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Review Article

SELECTION OF OPTIMUM REPLACEMENT OPTION FOR AMINE PUMP IN A GAS PROCESSING PLANT USING FUZZY ANALYTICAL HIERARCHY PROCESS

[1]Freselam Mulubrhan, [2]Mebrahitom Asmelash

University Malaysia Pahang, Kampung Melayu Gambang, 26300 Gambang, Pahang (Author a) and (Author b)
*Corresponding author Email: *freselam@ump.edu.my

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Abstract
In order to excel in the competitive market, it is essential to make a flawless decision which is difficult without considering different factors that affect it. These factors can be qualitative or quantitative which are full of uncertainties. Fuzzy analytical hierarch process (FAHP) is a very useful tool to model such a decision making process. In this study FAHP is used to select the optimum replacement option of amine pump in a gas processing plant. The gas processing plant has 10 unit of amine circulation pumps. These pumps have been installed since 1996. After installation, various problems occurred which lead to low reliability and availability of the amine pump system and a lot of design modification has been done since then. In this study three different replacement options are investigated to solve the problem. These options are a) To continue with the existing pump system through repair, b) To modify the existing system by changing one or two of the old pumps which has low performance by `a new one and c) To add a new pump. These options were assessed with four criteria; Ease of operation, Flexibility, Maintainability and environment. Data was collected from 25 employees and a pairwise comparison was conducted. It is found that the weight of the first option which is continuing with the existing system is higher with 0.47 values which show this option is preferable for the selected case. A sensitivity analysis is conducted to explore how the ranking of the analysis varies when the input data were changed.

Keywords: Decision making; Analytical hierarchy process; Amine pump

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INTRODUCTION

In order to excel in the competitive market, industries need to make a flawless decision. Even though it is difficult to make immaculate decisions it is possible to minimize the error in decision making by taking into account all possible factors which contribute the lion share. These factors can be quantitative or qualitative. Taking into account only quantitative factors like cost doesn't bring a convincing decision making analysis. The decision making in many industries is complex due to a degree of inherent uncertainty. This increasing complexity and the need to incorporate the non-financial factors with the financial factors decision support model should be developed to aid the process [1]. One of the many industries which face a complexity in making a decision is the oil and gas industry. In this study fuzzy analytical hierarchy is applied on amine pump of the gas processing plant found in Malaysia. The primary function of gas processing plant is separating natural gas into Sales Gas, Ethane, Propane, Butane & Stabilized Condensate. The amine pump systems analyzed is a critical part of the gas processing plant which is consider as the core of the business. The gas processing plant has 10 unit of amine circulation pumps. These pumps have been installed since 1996. For each plant, there are five amine circulation pumps to the main absorbers. Four of these pumps, PA/PB/PC/PD are driven by steam turbines (A1-D1) and Hydraulic Power Recovery Turbines (HPRT) (A2-D2) on a common shaft. The fifth pump, E, is driven by an electric motor and is used as a spare. Pumps A and B feed amine to absorber C5/C6 and pumps C and D feed amine to absorber C5/C6. In normal operation about half of the power required by the circulation pumps is supplied by the HPRT. HPRT A2/B2 obtains its power from absorber only able to feed 1 HPRT only due to operational constraint. A numbers of improvements have been made for the sustainability of amine pump operation. Among the significant improvement are: Minimum flow line installation, pump impeller upgrade, mechanical seal upgrade and 3rd bearing installation. However, despite all the improvement being made the availability and reliability of amine pump is still a concern. Recent statistics showed that the amine pump is still struggling to achieve high availability and reliability due to repetitive failure cause by vibration and mechanical seal issue. According to the industry report and the expert opinion there are three options to consider in order to increase the reliability and availability of the amine pump.

Option 1 (O1): To continue with the existing pump system through repair. Since the commissioning year; 1996 the pumps are totally 19 years old. Since then a lot of design modification has been done. The latest design modification is done in 2003/2004. In this research option one (O1) is investigated by estimating the LCC of the existing pump and also by predicting the availability and reliability of the pump for the future.

Option 2 (O2): To replace each pump step by step. This options suggest that rather than adding new pumps or continuing with the existing system it is better to replace each pumps step by step by predicting their performance for the future. The pump with the highest downtime will be replaced first and will check the improvement that it made on the system. Similarly, the replacement will be conducted for the pump which causes the second highest downtime and so on.

Option 3 (O3): To add a new pump. Since it is discussed that the number of failure for each pumps is escalating each year for as shown in Table 5.3, the downtime will be very high. Table 5.3 shows that there is improvement for P2 in 2013, but then again it increases in the next year 2014. In this research, option two (O2) will be investigated by conducting a cost benefit ratio. The question to be answer is "Does the addition of these pumps improves the availability of the system with minimum life cycle cost?" Before deciding which new pump to install, there different new pumps from different suppliers are compared to select the best one.

LITERATURE REVIEW

Multi-Attribute Decision Making (MCDM) is the most well-known branch of decision making. MCDM refers to making decisions in the presence of multiple, usually conflicting criteria [2]. There are different methodologies for MCDM that are currently in use these are; Goal programming (GP), Grey relational analysis (GRA), Analytic hierarchy process (AHP) and so on. Due to its convenient way to quantify the qualitative attributes of the options presented, hence removing subjectivity in the result AHP is highly chosen among other [3].

Analytic hierarchy process (AHP) is proposed in the 1970s by Professor T. L. Saaty, an American operations researcher. The pair-wise comparison has three hierarchies; the goal, criteria and alternative. The criteria will be assessed by the goal and each alternative will be assessed by each criterion which will give a final value by the determined weight coefficient [4]. In the traditional AHP method, the subjective descriptions of reviewers' decision are often corresponding to exact value. As a result, the vague descriptions are often ignored by the researchers. In order to make the analysis results more reasonable, using fuzzy set theory to deal with the problems of fuzziness is very important [5]. Fuzzy theory is based on fuzzy sets, which is the expansion of crisp sets. Fuzzy theory overthrows the two/dual value (yes or no) so that its multi-value could be pressed close to reality.

The earliest work integrating between fuzzy logic and AHP concepts appeared in the early 1980s, with several researchers working on the concepts and starting to determine fuzzy priorities of comparison ratios by using the geometric mean [6, 7]. In the 1990s, studies in FAHP became more popular and several improvements on the methods were developed [8, 9]. The concept of using triangular fuzzy numbers for pair wise comparison scale and the extent analysis methods first introduced by Chang in 1996 [9]. Several research studies have proved the effectiveness of this method [9, 10, 11]. From different approaches of FAHP, this method is preferred in different application due to its computational simplicity and effective final result. Even though it is applied in different application, its application in an oil and gas platform is limited.

METHODOLOGY/MATERIALS

The FAHP method is used in this paper for selecting the best solution for the amine pump of the gas processing plant.

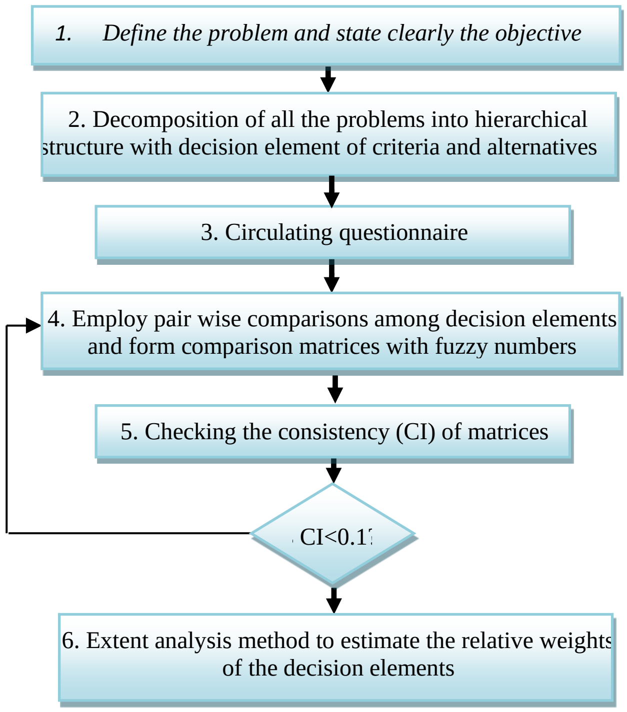

Figure 1. FAHP method

Defining the problem and stating the objective

The different options of amine pump in the gas processing plant is discussed in the introduction part. Each available options have pro's and con's depending on the characteristics of the platform under study. The pros and cons should be analyzed and evaluated before selecting the options. The selection of one of these options highly depends on numerous issues which in turn affects the cost and time of it.

Decomposition into hierarchical structure

The top in the hierarchy is selecting of optimum option which is considered as the goal of the decision. The second level is the criterions. Three major criterions; Ease of operation (EO), Environment (ENV) and Flexibility (F) are selected to conduct qualitative analysis for the identified options in chapter four. These criterions have the ability to influence the decision made by using the result of the quantitative analysis. Even if there are ways to quantify these factors, quantifying each of the criterion by itself is one major research. Instead expert opinion is gathered and quantified using fuzzy AHP. The detail of these criterions are discussed below.

Ease of operation (EO):- Ease of operation is one of the main subjective factors for selection of a new amine pump. ISO 20282-1:2006 provides requirements and recommendations for the design of easy-to-operate everyday products, where EO addresses a subset of the concept of usability concerned with the user interface by taking account of the relevant user characteristics and the context of use. ISO 20282-1:2006 is intended to be used in the development of everyday products, for which it defines ease of operation, explains which aspects of the context of use are relevant, and describes the characteristics of the intended user population that may influence usability.

Environment (ENV): - Today environmental impact of technology is highly weighted globally. When a pumping option is selected for a particular area, if energy is not available while system is in operating condition then there is a chance of failure of pumping system includes Environmental cost as part of LCC estimation. Many researchers, develop a quantitative model to analyze the environmental cost in estimation of life cycle costing. Environmental factors are taken as a subjective or qualitative assessment since the analytical estimation is out of its scope.

Flexibility (F): Flexibility is the ability to adapt to changes in requirement. It can be achieved through the ability to expand the production facility. When a system user is confronted by evenly-matched options, a flexible solution that works for both options is attractive Flexibility and capacity are major cost drivers that have direct impact on the gas processing's business sustainability and shareholders return on investment (ROI).

The main goal of the fuzzy AHP is to select the optimum method using the above stated criterions. The hierarchical representation of the goal, criterions and options is shown in Figure 2.

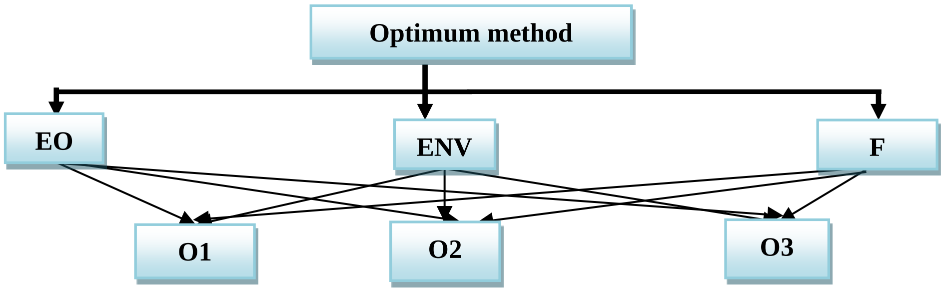

Figure 2. Hierarchical representation of the options and criterion

Circulating questionnaire
This study will use questionnaire-based surveys as a method to identify the opinion of the expert in the gas processing plant. Using the data which is found from the questionnaire a pair wise comparison will be conducted. To create pair wise comparison matrices a background analysis is done with the personnel's operating directly to the amine pump as shown in Table 1.A sample of employees from each area of expertise are selected to fill the questioner.

Table 1: Background of employee working with the amine pump

No	Area of expertise	Qualification	Institutes	No of employee
1	Executives	Degree	Universities	8
2	Operation	Diploma	PETRONAS institute of technology	6
3	Technicians	Diploma	PETRONAS institute of technology	11

Consensus is needed during a group decision. The judgments of the experts on each of the pairwise comparisons are determined after long-run discussions to ensure the different points of view as final group decisions in a consensus.

Employ pair wise comparison
Usually in AHP, decision maker expresses judgments in terms of pair wise comparisons on each level of hierarchy with respect to their impact on the next level (from criteria to sub-criteria). The verbal judgments made by the decision maker are translated into numbers. In the real world, linguistic environment is used by human beings to make decisions. Fuzzy can be used for vague and qualitative assessment of human beings [14]. This research uses linguistic variable to express reasonably situation that difficult to define. The triangular fuzzy numbers (TFN) used in this study are shown in Table 2 below.

Table 2 Pairwise comparison of FAHP (12)

Linguistic scale	TFN	Inverse TFN
Equal importance	(1/2,1,3/2)	(2/3,1,2)
Weakly important	(1,3/2,2)	(1/2,2/3,1)
Essentially important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely important	(5/2,3,7/2)	(2/7,1/3,2/5)

The membership function of a triangular fuzzy number which associated with a real number in the interval [0, 1] can be defined as:

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, \dots\dots\dots\dots\dots\dots x \in [l,m], \\ \frac{x}{m-u} - \frac{u}{m-u}, \dots\dots\dots\dots\dots x \in [m,u] \\ 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots otherwise \end{cases} \quad (1)$$

where $l \le m \le u$, l, the lower value of the modal m, and u upper value of the modal m. The triangular number which is shown in Figure 3 is denoted by (l, m, u). If $l = m = u$, it is ordinary number (non – fuzzy). The support of m is the set $\{x \in R / l, x, u\}$, where R is a real number and $\mu_A(x)$ is the membership function.

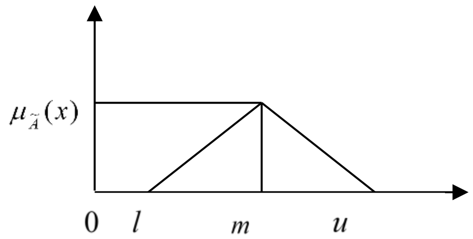

Figure. 3. Triangular fuzzy number

If a matrix contains a fuzzy number, then it is called fuzzy matrix. Like a normal matrix there also involve an operation in a fuzzy matrix. The sum, subtraction, multiplication and inverse of a two triangular fuzzy number is shown in

$M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$

Addition:

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

(2)

Multiplication:

$$(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) \approx (l_1 l_2, m_1 m_2, u_1 u_2)$$

(3)

Multiplication by a scalar:

$$(\lambda, \lambda, \lambda) \otimes (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1)$$

$$\lambda > 0, \lambda \in R$$

(4)

Inverse:

$$(l_1, m_1, u_1)^{-1} \approx (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1})$$

(5)

Checking the consistency (CI) of matrices

The pair wise comparison in AHP is given by the expert opinion; this opinion could be or could not be consistent. In order for the results to be true, it is a must to check the consistency of these opinions [13]. The Analytical hierarchy method develops a consistency measure, by using consistency ratio. Consistency ratio is calculated using the Consistency index (CI) and Random index (RI). The consistency index is determined using eigenvalue λ and eigenvector value. It shows weather the expert opinion is consistent or not.

$$CI = (\lambda_{max} - n)/(n-1)$$

(6)

where λmax is the maximum eigenvalue, and n is the dimension of the judgment matrix. The Random index is obtained by averaging the CI of a randomly generated reciprocal matrix. It is given in the below

N	1	2	3	4	5	6	7	8	9	10
R	0	0	0.5	0.8	1.1	1.2	1.3	1.	1.4	1.4
I			2	9	1	5	5	4	5	9

The calculated consistency ration should be less than or equal to 0.1, that means it is only acceptable if the inconsistency is below 10%.

Extent analysis method

Extent analysis method is used to consider the extent of an object to be satisfied for the goal, that is, satisfied extent. In the method, the "extent" is quantified by using a fuzzy number [16] [17] [18].

Let $X = \{x_1, x_2, ... x_n\}$ be an object set and

$G = \{g_1, g_2, ... g_n\}$ be a goal set

Using the extent analysis method [1], by taking each object extent analysis is performed for each goal respectively, to find the extent analysis values with the following sign:

$\tilde{M}^1_{g_1}, \tilde{M}^2_{g_2}, \tilde{M}^3_{g_3} .... \tilde{M}^j_{g_i}$ for i=1, 2,………n

where, all the $\tilde{M}^j_{g_i}$ for j=1,2,……are triangular fuzzy numbers. The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$\tilde{S}_1 = \sum_{j=1}^{m} \tilde{M}^j_{g_i} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{M}^j_{g_i} \right]^{-1}$$

(7)

Here $\tilde{S}_1$ is defined as the fuzzy synthetic extent value and $\otimes$ as the fuzzy multiplication operation. Fuzzy addition operation of m extent analysis values from a particular matrix will be performed to found the below value,

$$\sum_{j=1}^{m} \tilde{M}^j_{g_i} = (\sum_{j=1}^{m} l_{1j}, \sum_{j=1}^{m} m_{1j}, \sum_{j=1}^{m} u_{1j})$$

(8)

A principle of comparison of fuzzy numbers is used to attain the weigh vales under each criterion. Consider two fuzzy triangular numbers M1 and M2, the degree of possibility of M1≥M2 [$\tilde{M}_2 = (l_2, m_2, u_2) \geq \tilde{M}_1 = (l_1, m_1, u_1)$] is defined as:

$$V(\tilde{M}_1 \geq \tilde{M}_2) = Sup\left\lfloor \min(\mu_{\tilde{M}_1}(x), \mu_{\tilde{M}_2}(y) \right\rfloor$$

(9)

where, sup is supremum for all x ≥ y

when, $\mu_{\tilde{M}_1}(x) = \mu_{\tilde{M}_2}(y) = 1,$ then

$V(\tilde{M}_1 \geq \tilde{M}_2) = 1$ and $V(\tilde{M}_2 \geq \tilde{M}_1) = 0$.

Since M1 and M2 are convex fuzzy numbers defined by the triangular fuzzy numbers (l1, m1, u1) and (l2, m2, u2) respectively, it follows that and this can equivalently be expressed as follows;

$V(\tilde{M}_1 \geq \tilde{M}_2) = 1$ If and only if m1≥m2;

$$V(\tilde{M}_2 \geq \tilde{M}_1) = hgt(\tilde{M}_1 \cap \tilde{M}_2) = \mu_{\tilde{M}_2}(x_d)$$

(10)

Where, hgt is the height of fuzzy numbers on the intersection of M1 and M2.d is the ordinate of the highest intersection point D between μM1 and μM2 is shown in the Figure 4 below.

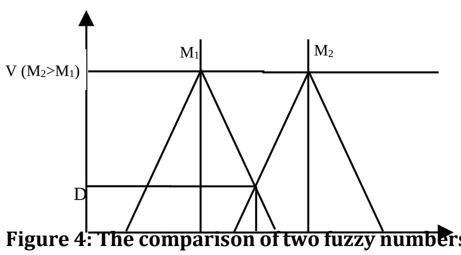

Figure 4: The comparison of two fuzzy numbers M1 and M2

The degree of possibility for a convex fuzzy number can be obtained from the use of Equation (12):

$$V(\tilde{M}_2 \geq \tilde{M}_1) = hgt(\tilde{M}_1 \cap \tilde{M}_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} = d$$

(11)

The degree of possibility for a convex fuzzy number to be greater than K convex fuzzy numbers $\tilde{M}_i (i = 1,2,........, K)$ the use of the operations max and min and can be defined by

$$V(\tilde{M} \geq \tilde{M}_1, \tilde{M}_2, ..., \tilde{M}_k)$$

$$V[(\tilde{M} \geq \tilde{M}_1).(\tilde{M} \geq \tilde{M}_2).(\tilde{M} \geq \tilde{M}_k)]$$

$$= \min V(\tilde{M} \geq \tilde{M}_i), i = 1,2,........, K$$

Assume that

$$d'(A_i) = \min V(\tilde{S}_i \geq \tilde{S}_k)$$ (12)

where K=1, 2 ....n; k≠I, and n is the number of criteria.

The weight vector is given by

W'= [d' (A1), d' (A2)…d' (An)] T (13)

Ai (i=1, 2...... n) = are n elements.

Each d'(Ai) value corresponds to the relative predilection of each DA. To allow the values in the vector to be analogous to weights defined from the AHP type methods, the vector W' is normalised and denoted:

W= [d(A1),d(A2),……..d(An)]T (14)

where, W is the non-fuzzy number

RESULTS AND FINDINGS

The pairwise comparison between criterions is shown in Table 3.

Table 3: The fuzzy evaluation matrix between criterions

	EO	ENV	F	Column sum
EO	(1,1,1)	(2/3,1,3/2)	(1,3,5)	(2.2,4.3, 7)
ENV	(1,3,5)	(1,1,1)	(1/7,1/5,1/3/2)	(4.2, 6.33, 9)
F	(1/5,1/3,1)	(3,5,7)	(1,1,1)	(2.14,4.2,6.33)

In order to determine the extent value of each criterion, the first step will be to find the sum of the column and row. The total sum of the column sum is (18.26.28.28 and 42.83). Using Equation 3.50, the extent value is found to be

SEO = (2.2, 4.33, 7) * (8.54, 14.86, 22.33) T

= (0.099, 0.291, 0.819)

SENV = (2.14, 4.2, 6.2) * (8.54, 14.86, 22.33) T

= (0.05, 0.148, 0.34)

SF= (4.2, 6.33, 7) * (8.54, 14.86, 22.33) T

= (0.098, 0.224, 0.383)

Using the degree of possibility concept in Equation (3.52) the compared weight value is found.

V (SEO ≥ SENV) =1.22

V (SEO ≥ SF) =1.1

V (SENV ≥ SEO) = 0.62

V (SENV ≥ SF) = 0.76

V (SF ≥ SEO) = 0.8

V (SF ≥ SENV) = 1.2

Then the weight vector is found using Equation (3.56)

d'(EO)=V (SEO ≥ SENV, SF) = min (1.22,1.1) =1

d'(ENV)= V (SENV ≥ SEO, SF) = min (0.62, 0.76) =0.62

d' (F) = V (SF ≥ SEO, SENV,) = min (0.8, 1.2) =0.8

Hence W'= (1, 0.62, 0.8) T

Normalization is used in this step to find the weight vector with respect to each decision criteria EO, ENV, and F.

W= (0.41, 0.26, 0.33)

The consistency ratio for each matrix is calculated and it is found that 0.08204, 0.039951 and 0.035 for EO, ENV and F respectively. All the CR is less than 0.1 which shows the opinions of the experiment are consistent. Next each options O1, O2 and O3 will be compared under each of the criteria separately. This is shown in Tables 4.

Table 4. Expert Opinion on the available options

EO	)1	O2	3	'(EO)
O1	(1,1,1)	3,5,7)	(1,3,5)	0.54
O2	(1/7,1/5,1/3)	(1,1,1)	(7,9,11)	0.46
O3	(1/5,1/3,1)	(1/11,1/9,1/7)	(1,1,1)	0

V	)1	O2	3	NV)
O1	(1,1,1)	(3,5,7)	(7,9,11)	0.66
O2	(1/7,1/5,1/3)	(1,1,1)	(7,9,11)	0.34
O3	(1/11,1/9,1/7)	(1/11,1/9,1/7)	(1,1,1)	0

	)1	O2	3	F)
O1	(1,1,1)	(3,5,7)	(1/11,1/9,1/7)	0.5
O2	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	0
O3	(7,9,11)	(1,3,5)	(1,1,1)	0.5

Finally, adding the weights for each option and multiplying by the weight of the corresponding criteria, a final score is obtained as shown in Table 5

Table 5: Final Score for each option with respect to the criterion

	O1	O2	O3
EO	0.54	0.46	0
ENV	0.66	0.34	0
F	0.5	0	0.5
Final score	0.50	0.34	0.17

The qualitative analysis indicates that rather than replacing each pump step by step (option two) or adding new pumps (option three) it is better to continuing with the existing system through maintenance (option one) which quite a different result from the quantitative analysis.

CONCLUSION

Amine pump options selection is a strategic importance for gas processing plant. When making these selections the great deal of focus should be given to which criteria to select, since the time and cost of the options depends on it. The study assesses all criterion and options and tries to select the best one. Three criteria; Ease of operation (EO), Environment (ENV) and Flexibility (F) and three alternatives; Continue with the existing pump (O1), Replace the pumps (O) and to add a new pump (O3) are analysed. This multiple criteria decision-making analysis problem was solved using the fuzzy AHP method and it is found that from the priority weight of the three available options O1 is selected since it has the highest percentage of all which is 50%, the second one is O2 with a weight of 34% and finally O3 with 17%.

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