Designing Supplier Selection Support System Using Fuzzy Analytical Hierarchy Process and Weighted Sum Model for Coated Duplex Industry

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Abstract. Supplier selection is one of the activities that needs to be considered by the company because 50-90% company's turnover is obtained from purchasing activities. Supplier selection belongs to the multi criteria decision making (MCDM) problem because there are various criteria, sub-criteria and various alternative supplier which need to be considered. supplier selection activities contain qualitative and quantitative elements, qualitative elements focus on weighting criteria and sub-criteria while quantitative focuses on the weight of supplier offers. To choose supplier optimally will be difficult if the company does not have the tools to find the weight of criteria, sub-criteria and supplier offers. This study proposed a decision support system design that able to help companies choose suppliers using the fuzzy analytical hierarchy process (FAHP) and the weighted sum model (WSM) method on various criteria, sub-criteria and alternative suppliers. To know the weight of each criteria and sub-criteria that be based to select supplier use FAHP, that can decompose multi criteria decision making (MCDM) to be a hierarchy and determine consistency ratio of expert judgement assessment in criteria and sub-criteria. WSM used to change all sub-criteria becomes a unitary weight and find the weight of each supplier on all sub-criteria and WSM used to aggregation the global weight and supplier offer weight to be final score and find the supplier rank. This study shows the correlation of manual data processing, function in system to processing data and front-end to show the layout of system. The result of this study is a supplier selection system using CodeIgniter Framework, XAMPP, PHP and HTML languages.

Keywords: Decision support system, fuzzy analytical hierarchy process (FAHP), weighted sum model (WSM), multi criteria decision making (MCDM), supplier, criteria, sub-criteria.

1. INTRODUCTION

Supplier selection is an important activity because cost of goods purchased affect more than 60% profit of goods sold and affect 50-90% company's turnover (Luitzen de Boer, Eva Labro, 2001), So supplier selection is one of the critical activities in procurement (Ariyansyah, Ridwan, & Andreswari, 2016). supplier selection has 4 stages, there are goal setting, determine criteria and sub-criteria, pre- qualifying and decision-making. Suppliers selected are reviewed from assessment

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and evaluations of company criteria (Junior & Carpinetti, 2016). Supplier selection is done to get supplier offers that able to provide material with the right quality, price, quantity and time (Ayhan, 2013). History data from purchasing department used to make supplier selection decisions (Rasyid, Ridwan, & Alam, 2018). One of coated duplex board company in Indonesia don't have tools to weighting criteria, sub- criteria and supplier offer, so the company feel difficult to find the best alternative.

Based on FAHP method is fuzzy, that integrated with analytical hierarchy (AHP) method (Vaidya & Kumar, 2006). MCDM problem that contains various criteria and alternative can solve with

hierarchy on AHP (Waaly, Ridwan, & Akbar, 2018). In AHP method contain pair-wise comparison to mapping qualitative values on criteria assessment (Harlawan, Ridwan, & Kenaka, 2018), Its value get from persons that have knowledge and experience on related problem (Ilhamizar, Ridwan, & Akbar, 2018). Fuzzy logic in FAHP use to reduce doubt assessment of AHP method from decision maker judgement (Ayağ & Özdemir, 2006). So, FAHP method can use to determine weight of criteria dan sub-criteria in supplier selection problem (Jain, Singh, & Mishra, 2013).

On supplier selection problem there is quantitative element which must be considered that is data of supplier offer. WSM method can use to unified the different sub-criteria in supplier offer and determine score of alternative for get the rank of all alternative (Arshad et al., 2018).

The decision support system desired by the company must have a database so that the company does not need to recalculate the criteria and sub-criteria weights. A database can be related to fuzzy, that can see at Akbar's study about formal equivalence classes model of fuzzy relational databases using relational calculus (Akbar & Mizoguchi, 2017), Akbar study about class dependency of fuzzy relational database using relational calculus and conditional probability (Akbar & Mizoguchi, 2018) and Akbar's study about a formalization of a fuzzy relational database model using relational calculus (Akbar & Mizoguchi, 2016). From the above literature it is evident that FAHP can solve the problem of MCDM supplier selection.

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From the previous explanation and literature this study makes a data flow diagram that can help in making a supplier selection decision support system that can be seen in Fig.1.
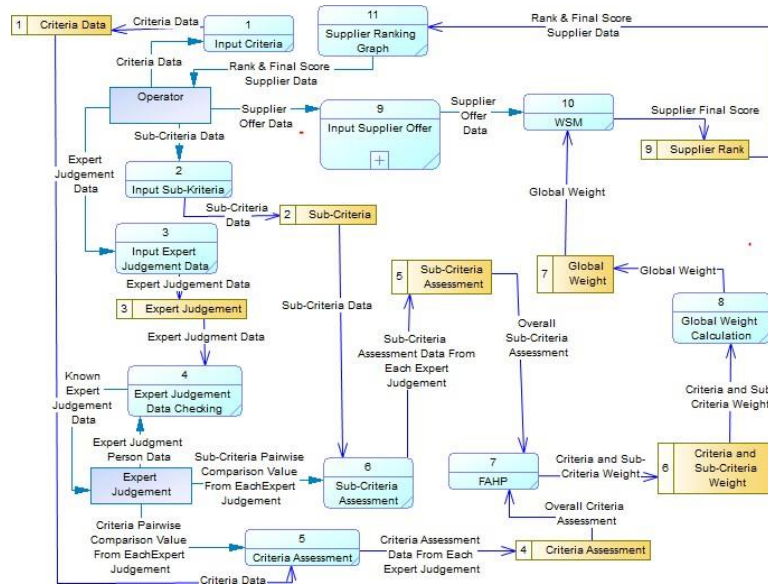

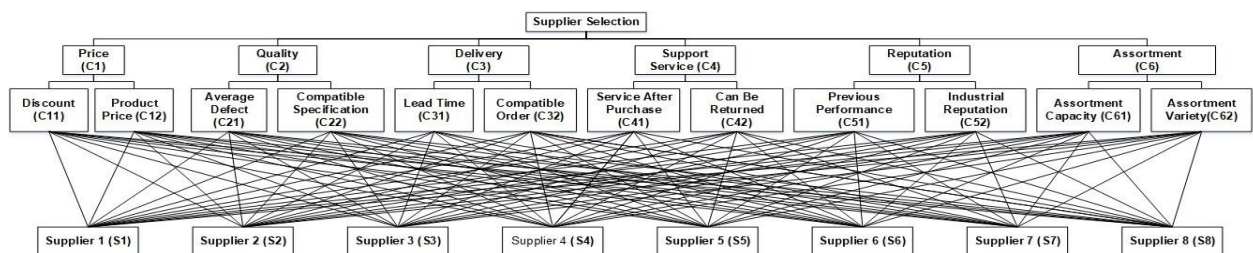Fig. 1: Data Flow Diagram

2. METHODOLOGY

Fig. 2: Supplier Selection Problem Hierarchy

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First stage of supplier selection is goal setting that can be relate with supplier selection problem hierarchy in Fig.2. After that, determine criteria and sub-criteria based on business process and provisions of the company regulator. At pre-qualifying stage, the AHP and WSM methods are used to calculate the criteria weight and sub-criteria along with the final value of each supplier. Company make decision of selected supplier based on final score of the largest supplier. Overall stage of supplier selection can see on Fig.3.
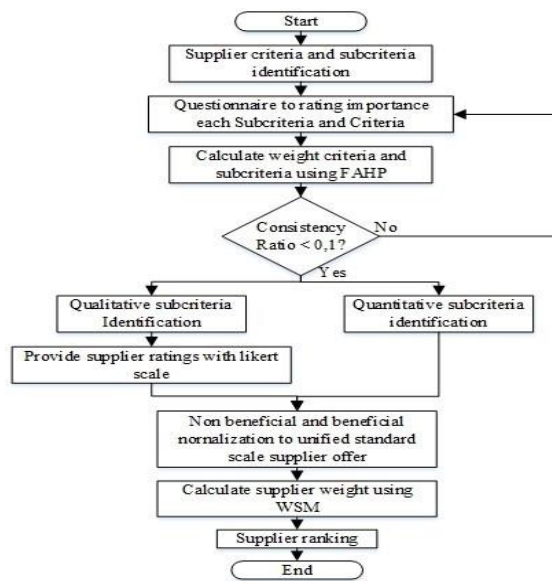
Fig. 3: Flowchart Solving Supplier Selection Using FAHP and WSM

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3. DECISION SUPPORT SYSTEM INPUT

3.1. Criteria Pairwise Comparison Value

Tabel 1: Questionnaire to Compare Importance of Criteria

Criteria A	Importance Scale																	Criteria B
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Price(C1)							x											Quality (C2)

To find criteria weight, expert judgement must do assessment in questionnaire of pairwise criteria comparison like Table 1. From that table, the first expert judgement give assessment that price criteria moderate important than quality. This decision support system have a page that expert judgement give assessment comparison criteria in menu settings on sub-menu expert judgement and press criteria to go assessment page that can see on Fig.4.

Fig. 4: Criteria Assessment Page

3.2. Supplier Offer Data

Table 2: Data of Supplier Offer

Supplier	C11	C12	C21	C22	C31	C32	C41	C42	C51	C52	C61	C62
S1	0%	2500	4.23%	88.23%	24	92.64%	5	9	96.28%	15	5	1
S2	0%	2250	3.11%	76.00%	30	96.00%	3	9	99.64%	9	3	5
S3	4%	2500	1.33%	94.02%	24	95.52%	3	9	99.16%	18	4	5
S4	8%	2500	1.70%	81.81%	30	90.90%	3	9	94.54%	13	3	1
S5	0%	2700	1.17%	78.95%	24	94.73%	3	9	98.37%	16	1	3

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S6	0%	2500	1.59%	87.50%	30	93.75%	1	9	97.39%	10	2	1
S7	5%	2500	2.01%	80.76%	24	92.30%	3	9	95.94%	14	5	1
S8	5%	2700	0.97%	78.94%	30	94.74%	5	9	98.38%	11	5	3
BEST	8%	2250	0.97%	94.02%	24.00	96%	5	9	99.64%	18	5	5

Table 2. show all data of all supplier offer in all sub-criteria that must input on system to get final score and rank of supplier. This data can be input on menu setting in sub-menu supplier and choose input supplier offer button. The form page to input supplier offer that can see in Fig.5.
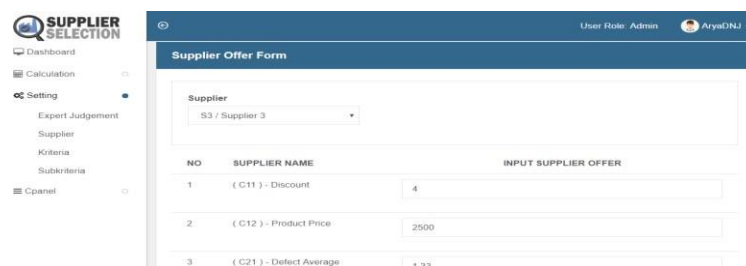
Fig. 5: Supplier Offer Form

4. DATA PROCESSING IN DECISION SUPPORT SYSTEM

4.1. Pairwise Comparison Matrix

If the expert judgement has provided all assessment of comparison each criteria, it will be a matrix criteria pair-wise comparison that can see on Table 3.

Table 3: Comparison Matrix for Criteria

Criteria	C1	C2	C3	C4	C5	C6
C1	1	3	1	7	5	3
C2	1/3	1	2	7	7	6
C3	1	1/2	1	6	4	3
C4	1/7	1/7	1/6	1	1/3	1/3
C5	1/5	1/7	1/4	3	1	1
C6	1/3	1/6	1/3	3	1	1

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Based on Table 3. Because The expert judgement give assessment that price criteria is moderate important than quality on column C2 and row C1 the value will be 3 and column C1 and row C2 will be 1/3. It references from Table 4.

Table 4: Triangular Fuzzy Number Scale (Saaty, 2006) & (Wang, Nguyen, Thai, Tran, & Tran, 2018)

Linguistic Variables	Importance Scale	TFN	Importance Scale	TFN
Equal Importance	1	(1,1,1)	1/1	(1,1,1)
Weak	2	(1,2,3)	1/2	(1/3, 1/2, 1)
Moderate Importance	3	(2,3,4)	1/3	(1/4, 1/3, 1/2)
Moderate plus	4	(3,4,5)	1/9	(1/5, 1/4, 1/3)
Strong Importance	5	(4,5,6)	1/5	(1/6, 1/5, 1/4)
Strong plus	6	(5,6,7)	1/6	(1/7, 1/6, 1/5)
Very strong	7	(6,7,8)	1/7	(1/8, 1/7, 1/6)
Very, very strong	8	(7,8,9)	1/8	(1/9, 1/8, 1/7)
Extreme Importance	9	(9,9,9)	1/9	(1/9, 1/9, 1/9)

Each cell of matrix criteria pairwise comparison will be 3 elements there are lower(l), middle(m), and upper(u). To convert matrix criteria pairwise comparison to be fuzzy matrix criteria pairwise comparison it can use Table 4. In Table 3, on column C2 and row C1 the value will be 2 for lower(l), 3 for middle(m), and 4 upper(u) that can see on Table 5.

Table 5: Fuzzy Comparison Matrix Criteria

Criteria	C1			C2			C3			C4			C5			C6		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
C1	1	1	1	2	3	4	1	1	1	6	7	8	4	5	6	2	3	4
C2	1/4	1/3	1/2	1	1	1	1	2	3	6	7	8	6	7	8	5	6	7
C3	1	1	1	1/3	1/2	1	1	1	1	5	6	7	3	4	5	2	3	4
C4	1/8	1/7	1/6	1/8	1/7	1/6	1/7	1/6	1/5	1	1	1	1/4	1/3	1/2	1/4	1/3	1/2
C5	1/6	1/5	1/4	1/8	1/7	1/6	1/5	1/4	1/3	2	3	4	1	1	1	1	1	1
C6	1/4	1/3	1/2	1/7	1/6	1/5	1/4	1/3	1/2	2	3	4	1	1	1	1	1	1

In data processing of decision support system to create matrix criteria pairwise comparison and fuzzy matrix criteria pairwise comparison, this study create a function with name _set_matrix_compare in controller of CodeIgniter Framework that can see on Fig.6.

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Fig. 6: Code To Create Matrix

$$l_{ij} = (\prod_{m=1}^{M} l_{ij}^m)^{1/M}, \ m_{ij} = (\prod_{m=1}^{M} l_{ij}^m)^{1/M}, \ u_{ij} = (\prod_{m=1}^{M} l_{ij}^m)^{1/M}$$ (2) (Lin, 2013)

In this study there are three expert judgement there are production director, purchasing manager, and purchasing employee. To combine all expert judgement assessment of each criteria pairwise comparison can use geometric mean as equation (2). On column C2 and row C1 in lower element first expert judgment give 2, second expert judgment give 1 and third expert judgement give 1. So the example on column C2 and row C1 the calculation as follows:

$l12 = 3\sqrt{2x1x1} = 1,260$

$m12 = 3\sqrt{3x1x2} = 1,817$

$u12 = 3\sqrt{4x1x3} = 2,289$

Fig. 7: Code to Combine Assessment of Criteria Pairwise Comaparison

In data processing of decision support system to combine all expert judgement assessment of each criteria pairwise comparison using geometric mean, this study create a function with name

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_calculate_fuzzyMean_compare, in controller of CodeIgniter Framework that can see on Fig.7. The result of fuzzy matrix from combined all expert judgement assessment you can see on Table 6.

Table 6: Combined Comparison Matrices for Criteria

CRITERIA	C1			C2			C3			C4			C5			C6		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
C1	1,000	1,000	1,000	1,260	1,817	2,289	0,630	0,693	0,794	5,241	6,257	7,268	3,634	4,642	5,646	2,000	3,000	4,000
C2	0,437	0,550	0,794	1,000	1,000	1,000	1,000	1,587	2,080	5,241	6,257	7,268	5,241	6,257	7,268	3,420	4,481	5,518
C3	1,260	1,442	1,587	0,481	0,630	1,000	1,000	1,000	1,000	4,932	5,944	6,952	3,302	4,309	5,313	2,000	3,000	4,000
C4	0,138	0,160	0,191	0,138	0,160	0,191	0,144	0,168	0,203	1,000	1,000	1,000	0,275	0,382	0,630	0,275	0,382	0,630
C5	0,177	0,215	0,275	0,138	0,160	0,191	0,188	0,232	0,303	1,587	2,621	3,634	1,000	1,000	1,000	0,481	0,630	1,000
C6	0,250	0,333	0,500	0,181	0,223	0,292	0,250	0,333	0,500	1,587	2,621	3,634	1,000	1,587	2,080	1,000	1,000	1,000

4.2. Relative Weight

To calculate relative weight of each row criteria, can use equation (Kannan, Khodaverdi, Olfat, Jafarian, & Diabat, 2013):

$$\tilde{r}_i = (l, m, n) \tag{3}$$

Where

$$l = (l_1 \times l_2 \times \ldots \times l_k)^{1/k}$$
$$m = (m_1 \times m_2 \times \ldots \times m_k)^{1/k}$$
$$n = (u_1 \times u_2 \times \ldots \times u_k)^{1/k}$$

$$\tag{4}$$

Table 7: Relative Weight for All Criteria

Criteria	Fuzzy Geometric Mean Value (ri)		
	l	m	u
C1	1,765058466	2,188198208	2,584882645
C2	1,857235062	2,313391198	2,79940537
C3	1,643816749	2,029170653	2,483346097
C4	0,24304983	0,292449037	0,378247722
C5	0,389648916	0,486093487	0,621769941
C6	0,511838347	0,684818828	0,90587672

Table 7 show all relative weight of each criteria from fuzzy comparison matrix criteria, and example calculation of relative weight for each criteria as follows:

$\tilde{ri}l1 = \sqrt{1 x 1.260 x 0.630 x 5.241 x 3.634 x 2}\ 6 = 1,765058466$

$\tilde{ri}\ m1 = \sqrt{1 x 1.817 x 0.693 x 6.257 x 4.642 x 3}\ 6 = 2,188198208$

$\tilde{ri}\ u1 = \sqrt{1 x 2.289 x 0.794 x 7.268 x 5.646 x 4}\ 6 = 2,584882645$

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4.3. Fuzzy Value of Weight

To calculate weight of the fuzzy value in each criteria can use the following equation (Ayhan, 2013):

$$\tilde{w} = \tilde{r_i} (\tilde{r_1} + \tilde{r_2} + ... + \tilde{r_n}) \tag{5}$$

In reciprocal relationships will use the following equation (Junior & Carpinetti, 2016):

$$\tilde{w} = \tilde{r_i} (\tilde{r_1} + \tilde{r_2} + ... + \tilde{r_n})^{-1} \tag{6}$$

To calculate weight of the fuzzy value you can see on this example.

$(\tilde{r_1} \oplus \tilde{r_2} \oplus r_{13} \oplus r_{14} \oplus r_{15} \oplus r_{16}) = ((1.76506 + 1.85724 + 1.64382 + 0.24305 + 0.38965 + 0.51184), (2.1882 + 2.31339 + 2.02917 + 0.29245 + 0.48609 + 0.68482), (2.58488 + 2.79941 + 2.48335 + 0.37825 + 0.90588 + 0.90588)) = (6.410647369, 7.994121412, 9.773528495)$

$(\tilde{r_1} \oplus \tilde{r_2} \oplus r_{13} \oplus r_{14} \oplus r_{15} \oplus r_{16})^{-1} = (6.410647369, 7.994121412, 9.773528495)^{-1} = \dfrac{1}{9.773528495}, \dfrac{1}{7.994121412}, \dfrac{1}{6.410647369}$

$\tilde{W_1} = (1.76506, 2.1882, 2.58488) \otimes (\dfrac{1}{9.773528495}, \dfrac{1}{7.994121412}, \dfrac{1}{6.410647369}) = (0.1806, 0.27373, 0.40322)$

4.4. Defuzzification

To determine weight of criteria can use Center Of Area (COA) as following equation (Ayhan, 2013) :

$$W_i = \dfrac{l\tilde{W_i} + m\tilde{W_i} + n\tilde{W_i}}{3} \tag{7}$$

W1 = (0.1806x0.274x0.403) : 3 = 0.285846281

4.5. Normalization Weight

Because membership of fuzzy value is between 0 and 1, if total weight of criteria more than 1, need to use normalization weight as following equation (Kannan et al., 2013).

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$$NWi = \frac{Wi}{\Sigma Wi} \qquad (8)$$

$\Sigma Wi = 0.285846281 + 0.305364744 + 0.269800645 + 0.040151411 + 0.065888116 + 0.093114438 = 1.060165635$

$NW_1 = \frac{0.285846281}{1.060165635} = 0,269624172$

The result all weight of the fuzzy value, weight value from defuzzification and normalization weight for criteria shown in Table 8.

Table 8: Fuzzy Weight, Defuzzification Weight, and Normalization Weight Value for Criteria.

Criteria	Fuzzy Weight (W_j)			Weight (W_i)	Normalization Weight
	l	m	u		
C1	0,1806	0,274	0,403	0,285846281	0,269624172
C2	0,19	0,289	0,437	0,305364744	0,288034939
C3	0,1682	0,254	0,387	0,269800645	0,254489144
C4	0,0249	0,037	0,059	0,040151411	0,037872772
C5	0,0399	0,061	0,097	0,065888116	0,062148888
C6	0,0524	0,086	0,141	0,093114438	0,087830086
Total				1,060165635	1

In this decision support system, for all data processing in section 4.1 until 4.5, this study create a function with name _calculate_fuzzyWeight, to calculate weight of each criteria. That code can see on Fig.8.

Fig. 8: Code to Determine Criteria Weight

To find all sub-criteria weight of each criteria, can follow step section 4.1 until 4.5 with similar step that only need to adjust the number of sub-criteria and assessments given to the expert judgment.

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4.6. Consistency Value

The value of assessment consistency needs to be measured to conclude whether the assessment is acceptable or not. To measure the value of consistency of expert judgment assessment, can use this following equation (Wind & Saaty, 1980) ;

$$CI = \frac{\lambda \max - n}{n-1} \tag{9}$$

$$CR = \frac{CI}{RI} \tag{10}$$

Where:
CI = Consistency Index
λmax = maximum eigenvalue
n= Matrix order
CR = Consistency Ratio
CI = Consistency Index
RI = Index Random

able 9: Random Indeks Value (Saaty, 2006)

n	1,2	3	4	5	6	7	8	9	10
RI	0	0,52	0,89	1,11	1,25	1,35	1,4	1,45	1,49

To determine the value of RI you can refers to Table 9. with adapted to n value. If the CR value <0.1 the assessment can be accepted while above 0.2 the assessment is rejected. If it is above 0.10 and below the value of 0.2, a reassessment is carried out. The example of consistency ratio calculation as follows:

$$CI = \frac{\lambda \max - n}{n-1} = \frac{6.190431 - 6}{6-1} = 0.038086$$

$$CR = \frac{CI}{RI} = \frac{0.094241}{1.25} = 0.030469$$

Table 10: Consistency Value from Table 1

λmax	6,501152
CI	0,10023
RI	1,25
CR	0,080184

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From the assessment of first expert judgement is consistent because from Table 10 show the CR less than 0,1.

Fig. 9: Consistency Ratio Code

To find consistency ratio in this decision support system, this study create a function called calculate_fuzzyEigen that can see on Fig.9. this system references value of random index in Table 9.

4.7. Weighted Sum Model (WSM)

To convert all supplier offer in each sub-criteria to be uniformity weight must consider beneficial and non-beneficial sub-criteria, to uniformity weight you can use equation (11) for beneficial sub-criteria and equation number (12) to non-beneficial equation (Arshad et al., 2018):

$$X^+_{ij} = \frac{C_{ij}}{\max A_i \in A\ C_{ij}} \tag{11}$$

$$X^-_{ij} = \frac{\min A_i \in A\ C_{ij}}{C_{ij}} \tag{12}$$

WSM method is used to get final score off all supplier in several sub-criteria, so supplier rank will be obtained. The WSM equation as follows:

$$S_i = \sum_{j=1}^{n} W_j\ A_{ij} \tag{13}$$

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where,

W_j = Criteria Weight

A_{ij} = value of alternative ability on criteria

From Table 2. That supplier offers on sub-criteria C11, supplier S4 offer 8% discount, because the bigger discount given more benefit to company so this study use equation (11) to uniformity weight discount sub-criteria. Because supplier S1 offer 2250 which shows the cheapest prices, this study use equation (12) to uniformity weight product price sub-criteria because the bigger price is non-benefit to company. For the example calculation as follows:

$$X^+{}_{11} = \frac{0}{8} = 0$$

And for price sub-criteria (C12) use equation number 13

$$X^-{}_{12} = \frac{2250}{2500} = 0.9$$

Table 11: Calculate Final Score

		Criteria										
		C1		C2		C3		C4		C5		C6
		0.270		0.288		0.254		0.038		0.062		0.088
		Sub-criteria										
		C11	C12	C21	C22	C31	C32	C41	C42	C51	C52	C61	C62
		0.335	0.665	0.330	0.670	0.679	0.321	0.670	0.330	0.775	0.225	0.550	0.450
Pemasok		**Global Weight**										
		0.090	0.179	0.095	0.193	0.173	0.082	0.025	0.013	0.048	0.014	0.048	0.040
S1		0.000	0.900	0.229	0.938	1.000	0.965	1.000	1.000	0.966	0.833	1.000	0.200
S2		0.000	1.000	0.312	0.808	0.800	1.000	0.600	1.000	1.000	0.500	0.600	1.000
S3		0.500	0.900	0.729	1.000	1.000	0.995	0.600	1.000	0.995	1.000	0.800	1.000
S4		1.000	0.900	0.571	0.870	0.800	0.947	0.600	1.000	0.949	0.722	0.600	0.200
S5		0.000	0.833	0.829	0.840	1.000	0.987	0.600	1.000	0.987	0.889	0.200	0.600
S6		0.000	0.900	0.610	0.931	0.800	0.977	0.200	1.000	0.977	0.556	0.400	0.200
S7		0.625	0.900	0.483	0.859	1.000	0.961	0.600	1.000	0.963	0.778	1.000	0.200
S8		0.625	0.833	1.000	0.840	0.800	0.987	1.000	1.000	0.987	0.611	1.000	0.600

Table 11. show all uniformity weight of supplier offer in all sub-criteria, and the global weight is aggregation of criteria weight and sub-criteria weight in each criteria. so this study can use WSM method to find the final score of all supplier. With the example calculation as follows:

Global weight C11 = 0,270 x 0,335 = 0,09

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S1 = (0,09x0.000) + (0.179x0.900) + (0,095x0.229) + (0,193x0.938) + (0,173x1) + (0,082x0.965) + (0,025x1) + (0,013x1) + (0,048x0.966) + (0,014x0.833) + (0,048x1) + (0,040 x 0,2) = 0.768074

Supplier ranking is determine based on the largest final score from S1 to S8, for all supplier ranking and final value can be seen in Table 12.

Table 12: Final Score and Supplier Ranking

Ranking	5	7	1	4	6	8	3	2
Supplier	S1	S2	S3	S4	S5	S6	S7	S8
Final Score	0.768074	0.736267	0.890719	0.809809	0.764811	0.71663	0.821919	0.847835
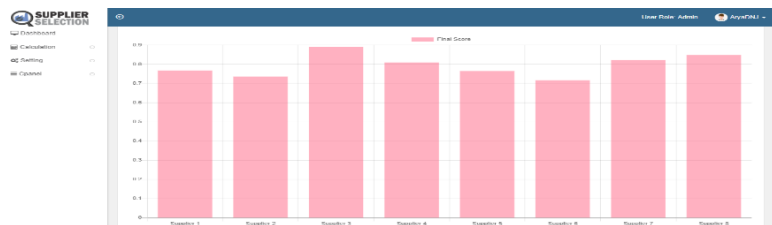
5. OUTPUT OF DECISION SUPPORT SYSTEM

Fig. 10: Final Score Graph

In the ranking section of the calculation sub-menu it is useful to display a graph of the final value of each supplier to make it easier to see results so that decision makers can simply understand the alternative suppliers to be chosen. In accordance with Fig.10.

Table 13: Data Flow Diagram Level 0

Supplier	Final Score on Data Processing	Final Score on Decision Support SystemS	Difference Percentage
S1	0.768074	0.768074	0 %
S2	0.736267	0.736267	0 %
S3	0.890719	0.890719	0 %
S4	0.809809	0.809809	0 %
S5	0.764811	0.764811	0 %
S6	0.716630	0.716630	0 %
S7	0.821919	0.821919	0 %
S8	0.847835	0.847835	0 %

Table 13. Show a comparison of the final value of manual data processing and the decision support system using the FAHP and WSM methods do not have a difference or it can be said that all the alternative value of the supplier's final percentage difference in results is 0%. So, the

system can be trust and the system can be used by companies to assist in making decisions to choose supplier.

6. CONCLUSION

To assist the company in selection supplier activities, a decision support system can be created using the CodeIgniter Framework, XAMPP, PHP and HTML languages with an algorithm following the fuzzy analytical hierarchy process method and the weighted sum model. There are 3 entities involved in this system, there are operators, expert judgment and suppliers. this system has a function to input data criteria, sub-criteria and expert judgement, processing criteria and sub-criteria from expert judgment assessment and enter supplier offer data to be charts based on supplier final score. This system can be trusted because percentage difference in results is 0% where compare result of manual data processing and result from decision support system.

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