

## Determining maintenance strategy by using Fuzzy Group MADM approach

**Esmaeili Mohammadreza, Seyedi Seyed Masoud, Iranban Seyed Javad**

Economic and Management, Shiraz branch, Islamic Azad University,  
Shiraz, Iran

E-mail: rezaes57@yahoo.com

### Abstract

This paper aimed to select the best maintenance strategy in the Sirjan Gol-Gohar ironstone complex. The aim of maintenance is increasing equipment life length, increasing availability and reliability, improving equipment availability, and efficiency and retaining equipment in proper condition. Theoretical frame work of research based on four main Criteria and 11 sub criteria like: Safty (Personnel, Facilities, and Environment), Added-value (Spare Part Inventories, Production Loss, and Fault Identification), Cost (Hardware, Software, Personnel Training) and Feasibility (Acceptance by Labors, Technique Reliability). For collecting information, questionnaires had given to senior managers of maintenance in the Sirjan Gol-Gohar ironstone complex. As the society was limited, the survey was done in the whole society and using Group fuzzy AHP. Findings show that the first prioritization of maintenance strategy is Condition-Based Maintenance (CBM) strategy. Finally, best prioritization maintenance strategy is predictive maintenance (PM), time base maintenance (TBM) and corrective maintenance (CM) correctly.

**Keywords:** maintenance strategy, fuzzy AHP, Gol-Gohar

### Introduction

Nowadays the subject of maintenance becomes more important in organization. Manufacturing firms search way to reduce product cost. One of the main expenditure items for these firms is maintenance cost which can reach 15–70% of production costs, varying according to the type of industry (Bevilacqua and Braglia, 2000). By noticing to important maintenance for manufacturing firms, this paper intend to use group fuzzy analytic hierarchy process (AHP ) to select best maintenance strategy in Sirjan Golgohar Ironstone complex. An optimal maintenance strategy mix is necessary for increasing availability and reliability levels of production facilities without a great increasing of investment. The selection of maintenance strategies is a typical multiple criteria decision-making (MCDM) problem (Wang et al., 2006). Maintenance plants are one of the most important production part and can effect on competition priority and Business strategy from aspect negative and position. Also, all of the manufacturing firm invest a substantial amount of capital in procuring physical assets. One of the important factors that influence the return on investments is maintenance of these assets. However, when it comes to maintaining these assets, maintenance is being treated as any other budget line item. On the other hand, many developments have taken place in terms of technology, concepts, and philosophies both in production and maintenance (Pinjala et al., 2006). The cost of maintenance is increasing by using automation, robot and computer equipment in firms and office.

Today, research in this area is on the rise. Moreover, the role of maintenance is changing from a “necessary evil” to a “profit contributor” and towards a “partner” of companies to achieve world-class competitiveness (Waeybergh and Pintelon, 2002). According to Ilangkumaran and Kumanan (2009), maintenance is viewed as value-adding activity, instead of necessary evil for the expenses (Ben-Daya and Duffuaa, 1995; Anil Sharma and Yadava, 2011).

### Maintenance strategy

The term maintenance strategy is generally viewed from the perspective of maintenance policies and concepts. For instance, it is defined in terms of reactive or breakdown maintenance, preventive and predictive maintenance (Kevin and Penlesky, 1988; Cook, 2003). Swan-

son(2001)explains three types of maintenance strategies: reactive strategy (breakdown maintenance), proactive strategy (preventive and predictive maintenance), and aggressive strategy (TPM).

Maintenance is usually categorized in to the following three types (Dhillon, 2002):

(1) Preventive maintenance – all actions carried out on a planned, periodic and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning.

(2) Corrective maintenance – unscheduled maintenance or repair to return items/equipment to a defined state, carried out because maintenance persons or users perceived deficiencies or failures.

(3) Predictive maintenance – the use of modern measurement and signal processing methods to accurately predict and diagnose items/equipment condition during operation (Sharma and Yadava, 2011)

However, the above-mentioned maintenance strategies classified in the different group by the view of researcher. Thus, the article of some researchers were studied. The researcher considered a comprehensive survey MR of Wang et al in 2007 and provided model with composition of total criteria in this topic. This strategy includes corrective maintenance time-based preventive maintenance, condition-based maintenance, and predictive maintenance.

#### **Time-based preventive maintenance (TBM)**

It is known as a preventive and periodic maintenance, something that is done in periodic and certain intervals time. TBM operation is basic on suggestion, advice of maker, technical knowledge and acquires experience in factory from work with equipment and the attention on condition environment equipment in the fix time maintenance function done without noticing the availability and reliability plants. There is a regular plan to replace and renew parts and sub section equipment or overall complete repair of system. This plan relatively indicates kind of preventive action, interval time operation and other information. According to reliability characteristics of equipment, maintenance is planned and performed periodically to reduce frequent and sudden failure. Time-based preventive maintenance is applied widely in industry. For performing time-based preventive maintenance, a decision support system is needed, and it is often difficult to define the most effective maintenance intervals because of lacking sufficient historical data (Manna et al. 1995; Wang et al, 2007).

#### **Condition-based maintenance CBM**

In the CBM, maintenance does basic on performance situation of plant and equipment. In the CBM maintenance, maintenance done by monitoring on performance of plants and equipment into periodic fix time. Rostamiyan (2006) state the desire situation is predicted before occurring failure like demographic analysis (heat), voice disseminate, lubricating analysis and vibration analysis.

The benefit of prevent maintenance reduce failure and increases equipment life length. The advantage of CBM is reducing maintenance expenditure and stopping plants and equipment and the disadvantage is to turn down plant in intervals of work plan. Maintenance decision is made depending on the measured data from a set of sensors system when using the condition-based maintenance strategy.

#### **Advantage of CBM**

We can mention some of the advantages of CBM including reducing number of stop plant and equipment, reducing time of stop plant and equipment , reducing the consumption of spare part, reducing cost, increasing product quality, increasing safety and insurance rate of plant.

### Predict maintenance (PM)

Predict maintenance is a planning and scheduling systematic method as a necessary action for maintenance base on regular plan in the retain equipment optimal situation and equipment by increasing useful life length and reducing fault product that cause break down of plants and equipment. Predictive maintenance (PM) can be defined as methods of surveillance used to indicate as to how well the machine is, while performing its intended tasks. In order to get maximum number of on stream days of operation, the system of maintenance operation will be able to reduce downtime to absolute minimum. So, monitoring the plant continuous and diagnosing actual condition of equipment by on-stream non-destructive testing methods are increased. The main objective is to predict an impending failure in times, thus avoiding failures which could cause heavy penalty costs and even safety hazards. This maintenance is best for safety premises and also it increases stream availability (Ilangkumaran and Kumanan, 2009). Unlike the condition-based maintenance policy, in predictive maintenance the acquired controlled parameters, data are analyzed to find a possible temporal trend (Bevilacqua and Braglia, 2000).

### Corrective maintenance (CM)

Corrective maintenance is the simple and rudimentary kind of maintenance including replacement and repair factor that is the cause of failure. CM also named as fire-fighting method and equipment continue until breaking down then failure equipment replacement and repair. It is worth mentioning that equipment failure and corrective actions of maintenance cannot be avoided completely when the preventive maintenance strategies including the time-based, condition-based, and predictive maintenance) are applied (Wang et al., 2006). This maintenance often is damaged in equipment and personal and environment. In additional increasing world competition, low profit forces the management to use a maintenance strategy with reliability and more efficiency.

The different manufacturing firms has maintenance various aims but in some case this aim can be analysis into 4 aspects as follows:

- 1) Safety: Personnel, Facilities, Environment
- 2) Cost: Hardware, Software, Personnel training:
- 3) Added-value: Spare parts inventories, Production loss, and Fault identification:
- 4) Feasibility: Acceptance by labors, Technique reliability

### Materials and Methods

#### *Analytic hierarchy process (AHP) method*

The AHP was first suggested by Saaty in 1970 .This method of analysis like a human brain and decision maker is able to determine mutual and coincident effect. Analytic hierarchy process (AHP) method is based on three principles including Hierarchy tree draw principle, Priority and determined principle, and Judgment logical Consistency principle

Suppose that there is only one decision maker to evaluate alternative and criteria. At present, instead of using one decision maker, we want to use two or more decision makers. In this case group fuzzy AHP, we can earn geometric mean which is used by many expert surveillance attention as a main matrix

$$X_{ij} = \prod_{l=1}^k x_{ij} \quad (1)$$

I: Decision maker number K: Decision makers number J: criteria or alternative comparisons

$$I_j = 1, 2, \dots, n, \quad i \neq j \quad L = 1, 2, 3, \dots, k$$

Fuzzy theory was prepared by Lotfi Askar Zade in 1965 . Fuzzy theory was done in uncertain situation first time by LOO & Perdic by replacing triangular fuzzy number in pair-wise

judgment matrices comparisons and extensive AHP process analysis to fuzzy AHP data by collecting questionnaires and by group fuzzy to priority and analysis (Momeny, 2006).

**Ranking criteria by Cheng and Moon interval method**

Chen and Moon (as cited in Kaufmann and Gupta,1988) believe that the inverse is a triangular fuzzy number and maybe it is not a triangular fuzzy, Survey the 9 fuzzy number prepare by (Juang and lee, 1991) and then by receive expert judgment based on triangular fuzzy number 1 till 9 by using  $\alpha$  cut and calculate interval agreement matrix vector by Saaty method. The fuzzy number is used on this method like below table.

**Table 1.** Member function for Cheng and Moon AHP method

Membership function	Fuzzy numbers
(1,1,3)	$\tilde{1}$
(x-2,x,x+2)	$\tilde{x}$
(7,9,11)	$\tilde{9}$

The following steps are used to solve based on Cheng and Moon method

Step 1. Draw a Hierarchy tree

Step 2. Pair-wise comparisons matrix by use a triangular number  $\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}$

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{12}^{-1} = \frac{1}{\tilde{a}_{12}} & 1 & \tilde{a}_{23} & \dots & \tilde{a}_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \tilde{a}_{1n}^{-1} = \frac{1}{\tilde{a}_{1n}} & \tilde{a}_{2n}^{-1} = \frac{1}{\tilde{a}_{2n}} & \tilde{a}_{3n}^{-1} = \frac{1}{\tilde{a}_{3n}} & \dots & 1 \end{bmatrix}$$

Pair-wise comparisons matrix (1)

Step 3. Apply  $\infty$  cutting

Triangular fuzzy number  $\infty$  cutting in the matrix is replaced by using definition of this number in figure 1.

$$\tilde{A}^{\infty} = \begin{bmatrix} 1 & \left[ \frac{1}{a_{12}^{\infty}}, \frac{1}{a_{12}^{\infty}} \right] & \left[ \frac{1}{a_{13}^{\infty}}, \frac{1}{a_{13}^{\infty}} \right] & \dots & \left[ \frac{1}{a_{1n}^{\infty}}, \frac{1}{a_{1n}^{\infty}} \right] \\ \left[ \frac{1}{a_{12}^{\infty}}, \frac{1}{a_{12}^{\infty}} \right] & 1 & \left[ \frac{1}{a_{23}^{\infty}}, \frac{1}{a_{23}^{\infty}} \right] & \dots & \left[ \frac{1}{a_{2n}^{\infty}}, \frac{1}{a_{2n}^{\infty}} \right] \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \left[ \frac{1}{a_{1n}^{\infty}}, \frac{1}{a_{1n}^{\infty}} \right] & \left[ \frac{1}{a_{2n}^{\infty}}, \frac{1}{a_{2n}^{\infty}} \right] & \left[ \frac{1}{a_{3n}^{\infty}}, \frac{1}{a_{3n}^{\infty}} \right] & \dots & 1 \end{bmatrix}$$

Cut  $\infty$  on pair-wise comparisons matrix(2)

Apply  $\infty$  cutting on a triangular fuzzy number done like below

$$\tilde{A}_\alpha = (a_1, a_2, a_3) \tag{2}$$

$$\tilde{A}_\alpha = [a_1^\alpha, a_3^\alpha] = [a_1 + (a_2 - a_1)\alpha, a_3 - (a_3 - a_2)\alpha] \tag{3}$$

Step 4. Synthetic convexity limit: by using an optimal index ( $\lambda$ ) for decision number, the judgment is as the below formula:

$$\forall \lambda \in [0,1] \quad \tilde{a}^\alpha_{ij} = \lambda \tilde{a}^\alpha_{iju} + (1 - \lambda) \tilde{a}^\alpha_{ijt} \tag{4}$$

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}^\alpha_{12} = \lambda a^\alpha_{12u} + (1-\lambda)a^\alpha_{12l} & \dots & \tilde{a}^\alpha_{1n} = \lambda a^\alpha_{1nu} + (1-\lambda)a^\alpha_{1nl} \\ \tilde{a}^\alpha_{21} = \lambda \frac{1}{a^\alpha_{12l}} + (1-\lambda)\frac{1}{a^\alpha_{12u}} & 1 & \dots & \tilde{a}^\alpha_{2n} = \lambda a^\alpha_{2nu} + (1-\lambda)a^\alpha_{2nl} \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ \tilde{a}^\alpha_{n1} = \lambda \frac{1}{a^\alpha_{1nl}} + (1-\lambda)\frac{1}{a^\alpha_{1nu}} & \tilde{a}^\alpha_{n2} = \lambda \frac{1}{a^\alpha_{2nl}} + (1-\lambda)\frac{1}{a^\alpha_{2nu}} & \dots & 1 \end{bmatrix}$$

Synthetic convexity limit cut <sup>$\alpha$</sup>  comparisons matrix (3)

Step 5. Normalization : The below matrix by Saaty method is used for normalization.

$$a_{ij} = \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \tag{5}$$

Step 6. Arithmetic mean: the mean of any row is used an item weight

$$r_{ij} = w_i = \frac{\sum_{j=1}^n r_{ij}}{n} \tag{6}$$

Step 7. Weight composes from multiply criteria weight in solving weight is calculated as final weight

$$u_i = \sum_{j=1}^n w_j r_{ij} \tag{7}$$

Step 8. For different data of  $\infty$  rewrite above matrix. By comparing weight data different data of  $\infty$ , we can evaluate the solving final priority from various data together (Zanjirchi, 2011).

**Consistency**

Pair-wise comparison matrix, as important prerequisites for AHP about alternative, is better because of inconsistency compression matrix, and generating weight inconsistency. So, the

survey of high power transmission pair-wise comparisons is needed. Gougos and Boucher by generation 400 random matrix again generated random index chart (RI) (table 2) for fuzzy pair-wise comparisons matrix.

Before surveying the consistency, it is needed to survey high power transmission

$$a_{ijm} \cdot a_{jkm} = a_{ikm} \tag{8}$$

$$\sqrt{a_{iju} \cdot a_{ijl}} \cdot \sqrt{a_{jku} \cdot a_{jkl}} = \sqrt{a_{iku} \cdot a_{ikl}} \tag{9}$$

Then fuzzy comparisons matrix is high power transmission (Zanjirchi, 2011).

**Table 2. Random indexes chart**

$RI^g$	$RI^m$	Matrix size
0	0	1
0	0	2
.1796	.4890	3
.2627	.7937	4
.3597	1.0720	5
.3818	1.1996	6
.4090	1.2874	7
.4164	1.3410	8
.4348	1.3793	9
.4455	1.4095	10
.4536	1.4181	11
.4776	1.4462	12
.4691	1.4555	13
.4804	1.4913	14
.4880	1.4986	15

**The step of survey consistency by Gougus and Boucher method**

Step1: Dividing fuzzy matrix into two matrix

Fuzzy comparisons middle number

$$A^m = [a_{ijm}] \tag{10}$$

Geometric mean of triangular number low and high limit

$$A^g = \sqrt{a_{iju} \cdot a_{ijl}} \tag{11}$$

Step2: Calculating weight vector earn matrix by using a Saaty method

Into  $w_i^m = [w_i^m]$  
$$w_i^m = \frac{1}{n} \sum_{j=1}^n \frac{a_{ijm}}{\sum_{i=1}^n a_{ijm}} \tag{12}$$

Into  $w_i^g = [w_i^g]$  
$$w_i^g = \frac{1}{n} \sum_{j=1}^n \frac{\sqrt{a_{iju} \cdot a_{ijl}}}{\sum_{i=1}^n \sqrt{a_{iju} \cdot a_{ijl}}} \tag{13}$$

Step 3: Calculating the biggest particular quantity for each matrix

$$\lambda_{\max}^m = \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n a_{ijm} \left( \frac{w_j^m}{w_i^m} \right) \quad (14)$$

$$\lambda_{\max}^g = \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n \sqrt{a_{iju} \cdot a_{ijl}} \left( \frac{w_j^g}{w_i^g} \right) \quad (15)$$

Step 4: Calculating consistency index by use relate below

$$CI^m = \frac{(\lambda_{\max}^m - n)}{n - 1} \quad (16)$$

$$CI^g = \frac{(\lambda_{\max}^g - n)}{n - 1} \quad (17)$$

Step 5: Calculating consistency

$$CR^m = \frac{CI^m}{RI^m} \quad (18)$$

$$CR^g = \frac{CI^g}{RI^g} \quad (19)$$

In this case, the criteria  $CR^m$  and  $CR^g$  be less than ./1 completely consistent and when the both of them become more than ./1 ask the decision maker to revise in priority and when the only  $CR^m$  is more than ./1 want the decision maker revise in middle priority( zanjirchi 1390).

#### **Framework of the study**

Criteria used in this paper is the criteria used by Wang (2006). They are used as the source of this paper including

- 1) Safety: Personnel, Facilities, Environment
- 2) Cost: Hardware, Software, Personnel training:
- 3) Added-value: Spare parts inventories, Production loss, Fault identification
- 4) Feasibility: Acceptance by labors, Technique reliability (Wang et al 2006).

This criteria based on four maintenance strategy is used to determinate satisfied strategy by use FAHP as figure 1.

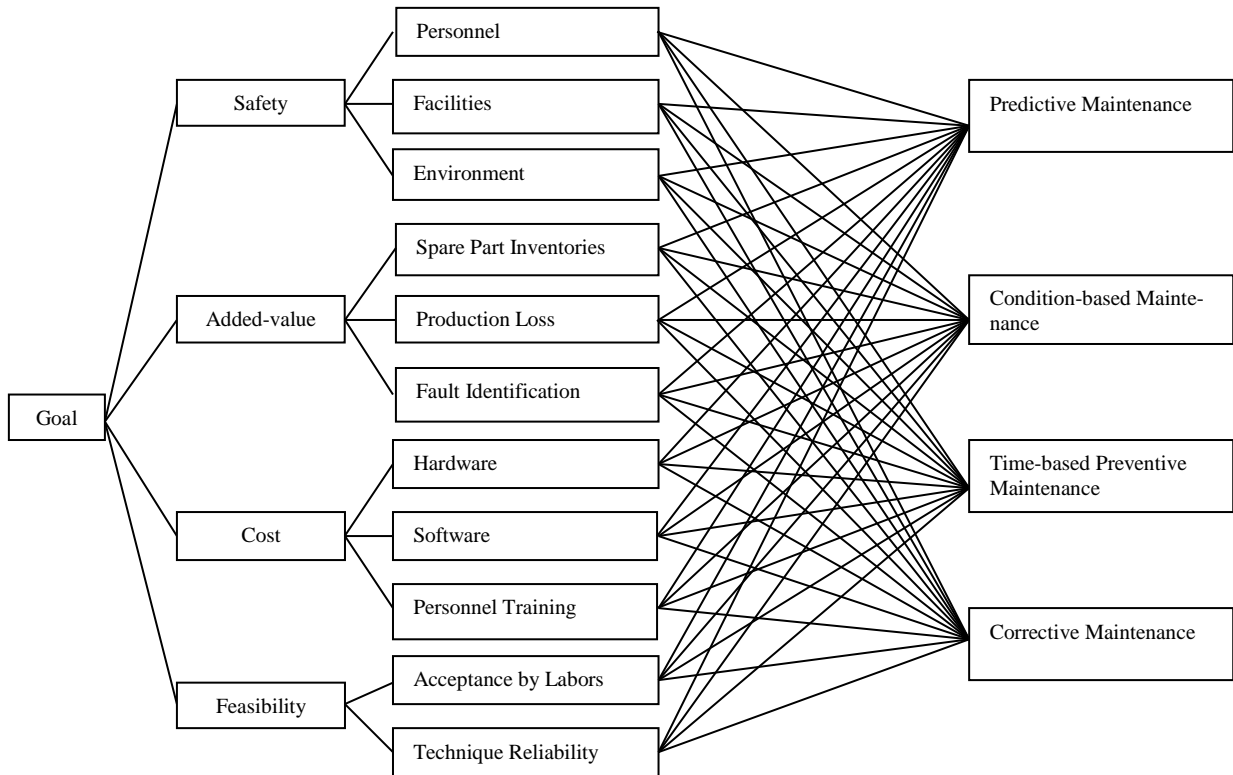
- 1) Corrective maintenance
- 2) Time-based preventive maintenance
- 3) Condition-based maintenance
- 4) Predictive maintenance

The question is how maintenance strategy priority in Sirjan Golgohar Ironstone complex from satisfied is.

In this case, a complete model was prepared and four main criteria in eleven sub criteria were selected. The questionnaire were distributed among the maintenance management Sirjan Golgohar Ironstone complex. After data collection, they were analyzed and any of the strategy final ranking were elicited. In this section, by using earn data, I mean, pair-wise comparisons matrices criteria by aim, pair-wise comparisons matrices sub criteria by criteria, pair-wise comparisons matrices alternative by sub criteria. Research result of the statistical testing showed that from opinion management maintenance of Sirjan Golgohar Ironstone complex at the present from 4 main criteria safety, cost, added value and acceptance. Safety can be more important than other.

Safety is the fundamental of successful and it is needed if retain person feels peace and thinks about progress in life dimension and another thing becomes important.

Safety criteria includes three sub criteria as personnel, facilities and environment. Personnel sub criteria is more important than others. Nowadays, importance and role of personnel in product process and service in human society are regarded as an important factor because of progress technology without attempting labor is not efficient.



**Figure 1. Hierarchy structure of the fuzzy analytic hierarchy process**

The companies are trying to have spare part in warehouse because of boycott and other problem. Cost criteria component includes three sub criteria: Hardware, Software and Personnel training. Cost is the factor that firm and factory have special attention to it and consistently try to reduce it by analysis to earn more profit. Among sub criteria of cost software is more important than others. Feasibility criteria component has two sub criteria including acceptance by labors and technique reliability. The management must have acceptable reason for strategy and plan to be accepted by labors. In feasibility criteria, acceptance by labors is important. It shows that the labor must accept plan or plants and should not be resistant. Resistance reduces efficiency labor and plant if the plan or plant has more competence and qualification. This paper selected satisfied strategy in maintenance Sirjan Golgohar Ironstone complex. In this paper, four strategies were used including PM, CBM, TBM, CM. By integrating the weight of the rate of importance and obtaining final priority, any of the alternative and so CBM is the best priority in the first and PM TBM CM as the second priority.

### Conclusion

The result of research shows that CBM is the maintenance strategy at the present in Sirjan Golgohar and after that PM, TBM and CM have been considered.

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