Journal of Engineering Science and Technology
Vol. 13, No. 12 (2018) 3894 - 3907

MODIFIED AHP TO SELECT NEW SUPPLIERS IN THE INDONESIAN STEEL PIPE INDUSTRY

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Abstract

The analytical hierarchy process (AHP) is not as effective and efficient as the pairwise comparison (PWC) matrix. The aim of this research is to tackle the weaknesses of the AHP and then applied them to a real-life case of new supplier selection in the Indonesian steel pipe industry. Some criteria are identified that are relevant in the Indonesian steel pipe companies to select new suppliers. A total score is calculated for each supplier and this ranking is used to identify the best one. In this research, the decision maker created the sorting of the criteria used in supplier selection. The matrix of PWC was constructed based on the sorting. Then, the weight of each criterion was calculated using AHP. The result of the method was an improvement over previous methods, because the value of the consistency ratio (CR) was zero, indicating a high degree of validity. This modified method was an improvement on the AHP, with a consistent solution without the need to repeat the calculation.

Keywords: Analytical hierarchy process (AHP), Consistency ratio (CR), Criteria, Pair-wise comparison (PWC) matrix, Supplier selection.

1. Introduction

Indonesia is developing a steel pipeline network for integrated gas distribution in islands of Sumatera, Sulawesi, Kalimantan and Java. Thus, demand for steel for pipes in Indonesia is increasing. Increased production capacity of steel pipes must be balanced with the amount of supplied material. If suppliers of materials for steel of pipes cannot guarantee the availability of materials required by the steel pipe industry, many companies will be forced to stop or slow production. The availability of materials is an important factor for the sustainability of the steel pipe industry. Therefore, selection of suitable suppliers affects the performance and long-term sustainability of each company [1, 2]. Saen [3] commented that the objective of selecting suppliers is not just to choose a supplier based on price or delivery time, but the supplier is also expected to be a part of the life of the company. Thus, errors in supplier selection should be avoided at the earliest possible time.

In order not to be wrong in choosing a supplier, it is necessary to assess them first. The assessment should be based on criteria considered very important to the company. Supplier selection is usually done by looking at past data relevant to each criterion considered by the company. In fact, companies are often faced with the problem of deciding on the selection of new suppliers who do not have a performance record. In fact, these new suppliers could have a better performance going forward than the old suppliers. Therefore, there is a need to select the right criteria for the company so that they can be used appropriately in choosing a new supplier.

One method often used to choose suppliers is the Analytical Hierarchy Process (AHP). According to Anojkumar et al. [4] and Azizi et al. [5], the quality of AHP solutions are determined by a pairwise comparison matrix (PWM). The AHP solution is considered valid if the PWM is declared consistent. The weakness of AHP is that if there are too many criteria (i.e., above 7 criteria), the decision maker must perform a large number of pairwise comparisons [6], where it will be difficult to achieve consistent results [7]. Then, AHP fails to reflect associated uncertainty and ambiguity based on capture of expert judgments [8-10]. Saaty and Ozdemir [11], therefore, recommended to use seven or fewer criteria. This recommendation is not easy to achieve, because the number of criteria must be relevant to the real-life cases.

Another weakness of AHP is that it is not efficient. Patil and Kant [9] commented that the pairwise matrix is formed via human judgment, which can very easily lead to inconsistency due to great influence of subjective expert judgment and preference. Thus, the decision maker should perform some revisions of the judgements provided [5]. The decision maker must fill the matrix continuously until a consistent matrix is obtained [4]. This is a waste of time, effort, and cost. A further weakness of the PWC matrix is it only uses nine-point scale numbers for judgments and for their resulting priorities [12]. According to Routroy and Kumar [10] and Bakhshimazdeh and Alikhasi [13], the resulting PWC matrix is not sufficient to represent one's perceptions and Ravikumar et al. [14] explained it cannot accurately capture the correct decision. Thus, the matrix of PWC is limited in solving vague problems and cannot reflect human thinking styles [10, 12].

Based on the explanation above, it can be concluded that the cause of AHP's lack of effectiveness and efficiency is the PWC matrix. This research proposes a modification in making of the PWC matrix to produce more consistent results. Thus, the AHP solution is much more likely to be valid. In addition, the study also proposes new criteria that can be used to select new suppliers for the Indonesian steel pipe industry.

2. Literature Review

Our initial goal was to investigate the selection of criteria in previous supplier selection research. The articles were retrieved from academic databases including Science Direct, Emerald, Springer-Link Journals, Francis & Taylor, and Inderscience. The keywords for our search were "supplier selection" and "vendor selection." Only articles that had been published between 2016 and 2018 was use. To achieve the highest level of relevance, this study only included articles from international journals. Conference articles, master and doctoral dissertations, textbooks, unpublished articles, and notes were not included in this review.

A number of 349 articles is collected. Every article was carefully and strictly selected in accordance with the scope of our research. There were 25 articles included in total. Criteria that were used in the research sample were price [15-37], discount [20], payment term [19, 38], quality [16-39], quality management [23, 25, 30, 33, 35, 38], delivery [16-18, 20-30, 34-40], packaging [20, 38], flexibility [16-20, 23, 26, 28, 32, 34-37, 40], shipment [23, 39, 41], location [17, 20, 23, 38, 40], accessibility [19, 20, 31, 35, 38], customer service [19, 22, 23, 25, 27-29, 35-39], relationship [9, 16, 17, 20, 23, 25-28, 34], financial and capital [15, 16, 19, 23, 25, 27-29, 40], reputation and experience [15, 19, 20, 23-25, 28, 29, 33, 38], organization and management [16,19,26,28,30,38], human capital [15, 16, 19, 23, 39], company culture [17, 31], production planning [19, 23, 32], facilities support system [15, 19, 24, 29, 37, 40], production capacity [18, 20, 23, 24, 26, 33, 34, 37, 40], product design [19, 25, 26, 28, 32, 33, 41], technology capability [17, 19, 21, 23, 25-29, 33, 34, 36, 40], health and safety [19, 23, 28, 37], stakeholders rights [23, 30, 37], social responsibility [19, 25, 30, 31, 33], unrest of social politic [31], legality [19, 31, 37], pollutant control [19, 30, 31, 34, 35, 37], and green competence [21, 24, 25, 28, 30, 31, 34, 35].

Companies can easily evaluate old suppliers, but it is very difficult to evaluate new suppliers. New suppliers usually offer proposals consisting of offered price, terms of payment, discounted price, and warranty, but all these criteria are commonly used to select suppliers in general. The new suppliers do not have historical performance data, however, so the company can only estimate their performance. This is inherently risky for the company. Therefore, it is necessary to identify new criteria in the selection of new suppliers, which can only be found in real cases; often each case will have different new criteria. The criteria found in the literature were ultimately used as a source for the seven evaluation criteria used in the case study discussed below; these criteria were narrowed down based on the circumstances of the particular supplier situation in the case study.

3. Theory Foundation

3.1. Analytical hierarchy process (AHP)

Saaty [42] fully described, that there are three steps in AHP. The first, we must make the PWM, shown in Eq. (1). This matrix contains the values of comparison between criteria. The values of these comparisons involve the judgment of the decision maker. The next step is to calculate the normalization matrix, as in Eq. (2). Equation (3) is the final step, producing the relative weights of each criterion.

$$a_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

The a_{ij} value is equal to 1 if criteria i and criteria j are equally important. The values of a_{ij} differ depending on the relative importance of the two criteria. For instance, a_{ij} = 3 if criteria i is moderately more important than criteria j; 5 if criteria i is strongly more important than criteria j; 7 if criteria i is very strongly more important than criteria j; and 9 if criteria i is extremely more important than criteria j. If criteria i is compared with the criteria j and that a judgment matrix a_{ij} is obtained, then the judgment matrix between criteria j and criteria i is $r_{ji} = 1/r_{ij}$ [42].

$$N_{ij} = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \\ \frac{a_{21}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{22}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{2n}}{\sum_{i=1}^{n} a_{in}} \\ \dots & \dots & \dots & \dots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} & \dots & \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \end{bmatrix} \quad (2)$$

$$W_i = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} \left[\frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} + \dots + \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \right] \cdot \left(\frac{1}{n} \right) \\ \left[\frac{a_{21}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{22}}{\sum_{i=1}^{n} a_{i2}} + \dots + \frac{a_{2n}}{\sum_{i=1}^{n} a_{in}} \right] \cdot \left(\frac{1}{n} \right) \\ \vdots \\ \left[\frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} + \dots + \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \right] \cdot \left(\frac{1}{n} \right) \end{bmatrix} \quad (3)$$

3.2. Model validation

The goal of this stage is to assess the validity of the AHP solution. As noted in [42], there are three calculations involved in this process, shown in Eqs. (4) and (5). The result of this second stage is the CR value. If this value is below 0.1, the CR is acceptable, and then the solution in the first stage is valid [42]. The 10 percent rate is the minimum limit where a disagreement can be tolerated. This limit of CR indicates a good level of consistency in the comparative judgments, which are represented in the PWC matrix [4]. Based on the studies by Anojkumar et al. [4], in contrast, if CR value is more than 10 percent, inconsistency of judgments within the matrix of PWC has occurred. The greater the CR value the greater the difference of judgements, and the greater their inconsistency. Thus, the smaller the difference of judgements the more consistent they are, and the greater the agreement between decision makers. If the solution is invalid, then the process of AHP is repeated.

$$\lambda_i = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{bmatrix} = \begin{bmatrix} (a_{11}W_1 + a_{12}W_2 + ... + a_{1n}W_n)(1/W_1) \\ (a_{21}W_1 + a_{22}W_2 + ... + a_{2n}W_n)(1/W_2) \\ ... \\ (a_{n1}W_1 + a_{n2}W_n + ... + a_{nn}W_n)(1/W_n) \end{bmatrix} \quad (4)$$

$$CR = \frac{\left[\left(\frac{1}{n}\sum_{i=1}^{n}\lambda_i\right) - n \right]}{\left[RI\,(n-1) \right]} \quad (5)$$

The random index (*RI*) values for each number of different criteria are given in Table 1.

Table 1. Random index [11].

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.52	1.54

3.3. Modified AHP

In modified PWC matrix proposed here, the decision maker must determine the importance level of the criteria. The importance level is based on the opinion of the decision maker. The decision maker first determines what criteria will be used to select suppliers. Then, they will write down the criteria in order. The first sequence is more important than the next sequence. This sequence indicates the importance level of each criterion. for supplier selection. The final level of importance of each criterion from many decision makers is combined by geometric means. According to Hruska et al. [43], in this step, Eq. (6) is used. Then, the PWC can be obtained by comparing the importance level of the criteria.

$$C^G{}_i = \sqrt[m]{C_i^1 C_i^2 ... C_i^m} \quad (6)$$

The various stages in the selection of suppliers of the proposed method are seen in Fig. 1. The first stage is identification of the criteria considered in the supplier selection. The second stage is determining the ranking of criteria. Both of these stages are performed by the company prior to the PWC procedure. The third stage is determination of criteria weights using the PWC matrix. The fourth stage is supplier scoring. This scoring is based on the data about or provided by the supplier and the weighting of the criteria. Model validation uses the CR value. If CR is less than one, then the solution of criteria weights and supplier scoring are valid. If CR is more than one, then the second stage is repeated again.

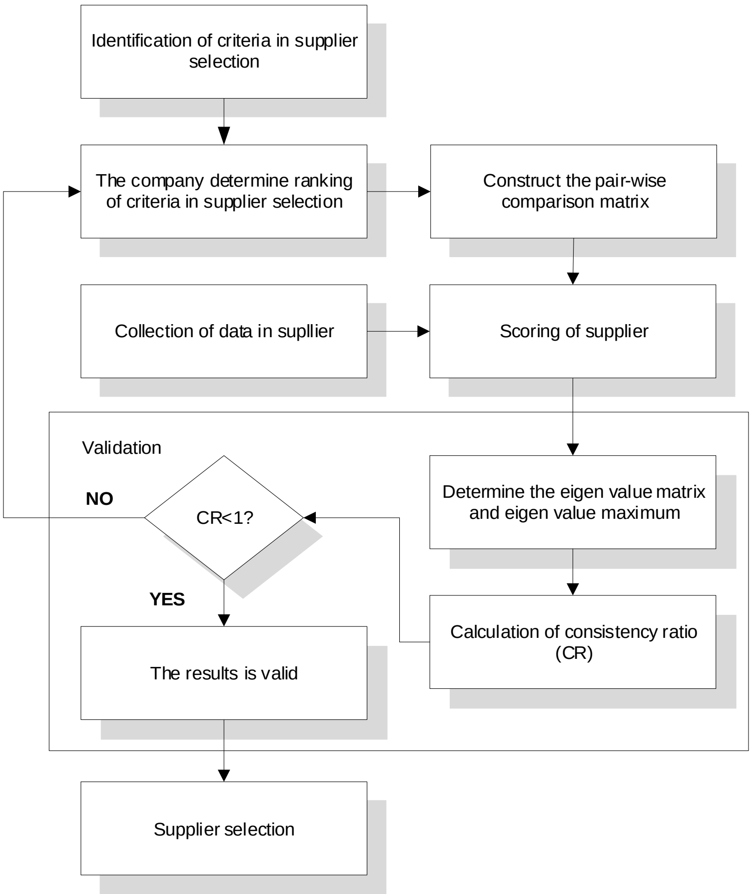

Fig. 1. Flow chart of the proposed method to select supplier.

4. Case Study

4.1. New supplier

Most supplier selection research is only on selection of old suppliers; this study focused on selecting new suppliers. To build the concept of research on the selection of new suppliers, the case of steel pipe companies in Indonesia was used.

The steel pipe industry in Indonesia has undergone some recent retrenchment and reorganization. Therefore, there only three companies were used in this research, namely PT. Bumi Kaya Steel; PT. Bakrie Pipe Industries; and PT. Raja Besi. PT. Steel Pipe Industry of Indonesia (SPINDO) only produces seamless steel pipe, while this research focused on companies that produce welded straight pipe.

Typically, the main supplier of raw materials is PT. Krakatau Steel. However, there are nine potential competitors with the ability to produce steel plate as raw material of steel pipe industry that could become new suppliers: PT. Master Steel Manufacturing; PT. Gunung Garuda; PT. Toyo Giri Iron; PT. Interworld; PT. Jakarta Central Asia; PT. Jakarta Cakra Tunggal; PT. Jatim Taman; PT. Hanil Jaya; and PT. Ispatindo. Of these, the latter three companies were not willing to become new suppliers, as they only focus on supplying companies in their immediate area. Thus, the sample was restricted to the first six listed suppliers.

Thus, the case study involved three existing steel pipe factories in Indonesia selecting a new supplier to meet the raw material of steel plate (slab). As noted above, the prospective suppliers of slab previously had never produced steel plate for the steel pipe industry, but had the ability or technology to produce steel plates. Steel products that have been produced from the potential suppliers have been used by other companies, and thus already have a number of cooperative relationships with other companies and a strategy to maintain this cooperation, such as enhanced delivery performance. Thus, a reputable supplier will easily obtain recommendations or awards and references from external or other companies. This reputation is also reflected in how long the cooperative relationship has existed between the supplier and the other customers.

Based on the brief description of the prospective suppliers, and by looking at the literature study in the previous chapter on the list of criteria that has been used in previous research, the research proposed seven criteria that are highly relevant as consideration of new supplier selection but have not been used in previous research: supplier motivation, the number of suppliers supplied, the length of cooperation with other companies, supplier strategies in order to maintain cooperation with other companies, delivery performance, awards from outsiders, and the supplier’s references.

4.2. Result and discussion

Usually, the criteria that are often used to choose suppliers are price, discount, ease of payment method, and quality. These criteria will surely be the same for each supplier. Therefore, new criteria were needed to select new suppliers. These criteria are the supplier's motivation, the number of suppliers supplied, the length of time in a cooperative relationship with other companies, the supplier's strategies in order to maintain cooperation with other companies, the delivery performance that has been given to other companies, the award from outsiders, and the suppliers' references. Each of these criteria were weighted using modified AHP. The data required in weighting is the value data for each criterion, obtained from the procurement manager of each steel pipe company, and shown in Table 2.

The explanation of Table 2 is as follows. First of all, the decision maker listed all the criteria used. This list starts from the criteria considered the most important to the criteria that is not important. Criteria that are in the first list are given the greatest value. If there are *n* criteria, then the largest value is *n*, and the smallest value is 1. For example, the decision maker of PT Bakrie chose the motivation (C_1) as the first on the list. Then the value of the criteria of motivation is 7 (C^r_1 =7), because there are 7 criteria considered. While the criteria of references (C_7) have a value of 1 (C^r_7 =1), because it is last on the list. Because there is more than one decision maker, then the final value of the motivation criteria should be combined. This combined value is obtained using Eq. (6). So, the final value of the motivation criteria (C^G_1) is $\sqrt[3]{C_1^1 C_1^2 C_1^3} = \sqrt[3]{7x7x5}$ or 6.26.

Using Table 2, the PWC and criteria-weighting were established, as shown in Table 3. If criteria C_i is compared with criteria C_j, then the a_{ij} for PWC matrix is

C_i/C_j. When, for example, criteria C_1 is compared with criteria C_2, then the a_{12} for PWC matrix is C_1/C_2 or 6.26/3.30 or 1.895. To obtain the relative weights of each criterion, we used Eq. (3). For example, the relative weights of criteria C_1 (W_1) are the value of $[a_{11}/\sum_{i=1}^{n=7} a_{i1} + a_{12}/\sum_{i=1}^{n=7} a_{i2} + a_{13}/\sum_{i=1}^{n=7} a_{i3} + a_{14}/\sum_{i=1}^{n=7} a_{i4} + a_{15}/\sum_{i=1}^{n=7} a_{i5} + a_{16}/\sum_{i=1}^{n=7} a_{i6} + a_{17}/\sum_{i=1}^{n=7} a_{i7}]$ or [(1/4.35) + (1.895/8.243) + (2.733/11.888) + (4.966/21.603) + (1.053/4.58) + (1.108/4.82) + (2.483/10.802)] multiplied by [1/n or 1/7]. From this calculation, the relative weights of criteria C_1 (W_1) of 0.23 is obtained.

Table 2. Data of each criterion.

Criteria	PT. Bakrie		PT. Bumi Kaya		PT. Raja Besi		C^G_{ij}
	Rank	C^r_1	*Rank*	C^r_2	*Rank*	C^r_3	
Motivation (C_1)	1	7.00	1	7.00	3	5.00	6.26
No of company supplied (C_2)	4	4.00	5	3.00	5	3.00	3.30
Long cooperation (C_3)	5	3.00	6	2.00	6	2.00	2.29
Maintain cooperation (C_4)	6	2.00	7	1.00	7	1.00	1.26
Delivery history (C_5)	3	5.00	2	6.00	1	7.00	5.94
Award form outsider (C_6)	2	6.00	3	5.00	2	6.00	5.65
References (C_7)	7	1.00	4	4.00	4	4.00	2.52

Table 3. Pairwise comparison.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	1.000	1.895	2.733	4.966	1.053	1.108	2.483
C_2	0.528	1.000	1.442	2.621	0.556	0.585	1.310
C_3	0.366	0.693	1.000	1.817	0.385	0.405	0.909
C_4	0.201	0.382	0.550	1.000	0.212	0.223	0.500
C_5	0.950	1.800	2.596	4.718	1.000	1.053	2.359
C_6	0.902	1.710	2.466	4.481	0.950	1.000	2.241
C_7	0.403	0.763	1.101	2.000	0.424	0.446	1.000
Weight	0.230	0.121	0.084	0.046	0.218	0.207	0.093
CR	0.000	(Consistent)					

The most important thing in supplier assessment is the scoring for each criterion. In order that the score for each criterion is uniform, a scale based on 10 was used. The scores assigned are 0, 2, 4, 6, 8, and 10. Thus, if the supplier has an amount of motivation is 1, then the score is 2; if the supplier has the amount of motivation is 2, then the score is 4, and so on. The explanation of the scores of each criterion can be seen in Table 4.

The averaged data for each supplier for each criterion can be seen in Table 5. Each supplier had one reason to motivate them to supply the pipe manufacturers. PT. Mater Steel had the largest number of supplied companies. However, the average length of cooperation with the supplied company was smaller than that of PT. Gunung Garuda. PT. Gunung Garuda worked with other companies for about 24 years. Both of the abovementioned companies had the same number of ways (three) to maintain such cooperation, less compared than PT. Cakra Tunggal, i.e., five. PT. Master Steel had the longest delivery history compared to other suppliers. All suppliers had no reference, but all have external rewards. The supplier with the most number of outside awards was PT. Cakra Tunggal.

The data are then scored based on the score shown in Table 4, then multiplied by the criteria weight. The results of multiplying the score with the weight of criteria for each factor are then summed up. This sum is called the total score. The result of multiplying the score with criteria weight and total score for each supplier can be seen in Table 5. An example of the calculations in Table 5 follows.

Table 4. Score of each criterion.

Motivation (C_1)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10
Number of companies supplied (C_2)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10
Rate of long cooperation (C_3) (year)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10
Maintain cooperation (C_4)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10
Rate of delivery history (C_5)(day)	>5	5≥x>4	4≥x>3	3≥x>2	2≥x>1	≤1
Score	0	2	4	6	8	10
Award from outsider (C_6)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10
References (C_7)	0	1	2	3	4	≥5
Score	0	2	4	6	8	10

PT Master Steel has an amount of motivation is 1, giving a score for criteria C_1 of 2. The number of companies it supplies is 11 with rate of long cooperation 5 years; the scores of criteria C_2 and C_3 are both 10. PT Master Steel has three strategies to maintain the cooperation, giving a score for criteria C_4 of 6. Time of delivery in PT Master Steel was on average 4 days, giving a score of criteria C_5 of 4. PT Master Steel has five awards from outsiders and has no references; the scores of criteria C_6 and C_7 are 10 and 0, respectively. The total score of PT Master Steel is $W_1 \cdot C_1 + W_2 \cdot C_2 + W_3 \cdot C_3 + W_3 \cdot C_3 + W_4 \cdot C_4 + W_5 \cdot C_5 + W_6 \cdot C_6 + W_7 \cdot C_7$ or (0.23)(2) + (0.121)(10) + (0.084)(10) + (0.046)(6) + (0.218)(4) + (0.207)(10) + (0.093)(0) = 5.74.

The total scoring of each supplier is seen in Fig. 2, which the best supplier based on the weighted criteria scores is PT. Cakra Tunggal. These results are based on a combination of assessments of three steel pipe companies. In fact, each company provides different assessments. This is another advantage of the proposed method. By using contiguous contribution levels, then the criterion weight has a small margin. Thus, if a criterion ranks differently for different companies but not too much different, then the results will be the same.

Table 5. Data and total score of each supplier

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Total score
PT. Master Steel	1.00	11.0	5.00	3.00	4.00	5.00	0.00	5.74
PT. Gunung Garuda	1.00	2.00	24.0	3.00	1.50	3.00	0.00	5.06
PT. Toyo Giri	1.00	6.00	4.67	1.00	1.50	2.00	0.00	5.02
PT. Interworld	1.00	3.00	21.0	1.00	1.50	2.00	0.00	4.70
PT. Jakarta Central Asia	1.00	2.00	4.00	1.00	1.50	0.00	0.00	3.46
PT. Cakra Tunggal	1.00	7.00	9.00	5.00	1.50	7.00	0.00	6.80
Weight	0.230	0.121	0.084	0.046	0.218	0.207	0.093	

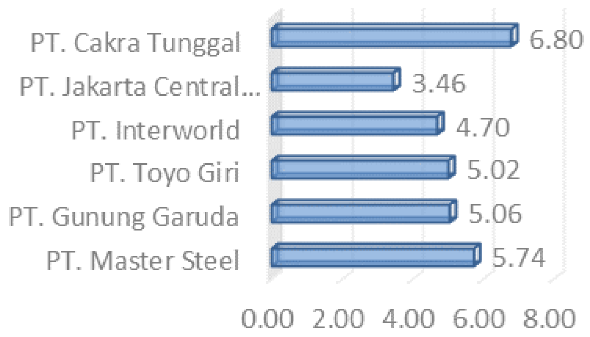

Fig. 2. Total score of suppliers.

4.3. Validation

To validate the result, CR was used. The first step this step is calculation of the eigenvalue of each criterion (λ_i) using Eq. (4). The example of this calculation follows. For criterion 1, $\lambda_1 = [a_{11}{\cdot}w_1 + a_{12}{\cdot}w_2 + a_{13}{\cdot}w_3 + a_{14}{\cdot}w_4 + a_{15}{\cdot}w_5 + a_{16}{\cdot}w_6 + a_{17}{\cdot}w_7] \cdot [1/w_1] = [(1 \cdot 0.23) + (1.895 \cdot 0.121) + (2.733 \cdot 0.084) + (4.966 \cdot 0.046) + (1.053 \cdot 0.218) + (1.108 \cdot 0.207) + (2.483 \cdot 0.093)] \cdot [1/0.23] = (1.609/0.23) = 7$.

By using Eq (5) consistency index (CI) can be calculated, CI = $[\lambda_1 - n]/[n - 1] = [7 - 7]/[7 - 1] = 0$. Then, CR is zero, because CR = 0 / RI=0. Based on this CR value, it can be seen that the result is absolutely consistent. This is the most important advantage over using the original AHP method; the proposed method is more likely to produce a valid solution. Using the original AHP, it will be very difficult to obtain CR equal to or approaching zero.

5. Conclusions

A modification of AHP-based model of MCDM, which enables Indonesian steel pipe companies to assess the critical criteria in supplier selection, has been developed. The proposed scorecard model enables steel pipe companies to assess suppliers. First, in order to obtain the data for the model, it requires steel pipe companies to first acquire an in-depth understanding about the suppliers in its sector or industry. Second, the output obtained by the model focuses supplier selection. Third, it allows reliable discovery of suppliers with the highest score, enabling the optimal choice of new suppliers. The proposed model allows varying the weights of the criteria based on decision maker. Proposed method of modified AHP is effective without repeating judgement processes and capable of obtaining consistent PWC matrices.

Funding

This research was financially supported by the PDD Program of the Ristekdikti Republic of Indonesia.

Acknowledgements

The authors thank the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for its financial support.

Nomenclatures

a_{ij}	Pair-wise comparison value of criteria *i* and criteria *j*
$C^G{}_i$	Combination of importance level of criteria *i*
C_i	Criteria *i*
$C^r{}_i$	Importance level of criteria *i* by decision maker *r*
M	Number of decision maker, person
N_{ij}	Normalisation of pair-wise comparison matrix of criteria *i* and criteria *j*
n	Number of criteria
W_i	Weight of criteria *i*

Greek Symbols

λ_i	Eigen value of the criteria *i*.

Abbreviations

AHP	Analytical Hierarchy Process
CR	Consistency ratio
MCDM	Multi criteria decision making
PWC	Pair wise comparison
RI	Random index

References

1. Songhori, M.J.; Tavana, M.; Azadeh, A.; and Khakbaz, M.H. (2011). A supplier selection and order allocation model with multiple transportation alternatives. *The International Journal of Advanced Manufacturing Technology,* 52(1-4), 365-376.
2. Hammami, R.; Temponi, C.; and Frein, Y. (2014). A scenario-based stochastic model for supplier selection in global context with multiple buyers, currency fluctuation uncertainties, and price discounts. *European Journal of Operational Research*, 233(1), 159-170.
3. Saen, R.F. (2007). Supplier selection in the presence of both cardinal and ordinal data. *European Journal of Operational Research*, 183(2), 741-747.

4. Anojkumar, L.; Ilangkumaran, M.; and Vignesh, M. (2015). A decision making methodology for material selection in sugar industry using hybrid MCDM techniques. *International Journal of Materials and Product Technology*, 51(2), 102-126.
5. Azizi, M.; Mohebbi, N.; Gargari, R.M.; and Ziaie, M. (2015). A strategic model for selecting the location of furniture factories: A case of the study of furniture. *International Journal of Multicriteria Decision Making*, 5(1/2), 87-108.
6. Aghdaie, M.H.; and Alimardani, M. (2015). Target market selection based on market segment evaluation: A multiple attribute decision making approach. *International Journal of Operational Research*, 24(3), 262-278.
7. Saaty, T.L.; and Kearns, K.P. (1985). *Analytical planning: The organization of system (1st ed.).* Oxford, New York: Pergamon Press.
8. Khatwani, G.; and Das, G. (2016). Evaluating combination of individual pre-purchase internet information channels using hybrid fuzzy MCDM technique: Demographics as moderators. *International Journal of Indian Culture and Business Management*, 12(1), 28-49.
9. Patil, S.K.; and Kant, R. (2014). Ranking the barriers of knowledge management adoption in supply chain using fuzzy AHP method. *International Journal of Business Innovation and Research*, 8(1), 52-75.
10. Routroy, S.; and Kumar, C.V.S. (2016). An approach to develop green capability in manufacturing supply chain. *International Journal of Process Management and Benchmarking*, 6(1), 1-28.
11. Saaty, T.L.; and Ozdemir, M.S. (2003). Why the magic number seven plus or minus two. *Mathematical and Computer Modelling*, 38(3-4), 233-44.
12. Ilangkumaran, M.; Sakthivel, G.; and Sasirekha, V. (2014). Waste water treatment technology selection using FAHP and GRA approaches. *International Journal of Environment and Waste Management*, 14(4), 392-413.
13. Bakhshimazdeh, M.; and Alikhasi, M. (2015). Analysis of strategic and organisational factors of mobile government by using fuzzy approach. *International Journal of Business Information Systems*, 19(1), 119-138.
14. Ravikumar, M.M.; Marimuthu, K.; and Parthiban, P. (2015). Evaluating lean implementation performance in Indian MSMEs using ISM and AHP models. *International Journal of Services and Operations Management*, 22(1), 21-39.
15. Polat, G. (2016). Subcontractor selection using the integration of the AHP and PROMETHEE methods. *Journal of Civil Engineering and Management*, 22(8), 1042-1054.
16. Bruno, G.; Esposito, E.; Genovese, A.; and Simpson, M. (2016). Applying supplier selection methodologies in a multi stakeholder environment: A case study and a critical assessment. *Expert Systems with Applications*, 43, 271-285.
17. Heidarzade, A.; Mahdavi, I.; and Mahdavi-Amiri, N. (2016). Supplier selection using a clustering method based on a new distance for interval type-2 fuzzy sets: A case study. *Applied Soft Computing*, 38, 213-231.
18. Pramanik, D.; Haldar, A.; Mondal, S.C.; Naskar, S.K.; and Ray, A. (2017). Resilient supplier selection using AHP-TOPSIS-QFD under a fuzzy environment. *International Journal of Management Science and Engineering Management*, 12(1), 45-54.

19. Wood, D.A. (2016). Supplier selection for development of petroleum industry facilities, applying multi-criteria decision making techniques including fuzzy and intuitionistic fuzzy TOPSIS with flexible entropy weighting. *Journal of Natural Gas Science and Engineering*, 28, 594-612.
20. Yadav, V.; and Sharma, M.K. (2016). Multi-criteria supplier selection model using the analytic hierarchy process approach. *Journal of Modelling in Management*, 11(1), 326-354.
21. Darabi, S.; and Heydari. J. (2016). An interval-valued hesitant fuzzy ranking method based on group decision analysis for green supplier selection. *IFAC (International Federation of Automatic Control) Papers On-Line*, 49(2), 12-17.
22. Dweiri, F.; Kumar, S.; Khan, S.A.; and Jain, V. (2016). Designing an integrated AHP based decision support system for supplier selection in automotive industry. *Expert Systems with Applications*, 62, 273-283.
23. Galankashi, M.R.; Helmi, S.A.; and Hashemzahi, P. (2016). Supplier selection in automobile industry: A mixed balanced scorecard-fuzzy AHP approach. *Alexandria Engineering Journal*, 55(1), 93-100.
24. Rezaei, J.; Nispeling, T.; Sarkis, J.; and Tavasszy, L. (2016). A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. *Journal of Cleaner Production*, 135, 577-588.
25. Wu, Y.; Chen, K.; Zeng, B.; Xu, H.; and Yang, Y. (2016). Supplier selection in nuclear power industry with extended VIKOR method under linguistic information. *Applied Soft Computing*, 48, 444-457.
26. Hosseini, S.; and Al-Khaled, A. (2016). A hybrid ensemble and AHP approach for resilient supplier selection. *Journal of Intelligent Manufacturing*, 1-22.
27. Jain, V.; Sangaiah, K.; Sakhuja, S.; Thoduka, N.; and Aggarwal, R. (2018). Supplier selection using fuzzy AHP and TOPSIS: A case study in the Indian automotive industry. *Neural Computing and Applications*, 29(7), 555-564.
28. Fallahpour, A.; Wong, K.Y.; Olugu, E.U.; and Musa, S.N. (2017). A predictive integrated genetic-based model for supplier evaluation and selection. *International Journal of Fuzzy System*, 19(4), 1041-1057.
29. Luzon, B.; and El-Sayegh, S.M. (2016). Evaluating supplier selection criteria for oil and gas projects in the UAE using AHP and Delphi. *International Journal of Construction Management*, 16(2), 175-183.
30. Nia, A.S.; Olfat, L.; Esmaeili, A.; Rostamzadeh, R.; and Antucheviciene, J. (2016). Using fuzzy Choquet Integral operator for supplier selection with environmental considerations. *Journal of Business Economics and Management*, 17(4), 503-526.
31. Tavana, M.; Yazdani, M.; and Di Caprio, D. (2017). An application of an integrated ANP-QFD framework for sustainable supplier selection. *International Journal of Logistics Research and Applications*, 20(3), 254-275.
32. Sahu, A.K.; Datta, S.; and Mahapatra, S.S. (2016). Evaluation and selection of resilient suppliers in fuzzy environment: Exploration of fuzzy-VIKOR. *Benchmarking: An International Journal*, 23(3), 651-673.
33. Yu, Q.; and Hou, F. (2016). An approach for green supplier selection in the automobile manufacturing industry. *Kybernetes*, 45(4), 571-588.

34. Pandey, P.; Shah, B.J.; and Gajjar, H. (2017). A fuzzy goal programming approach for selecting sustainable suppliers. *Benchmarking: An International Journal*, 24(5), 1138-1165.
35. Mohammadi, H.; Farahani, F.V.; Noroozi, M.; and Lashgari, A. (2017). Green supplier selection by developing a new group decision-making method under type 2 fuzzy uncertainty. *The International Journal of Advanced Manufacturing Technology*, 93(1-4), 1443-1462.
36. Fallahpour, A.; Wong, K.Y.; Olugu, E.U.; and Musa, S.N. (2017). A predictive integrated genetic-based model for supplier evaluation and selection. *International Journal of Fuzzy System*, 19(4), 1041-1057.
37. Luthra, S.; Govindan, K.; Kannan, D.; Mangla, S.K.; Garg, C.P. (2017). An integrated framework for sustainable supplier selection and evaluation in supply chains. *Journal of Cleaner Production,* 140(3), 1686-1698.
38. Erginel, N.; and Gecer, A. (2017). Fuzzy multi-objective decision model for calibration supplier selection problem. *Computers and Industrial Engineering*, 102, 166-174.
39. Banaeian, N.; Mobli, H.; Fahimnia, B.; Nielsen, I.E.; and Omid, M. (2018). Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. *Computers and Operations Research*, 89, 337-347.
40. Rezaeisaray, M.; Ebrahimnejad, S.; and Khalili-Damghani, K. (2016). A novel hybrid MCDM approach for outsourcing supplier selection: A case study in pipe and fittings manufacturing. *Journal of Modelling in Management*, 11(2), 536-559.
41. Secundo, G.; Magarielli, D.; Esposito, E.; and Passiante, G. (2017). Supporting decision-making in service supplier selection using a hybrid fuzzy extended AHP approach. A case study. *Business Process Management Journal*, 23(1), 196-222.
42. Saaty, T.L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, 48(1), 9-26.
43. Hruska, R.; Prusa, P.; and Babic, D. (2014). The use of AHP method for selection of supplier. *Transport*, 29(2), 195-203.