Using AHP Methods in Maintenance to Improve Reliability and Equipment Performance

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Abstract. The engineers are usually expected to consider several influential criteria when selecting as a single best alternative for water maintenance system (WMS). This research discusses the approach based on the Analytic Hierarchy Process (AHP) as a decision making tool for selecting WMS. Supported with information of equipment breakdown, the questionnaire method as well as personal interviews as a main tool to collect data and information in the practical aspect of the study. In this study, the AHP decision support tool was applied in a maintenance systems field in the town of AL-Fallujah Water Treatment Project, Iraq. The AHP was applied to evaluate and an alternative is chosen from a set of maintenance alternatives: [Preventive Maintenance (M1), Proactive Maintenance (M2), Total Productive Maintenance (M3), Predictive maintenance (M4) and Corrective Maintenance (M5)] vs eight of Maintenance pillars. Results indicate the advantages over traditional Decision Making selection methods. By using this information with AHP the best rank of alternatives was M3(11.85), M4(9.67) and so on. Moreover, the relationship between M3 and the pillars of maintenance: indicates a very high correlation 78%. The study reached a number of conclusions, the most important of which is the existing of a very strong impact for the proposed maintenance system in improving the performance and reliability of FWTP project operations.

Keywords: maintenance systems; decision making; Analytic Hierarchy Process (AHP); Pareto analysis; Reliability function.

1. Introduction

It has become clear that the continuation of industrial and service projects depends on the efficiency of
the operation of the machinery and equipment. So, it is necessary to rely on maintenance work, which includes all activities that industrial projects need to maintain machinery, equipment and buildings and make them conform to the standard operating condition. Saxena et al [1] As a result of this role that maintenance plays, scientific and practical measures must be taken to apply maintenance activities at certain times. Vishnu & Regikumar, [2] By means of which the operational processes continue with a high efficiency and reduce the occurrence of sudden failures with at the lowest possible cost, so for the purpose of achieving this goal. Ahmad et al. [3] a modern scientific methods are adopted, which have become that can be relied upon in choosing the appropriate time for implementation and at the lowest possible cost. Harrison, et al. [4] the function used to evaluate the functional performance of systems and machines is the reliability function. There are some auxiliary tools that are used in this evaluation such as failure rate, Pareto analysis, maintenance function, and others tools [5,6]. The research problem: through field visits to the reality of the FWTP in Fallujah, it was found that the project suffers from a problem of high maintenance costs and fluctuation in its implementation times, which in turn created a gap between the current performance of the project and the expected performance of it, and it cannot bridging this gap except by developing existing maintenance policies and processes, by applying a modern and advanced maintenance system (predictive maintenance system based on Preventive maintenance system)[7]. This system is considered one of the most important factors for the success of contemporary production systems [1,7]. Depending on the above, the research aims to improve the reliability and performance of FWTP equipment using modern scientific methods of maintenance. Thus, despite many researchers have already discussed about criteria, sub-criteria and criteria and allocation of resources, the criteria and criteria selection of each scenario is particularly unique.

2. Material and Methods

The choice of an optimal maintenance strategy for a system is a complex and multidimensional decision-making problem because of the data collection phase, numerous, conflicting criteria and decision makers from various fields, as well as a variety of components and functions that need to be addressed as a systematic approach Mohammad et al. [5]. The MCDM approach has received great interest in the last half of the 2000s. MCDM methodology is applied to select the most appropriate maintenance strategies in various industries [7]. Many MCDM approaches have been proposed in the literature. Bevilacqua & Marcello [8] in an Italian petrol company, Zain [9] et al. and Wang et al [10] and Mutlag and Kassam [11] in a water treatment plant, and Lizot et al, [7] in the water treatment system in a Brazilian sanitation company, have chosen the most appropriate maintenance strategy using the Analytic Hierarchy Process (AHP) method. Giada [12] evaluated cost, safety, added value, equipment and technology criteria, and CM, time-based preventive maintenance (TBPM) and condition-based maintenance (CBM) strategies with the AHP method. Triantaphyllou et al. [13] selected the most appropriate maintenance strategy for a hospital with the AHP method. The study evaluates Preventive Maintenance (M1), Proactive Maintenance (M2), Total Productive Maintenance (TPM)(M3), Predictive maintenance (M4) and Corrective Maintenance (M5) as a maintenance strategies alternatives.

2-1. Total Productive Maintenance (TPM):

Melesse & Ajit [14] is a maintaining system and improving the integrity of production, safety and quality systems through the machines, equipment, processes, and employees. The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPM activities, Kaizen pursues efficient equipment, operator and material and energy utilization, that is extremes of productivity and aims at achieving substantial effects.

Ikuo base et al. [15] collected two traditional maintenances (predictive preventive maintenances) were developed by Seiichi Nakajima of Japan. The results of his work on the subject led to the Total Productive Maintenance TPM process in the late 1960s and early 1970s. Nippon Denso (now Denso), a company that created parts for Toyota, was one of the first organizations to implement a TPM program. Abbas et al [16] This resulted in an internationally accepted benchmark for how to implement TPM. Incorporating lean manufacturing techniques, TPM is built on eight pillars. The eight pillars of total productive maintenance focus on proactive and preventive techniques to help improve equipment
reliability. The eight pillars are [13-18]: Supporting top management P1, focused improvement P2, Educating and Training P3, Maintenance Information Support Systems P4, Supporting and Assistance all Departments P5, The Total Cost of Maintenance P6, Quality Maintenance P7, Participation of all employees P8.

2.2. Statistical Probability Distributions in Reliability Analysis:

**Exponential Distribution:** It is the most widely used distribution in the field of reliability analyzes and is used to describe equipment with a fixed fault rate. As in the following equation [5]:

\[ R(t) = e^{-\lambda t} \quad \text{where:} \lambda, \text{Distribution parameter and } t, \text{time} \] (1)

**Weibull Distribution:** It comprehensively describes all stages of the life cycle of the stomach, as it describes the phenomenon of decreasing and increasing failure rate, in addition to the phenomenon of stability. Reliability function is measured [5]:

\[ R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \text{where:} \beta, \alpha \text{ Distribution parameters and } t, \text{time.} \] (2)

**Pareto Chart Analysis:** One of the seven basic tools for quality control data analysis is the Brito chart. Pareto notes that “the majority of the holidays are due to the small (few) reasons.” Accordingly, he divided the elements to be studied into two parts: “vital few” and “trivial many” [3]. Then he put the following rule (90% -80%) from the results that occur due to (20% -10%) of the causes. The method was developed by (Juran 1990) to become its present form [9].

\[ \text{The percentage of failure repeated Fr\%} = \frac{\text{Number of occurrences of Failure NF}}{\text{Total Number of Failures TNF}} \] (3)

**The impact of TPM on reliability:** Reliability improvement due to maintenance, Improving the reliability of a complex system can be achieved through TPM that aims to keep the system in good condition with a certain level of performance and reliability, as it maintains a constant malfunction rate and increases the actual operating period of the TBF system [5]. The expected goal of maintenance involves reducing the costs of unreliability, which is the loss of production as a result of the waiting period for components to be repaired or maintained to return to service [2]. To reach this goal by using the Integrated Approach methods within management, operation and maintenance as activities for the reliability improvement program for customer satisfaction [5]. The system reliability with preventive maintenance Rm(t) is [2,5]:

\[ R_m(t) = R(T)^n R(t - nT) \quad \text{for } nT \leq t < (n + 1)T \]

\[ n = 0,1,2,3 \ldots \] (4)

Where: Rm(t): system reliability with predictive maintenance. R(t): reliability of the system without maintenance. T: is the time between two preventive maintenance cycles. R(T)^n: The possibility of the system remaining running up to n maintenance cycles. R(t - nT): The probability that the system will remain up to (t-nT) from the time after the last maintenance cycle.

Figure (1) Shown reliability R(t) without preventive maintenance, reliability Rm(t) with preventive maintenance. Therefore, the reliability improvement over time by preventive maintenance, and the curve at the top represents preventive maintenance and TPM maintenance returns the system as good as new at the end of each preventive maintenance cycle. the reliability function Rm(t) appears as a decreasing function over time [5].

Therefore, the reliability Equation (5) with maintenance when Tp = nT can be [2]:

\[ R_m(T_p) = \exp \left[ -n \left( \frac{T_p}{\eta} \right)^{\beta} \right] = \exp \left[ -n^{1-\beta} \left( \frac{T_p}{\eta} \right)^{\beta} \right] \] (5)
Periodic maintenance reliability curve for an increasing failure rate

2-3. The Mathematical model to calculate the total cost of maintenance:

The expected total cost per unit of working time represented by the symbol $C(t_P)[5]$

$$C(t_P) = \frac{C_P + C_F + H(T_P)}{T_P - B + H(T_P)}$$

where: $C_P$: the cost of a preventive replacement before a breakdown occurs, and includes the cost of the idle segment and the cost of stopping production. $C_F$: replacement cost after the breakdown, and includes the cost of spare parts and cost of production loss, as that $C_F > C_P$ B: breakdown period to repair the failure when it occurs. $H(T_P)$: hazard rate during the period $(T_P, 0)$ and as in the following formula:

$$H(T_P) = \int_0^{T_P} \frac{\beta}{\alpha} \left(\frac{t}{\alpha}\right)^{\beta - 1} dt \text{ where: } (T_P, \beta, t, \alpha) \text{: explained earlier}$$

3. Case Study

3-1. The city of Al-Fallujah is one of the most important and largest cities in Anbar Governorate. It is witnessing rapid population growth and growth as the population has reached approximately (200,000 people), so improving the infrastructure, especially drinking water purification plants, will lead to improve the social level of the health for them. The study of the new Fallujah Water Treatment Project (FWTP), which is the largest and most important drinking water supply station in the city of Al-Fallujah, where this station supplies nearly 80% of the city’s population with drinking water. It is design capacity 2000 cubic meters / hour and its working system is 24 hours. The project consists of a group of systems [23]:

1- Intake System (A1,2,3): The intake system consists of three Pumps. The design capacity of each pump is 720 m3 / hour.
2- Deposition station(B1,2,3). It consists of a mud sweeper containing on the motor and a gear box and a median mixer for the tub, and valve to enter and other to exit water for sedimentation process.
3- Alum system(C1,2,3,4): It consists of four alum injector.
4- Chlorination system(D1,2): It consists of two chlorine devices and two posters. Liquid chlorine is added from large cylinders to the water by means of a chlorine injection device.
5- Clay station(F1,2): It consists of three pumps.
6- Filters station(G1,2). It consists of ten filters for each entry and exit gate filter; in addition to that it has two reverse wash pumps, and also contains two air compressors.
7- Ground tank(H): It store the water that all the treatment operations have been made to be ready to be pumped into the water networks through main Lifting system.
8- The high Lifting system (E1,2,3,4,5,6): consists of two lines (two tubes) with a diameter of 500 mm. Each line contains three pumps with a capacity of 540 m3 / hour.

3-2. Analysis of the actual reality of maintenance operations: in the FWTP Based on personal interviews with the officials (top management, engineers, Expert technicians, workers) of FWTP Project, or observations of researchers. The maintenance unit is one of the main units in FWTP Project. so, the maintenance main partner that production operations in the project cannot be completed successfully unless they are based on efficient and effective maintenance actives. The reason is that the production
operations in the water project are largely based on (equipment and machinery) that consists including project equipment. Therefore, top management took a pioneering step towards the maintenance unit by giving it a distinctive role in the decision-making process by occupying a vital position in the project organizational structure, as is the case with other units such as (management and operation) and this means obtaining financial support sufficient moral from top management.

3-3 Data Analysis Steps: To study and evaluate the project reliability, some auxiliary tools were used to analyze and measure reliability, which are explained in paragraph (2-3).

3-3-1 Calculation of reliability analysis:

Calculating the number of frequently of failure: From the preliminary data of the project failures, which were taken from the project records and after their classification, and calculating the number of recurring failures for each part of the project and arranged.

| A1 | Intake Pump A1 | date | FROM(days) | TO(days) | TRB(days) | TTR(days) |
|----|----------------|------|-------------|----------|-----------|-----------|
| 1  | 01/01/2018     | 2.5  | 3.5         | 108.7    |
| 103| 01/01/2018     | 19.2 | 10.5        | 169.0    | 0.4       |
| 109| 03/03/2018     | 13.0 | 19.5        | 44.5     | 0.4       |
| 45 | 1/12/2018      | 7.0  | 12.5        | 28.9     | 0.2       |
| 29 | 15/12/2018     | 10.0 | 1.0         | 4.0      |
| A2 | Intake Pump A2 | date | FROM(days) | TO(days) | TRB(days) | TTR(days) |
| 31 | 01/01/2018     | 9.0  | 7.0         | 104.8    |
| 106| 01/01/2018     | 25.7 | 14.0        | 78.1     | 0.5       |
| 29 | 01/01/2018     | 17.5 | 23.0        | 94.6     | 0.2       |
| 95 | 05/31/2018     | 13.5 | 16.0        | 0.1      |
| E5 | High Lifting Pumping E5 | date | FROM(days) | TO(days) | TRB(days) | TTR(days) |
| 14 | 31/03/2018     | 3.9  | 10.6        | 15.4     |
| 22 | 24/04/2018     | 20.6 | 17.6        | 54.8     | 0.1       |
| 59 | 17/11/2018     | 12.4 | 26.6        | 0.6      |
| E4 | High Lifting Pumping E4 | date | FROM(days) | TO(days) | TRB(days) | TTR(days) |
| 14 | 25/04/2018     | 3.9  | 10.6        | 15.4     |
| 59 | 31/05/2018     | 12.4 | 26.6        | 0.6      |

Calculating the value of TTR: Calculating the value of time to repair (TTR), by calculating the difference between the time of the start of the break and the time of completion of the maintenance, inspection and operation, in hourly and minute and converted into days.

Calculating TBF: the value of Time Between Failure (TBF) by calculating the difference between the start time of the equipment after a failure and the next failure in hour and minute and convert it into days. The popular statistical software (Minitab-19) was used to process these basic and subsequent basic and complementary accounts in the research. By relied on Table (1) as input for calculating TBF and TTR.

3-3-2. Calculating Pareto Analytics:

From Table (1), and using Equation (7), the frequency of the failure of each part was calculated, the results are listed in Table (2). The results analyzed using the Pareto rule to determine which parts have the most impact on project performance. From figure (2) conclude that the intake system A and high
lifting system E are the most influential as they cause more than 75% of the project's failures from work, so we will focus the study on these two systems.

**Table 2.** Repetition of failure for each system (station) of the FWTP

| System              | Frequency | F%  | Cumulative F% |
|---------------------|-----------|-----|----------------|
| Intake System       | 18        | 0.36| 36%            |
| High Lifting system | 18        | 0.32| 68%            |
| Alum system         | 7         | 0.14| 82%            |
| Deposition station  | 5         | 0.1 | 92%            |
| Filters station     | 2         | 0.04| 96%            |
| Clay station        | 1         | 0.02| 98%            |
| Chlorination system | 1         | 0.02| 100%           |
| Ground tank         | 0         | 0   | 100%           |

![Figure 2. Pareto’s analysis](image)

**3-3-3. Calculation of Parameters of Project Parts:**

The computational steps for estimating distribution parameters are done by using the Minitab 19 software and listed in Table (3). The most parts of the project have an increased rate of failure $\beta > 1$, especially the two systems of Intake system and High Lifting system.

**Table 3.** Elements of system parameters $\alpha$, $\beta$, and for project equipment

| System              | $\beta$ value | $\alpha$ days |
|---------------------|---------------|---------------|
| Intake System       | 2.58          | 122.33        |
| High Lifting system | 2.77          | 183.40        |
| Alum system         | 2.57          | 27.98         |
| Deposition station  | 1.40          | 37.90         |
| Filters station     | 1.21          | 53.55         |
| Clay station        | 0.78          | 22.30         |
| Chlorination system | 0.59          | 42.45         |

**3-3-4. Reliability analyzes: the impact of TPM on improving project reliability:**

1- One of the most important elements of the total cost of maintenance is the cost of repair time and loss in production. Table (4) shows TTR$_{\text{plan}}$ and TTR$_{\text{unplan}}$, project, maintenance cost MC, spare parts price SPP, cost of maintenance workers MW, which were collected from the FWTP project data.

2- Estimate the cost of failure maintenance: the total maintenance costs are divided into two main types:

A- To estimate the total maintenance cost for the intake system, for example: From Table (4):

\[
C_f = (\text{Production Capacity} \times \text{Unit Price} \times TTR_{\text{unplan}}) + \text{SPP} + (\text{Cost of MW} \times TTR_{\text{unplan}}). \\
= (2000 \text{ m}^3 / \text{hour} \times 24 \times [2 \times 10^3 \text{Dr}] \times 0.34 \text{ days}) + (250 \times 10^3) + (170 \times 10^3 \text{ Dr/ day} \times 0.34 \text{ days}). \\
= 18259.8 \times 10^3 \text{Dr}
\]

B- Estimate the total cost of predictive maintenance of the failure:

\[
C_p = (\text{Production Capacity} \times \text{Unit Price} \times TTR_{\text{planned}}) + \text{SPP} + (\text{Cost of MW} \times TTR_{\text{planned}}). \\
= (2000 \text{ m}^3 / \text{hour} \times 24 \times [2 \times 10^3 \text{Dr}] \times 0.2 \text{ days}) + (250 \times 10^3) + (170 \times 10^3 \text{ Dr/ day} \times 0.2 \text{ days}). \\
= 10844 \times 10^3 \text{Dr}
\]

The above steps can be repeated to calculate the maintenance cost of the high lifting system. Table 4 shows a summary of the results of maintenance cost calculations for intake and high lifting systems,
which will rely on in calculating the optimal time period for preventive maintenance.

Table 4. Summary of the results of maintenance cost calculations for intake and high lifting systems

| Average β | Average n | value β | Average t | C₀ | Cₚ | TTR maint day | TTR maint day | symbol | system |
|-----------|-----------|---------|-----------|----|----|---------------|---------------|-------|--------|
| 1.58      | 122.33    | 2.59    | 10844     | 18259.8 | 0.34 | 0.20 | A1 | Intake system |
| 2.51      | 120       | 10844   | 19848.9   | 0.37 | 0.20 | A2 | Intake system |
| 2.75      | 127       | 10844   | 17764.5   | 0.33 | 0.20 | A3 | Intake system |
| 2.77      | 183.4     | 2.79    | 16141     | 24086.5 | 0.45 | 0.30 | E1 | High lifting pump |
| 2.82      | 182       | 16141   | 25145.9   | 0.47 | 0.30 | E2 | High lifting pump |
| 2.72      | 176       | 16141   | 30569.1   | 0.57 | 0.30 | E3 | High lifting pump |
| 2.77      | 182       | 16141   | 20378.6   | 0.38 | 0.30 | E4 | High lifting pump |
| 2.73      | 184       | 16141   | 22376.2   | 0.45 | 0.30 | E5 | High lifting pump |

3-3-5. Calculating the optimum time period for preventive maintenance based on TPM: cost and method of calculation are described in the paragraph (2-3) by using the Equation (6,7) to calculate the total cost against the expected period of maintenance. By using Table (4) the expected total cost of maintenance for high lifting and intake pumps summarized in Table (5), which can be represented by the maintenance cost vs operation period in scheme, from the Table (5) & Figure (3) shows the optimal cycle time of preventive maintenance for high lifting pumps (86) days and intake pumps (121) days.

Table 5. Optimum cost and optimum time maintenance by TPM method

| lifting pump | intake station | work time day |
|--------------|----------------|---------------|
| 354.13       | 371.60         | 31            |
| 306.84       | 328.32         | 35            |
| 192.03       | 234.36         | 61            |
| 180.69       | 227.49         | 60            |
| 174.47       | 222.71         | 71            |
| 163.71       | 219.66         | 75            |
| 157.40       | 214.03         | 81            |
| 152.25       | 217.66         | 85            |
| 145.07       | 215.21         | 91            |
| 144.73       | 210.71         | 96            |
| 142.12       | 221.99         | 101           |
| 140.30       | 224.90         | 106           |
| 138.77       | 228.53         | 111           |
| 137.47       | 227.27         | 114           |
| 137.47       | 242.84         | 120           |
| 137.85       | 247.85         | 133           |
| 135.58       | 253.98         | 136           |
| 130.64       | 259.89         | 139           |
| 143.00       | 266.43         | 140           |
| 142.64       | 273.37         | 153           |

3-3-6. Calculating a Reliability Improvement Ratio using TPM:

To calculate the reliability improvement ratio of the intake system, for example: The time period for the predictive preventive maintenance cycle was calculated in the previous paragraph and it was (121 days). Therefore, the improvement rate is calculated using the two Equations (4,5) as follows:

Reliability with corrective (sudden) maintenance, that is, without preventive maintenance:

\[ R_{(CT)} = e^{-\frac{1}{\lambda \frac{t}{\sigma}}} = e^{-\frac{121}{183.4}} = 0.73 \]  \hspace{1cm} (10)

Reliability with preventive maintenance:
$$R_m(\eta_T) = e^{-\left[(n^{1-\beta})(\frac{T}{\alpha})^\beta\right]} = e^{-\left[(2^{(1-2.77)})(\frac{121}{1254})^{2.77}\right]} = 0.89 \quad (11)$$

The reliability improvement ratio of the intake system

$$\frac{R_m(\eta_T)}{R(\eta_T)} = \frac{0.89}{0.73} = 0.17 = 17\% \quad (12)$$

The reliability improvement ratio of the intake system is 17%. With the same steps above the reliability improvement ratio of the high lifting system is 14%.

3-4 The Hierarchical Analysis Process AHP method: AHP is a way to classify solutions and work out the best solutions when providing more than one alternative. The study was made up of several alternatives. The proposed methodology for choosing a maintenance system method consists of two basic stages: (1) the hierarchical of problem, and (2) the process of calculating AHP.

3-4-1. The first step: defining the problem and then formulating the problem as a hierarchical structure. Where the hierarchy of the FWTP decision is created as explained in Figure 4.

![Figure 4. The hierarchical structure of the FWTP](image)

3-4-2. The second step: building binary comparison matrices [11], used to determine the scores achieved by each alternative according to each criterion ($P_{ij}$), where the decision maker compares each of the two alternatives according to each criterion individually using the preference scale which consists of nine degrees (1-9), where (9 very high important and 1 low important), to build the comparison matrix as in Equation (13)

$$P = (p_{ij})_{n \times n} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \quad (13)$$

3-4-3. The third step: 1- Prioritization calculation: Weights are estimated to obtain a rough estimate of relative priorities by the following equations [11]:

$$P_{ij\text{Norm}} = \frac{P_{ij}}{\sum_{k=1}^{n} P_{kj}}, \quad i, j = 1, 2, ..., \ n \quad (14)$$

$$P_{\text{Norm}} = (P_{ij\text{Norm}})_{n \times n} \quad (15)$$

$$W_{l\text{Norm}} = \sum_{j=1}^{n} P_{ij\text{Norm}}, \quad l = 1, 2, ..., \ n \quad (16)$$

$$W_i = \frac{w_i\text{Norm}}{\sum_{k=1}^{n} W_k}, \quad i = 1, 2, n \quad (17)$$

$$\lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \frac{(PW)i}{Wi} \quad (18)$$
2- Finding the consistency ratio by the following equations:

\[
CR = \frac{CI}{RI} \quad \text{where: } CI = \frac{(\lambda_{max} - n)}{(n - 1)}
\]  
(19)

3- RCI from the table (6):

| N | 2 | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|---|---|----|----|----|----|----|----|----|----|
| RCI | 0 | 0.58 | 0.90 | 1.12 | 1.024 | 1.32 | 1.41 | 1.45 | 1.51 |

Create a binary comparison matrix for the main criteria and the set of alternatives within each standard and as in tables (7-9).

Table 6. Random consistency index (RC) values [10]

\[
\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} (P \cdot W)i/Wi = \frac{1}{8} \left[ 1.34399 + 1.3122 + 0.8123 + 0.5064 + 0.4913 + 0.4854 + 0.5302 + 0.4216 \right] = \\
\frac{65.1220}{8} = 8.1403 \quad \text{..............................(20)}
\]

\[
Cl = \frac{8.1403 - 8}{8 - 1} = 0.020
\]

Table 7. \(P_{ij}^{Norm}\) Matrix with Weight of each \(W_{max}\) Standard

Table 8. (\(P^* w_{max}\)) for each subcriteria
Table 9. Result of matrix for subcriteria P1

Table 10. AHP method results for choosing the best maintenance strategy alternative
Table 11. Results of calculations for all subcriteria

| Alternatives | Score of AHP prosess | \( R^2 \) | \( \sum w_i/n \) | Score |
|--------------|----------------------|----------|----------------|-------|
| M1           | 7.80 9.27 7.18 10.44 9.43 9.55 9.10 11.27 | 68.00% | 0.389 | 8.69 |
| M2           | 17.84 16.93 17.46 15.09 16.80 16.65 16.31 16.11 | 55.00% | 0.209 | 7.75 |
| M3           | 17.70 8.68 18.65 13.12 17.32 16.01 16.87 12.25 | 78.00% | 0.098 | 11.85 |
| M4           | 17.55 14.37 16.47 16.63 14.81 16.06 15.21 13.49 | 60.00% | 0.069 | 9.67 |
| M5           | 6.17 6.64 6.24 19.42 8.69 7.47 8.39 10.11 | 19.00% | 0.063 | 7.42 |

4. Analyzing the results of field research in the FWTP:

Through theoretical and analytical study by adopting modern methods of operations research and advanced tools for data analysis and by using simple and available information in the project, a set of valuable conclusions can be reached that enables the administration to raise the level of performance of the project as follows:

1- The adoption of the method of predictive maintenance system based on Preventive maintenance system improved and raised the reliability and performance of the intake and high lifting systems in theory, high lifting (17%) and intake system (14%).

2- Predictive maintenance based on preventive maintenance (TPM) from recent innovations to assist top management in making maintenance decisions. From Table (5), the optimum maintenance time for both the intake system (85 days) and the high lifting system (121 days).

3- Top management, middle management, and experts realized that the TPM maintenance system (proposed) could advance the reality of production in the project through its focus on technical, engineering and administrative aspects of maintenance operations, and these results were consistent with the results reached by the study of Zaim and colleagues [9].

4- Table (11) provided a summary of the study results from the impact ratio of TPM pillars \{P1-P8\} on the alternative available maintenance system alternatives \{M1-M5\}. Analysis of the AHP method refers to the relationship between the alternative of maintenance system and the pillars of maintenance in FWTP, individually and as follows:

1- The relationship between Corrective Maintenance M5 and the pillars of maintenance, indicates the weak relationship between the sudden maintenance and pillars 19%. The correlation score for top Management Support P1 (6.17), Focused Improvement P2 (6.64), Educating and Training P3 (6.24), Maintenance, Supporting and Assistance all Departments P5 (8.69), and Total Cost of Maintenance P6 (7.47) (weak relationship). This is a logical conclusion, as in the sudden maintenance, management support, the expected performance of it, and the training of workers are very weak, and this results in a lack of quality of the product in addition to that it did not take into account maintenance costs (a very small relationship), which causes significant losses that cost the project management through stop losses. Production and high maintenance cost. Since the score is 7.42.

2- The relationship between TPM M3 and the pillars of maintenance: indicates a very high correlation 78%. Where high levels of correlation refer to P1 (17.7), P3 (18.6), P4 (13.1), P5 (17.3), P6 (16.0), P7 (16.8), P8 (12.3) all high Relationship. This indicates that there is a need for high support for top management and other departments of the Maintenance Division, in addition to training workers to the required level and the participation of all workers in the maintenance process. The table indicates a major point, which is the high relationship between TPM and its cost, which reduces large amounts and losses of project that were caused by the other of maintenance if used.
3- From Table (1), the last column indicates a summary of the results of the AHP where it was pointed out that the highest result from the effect of the eight pillars on the maintenance process is on the TPM (11.85).

4- By using AHP helped us and top management to come up with a set of options that enable the top management to take the appropriate decision based on logical and scientific considerations in choosing one of the set of options available to solve the problem of selecting the type of appropriate maintenance at the optimal time that takes place against the lowest possible cost in carrying out maintenance work to raise the performance and reliability of the project equipment.

5. conclusions

Considering the existence of a many number of maintenance criteria selection for WTP, the research highlights the importance of using MCDM tools in water treatment, since selection a maintenance system based on inadequate criteria can have serious long-term consequences. The novelty is related to the use of specific criteria by a multi-criteria analysis applied to a real case study. For an overall analysis, the AHP was applied to evaluate and an alternative is chosen from a set of maintenance alternatives vs eight of Maintenance pillars. In this research investigated improved and raised, in theory, the reliability and performance of the intake and high lifting systems high lifting (17%) and intake system (14%) by adoption of the predictive maintenance system based on Preventive maintenance.

AHP provides redundancy for preference assignment of criteria, alternatives and mechanism to validate consistency. As with all complex system problems, selecting the most suitable maintenance system for WTP, where showed the results obtained from (AHP) that the best rank of the alternative was M3(11.85), M4(9.67) and so on for the other alternatives. Moreover, the relationship between M3 and the pillars of maintenance: indicates a very high correlation 78%. from these results we conclude that the existing of a very strong impact for the proposed maintenance system in improving the performance and reliability of FWTP project operations. These results indicate the advantages over traditional Decision Making selection methods. The AHP allows diction makers of WTP to make these decisions in a clear and straightforward manner, taking into account during DM all the variables that directly influence the outcome of this process. Fuzzy AHP can be used for further study with other systems

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