The Analytical Hierarchy Process Concept for Maintenance Strategy Selection in Manufacturing Industries.

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ABSTRACT

This paper describes an application of the Analytic Hierarchy Process (AHP) for selecting the best maintenance strategy in manufacturing industries. Three maintenance strategies were considered as possible alternatives: corrective, preventive and predictive maintenance. These maintenance strategies were evaluated with eight criteria: low maintenance cost, improved reliability, improved safety, high product quality, Minimum Inventory, return on investment, acceptance by labour and enhanced competitiveness.

(Keywords: effective maintenance strategy, manufacturing, analytical hierarch process, AHP)

INTRODUCTION

Maintenance is any activity carried out on an asset in order to ensure that the asset continues to perform its intended functions (Mulugeta, 2009). Maintenance strategy is the coordination, control, planning, execution and monitoring of the right equipment maintenance activities in manufacturing and facilities operations. In a maintenance improvement programme, the maintenance activities are analysed to ensure that the correct blend of maintenance strategies is utilized (Kahn, 2006).

Maintenance has ceased to be considered a tactical subject with relevant repercussions regarding company costs, but not profits, and started to be viewed as having a strategic dimension (Tsang, 1998), due to its implications in quality (Andijani and Duffuaa, 2002), availability, safety, and costs, making it just another requirement for doing business (Autin, 1998); as a result maintenance performance has a direct influence on the fulfilling of the objectives established by an organization. Consequently, the maintenance function is an important element of modern business and must be managed effectively (Murthy, et al., 2002). The implementation of advanced technologies in manufacturing plants with increased automation demands more efficiency on the part of the maintenance function because these new technologies make detection, diagnosis and correction of equipment problems more difficult (Swanson, 1997). The increase in the complexity of the assets already experienced by the manufacturing industries now extends to service industries.

The classic maintenance strategies can be defined as follows (Bevilacquaa and Bragliab, 2000):

- Corrective maintenance. The main feature of corrective maintenance is that actions are only performed when a machine breaks down. There are no interventions until a failure has occurred.

- Preventive maintenance. Preventive maintenance is based on component reliability characteristics. This data makes it possible to analyse the behaviour of the element in question and allows the maintenance engineer to define a periodic maintenance program for the machine. The preventive maintenance policy tries to determine a series of checks, replacements and/or component revisions with a frequency related to the failure rate. In other words, preventive (periodic) maintenance is effective in overcoming the problems associated with the wearing of components. It is evident that, after a check, it is not always necessary to substitute the component: maintenance is often sufficient.

- Opportunistic maintenance. The possibility of using opportunistic maintenance is determined by the nearness or concurrence of control or substitution times for different components on the same machine or plant. This type of maintenance can lead to the whole plant being shut down at set times to perform all relevant maintenance interventions at the same time.

- Condition-based maintenance. A requisite for the application of condition-based maintenance is the availability of a set of measurements and data acquisition systems to monitor the machine performance in real time. The continuous survey of working conditions can easily and clearly point out an abnormal situation (e.g., the exceeding of a controlled parameter threshold level), allowing the process administrator to punctually perform the necessary controls and, if necessary, stop the machine before a failure can occur.

- Predictive maintenance. Unlike the condition-based maintenance policy, in predictive maintenance the acquired controlled parameters data are analysed to find a possible temporal trend. This makes it possible to predict when the controlled quantity value will reach or exceed the threshold values. The maintenance staff will then be able to plan when, depending on the operating conditions, the component substitution or revision is really unavoidable.

Once one or more maintenance strategy has been set-up, different factors must be controlled so the state of the maintenance department can be established. Having established the state of the maintenance, a continuous improvement process can be developed whose aim is to correct the deficiencies and mistakes that commonly occur in a maintenance department. A tool able to detect the deficiencies and establish their importance should be applied.

In this project, an audit is proposed to evaluate the maintenance strategy of manufacturing industries. The deficiencies detected and corrected can be checked again in the audit. The improvements developed can be quantitatively measured and translated into a qualitative value that provides a general state of the maintenance department.

Selection of Maintenance Strategy in a Manufacturing Industry

Effective maintenance strategy in manufacturing industries permits fast, cost-effective responses to unpredictable circumstances. A judiciously selected maintenance strategy can provide significant advantages in relation to quality, safety, availability and production-cost reduction. A wrong decision can lead to the failure of the maintenance program, death and consequent economic losses. The selection of maintenance strategies is a typical Multiple Criteria Decision-Making (MCDM) problem with conflicting goals. Consideration of interdependence among the criteria and alternative policies for maintenance strategy provides valuable cost savings and greater benefits.

Selection of maintenance strategy in manufacturing industries is aimed at keeping the production resources operated in their best performances. A good maintenance strategy has a great importance in industries' profitability and is a factor that has an effect on industries' overall performance (Paz and Leigh, 1994). Maintenance strategy is an activity that has a significant contribution in operation costs, approximately 30 percent of operation costs, especially if the industry is implementing automated manufacturing system (Garg and Deshmukh, 2006).Therefore, this activity must be planned in advance, including in planning maintenance personnel to be allocated in each manufacturing section. The number of maintenance personnel is affecting the effectiveness of maintenance management, the improvement of industries' productivity, and also towards the availability and reliability of industries' manufacturing system.

Maintenance management activity must be done as effective and efficient as possible because it has a significant part in the industries' total operating costs. It is better not to consider maintenance activity as a cost center activity, but it is better for the company to consider it as an activity that could give profit for the company in the long term.

Statement of Problem

Over time, manufacturing industries do not perform quantitative evaluation of various maintenance strategies and select the optimum strategy based the maintenance decision criteria prior to them, they have not being measuring the efficiency of maintenance activity held by engineering department, whether it is optimum or not, so that it can lessen the industries' operation and maintenance cost, and also improve the efficiency of resources used for this activity. They only base their evaluation on hypothetical and qualitative conclusions that; they are doing well in maintenance if they make profit at the end of the fiscal year or not doing well if there is no profit. Maintenance strategy shouldn't be evaluated based on cost or profit alone but other factors such as mean time to repair (MTTR), safety, mean time between failures (MTBF), downtime, inventory size, acceptance of machineries by labor, etc.

According to William Thomson *"Until you can measure something and express it in numbers, you cannot manage it* (Simon, 2007). Hence the objective of this paper is to:

- To perform a quantitative evaluation of maintenance strategy in a manufacturing industry.
- To analysis various maintenance strategies and select the best strategy for manufacturing industries.

METHODOLOGY

Converting decision criteria into numerical values could be very intricate, however the decision maker (maintenance personnel) should be able to categories each criteria according to their importance. This can be done by a process called method called Analytical Hierarchy Process.

The Analytic Hierarchy Process

AHP is a multi-criteria decision-making method developed by Saaty (Saaty and Vargas, 1982). AHP aims at quantifying relative weights for a given set of criteria on a ratio scale. Two features of AHP differentiate it from other decision-making approaches. One, it provides a comprehensive structure to combine the intuitive rational and irrational values during the decision making process. The other is its ability to judge the consistency in the decision-making process.
To make a decision in an organised way to generate priorities we need to decompose the decision into the following steps:

1) Define the problem and determine the kind of knowledge sought.

2) Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

3) Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

4) Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority.

Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

The Concept of Pairwise Comparisons

One of the most crucial steps in many decision-making methods is the accurate estimation of the pertinent data. This is a problem not bound in the AHP method only, but it is crucial in many other methods which need to elicit qualitative information from the decision-maker. Very often qualitative data cannot be known in terms of absolute values. For instance,*" what is the worth of specific computer software in terms of a user adaptivity criterion?"* Although information about questions like the previous one are vital in making the correct decision, it is very difficult, if not impossible, to quantify them correctly. Therefore, many decision-making methods attempt to determine the **relative** importance, or weight, of the alternatives in terms of each criterion involved in a given decision-making problem.

An approach based on pairwise comparisons which was proposed by Saaty (1980) has long attracted the interest of many researchers. Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion. In this approach the decision-maker has to express his opinion about the value of one single pairwise comparison at a time. Usually, the decision-maker has to choose his answer among 10-17 discrete choices. Each choice is a linguistic phrase. Some examples of such linguistic phrases are: *"A is more important than B"*, or *"A is of the same importance as B"*, or *"A is a little more important than B"*, and so on (see also Table 1).

Table 1: Scale of Relative Importance (according to Saaty (1980))

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

The main problem with the pairwise comparisons is how to quantify the linguistic choices selected by the decision maker during their evaluation. All the methods which use the pairwise comparisons approach eventually express the qualitative answers of a decision maker into some numbers which, most of the time, are ratios of integers.

A case in which pairwise comparisons are expressed as differences (instead of ratios) was used to define similarity relations and is described by Triantaphyllou (1993). The following paragraphs examine the issue of quantifying pairwise comparisons. Since pairwise comparisons are the keystone of these decision-making processes, correctly quantifying them is the most crucial step in multi-criteria decision-making methods which use qualitative data.

Pairwise comparisons are quantified by using a scale. Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance, or weight, of the previous linguistic choices. The scale proposed by Saaty is depicted in Table 1.

Other scales have also been proposed by others. An evaluation of 78 different scales appears in Triantaphyllou, et al. (1994). All the alternative scales depart from some psychological theories and develop the numbers to be used based on these psychological theories.

This is the main reasoning used by Saaty to establish 9 as the upper limit of his scale, 1 as the lower limit and a unit difference between successive scale values.

The values of the pairwise comparisons in the AHP are determined according to the scale introduced by Saaty (1980).According to this scale, the available values for the pairwise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} (see also Table 1).

Background information

Let A_1, A_2, A_3…………A_n be the members of a fuzzy set (set containing elements with degree of membership). We are interested in evaluating the membership values of the above members. Saaty proposes to use a matrix A of rational numbers taken from the set $\{\frac{1}{9},\frac{1}{8},\frac{1}{7},........,1,2,...7,8,9\}$. Each entry of the above matrix A represents a pairwise judgment. Specifically, the entry a_{ij} denotes the number that estimates the relative membership of element A_i when it is compared with element A_j.

Obviously, $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$. That is, the matrix is a reciprocal one.

Let us first examine the case in which it is possible to have perfect values a_{ij}. In this case it is $a_{ij} = W_i/W_j$ (W$_s$ denotes the actual value of element s) and the previous reciprocal matrix A is consistent. That is,

$$a_{ij} = a_{ik} a_{kj} \quad \text{(i, j, k =1, 2, 3..,n)} \qquad \textbf{(1)}$$

where n = no. of element in the fuzzy set)
It can be proved that A has rank 1 with $\lambda = n$ its nonzero eigenvalue. Then we have

$$A_x = n_x \qquad \textbf{(2)}$$

where, x = an eigenvector.

From the fact that $a_{ij} = W_i/W_j$ the following are obtained:

$$\sum_{j=1}^{n} a_{ij} W_j = \sum_{j=1}^{n} W_1 = nW_i, \quad \text{i=1, 2, 3, ...,n,} \qquad \textbf{(3)}$$

Or

$$AW = nW \qquad \textbf{(4)}$$

Equation (4) states that n is an eigenvalue of A with W a corresponding eigenvector. The same equation also states that in the perfectly consistent case (i.e., $a_{ij} = a_{ik} a_{kj}$) the vector W, with membership values from the elements 1, 2, 3 . . . n, is the principal right-eigenvector (after normalization) of matrix A.

In the non-consistent case (which is most common) the pairwise comparisons are not perfect, that is, the entry a_{ij} might deviate from the real ratio W_i/W_j (i.e., from the ratio of the real membership values W_i and W_j). In the case, the previous Equation 1 does not hold for all the possible combinations. Now, the new matrix A can be considered as a perturbation of the previous consistent case. Moreover, the maximum eigenvalues is close to n (greater than n) while the remaining eigenvalues are close to zero. Thus, in order to find the membership values in the non-consistent cases, on should find an eigenvector that corresponds to the maximum eigenvalues $\lambda_{\max}$. That is to say, one must find the principal right-eigenvector W that satisfies:

$$AW = \lambda_{\max} W \qquad \textbf{(5)}$$

Where $\lambda_{\max} \approx n$

The principal right-eigenvector W is estimated by the entries in each row of matrix A together and taking the nth root (n is the number of the element in the fuzzy set). Since we desire to have values that add up to 1.00 we normalize the previously found vector. If we want to have the element with the highest value to have membership value to equal to 1.00 we divide the previously found vector by the highest value.

$$W = \frac{nth.root.of.product.of.row.entry.in.matrix.A}{Total.for.all.nth.root.value} \qquad \textbf{(6)}$$

Under the assumption of total consistency, if the judgments are Gamma distributed, the principal right-eigenvector of the resultant reciprocal matrix A is Dirichlet distributed. If the assumption of total consistency is relaxed, then the principal right-eigenvector follows a Dirichlet distribution is accepted if the consistency ratio is 0.10 or less

The consistency ratio (CR) is obtained by first estimating the $\lambda_{\max}$.

This is estimated by adding the column of matrix A and then multiplying the resulting vector with the vector W . Then using the consistency index (CI) of the matrix A . CI is defines as:

$$CI = {(\lambda_{\max} - n)}/{(n-1)} \quad \textbf{(7)}$$

Then the consistency ratio (CR) is obtained by dividing the CI by the Random Consistency index (RC) as given in Table 2.

$$CR = {CI}/{RC} \quad \textbf{(8)}$$

Table 2: Random Consistency index (RC).

N	1	2	3	4	5	6	7	8	9
RC	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Note, If CR is greater than 0.10 then a re-examination of the pairwise judgments is recommended until a CR less than or equal to 0.10 is achieved.

Maintenance Strategy Evaluation for a Manufacturing Industry

The basic problem to choose between set of alternatives, given some decision criteria. Let $A = \{a_i\}$; $i = 1,2,.....n$ be the set of decision alternatives and $C = \{c_j\}$; $j = 1,2,.....m$ be the set of criteria according to which the desirability of an alternative is to be judged. The aim here is to obtain the optimal alternative with highest degree of desirability with respect to all relevant criteria.

Three alternatives are considered: corrective maintenance (A_1), preventive maintenance (A_2), predictive maintenance (A_3) and eight cogent maintenance decision criteria namely: low maintenance cost (C_1), improved reliability (C_2), improved safety (C_3), High Product Quality (C4), Minimum Inventory (C_5), return on investment (C_6), Acceptance by Labor (C_7) enhanced competitiveness (C_8) by which to judge the three alternatives.

The values of the pairwise comparisons in the AHP are determined according to the scale introduced by Saaty as given on Table 1.

Data and Calculation

We first provide an initial matrix for the choice's pairwise comparisons using the Saaty (1994) rating scale in which the principal diagonal contains entries of 1, as each choice is as important as itself. However, There is no standard way to make the pairwise comparison but according to this scale the available value for the pairwise comparism are the members of the discrete set {9, 8, 7, 6, 5, 4, 3, 2, 1, ½, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9 } as shown in Table 1.

Data were collected and translate into AHP hierarchy priority. There are three alternative maintenance strategies described earlier, need to be evaluated in terms of the eight decision criteria. Suppose that the following matrices represent the corresponding judgment matrices with the pairwise comparisons. Note that the corresponding priority vectors (for the individual criteria) and the consistency coefficients will be calculated as well to know if the judgment was correct.

Firstly, the judgment matrix for the case of comparing the importance of the eight decision criteria is computed as shown in Table 3.

The priority weight **W** (*also called the principal right-eigenvector*) given by equation (6) is the relative importance of each criterion, and from Table 3, C_3 has the highest priority weight of 0.344 followed by C_2 with 0.213. This explains the reason why manufacturing industries should put safety first because it is the basis of the maintenance.

Table 3: The Judgment Matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	$\sqrt[n]{\ }$	W
C_1	1	1/2	1/3	4	5	4	6	3	1.984	0.166
C_2	2	1	1/4	3	8	4	9	4	2.539	0.213
C_3	3	4	1	4	7	6	8	5	4.105	0.344
C_4	1/4	1/3	1/4	1	4	3	8	3	1.251	0.105
C_5	1/5	1/8	1/7	1/4	1	1	5	1/6	0.406	0.034
C_6	1/4	1/4	1/6	1/3	1	1	4	1/3	0.511	0.043
C_7	1/6	1/9	1/8	1/8	1/5	1/4	1	1/6	0.199	0.017
C_8	1/3	1/4	1/5	1/3	6	3	6	1	0.938	0.079
	7.20	6.57	2.47	13.04	32.20	22.25	47.00	16.67	11.93	1.00

The corresponding maximum eigen value denoted by λ_{max} is calculated by Equation 5.

$$\begin{bmatrix} 1 & 1/2 & 1/3 & 4 & 5 & 4 & 6 & 3 \\ 2 & 1 & 1/4 & 3 & 8 & 4 & 9 & 4 \\ 3 & 4 & 1 & 4 & 7 & 6 & 8 & 5 \\ 1/4 & 1/3 & 1/4 & 1 & 4 & 3 & 8 & 3 \\ 1/5 & 1/8 & 1/7 & 1/4 & 1 & 1 & 5 & 1/6 \\ 1/4 & 1/4 & 1/6 & 1/3 & 1 & 1 & 4 & 1/3 \\ 1/6 & 1/9 & 1/8 & 1/8 & 1/5 & 1/4 & 1 & 1/6 \\ 1/3 & 1/4 & 1/5 & 1/3 & 6 & 3 & 6 & 1 \end{bmatrix} \begin{bmatrix} 0.166 \\ 0.213 \\ 0.344 \\ 0.105 \\ 0.034 \\ 0.043 \\ 0.017 \\ 0.079 \end{bmatrix} = \begin{bmatrix} 1.488 \\ 1.859 \\ 3.141 \\ 0.941 \\ 0.310 \\ 0.358 \\ 0.155 \\ 0.726 \end{bmatrix}$$

This vector of 8 elements (1.488, 1.859, 3.141, 0.941, 0.941, 0.310,0.358, 0.155 and 0.726) is, of course, the product AW and the AHP theory says that AW=λ_{max}W (Equation 5), so we can now get eight estimates of λ_{max} by the simple expedient of dividing each component of (0.900, 1.651, 2.769, 0.217, 0.283, 0.538) by the corresponding eigenvector element W. This gives:

- 1.488 / 0.166 = 8.964
- 1.859 / 0.213 = 8.728
- 3.141 / 0.344 = 9.131
- 0.941 / 0.105 = 8.966
- 0.310 / 0.034 = 9.131
- 0.358 / 0.043 = 8.337
- 0.155 / 0.017 = 9.131
- 0.726 / 0.079 = 9.194

The mean of these values is 8.948 and that is our estimate for λ_{max}. If any of the estimates for λ_{max} turns out to be less than n, or 8 in this case, there has been an error in the calculation, which is a useful sanity check.

The Consistency Index for a matrix is calculated from equation 7, since n=8 for this matrix, the CI is calculated as:

CI = (8.948-8) / (8-1) = 0.136

The final step is to calculate the Consistency Ratio for this set of judgments using the CI for the corresponding value from large samples of matrices of purely random judgments using Table 2, derived from Saaty's work, in which the upper row is the order of the random matrix, and the lower is the corresponding index of consistency for random judgments.

From Saaty's consistency index table shown by Table 2, the corresponding CI to n=8 is 1.41, hence the consistency ratio given by equation 8 is evaluated as 0.0096.

It is seen than the CR of the above pairwise judgment is less than 0.1(0.0096<0.1), and according to Saaty, if CR less than) 0.1 is achieved, it show that the judgment is well study, correct and well examined.

The next stage is to develop another decision matrix by examining our three maintenance strategy (alternatives) in term of each criterion. We start with C_1 (Low Maintenance Cost). This step is to extract the relative importance implied by the previous comparisons. That is, how important are the three alternatives when they are considered in terms of the Low Maintenance Cost criterion.

In Terms of Low Maintenance Cost (C_1)

C_1 (LMC)	A_1	A_2	A_3	$\sqrt[n]{\ }$	W
A_1	1	1/3	1/4	0.437	0.117
A_2	3	1	1/3	1.000	0.268
A_3	4	3	1	2.289	0.624
	8	4.333	1.583	3.726	1.000

The eigenvector is (0.117, 0.268 and 0.624) which is called the Priority Vector. The next stage is to calculate λ_{max} so as to lead to the Consistency Index and the Consistency Ratio. From Equation 5 we have:

$$\begin{bmatrix} 1 & 1/3 & 1/4 \\ 3 & 1 & 1/3 \\ 4 & 3 & 1 \end{bmatrix} \begin{bmatrix} 0.117 \\ 0.268 \\ 0.624 \end{bmatrix} = \begin{bmatrix} 0.362 \\ 0.827 \\ 1.896 \end{bmatrix}$$

This vector of three elements is (0.362, 0.827, and 1.896). the product AW and the AHP theory says that $AW=\lambda_{max}W$, so we can now get three estimates of λ_{max} by the simple expedient of dividing each component of (0.362, 0.827, 1.896) by the corresponding eigenvector element. This gives:

- 0.362 / 0.117 = 3.096
- 0.827 / 0.268 = 3.085
- 1.896 / 0.624 = 3.038

The mean of these values is 3.073 and that is our estimate for λ_{max}. If any of the estimates for λ_{max} turns out to be less than n or 3 in this case, there has been an error in the calculation, which is a useful sanity check.

The Consistency Index for a matrix is calculated from equation 7, since n=3 for this matrix, the CI is calculated as 0.0365. The Consistency Ratio for this set of judgments using the CI for the corresponding value from large samples of matrices of purely random judgments using the table below, derived from Saaty's work, in which the upper row is the order of the random matrix, and the lower is the corresponding index of consistency for random judgments. From Saaty's consistency index table shown by Table 2, the corresponding CI to n=3 is 0.58, hence the consistency ratio given by eqn 8 is evaluated as 0.063.

It is seen than the CR of the above pairwise judgment is less than 0.1(0.063<0.1), Therefore the judgments are acceptably consistent.

In Terms of Improved Reliability (C_2)

C_2 (IR)	A_1	A_2	A_3	$\sqrt[n]{\ }$	W
A_1	1	1/5	1/7	0.306	0.072
A_2	5	1	1/3	1.000	0.279
A_3	7	3	1	2.759	0.649
	13	4.200	1.476	4.250	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.07. The CI given by eqn 7 was calculated as 0.035, while the consistency ratio given by Equation 8 was evaluated to be 0.06 (0.06<0.1) thus the judgment is acceptably consistent.

In Terms of Improved Safety (C_3)

C_3 (IS)	A_1	A_2	A_3	$\sqrt[n]{\ }$	W
A_1	1	1/4	1/5	0.368	0.100
A_2	4	1	1	1.587	0.433
A_3	5	1	1	1.710	0.466
	10	2.250	2.220	3.660	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.07. The CI given by Equation 7 was calculated as 0.035, while the consistency ratio given by Equation 8 was evaluated to be 0.06 (0.06<0.1) thus the judgment is acceptably consistent.

In Terms of High Product Quality (C_4)

C_4 (HPQ)	A_1	A_2	A_3	$\sqrt[n]{\ }$	W
A_1	1	¼	1/2	0.500	0.149
A_2	4	1	1	1.587	0.474
A_3	2	1	1	1.260	0.376
	7	2.250	2.500	3.660	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.05. The CI given by Equation 7 was calculated as 0.027, while the consistency ratio given by Equation 8 was evaluated to be 0.046 (0.046<0.1) thus the judgment is acceptably consistent.

In Terms of Minimum Inventory (C_5)

C_5 (MI)	A_1	A_2	A_3	$\sqrt[n]{\ }$	W
A_1	1	1/6	1/9	0.265	0.056
A_2	6	1	1/4	1.145	0.243
A_3	9	4	1	3.302	0.701
	16	5.167	1.361	4.711	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.11. The CI given by Equation 7 was calculated as 0.054, while the consistency ratio given by Equation 8 was evaluated to be 0.093 (0.093<0.1) thus the judgment is acceptably consistent.

In Terms of Return on Investment (C_6)

C_6 (RoI)	A_1	A_2	A_3	$\sqrt[n]{}$	W
A_1	1	1/7	1/8	0.261	0.063
A_2	7	1	1	1.913	0.458
A_3	8	1	1	2.000	0.479
	16	2.143	1.311	4.174	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.01. The CI given by Equation 7 was calculated as 0.005, while the consistency ratio given by Equation 8 was evaluated to be 0.0086 (0.0086<0.1) thus the judgment is acceptably consistent.

In Terms of Acceptance by Labor (C_7)

C_7 (AbL)	A_1	A_2	A_3	$\sqrt[n]{}$	W
A_1	1	1/6	1/8	0.275	0.062
A_2	6	1	1/3	1.260	0.285
A_3	8	3	1	2.884	0.653
	15	4.167	1.458	4.420	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.07. The CI given by Equation 7 is calculated to be 0.037, while the consistency ratio given by Equation 8 was evaluated to be 0.06

In Terms of Enhanced Competiveness (C_8)

C_8 (EC)	A_1	A_2	A_3	$\sqrt[n]{}$	W
A_1	1	1/3	1/5	0.405	0.101
A_2	3	1	¼	0.909	0.226
A_3	5	4	1	2.714	0.674
	9	5.333	1.450	1.450	1.000

Following the previous procedures, the λ_{max} is calculated to be 3.08. The CI given by Equation 7 was calculated as 0.067, while the consistency ratio given by Equation 8 was evaluated to be 0.0086 (0.0086<0.1) thus the judgment is acceptably consistent.

Criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	
Alt	(0.166	0.213	0.344	0.105	0.034	0.043	0.017	0.079)	**Final Priority**
A_1	0.117	0.072	0.100	0.149	0.056	0.063	0.062	0.101	0.09
A_2	0.268	0.279	0.433	0.474	0.243	0.458	0.285	0.226	0.35
A_3	0.624	0.649	0.466	0.376	0.701	0.479	0.653	0.674	0.55

DISCUSSION

The priority vectors for the alternatives (corrective, preventive and predictive maintenance) has been calculated under each aforementioned criteria low maintenance cost (C_1), improved reliability (C_2), improved safety (C_3), High Product Quality (C4), Minimum Inventory (C_5), return on investment (C_6), Acceptance by Labor (C_7) enhanced competitiveness (C_8)}. This is shown in Table 4.

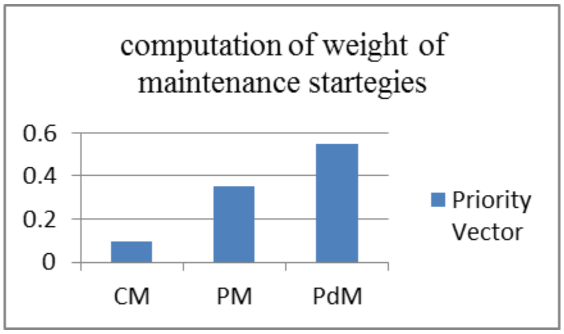
Table 4: Priority Vectors of Alternatives.

	A_1	A_2	A_3	TOTAL
C_1	0.117	0.268	0.624	1.000
C_2	0.072	0.279	0.649	1.000
C_3	0.100	0.433	0.466	1.000
C_4	0.149	0.474	0.376	1.000
C_5	0.056	0.243	0.701	1.000
C_6	0.063	0.458	0.479	1.000
C_7	0.062	0.285	0.653	1.000
C_8	0.101	0.226	0.674	1.000

The table above shows corresponding priority weight to the alternative. It could be seen that if Minimum Inventory is the priority of the manufacturing industry, alternative 3 should be employed. Also if high product quality is the priority, alternative 2 should be employed. This is because they have the highest weight on these alternatives. Please note, it is not compulsory for manufacturing industries to evaluate the choice of their maintenance strategy using all the eight criteria in this paper.

The maintenance engineer can choose those criteria prior to them out of the eight and use it to evaluate the strategy that suits them as shown below. As it was mentioned earlier, the previous priority vectors are used to form the entries of the decision matrix for this problem. The decision matrix and the resulted final priorities (which are calculated according to (equation 3) and Table 3 is shown above.

After computing the final priority of the decision matrix above it is seen that predictive Maintenance (A_3) has the highest priority of 0.550, followed by Preventive Maintenance (A_2) with priority 0.353 and corrective maintenance (A_1) with 0.098.



Therefore, the best maintenance strategy for a manufacturing industry according to the AHP is the Predictive Maintenance Strategy (A_3) followed by Preventive Maintenance (A_2) which is followed by Corrective Maintenance (A_1). This is based on the ranking yielded by AHP for these alternatives.

REFERENCES

1. Mulugeta, A. 2009. “Evaluation of Maintenance Management through Benchmarking in Geothermal Power Plants”. M.Sc. Thesis. Department of Mechanical and Industrial Engineering, University of Iceland. ISBN 978-9979-68-268-4 ISSN 1670-7427.
2. Kahn, J.D. 2006. “Applying Six Sigma to Plant Maintenance Improvement Programs”. *Proceedings MARCON 2006 - 3rd International Marketing Congress*. Lahore, Pakistan. March, 2006. 19.
3. Tsang, A. 1998. “A Strategic Approach to Managing Maintenance Performance”. *Journal of Quality in Maintenance Engineering*. 4(2):87-94.
4. Andijani, A. and S. Duffuaa. 2002. “Critical Evaluation of Simulation Studies in Maintenance Systems”. *Production Planning & Control*. 13(4): 336-341.
5. Autin, E. 1998. “Selection and Design of Computerized Maintenance Management Systems”. *IIE Solutions*. August. 32-35.
6. Murthy, D., A. Atrens and J. Eccleston. 2002. “Strategic Maintenance Management”. *Journal of Quality in Maintenance Engineering* 8(4):287-305.
7. Swanson, L. 1997. “An Empirical Study of the Relationship between Production Technology & Maintenance Management”. *International Journal of Production Economics*. 53:191-207.
8. Bevilacquaa, M. and M. Bragliab. 2000. “The Analytic Hierarchy Process Applied to Maintenance Strategy Selection”. *Reliability Engineering and System Safety*. 70:71–83.
9. Paz, N. and W. Leigh. 1994. “Maintenance Scheduling: Issues, Results, and Research Needs”. *International Journal of Operations & Production Management*. 14(8):47-69.
10. Garg, A. and S.Deshmukh. 2006. “Maintenance Management: Literature Review and Directions”. *Journal of Quality in Maintenance Engineering.* 12(3):205-238.
11. Simon, M. 2007. “Developing a Maintenance Strategy and Setting Performance Targets”. Training Services, AV Technology Ltd. University of Manchester: Manchester, UK.
12. Saaty, T. and L. Vargas. 1982. *The Logic of Priorities: Applications in Business Energy, Health and Transportation*. Kluwer - Nijhoff: London UK.

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