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Maintenance Heavy Equipment Management Through Contract Models or Company it Self

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***Abstract*—One important activity and cause high costs in the company is maintenance and in mining one of critical maintenance is heavy equipment. Issue of manpower, skill, expert and equipment population made company can't handle the maintenance it self. Agreement to the contractor made with several contract models. This maintenance management either by company it self or by different contract models have their strong and weakness point. This research will analyze which maintenance management is better using Fuzzy AHP as a multicriteria decision making tool. Responden will selected to define the criteria and sub-criteria. The result of this research are to select maintenance management that will use as standard in the company.**

***Keywords*—Contract, Fuzzy AHP, Maintenance.**

I. BACKGROUND

PT. Vale Indonesia is mining companies that produce nickel in Indonesia. PT. Vale Indonesia has a nickel refining facility in Sorowako, South Sulawesi. PT. Vale Indonesia covers 70,566 Ha in South Sulawesi, 22,699 Ha in Central Sulawesi and Southeast Sulawesi covering 24,752 Ha. PT Vale Indonesia mines nickel in the form of nickel ore and processing into nickel matte.

PT. Vale Indonesia in its operations both in the mining process or nickel refining process using a variety of equipment. The mining process uses heavy equipment such as: (1) Haul truck that serves to transport mined rocks to be brought to the processing area. (2) Dozer which functions to push or dig soil or rocks. (3) Wheel loader to move rocks or lift rocks into trucks. (4) Excavator to dig soil or rocks. (5) Graders to level the ground. Total heavy equipment at PT. Vale is 347 Units for the Caterpillar, Komatsu and Hitachi brands, with detail in Table 1.

This equipment operates 24 hours, and is operated by operators with 3 shifts. Heavy equipment is very critical, without this equipment the mining process will stop. Therefore, to ensure that the equipment operates optimally, a maintenance strategy is needed. A large number of units and variations, both from type, brand and age of the equipment, resulting in a maintenance process at PT. Vale becomes very complex. So, PT. Vale cooperates with the contractor for maintenance some equipment. This collaboration is in the form of a maintenance contract that is being processed by the procurement team.

Maintenance equipment performed by contractors has 3 contract schemes, which is:

A. Marc Contract

Where the full maintenance contract will be carried out by contractors for the service and spare part with lump sum payments per month. Currently the heaviest equipment units at PT. Vale carries out maintenance with this type of contract.

B. SSA Contract

Maintenance contract will be carried out jointly between the contractor and PT. Vale. The contractor will perform maintenance for services while PT. Vale will contribute to the spare parts needed by maintenance.

C. On Call Contract

Maintenance contract will be carried out jointly between the contractor and PT. Vale where contractor maintenance activities are categorized into several activities / work packages.

The choice of maintenance strategy requires a method for assessing from many of the criteria that arise from maintenance problems. One method for multi-criteria decision making is the Analytic Hierarchy Process. AHP method is often used in previous studies related to suppliers/contractors to determine supplier performance, determine supplier selection. Previous studies have used AHP to determine the type of contract awarded, previous research on grocery stores (S. M. Tazim Ahmed & Chitra Karmaker, Journal of Supply Chain Management Systems). In this study using fuzzy AHP, which is a method of combining fuzzy and AHP which is better at solving problems. In contrast to this study, where previously the research was for contracts for providers of foodstuffs to be sold, whereas this study was for heavy equipment maintenance service contracts.

The objective of this research is: (1) Knowing the criteria for determining system maintenance. (2) Determine the maintenance system that should be the standard to use in the company.

II. PROPOSED APPROACH

A. AHP

The AHP developed by Professor Thomas Saaty in 1980 made it possible to arrange decisions hierarchically (to reduce their complexity) and show the relationship between goals (or criteria) and possible alternatives. Perhaps the greatest advantage of this method is that it allows the inclusion of intangible objects such as experience, subjective preferences and intuition, in a logical and structured manner. the greatest advantage of this method is that it allows the inclusion of intangible objects such as experience, subjective preferences and intuition, in a logical and structured manner. This research use AHP for 3 following steps.

Table 1.
Total heavy equipment in PT. Vale

Manufacture	Unit
Caterpillar	248
Hitachi	27
Komatsu	72

Table 2.
Comparison scale

Scale	Linguistic Variable
1	Equally Important
3	Weakly Important
5	Strongly Important
7	Very strongly Important
9	Extremely Important
2,4,6,8	Intermediate value between adjacent scales

Table 3.
Fuzzy triangle scale

Linguistic variable	Scale	TFN	Scale	TFN
Equally Important	1	(1,1,1) if diagonal (1,1,3) beside	1/1	(1/1,1/1,1/1) if diagonal (1/1,1/1,1/3) beside
	2	(1, 2, 4)	1/2	(1/4, 1/2, 1/1)
Weakly	3	(1, 3, 5)	1/3	(1/5, 1/3, 1/1)
Important	4	(2, 4, 6)	1/4	(1/6, 1/4, 1/2)
Strongly	5	(3, 5, 7)	1/5	(1/7, 1/5, 1/3)
Important	6	(4, 6, 8)	1/6	(1/8, 1/6, 1/4)
Very strongly	7	(5, 7, 9)	1/7	(1/9, 1/7, 1/5)
Important	8	(6, 8, 10)	1/8	(1/10,1/8,1/6)
Extremely Important	9	(7, 9, 11)	1/9	(1/11,1/9,1/7)

1) Construct Hierarchy

Creating hierarchical forms of various elements as principle objectives, goals that are influenced by these criteria or criteria that are influenced by sub-criteria and are nothing but different substitutes available for the problem (Figure 1).

2) Pair-Wise Comparison (Determining Weights)

The comparison matrix between factors is the nxn dimension box matrix. The matrix component on the diagonal of this matrix takes 1 value. When i = j, the component on the diagonal of the comparison matrix takes 1 value; because the related factor has compared with itself in this situation. Comparing factors is done according to their importance to each other and reciprocally. One-by-one and reciprocally comparing the importance scale of factors, using a comparison scale in Table 2.

3) Consistency in Factor Comparisons was Calculated

AHP suggests a process for measuring the consistency of this comparison. Finally, by obtaining a Consistency Ratio (CR), there has been an opportunity to test the consistency of priority vectors and also the consistency of pair comparisons between criteria. The essence of CR calculation is based on comparison of the number of criteria and coefficients, called the Main Value (ƛ) by the AHP. In principle, from doubling the comparison matrix A and priority vector W, column vector D is obtained for calculation ƛ

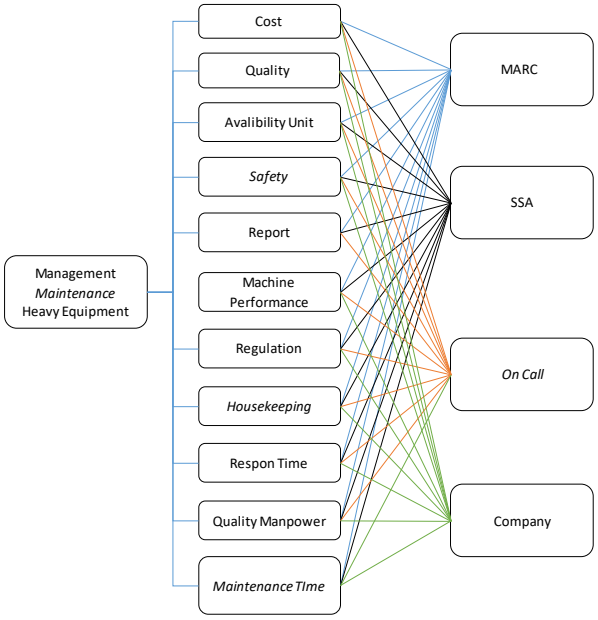

Figure 1. Hierarchical structure of maintenance system assessment.

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \quad (1)$$

After ƛ is calculated, the Consistency Index (CI) can be calculated according to the following formula.

$$CI = \frac{\lambda - n}{n-1} \quad (2)$$

And finally calculate the value of the ratio consistency with the formula.

$$CR = \frac{CI}{RI} \quad (3)$$

Consistency is acceptable if the CR value <0,100.

B. Fuzzy AHP

AHP combined with fuzzy logic known as Fuzzy AHP is a popular method for dealing with uncertainty and helps decision makers in complex problems with various conflicting criteria (Kubler et al., 2016). The Fuzzy AHP model (FAHP) is based on fuzzy set theory, where the membership of a given element is determined by the membership function. The value of the fuzzy decision variable is explained by the membership function which is between zero and one.

Chang (1996) defines AHP intensity values into triangular fuzzy scales. The fuzzy triangle scale used by Chang can be seen in Table 3. Fuzzy AHP step in research as following:

1) Calculate the Average Value of Fuzzy Geometric

The initial step is to determine the geometric mean of Fuzzy numbers with the formula:

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{C}_{ij}\right)^{1/n} \quad (4)$$

2) Calculate the Value of Fuzzy Weights

Calculate the value of Fuzzy weights with the formula:

$$\widetilde{w_i} = \tilde{r}_i \otimes (\tilde{r}_1 \otimes \tilde{r}_2 \otimes \dots \otimes \tilde{r}_n)^{-1}$$

$$\widetilde{w_i} = (lw_i, mw_i, uw_i) \quad (5)$$

Table 4.
Matrix criteria of respondent 1

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	R1	1	0,33	0,33	0,17	5	0,33	0,25	0,5	0,5	2	2
C2	R1	3	1	0,5	0,17	5	0,2	0,25	2	2	2	2
C3	R1	3	2	1	0,17	6	2	0,25	2	4	2	2
C4	R1	6	6	6	1	6	6	6	6	6	6	6
C5	R1	0,2	0,2	0,17	0,17	1	0,25	0,2	0,25	0,25	0,25	0,25
C6	R1	3	5	0,5	0,17	4	1	0,2	2	4	4	3
C7	R1	4	4	4	0,17	5	5	1	3	5	5	3
C8	R1	2	0,5	0,5	0,17	4	0,5	0,33	1	2	1	2
C9	R1	2	0,5	0,25	0,17	4	0,25	0,2	0,5	1	1	0,5
C10	R1	0,5	0,5	0,5	0,17	4	0,25	0,2	1	1	1	0,5
C11	R1	0,5	0,5	0,5	0,17	4	0,33	0,33	0,5	2	2	1
Total		25,2	20,5	14,3	2,67	48	16,1	9,22	18,8	27,8	26,3	22,3

Table 5.
CR calculation responden 1

Criteria		Priority vector	Total Weight Priority	Consistency measure
C1	R1	0,045868	0,532497497	11,609418
C2	R1	0,068532	0,812423279	11,8546174
C3	R1	0,094749	1,214294451	12,8159632
C4	R1	0,319008	4,404960808	13,8083153
C5	R1	0,017547	0,214391977	12,2179768
C6	R1	0,105931	1,343500044	12,6827325
C7	R1	0,171375	2,362197122	13,7837647
C8	R1	0,05502	0,668305045	12,1466799
C9	R1	0,03887	0,460472774	11,8463582
C10	R1	0,037478	0,442868129	11,8166575
C11	R1	0,045621	0,546195385	11,9723624
			λ	12,4140769
			CI	0,14140769
			CR	0,09364748

Table 6.
Fuzzy number criteria matrix

Criteria	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
C1	1	1	1	0,29	0,56	1,38	0,29	0,56	1,38	0,14	0,21	0,33	0,9	0,72	2,81	0,2	0,33	0,8	0,38	0,82	1,66	0,42	0,94	1,9	0,28	0,55	1,11	0,27	0,47	1,06	0,55	0,25	2,51
C2	0,72	1,78	3,47	1	1	1	0,29	0,57	1,2	0,14	0,19	0,3	0,72	0,63	0,75	0,49	0,67	1,06	0,87	1,05	1,28	1	1,78	2,51	0,72	1,15	1,82	0,72	0,92	1,32	1	1,43	1,82
C3	0,72	1,78	3,47	0,83	1,74	3,44	1	1	1	0,14	0,19	0,3	0,82	0,76	0,91	0,72	1,15	1,82	0,63	0,84	0,28	0,25	0,58	0,95	0,92	0,23	0,53	0,68	0,04	0,46	0,68	0,04	0,46
C4	3,02	4,86	7,04	3,35	5,19	7,4	3,35	5,19	7,4	1	1	1	3,02	4,86	7,04	3,02	4,86	7,04	3,02	4,86	7,04	2,83	4,62	6,76	3,02	4,86	7,04	3,02	4,86	7,04	3,02	4,86	7,04
C5	0,36	0,58	1,11	0,17	0,28	0,58	0,17	0,27	0,55	0,14	0,21	0,33	1	1	1	0,23	0,32	0,56	0,36	0,47	0,8	0,27	0,39	0,87	0,24	0,33	0,63	0,22	0,3	0,51	0,25	0,35	0,7
C6	1,25	3,06	5,11	0,94	1,5	2,04	0,55	0,87	1,38	0,14	0,21	0,33	0,78	1,13	1,3	1	1	1	0,84	1,25	1,63	1,25	1,97	2,69	0,83	1,32	1,97	1,15	1,64	1,97	1	1,55	1,9
C7	0,53	1,22	2,61	0,78	0,96	1,15	0,78	1,19	1,58	0,14	0,21	0,33	0,25	0,14	0,81	0,61	0,8	1,18	1	1	1	1	2,05	3,31	0,65	1,17	2,57	0,65	1,17	2,57	0,72	1,32	2,4
C8	0,53	1,06	2,4	0,4	0,56	1	0,51	0,63	0,8	0,15	0,22	0,35	0,15	0,55	0,76	0,37	0,51	0,8	0,3	0,49	1	1	1	1	0,47	0,72	1,26	0,47	0,62	0,96	0,53	0,85	1,74
C9	0,9	1,82	3,55	0,55	0,87	1,38	0,65	0,81	1,08	0,14	0,21	0,33	0,58	0,02	0,23	0,51	0,76	2	0,39	0,85	0,53	0,79	0,39	1,14	1	1	1	0,72	0,8	1	0,76	0,08	0,38
C10	0,94	2,14	3,71	0,76	1,08	1,38	0,68	0,96	1,48	0,14	0,21	0,33	0,97	1,35	1,52	0,51	0,61	0,87	0,39	0,85	0,53	0,05	0,6	1,14	1	1,25	1,38	1	1	1	0,76	0,35	1,9
C11	0,4	0,8	1,82	0,55	0,7	1	0,68	0,96	1,48	0,14	0,21	0,33	0,43	0,83	1,02	0,53	0,64	1	0,42	0,76	1,38	0,57	1,18	1,9	0,72	0,92	1,32	0,53	0,74	1,32	1	1	1

3) Perform the Fuzzy Element Defuzzification Process

Perform the fuzzy element defuzzification process using the Center of area (COA) method.

$$M_i = \frac{(lw_i, mw_i, uw_i)}{3} \quad (6)$$

4) Normalization of Mi Values

Normalization of Mi values by calculation:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (7)$$

This normalized priority weight calculation procedure must be applied to the evaluation of specific alternatives for each criterion (alternative preference matrix).

III. APPLICATION

A. AHP

1) Criteria Obtained from The Results of The Interview

Interviews were conducted with experts in companies related to heavy equipment maintenance. These experts are from the maintenance department as the maintenance

Table 7.
Criteria weighting

Criteria	Weight
Cost	0,0571
Quality	0,076912
Availability	0,085194
Safety	0,305789
Issued Report	0,0314
Machine Performance	0,093847
Government Regulation	0,081697
House Keeping	0,055706
Respond Time	0,071048
Manpower Quality	0,077363
Maintenance Time	0,063945

Table 8.
Alternative score

Alternative	Score											Total
	Cost	Quality	Availability	Safety	Issued Report	Machine Performance	Government Regulation	House Keeping	Respond Time	Manpower Quality	Maintenance Time	
MARC	0,00823	0,03723	0,039654612	0,0832	0,01212	0,041753758	0,016268298	0,02083	0,030803	0,0299164	0,029025891	0,349036
SSA	0,02122	0,02196	0,027269219	0,0804	0,0105	0,031436101	0,016464077	0,02103	0,022696	0,029327	0,022151753	0,304452
ON CALL	0,01866	0,00838	0,00802251	0,05146	0,00497	0,012076001	0,012510194	0,00819	0,00867	0,0069226	0,006266449	0,146123
PT. VALE	0,00899	0,00934	0,010247631	0,09073	0,00382	0,008581405	0,036454454	0,00565	0,008879	0,0111972	0,006500529	0,20039

executor and from the SCM department as the part that carries out the agreement / contract with the contractor.

2) Pair-Wise Comparison

Pair-wise comaparison using questionnaire to 5 respondent. Result of from the questionnaire shown in the example responden 1 Table 4. After find the example responden in Table 4, next step is to find the Consistenncy Ratio. Consistency ratio for responden 1 shown in Table 5.

From the Table 5, CR value 0,09364748 < 0,100, so the data is consistent.

B. Fuzzy AHP

Data from respondents is converted into triangular fuzzy numbers (TFN) using scale in Table 3 mention before. Matrix Fuzzy number matrix of 5 respondents were converted using the geometric mean method, and got the results in Table 6. Following process fuzzy step mention in section II, result of criteria weighting shown in Table 7.

After result in Table 7, process continue to find score of alternative fo each criteria, the result shown in Table 8.

From the Table 8 shows that the MARC alternative has the greatest value compared to the three other alternatives that is equal to 0.3490. The second alternative is SSA worth 0.2003 and the alternative with the smallest weight is the on call alternative.

IV. CONCLUSION

Fuzzy AHP is a method for dealing with uncertainty and helps decision makers in complex problems with various conflicting criteria. Fuzzy AHP is better method to reduce subjective comparing to AHP. Research shows that the method can be used to choose strategy maintenance in company and as the result is MARC alternative is the best strategy of maintenance that company should use with high score in quality aspect.

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