Case Study Company

The aim of the application of the lean performance measurement system in case study company is to measure, evaluate and decide upon the potential improvement for the lean activities, on the company's overall performance. The AHP method was employed to decide upon the priorities of the lean activities at an operational level, in order to link the competitive priorities to the business perspectives, which impact on the company's overall performance. Then, it was done for the FAHP method as well, and then the results were compared.

### 4.2 Determination of Perspectives and Performance Indicators, and Construction of a Hierarchy Structure

The company has a strategic plan to make sure the production processes increase and are efficient manner. Therefore, the company focuses on product processing has been enhanced. Consequently, the company needs to measure and improve the company's overall performance by achieving the company's strategic goals, which use six specific perspectives and performance indicators of the lean activities, in areas of the manufacturing efficiency process, which selected performance indicators are required to investigate as follows:

Manufacturing efficiency process:

- Eliminate time spent on engineering change
- Eliminate defects in products
- Eliminate excessive lead time
- Eliminate excessive movement of workers
- Eliminate excessive scrap
- Eliminate idleness of workers
- Eliminate machine down time

Subsequently, a hierarchy structure was constructed based on the selected perspectives and performance indicators of the lean activities. The hierarchy consists of:

Level 1: the overall objectives that improve the overall performance of the company.

Level 2: measurement perspectives: the financial perspective, supplier issues, customer issues, process, people and future.

Level 3: decision indicators/alternatives.

According to these elements outlined above, the hierarchy for the lean performance measurement of the company's case study is presented in Figure 2.

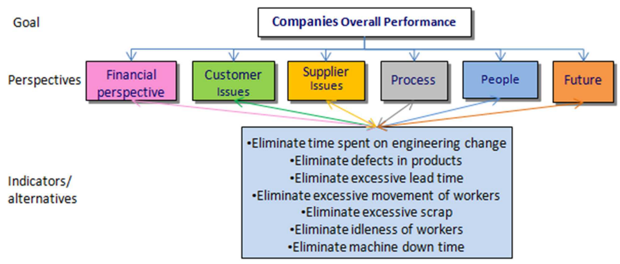


Figure 2: The lean manufacturing PMS hierarchy for company's case study

### 4.3 Conduct a Pairwise Comparison and Data Collection

The collection of data using a structured interview and a self-administered questionnaire were undertaken by two Head of Department Sections. They identified weights (relatively important) of selected lean manufacturing performance indicators using the pairwise comparison and the degree of confidence in their making of the pairwise comparison judgment. The collection of data and the resulting data pairwise comparison for performance perspectives and performance indicators on the selected manufacturing efficiency process at the company's case study were depicted in Tables 3 and 4 respectively.

Table 3: The pairwise comparison for the second level of the hierarchy.

| The lean perspectives | Decision making members | Financial perspective | | Customers issues | | Supplier issues | | Process | | People | | Future | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment |
| Financial perspectives | A | | | 3 | 90% | 1 | 90% | 2 | 90% | 4 | 90% | 2 | 90% |
| | B | | | 5 | 90% | 2 | 90% | 3 | 90% | 4 | 90% | 1 | 90% |
| Supplier issues | A | | | | | 1/5 | 90% | 1/2 | 90% | 2 | 90% | 1 | 90% |
| | B | | | | | 1/5 | 90% | 1/3 | 90% | 1/2 | 90% | 1/4 | 90% |
| Customer issues | A | | | | | | | 2 | 90% | 3 | 90% | 4 | 90% |
| | B | | | | | | | 1 | 90% | 3 | 90% | 2 | 90% |
| Process | A | | | | | | | | | 3 | 90% | 2 | 90% |
| | B | | | | | | | | | 2 | 90% | 2 | 90% |
| People | A | | | | | | | | | | | 1 | 90% |
| | B | | | | | | | | | | | 1 | 90% |
| Future | A | | | | | | | | | | | | |
| | B | | | | | | | | | | | | |

Table 4: The pairwise comparison for the third level of hierarchy in the manufacturing efficiency process.

| The lean indicators for the manufacturing efficiency process | Decision making members | Eliminate time spent on engineering change | | Eliminate defects in products | | Eliminate excessive lead time | | Eliminate excessive movement of workers | | Eliminate excessive scrap | | Eliminate idleness of workers | | Eliminate machine down time | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment | Scale | Confidence degree on judgment |
| Eliminate time spent on engineering change | A | | | 1/5 | 90% | 1 | 90% | 1 | 90% | 1/4 | 90% | 1/2 | 90% | 1/3 | 90% |
| | B | | | 1/4 | 90% | 1/3 | 90% | 1 | 90% | 1/4 | 90% | 1/2 | 90% | 1/3 | 90% |
| Eliminate defects in products | A | | | | | 3 | 90% | 2 | 90% | 3 | 90% | 1 | 90% | 1 | 90% |
| | B | | | | | 1 | 90% | 2 | 90% | 3 | 90% | 1/2 | 90% | 1/2 | 90% |
| Eliminate excessive lead time | A | | | | | | | 1 | 90% | 1 | 90% | 1/5 | 90% | 1/3 | 90% |
| | B | | | | | | | 1 | 90% | 1 | 90% | 1/5 | 90% | 1/4 | 90% |
| Eliminate excessive movement of workers | A | | | | | | | | | 2 | 90% | 1/2 | 90% | 1/2 | 90% |
| | B | | | | | | | | | 2 | 90% | 1/2 | 90% | 1/3 | 90% |
| Eliminate excessive scrap | A | | | | | | | | | | | 1/2 | 90% | 1/3 | 90% |
| | B | | | | | | | | | | | 1/4 | 90% | 1/3 | 90% |
| Eliminate idleness of workers | A | | | | | | | | | | | | | 1/2 | 90% |
| | B | | | | | | | | | | | | | 1/2 | 90% |
| Eliminate machine down time | A | | | | | | | | | | | | | | |
| | B | | | | | | | | | | | | | | |

### 4.4 Comparison of Weights between AHP Method and FAHP Method for Lean Manufacturing PMS

The comparison of original AHP and FAHP proposed methods was performed in this section. Steps to calculate weights priorities in the AHP and FAHP methods can be seen in Section Methodology. The comparison results of weights between for original AHP and FAHP methods were presented in Table 5 of the lean performance perspectives) and Table 6 of the lean performance indicators of manufacturing efficiency process).

Demonstrated sample calculation and procedure of the original AHP method.

1. *Construct hierarchy of the problem*

The lean manufacturing PMS hierarchy for company's case study was depicted in Figure 2.

2. *Pairwise comparison matrix for AHP method*

1= Financial perspectives; 2 = Supplier issues; 3 = Customer issues; 4 = Process; 5 = People; and 6 = Future.

Decision making 1

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 3 | 1 | 2 | 4 | 2 |
| 2 | 0.33 | 1 | 0.2 | 0.5 | 2 | 1 |
| 3 | 1 | 5 | 1 | 2 | 3 | 4 |
| 4 | 0.5 | 2 | 0.5 | 1 | 3 | 2 |
| 5 | 0.25 | 0.5 | 0.33 | 0.33 | 1 | 1 |
| 6 | 0.5 | 1 | 0.25 | 0.5 | 1 | 1 |

Decision making 2

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 5 | 2 | 3 | 4 | 1 |
| 2 | 0.2 | 1 | 0.2 | 0.33 | 0.5 | 0.25 |
| 3 | 0.5 | 5 | 1 | 1 | 3 | 2 |
| 4 | 0.33 | 3 | 1 | 1 | 2 | 2 |
| 5 | 0.25 | 1 | 0.33 | 0.5 | 1 | 1 |
| 6 | 1 | 4 | 0.5 | 0.5 | 1 | 1 |

Combine matrix by each decision maker using Equation (2).

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 1.5 | 2.5 | 4 | 1.5 |
| 2 | 0.267 | 1 | 0.2 | 0.415 | 1.25 | 0.625 |
| 3 | 0.75 | 5 | 1 | 1.5 | 3 | 3 |
| 4 | 0.417 | 2.515 | 0.75 | 1 | 2.5 | 2 |
| 5 | 0.25 | 0.75 | 0.333 | 0.417 | 1 | 1 |
| 6 | 0.75 | 2.5 | 0.375 | 0.5 | 1 | 1 |

3. *Calculate eigenvector and eigen value for getting the weights and* $\lambda_{max}$

n = 6

$$\text{Eigenvctor C (Weights)}=\begin{Bmatrix} \dfrac{(1*4*1.5*2.5*4*1.5)^{1/6}}{Sum\ c} \\ \dfrac{(0.267*1*0.2*0.1415*1.25*0.625)^{1/6}}{Sum\ c} \\ \dfrac{(0.75*5*1*1.5*3*3)^{1/6}}{Sum\ c} \\ \dfrac{(0.417*2.515*0.75*1*2.5*2)^{1/6}}{Sum\ c} \\ \dfrac{(0.25*0.75*0.333*0.417*1*1)^{1/6}}{Sum\ c} \\ \dfrac{(0.75*0.25*0.375*0.5*1*1)^{1/6}}{Sum\ c} \end{Bmatrix}$$

$$Sum\ c = (1*4*1.5*2.5*4*1.5)^{1/6} + (0.267*1*0.2*0.1415*1.25*0.625)^{1/6} + (0.75*5*1*1.5*3*3)^{1/6} + (0.417*2.515*0.75*1*2.5*2)^{1/6} + (0.25*0.75*0.333*0.417*1*1)^{1/6} + (0.75*0.25*0.375*0.5*1*1)^{1/6}$$

$Sum\ c$ = 7.1896

| | | | |
|---|---|---|---|
| Eigenvector (weights) | = 2.1169/7.1896 | = | 0.294 |
| | 0.5085/7.1896 | | 0.071 |
| | 1.9234/7.1896 | | 0.268 |
| | 1.2562/7.1896 | | 0.175 |
| | 0.5444/7.1896 | | 0.076 |
| | 0.8401/7.1896 | | 0.117 |

The weights:

| | | |
|---|---|---|
| 1. | Financial perspective | 0.294 |
| 2. | Supplier issues | 0.071 |
| 3. | Customer issues | 0.268 |
| 4. | Process | 0.175 |
| 5. | People | 0.076 |
| 6. | Future | 0.117 |

Calculate largest eigenvalue ( $\lambda_{max}$ ) using Equation 5:

$$\lambda_{max} = [3.43 \;\; 15.77 \;\; 4.16 \;\; 6.33 \;\; 12.75 \;\; 9.13] \begin{bmatrix} 0.294 \\ 0.071 \\ 0.268 \\ 0.175 \\ 0.076 \\ 0.117 \end{bmatrix}$$

$\lambda_{max}$=6.67

4. *The calculating of consistency*

Using Equation (6), $CI$= (6.67 - 6)/(6-1) = 0.075

From Table 1. RI table: n = 6, RI = 1.24.

Then using Equation (7), $CR = 0.075/1.24 = 0.061$

Meanwhile, the calculation and procedure of weights for the FAHP method was based on Susilawati et al. [29]. The FAHP analysis consistency is presented in Table 5. The consistency ratios (CR) for each member and group of decision makers are less than the 0.10 that was depicted in Table 5. Therefore, it can be concluded that the lean activities performance measurement is consistent and acceptable.

Table 5: Consistence Ratio (CR) for the FAHP method.

| Hierarchy | CR | | |
|---|---|---|---|
| | Decision maker A | Decision maker B | Group |
| Level 2 (perspectives) | 0.022 | 0.058 | 0.091 |
| Level 3 (indicators/alternatives) on process of manufacturing efficiency | 0.042 | 0.070 | 0.083 |

Table 6: The comparison using the FAHP proposed method and the original AHP method for the lean performance perspectives in company's case study

| The lean performance perspectives | The FAHP proposed method | | The original AHP method | |
|---|---|---|---|---|
| | Weight | Rank | Weight | Rank |
| Financial perspective | 0.297 | 1 | 0.294 | 1 |
| Supplier issues | 0.071 | 6 | 0.071 | 6 |
| Customer issues | 0.262 | 2 | 0.268 | 2 |
| Process | 0.171 | 3 | 0.175 | 3 |
| People | 0.083 | 5 | 0.076 | 5 |
| Future | 0.116 | 4 | 0.117 | 4 |

Table 7. The comparison using the FAHP proposed method and the original AHP method for performance indicators of the manufacturing efficiency process in company's case study

| The lean performance indicators of manufacturing efficiency process | The FAHP proposed method | | The original AHP method | |
|---|---|---|---|---|
| | Weight | Rank | Weight | Rank |
| Eliminate time spent on engineering changes | 0.059 | 7 | 0.059 | 7 |
| Eliminate defects in products | 0.193 | 3 | 0.198 | 3 |
| Eliminate excessive lead time | 0.084 | 6 | 0.084 | 6 |
| Eliminate excessive movement of workers | 0.099 | 4 | 0.097 | 4 |
| Eliminate excessive scrap | 0.087 | 5 | 0.085 | 5 |
| Eliminate idleness of workers | 0.211 | 2 | 0.210 | 2 |
| Eliminate machine down time | 0.267 | 1 | 0.267 | 1 |

The Tables 6 and 7 presented for the AHP and FAHP methods showed the weights were almost similar results. The data provided for both methods had been derived from two managerial levels in company's case study. The data was gathered using questionnaires and structured interviews, which contain the quantitative and the qualitative forms. The data results provided the extent of the degree of confidence on their judgment. In fact, both managers have 90% confidence in their judgment that was shown in Table 3 and 4. The FAHP proposed method has the capability to cope with variations in degrees of confidence; can obtain the relative importance in real practice where an uncertain pairwise comparison environment exists; and more exactly reflect human opinions. Meanwhile, it had not been accounted by the original AHP. Specifically, the CR result produced by both methods was also almost similar (less than 0.1). However, the FAHP proposed method has capability to check the CR twice as an individual judgment and then aggregated by each member group judgment. Whilst, the original AHP was only check once as aggregated by each member of group judgment. Therefore, in this case, the weights and the CR produced by the FAHP method were more natural, practical and accurate.

### 4.5 Analysis of the Data Weights

In Table 6 and 7 can observed the value of weights contribution improvement impacted upon the overall performance of the lean activities in the company's case study. The company's business impact had a high priority for the financial perspectives, with the weights at 0.297 for FAHP method and 0.294 for original AHP method. The lower priorities in the overall performance measurement of the company's case study were awarded to perspectives for supplier issues of 0.071 for both the FAHP and original AHP methods.

Table 7 presented the weights and priority ranking of the lean performance indicators/alternatives in the manufacturing efficiency impacted upon the perspectives of the company. To eliminate the idleness of workers was the high priorities, which the value of weights contribution improvement impacted at 0.267 for both the FAHP and original AHP methods. The lower priorities were awarded to the time spent on engineering changes of 0.059 for both the FAHP and original AHP methods.

## 5.0 CONCLUSION

In this paper, the proposed framework of lean manufacturing PMS consists of the indicators and perspectives of lean manufacturing activity. The development of a framework to measure the company's performance used Fuzzy Analytic Hierarchy Process (FAHP) and Analytic Hierarchy Process (AHP) in term of decision making. For benchmarking comparison, both methods (AHP and FAHP) were applied as a case study in automotive company, in Indonesian manufacturing industry. Both methods produced almost similar results to generate the weights and the CR. It can be noted if the data is certainty (degree of confidence = 100%) then the original AHP method might be preferred. However, if the data is uncertainty (degree of confidence between 0% and 100%) then the FAHP proposed method might be preferred. In this case study, the decision makers have uncertainty on their judgments (degree of confidence was 90%). So in this case, the FAHP proposed method was more applicable and realistic than the original AHP method to generate the weights and the CR.

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