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A Maintenance Management -based Decision Support System for Multicriteria using AHP Methodology for Power Plants

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Abstract:
The maintenance process of industrial machines and instrument is faced within the challenges as shortage of a systematic approach in setting maintenance process instruction, and shortage of robust decision making (DM) in maintenance process. A systematic approach (Maintenance Management System (MMS)) is often followed, either awareness or unawareness. Therefore when a MMS system is followed unconsciously, the expected result is often a negative approach. This research describes the implementation of Analytical Hierarchy Process (AHP) for selecting the best MMS system with a one case study of the electric power-generating plants (South Baghdad Power Plant). The selected set of alternatives from MMS are; succeed or fail M1, unplanned breakdown M2, Precautious Maintenance M3, Proactive Maintenance M4, Predictive Maintenance M5 with set of Keys Performance Indicators (KPIs) as the relative to Environment P1, safety P2, Maintenance operation P3, training P4, Fuel P5, Maintenance cost P6, Quality P7, and Crew size P8. Questionnaire is used to gather the information from Electric Power Plants, where it was distributed on employees of power plant, by (60) copies, each copy containing (34) questions. These information are used further by AHP the best rank of alternatives was preventive maintenance M3 (11.8531), the second was proactive maintenance (9.6722) and so on for the other alternatives. It is recommended to employ operational KPIs with maintenance KPIs and use of another alternative is design improvement maintenance strategy.

Keywords: *Predictive Maintenance, Preventive Maintenance, Proactive Maintenance, Analytical Hierarchy Process (AHP)**,** Maintenance Management System (MMS)**.***

I INTRODUCTION

The MMS system is defined "the systems that have a greatest influence on maintenance process in terms of performance measurement and control, maintenance organizational efficiency control, plant reliability control, short and long term maintenance work planning, scheduling, coordination and control, equipment spares management and document management" [Arunraj, et al., 2013]. For this reason MMS system is important in industrial plants; where most of researches on the selection of best MMS system applied in industrial plants. Power plants are generally faced with the pressure of reducing maintenance cost which does account for 20% to 40% of total operational cost of power plants. Therefore, interest must be taken when reducing maintenance cost to avoid a negatively impact on power plants reliability and safety. To realize these objectives, efficient MMS system must be employed in power plants. The British Standard defines the maintenance as "the group of all administrative and technical actions, intentioned to retain components in restore it to a state in

January - February 2020
ISSN: 0193 - 4120 Page No. 10146 - 10153

which it can perform a required action. [Levent, et al., 2016].

The importance of maintenance has an increased interest in development and implementation of optimal maintenance strategy that improve system reliability preventing the occurrence of failures and reducing the maintenance costs associated with deteriorating systems. In electrical power plants maintenance is critical any disappointment of major mechanical or electrical framework can put the total unit at risk". Various maintenance plans as clarified by various researches, many kinds of these plans are manifested below [Selim, et al, 2017]:

1.1 Unplanned Maintenance: has also been labeled"run to failure". Such maintenance is also known as emergency maintenance. This strategy is of high cost because of sudden stoppage. In addition broken machine components and time consumption. This strategy is used for many years ago.| [Pomorski, 2004].

1.2 Design Out Maintenance (DOE): It is another common maintenance strategy basically used to reduce the need for maintenance by modifying design of machine components. [Pomorski, 2004].

1.3 Planned Maintenance: The strategy of planned maintenance requires to accurate and reliable data. Predictive is used primarily when the performance data and visual inspections is available to assess equipment condition. Preventive maintenance strategy consisting of performance monitoring, its maintenance work properly especially if the person in charge of monitoring is doing the maintenance work done [Teresa, et al, 2015]. Proactive maintenance is one of the other types of maintenance described above. It improves maintenance through better design, installation, maintenance procedures, workmanship and scheduling [Emilio, et al, 2010]. This research aim is to select best maintenance strategy with the relative KPIs, for electrical power plant. The next paragraph shows the global interest in selections MMS system, followed by data collection and data analysis. AHP methodology is used to select best maintenance strategy and relative KPIs, where APH software is used.

II LITERATURE SURVEY

[Teresa, et al, 2015] A factory that is specialized in the manufacture, sale and maintenance of four-stroke medium and slow speed motors has proposed and assessed the maintenance decision issue. For their linguistic rating the information was provided, they used the hierarchical process (AHP) to obtain the weight of the criterion, and the system of TOPSIS as multistage decision. The findings of that investigation were used to determine the best maintenance technique in a facility.

In order to evaluate the feasible maintenance strategy for dump trucks in Sungun Copper in Iran, [Zenonas et al, 2015] suggested a new fuzzy multi criteria decision making based on the principles of hierarchical process AHP. In determining the weights of the evaluation criteria, Fuzzy AHP was used; then, the alternative classifications were determined according to the definition and the theory of fuzzy set CPA. In keeping with the CPA approach the best preventive maintenance alternative was selected.

The issue of choosing highly- effective maintenance plans, taking the strategic maintenance into consideration and management strategy of a client, was discussed by [Rahul and Sadhan, 2015]. They suggested using a Predictive Maintenance Indicator Efficiency (PMIE) mechanism which would indicate the AHP usage (capital costs, operating expense, reliability, service time, operability, versatility, available machines, protection, resource uses, and power consumption respectively). They look at three cases; the primary research questionnaire is carried out; the second is a sample; and the third is evaluated using the model created.

[Levent, 2016] presented an assessment and prioritization research report on ten main parts of thermal plant equipment used in the Turkish

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January - February 2020
ISSN: 0193 - 4120 Page No. 10146 - 10153

territory. The purpose of their analysis is to use the AHP to evaluate priorities for locational equipment, including five criteria and four sub-criteria, by covering different sets of weight of criteria. Other requirements include technology, design, material and equipment (equipment material and PP equipment), and production and equipment. There are also four more considerations (sub-criteria): preparedness, workforce, industry and competitiveness. Eleven alternatives: Boiling, Steam Turbine, Feed Water pump, condenser, Water circulation pump, Mill, boiler, generator, fans and Electric motors. Analytical results show the boiler is the key piece of equipment and that heaters and fans are listed as local under the boiler.

III BACKGROUND OF METHODOLOGY

AHP process is one of the major commonly used methodologies to selection the best alternative from set alternatives. AHP enables users to create different levels or hierarchies depending on the complexity of the problem [Bernard, et al, 2014]. Some of the main advantages of the AHP are that it provides a framework for decomposing and structuring complex, thus decision makers often gain better understanding of the problem and relationships of the individual criteria or attributes. Another key advantage of AHP is that it can synthesize the ranking of alternatives or options based on different criteria [Saaty, 1980]. The AHP uses three natural analysis principles to help structure the problem [6, 8]:

1) Create the Problem Hierarchy:

2) Assignment of Weights, and

3) The logical consistency, and the obtained results were through using the equations as below.

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

Where:

Pij is the importance degree of the i^{th} factor compared to the j^{th} factor.

$$P_{ijNorm} = \frac{Pij}{\sum_{k=1}^{n} Pkj}, \quad i, j = 1, 2 \ldots, n \quad (2)$$

$$P_{Norm} = (P_{ij\,Norm})_{n \times n} \quad (3)$$

$$W_{i\,Norm} = \sum_{j=1}^{n\,Norm} Pij, \; I = 1, 2 \ldots, n \quad (4)$$

$$Wi = \frac{Wi\,Norm}{\sum_{k=1}^{nNorm} W\,k}, \quad i = 1, 2, n \quad (5)$$

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(PW)i}{Wi} \quad (6)$$

$$CR = \frac{CI}{RI} \quad (7)$$

$$CI = (\lambda_{max} - n)/(n-1) \quad (8)$$

3. Data Collection and Analysis

Data have been gathering from several different for South Baghdad Power Plant departments, through interviews and documents in addition to the questionnaire, which included 40 copies of every copy and each of them contains 34 questions for managers, engineers and technicians, Maintenance of mechanical and electrical, Planning, operation (Mechanical , electrical and control), training, security, and environmental. Where the percentage of response was about (95%). Answers are analyzed using the AHP approach to select the optimal MMS system [13-17].

3.1 Create the Problem Hierarchy

The first step in the process of AHP is a hierarchy of goals to determine the decision basis. This includes verification of an objective, criteria, sub-criteria and alternatives as demonstrated in the figure1 [8].

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TEST Engineering & Management
January - February 2020
ISSN: 0193 - 4120 Page No. 10146 - 10153

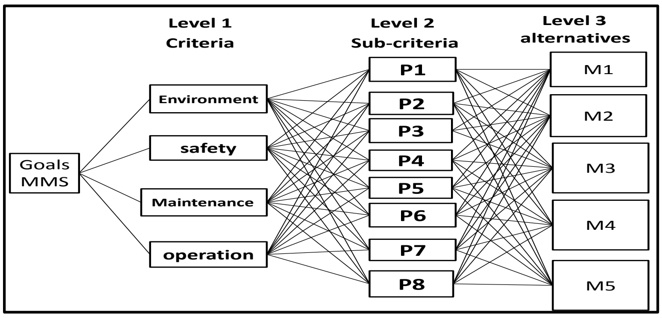

Fig. 1. Hierarchical decision tree

3.2 Assignment of Weights.

The desirable assignments for the specified criteria are summarized in Table 1 using AHP software. By adding up the lines of every column the vector priority is determined. The normal priority vector is determined by the initial priority vector separated by the sum, while the matrix of comparison (P) is constructed with the use of Equation 1.By subtracting the values in each column by the column number ($P_{normalized}$), the matrix is normalized. For each line the average of the standard matrix rows with the Equations (2, 3, 4 and 5) are determined to approximate the w_{max}. As shown in Table 2.

Table 1

Pairwise ranking of measures for sub-criteria

Result							
Eigenvalue			Lambda:	11.186		MRE:	92.4%
Consistency Ratio	0.37	GCI: 1.06	Psi:	24.4%	CR:	32.5%	

Matrix

		P1 1	P2 2	P3 3	P4 4	P5 5	P6 6	P7 7	P8 8	0 9	0 10	normalized principal Eigenvector
P1	1	1	7	1/5	3	1	2	1/3	1/7	-	-	11.64%
P2	2	1/7	1	1/9	1	4	1	1/6	1/4	-	-	5.95%
P3	3	5	9	1	4	4	4	2	2	-	-	27.27%
P4	4	1/3	1	1/4	1	2	5	5	4	-	-	16.85%
P5	5	1	1/4	1/4	1/2	1	2	2	1	-	-	7.45%
P6	6	1/2	1	1/4	1/5	1/2	1	1/4	1/2	-	-	3.54%
P7	7	3	6	1/2	1/5	1/2	4	1	2	-	-	13.14%
P8	8	7	4	1/2	1/4	1	2	1/2	1	-	-	14.16%
0	9	-	-	-	-	-	-	-	-	1	-	0.00%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%

The matrix is made normal by the division of the values in every column by the sum of the column ($P_{normalized}$). An approximate for $w_{max}$is determined for each row by the calculation of the average of the rows of the matrix being normalized using the Equations (2, 3, 4, and 5) as illustrated in Table 2.

Table 2

$p_{normalized}$ and W_{max} approximation

										Normalization	
0.06	0.24	0.07	0.30	0.07	0.10	0.03	0.01	.	.	0.1227	0.116
0.01	0.03	0.04	0.10	0.29	0.05	0.01	0.02	.	.	0.0641	0.060
0.28	0.31	0.33	0.39	0.29	0.19	0.18	0.18	.	.	0.2592	0.273
0.02	0.03	0.08	0.10	0.14	0.24	0.44	0.37	.	.	0.1554	0.168
0.06	0.01	0.08	0.05	0.07	0.10	0.18	0.09	.	.	0.0669	0.075
0.03	0.03	0.08	0.02	0.04	0.05	0.02	0.05	.	.	0.0351	0.035
0.17	0.21	0.16	0.02	0.04	0.19	0.09	0.18	.	.	0.1438	0.131
0.39	0.14	0.16	0.02	0.07	0.10	0.04	0.09	.	.	0.1359	0.142
.	.	.	.	.	.	.	.	.	.	0.0084	0.000
.	.	.	.	.	.	.	.	.	.	0.0084	0.000
										Eigenvalue:	11.18552

3.3 The Logical Consistency.

Weight matrix ($P.w_{max}$) by the initial matrix is multiplied to make certain masses valid (See Table 3). Such values are utilized to determine the Eigenvalue Approximation (λ_{max}) with Eq. (6, 7) and a continuity test by Eq uation. (8) is added.

$$CI = \frac{8.78-8}{8-1} = 0.111$$

Table 3

Value of sub-criteria (P* w_{max})

Subcriteria	$P*W_{max}$
P1	0.15
P2	0.083
P3	0.2
P4	0.107
P5	0.159
P6	0.165
P7	0.059
P8	0.078

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January - February 2020
ISSN: 0193 - 4120 Page No. 10146 - 10153

Upon determining the CI, the Random Index (RI) is compared to set if the comparative inputs are sufficiently reliable to produce statistically significant results. The RI table includes the values that have been randomly selected for n=1, 2,... n in a comparison matrix of pair values. Table 4 shows the RI values. λ_{max} = n and CI= 0 for a completely consistent decision maker. In the case of CI= 0, outcomes are usually not obtained during the evaluation phase in pairs. Differences in the CI / RI ratio can be put as:

- CI / RI<0.10, adequate stability
- CI / RI>0.10, great incoherence occurs.

$$CR = \frac{CI}{RI} = \frac{0.111}{1.41} = 0.079$$

Table 4

The random consistency index

Dimension	1	2	3	4	5	6	7	8	9
RI	00	00	58	90	12	24	32	41	**45**

There is no significant difference in this case of analysis, CR = 0.079 < 0.10. The next step is the measurement of the final matrix weights after the analyst has established that accuracy is adequate.

3.4 Identification and Prioritization of Alternative

Table (5) the alternative demonstrates the relative importance of the sub criterion (M1, M2, M3, M4, M5) in contrast to the alternative sub criterion (P1). Table 6 displays the example of the detailed Wmax calculation for alternative criteria.

Table 5

Alternative with respect P1and Normalization of alternative with respect maintenance performance

Matrix

		M1 1	M2 2	M3 3	M4 4	M5 5	normalized principal Eigenvector
M1	1	1	1	1/6	1/8	1/7	6.17%
M2	2	1	1	1/2	1/4	1/2	7.80%
M3	3	6	2	1	2	1	17.70%
M4	4	8	4	1/2	1	1	17.84%
M5	5	7	2	1	1	1	17.55%

					Normalization	
0.04	0.08	0.03	0.02	0.02	0.0634	0.062
0.04	0.08	0.08	0.03	0.08	0.0729	0.078
0.23	0.15	0.16	0.27	0.16	0.1751	0.177
0.31	0.31	0.08	0.14	0.16	0.2042	0.178
0.27	0.15	0.16	0.14	0.16	0.1867	0.175
-	-	-	-	-	0.0117	0.000
					Eigenvalue:	8.842764

Table 6

Alternative with respect to cratieria

Matrix P1

		M1 1	M2 2	M3 3	M4 4	M5 5	normalized principal Eigenvector
M1	1	1	1	1/6	1/8	1/7	6.17%
M2	2	1	1	1/2	1/4	1/2	7.80%
M3	3	6	2	1	2	1	17.70%
M4	4	8	4	1/2	1	1	17.84%
M5	5	7	2	1	1	1	17.55%

Matrix P2

		M1 1	M2 2	M3 3	M4 4	M5 5	normalized principal Eigenvector
M1	1	1	1	1/6	1/7	1/5	6.64%
M2	2	1	1	1	1/3	1/2	9.27%
M3	3	6	1	1	2	2	18.69%
M4	4	7	3	1/2	1	1	16.93%
M5	5	5	2	1/2	1	1	14.37%

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TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 10146 - 10153

Matrix P3

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	1	1/5	1/8	1/6	6.24%
M2	2	1	1	1/2	1/4	1/5	7.18%
M3	3	5	2	1	2	2	18.65%
M4	4	8	4	1/2	1	1	17.46%
M5	5	6	5	1/2	1	1	16.87%

Matrix P4

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	2	1/2	1/4	1/4	9.42%
M2	2	1/2	1	1/2	1	1	10.44%
M3	3	2	2	1	1	1/2	13.12%
M4	4	4	1	1	1	1	15.09%
M5	5	4	1	2	1	1	16.63%

Matrix P5

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	3	1/4	1/7	1/6	8.69%
M2	2	1/3	1	1	1/2	1	9.43%
M3	3	4	1	1	2	2	17.32%
M4	4	7	2	1/2	1	1	16.80%
M5	5	6	1	1/2	1	1	14.81%

Matrix P6

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	1	1/2	1/8	1/4	7.47%
M2	2	1	1	1	1/2	1/2	9.55%
M3	3	2	1	1	2	2	16.01%
M4	4	8	2	1/2	1	1/2	16.65%
M5	5	4	2	1/2	2	1	16.06%

Matrix P7

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	2	1/3	1/7	1/3	8.39%
M2	2	1/2	1	1	1/2	1/2	9.10%
M3	3	3	1	1	2	2	16.87%
M4	4	7	2	1/2	1	1/2	16.31%
M5	5	3	2	1/2	2	1	15.21%

Matrix P8

		M1 (1)	M2 (2)	M3 (3)	M4 (4)	M5 (5)	normalized principal Eigenvector
M1	1	1	1	1	1/3	1/2	10.11%
M2	2	1	1	1	1/2	1	11.27%
M3	3	1	1	1	1	1	12.25%
M4	4	3	2	1	1	1	16.11%
M5	5	2	1	1	1	1	13.49%

Table (7) displays final score findings as a preventive maintenance case study because the biggest score was (0.2448). Based on the selection of the desired choice in the MMS system of South Baghdad Power Plant, attained from a matrix of (choices with regard to sub criteria).

Table 7

Hierarchy of alternative

	score of (AHP)									
	1	2	3	4	5	6	7	8		
Alternatives	P1	P2	P3	P4	P5	P6	P7	P8	∑ wi/n	score
M1	6.17	6.64	6.24	19.42	8.69	7.47	8.39	10.11	0.150	8.69
M2	0.00	9.27	7.18	10.44	9.43	9.55	9.10	11.27	0.083	7.75
M3	17.70	8.68	18.65	13.12	17.32	16.01	16.87	12.25	0.200	11.85
M4	17.84	16.93	17.46	15.09	16.80	16.65	16.31	16.11	0.107	9.67
M5	17.55	14.37	16.47	16.63	14.81	16.06	15.21	13.49	0.159	7.42
									0.165	
									0.059	
									0.078	

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ISSN: 0193 - 4120 Page No. 10146 - 10153

Table (7) summarizes the results where the results are evaluated and determined in order to determine the optimal maintenance method for the KPIs used for the MMS system for electrical plants. The above system uses a number of key performance metrics to determine the optimal choice of alternatives. Type of fuel, the weather and maintenance workers are the most important KPIs in this decision.

IV CONCLUSION AND RECOMENDATIONS

1-AHP provides redundancy for preference assignment of criteria, alternatives and mechanism to validate consistency. As with all complex system problems, selecting the most suitable MMS system for Maintenance of Electric Power Plants (MEPP), where showed the results obtained from (AHP) that the best rank of the alternative was preventive maintenance M3 (11.85), followed by proactive maintenance M4(9.6722) and so on for the other alternatives.

2- The greatest effective in this choice are fuel P5 (17.3), environmentP1 (17.7), and training of maintenance worker skills P8 (16.87).

3- It is preferable that the top management of the power plants apply an appropriate system for maintenance management to ensure both the efficiency and the degree of operation of procedures with the lowest maintenance costs at their power plant and thus enhance productivity. Top management should also increase support, particularly in relation to the human (safety) in power plants.

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List of Symbols

λ max = Eigenvalue Approximation

W= Weights vector

Ƥ = pairwise comparison matrix

Pij = The importance degree of the ith factor compared to the jth factor

PNorm = Normalization Matrix

n = Dimension of the Comparison Matrix

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