Strategic Maintenance technique selection using AHP/QFD method

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Abstract

The competitiveness and performance of manufacturing organisations depend on the availability, reliability and productivity of their equipment, machineries and entire manufacturing system. Therefore, the role of maintenance managers is to keep manufacturing system always up by adopting most appropriate maintenance techniques. There are alternative maintenance techniques for each machine, the selection of which depends on the characteristics of the machine along with economic, environmental and social aspects. The main aim of this research is to develop a method for selecting most appropriate maintenance technique for manufacturing industry. The proposed method combines the quality function deployment (QFD) and analytic hierarchy process (AHP) applied to a manufacturing organisation to demonstrate its effectiveness. The application of the proposed model in three case studies reveals that their current maintenance techniques are predominantly based on cost economics.

Keywords: Maintenance techniques, Analytic Hierarchy Process, Quality Function Deployment, Stakeholders, Sustainability

1. Introduction

Proper maintenance of plant equipment significantly reduces overall operating cost of manufacturing. The development of new technologies and managerial practices means that maintenance staff must be endowed with growing technical and managerial skills (de Smidt-Destombes, C van der Heijden, & van Harten, 2004). Deterioration and failure of systems results high costs, due to production losses and delays, unplanned intervention on the system and safety hazards. Therefore, appropriate maintenance strategy is necessary in order to prevent failure (Muchiri, Pintelon, Gelders, & Martin, 2011). Moreover, maintenance crew must select the best maintenance technique for each machine and manufacturing system out of a set of possible alternatives. In particular, the development of maintenance strategies (i.e. a suitable combination of corrective, preventive and predictive maintenance) must take into account that resource limitation affects maintenance quality (de Smidt-Destombes et al., 2004). Maintenance is mainly classified into run-to-failure maintenance, preventive maintenance, predictive maintenance, total productive maintenance (TPM) and reliability-centred maintenance (RCM) (García Márquez, Tobias, Pinar Pérez, & Papaelias, 2012). Predictive maintenance is a condition-driven preventive maintenance program. Instead of relying on industrial or in-plant average-life statistics to schedule maintenance activities, predictive maintenance uses direct monitoring of the mechanical condition, system efficiency, and other indicators to determine the actual mean-time-to-failure (García Márquez et al., 2012). If the maintenance problem is detected early, major repairs can usually be prevented. Predictive maintenance is of two type's conditional based maintenance and Statistical-based predictive maintenance. This study is based on CBM (condition based maintenance). The current practices of the maintenance selection are mainly based on the managerial criteria giving utmost importance to the cost factor and the known notation about the maintenance technique rather than framing the maintenance strategy based on the strategic managerial importance with combination of technical requirements. There are number of studies on maintenance technique selection frame work development and decision making using it but research on maintenance technique selection based on the strategic intents of the organisation is scant. This study attempts to bridge this gap by developing a maintenance technology/technique selection framework considering voice of organisational management team and voice of the maintenance group. Appropriate maintenance selection helps reduce the down time and increase the productivity.

The paper is organised as follows. Section 2 articulates the methodology used for the study section 3 outlines the present practises in the maintenance selection strategies through literature survey. Section 4 explains the proposed model. Section 5 describes the application of the proposed framework in order to demonstrate its effectiveness. Section 6 elucidates the contributions of the study. Section 7 concludes the paper with information on further scope of research work.

2. Methodology

Firstly, a thorough literature review is undertaken to critically analyse contemporary methods for maintenance technique selection. This leads to develop a comprehensive framework for maintenance technique selection. Secondly, the proposed framework has been applied to a case study organisation to select maintenance techniques for three different machineries in order demonstrate its effectiveness. Thirdly, the framework is validated through questionnaire survey among the executives of the participating organization. The brief description of the case study organisation is enclosed in the Appendix 1 along with participants profile. The participating executives are all functional experts and having more than 15 years industry experience. The proposed framework was applied in workshop environment through group consensus and the validation was undertaken through structured questionnaire survey.

3. Literature review

The implementation of advanced manufacturing technologies demands reduction in buffers of inventory that increases pressure on selection of most appropriate maintenance technique (Crespo Marquez & Gupta, 2006). Therefore, maintenance technique selection has become strategic that needs attention of both voice of customers' (higher management and production people) and voice of technical persons (maintenance crews). Maintenance performance measurement (MPM) is perceived as an important function to achieve sustainable performance of any manufacturing organization (Muchiri et al., 2011). While maintenance performance indicators have been studied extensively little has been done to develop a systematic approach that embraces every level of business activities (i.e. strategic, tactical and operational) for maintenance technique selection (Kutucuoglu, Hamali, Irani, & Sharp, 2001). A maintenance plan which is based on a rational assessment of priorities and up to- date knowledge of the condition of the facilities and inventory will help to ensure the best use of available resources. Based on this, a model is presented using the analytical hierarchy process in deciding the importance of the criteria (Shen, Lo, & Wang, 1998). With asset availability and reliability becoming critical issues in capital-intensive operation, the strategic importance of maintenance in business is needed to be recognized and maintenance management should be based on certain strategic dimension (Tsang, 2002). Maintenance must be viewed in the long term strategic context and must integrate the different technical and commercial issues in an effective manner and a strategic maintenance approach emphasising on the quantitative business model integrating the maintenance need with other operational decision such as production etc. is presented [Murthy et al. 2002]. In their work, Marseguerra et al. (2002) considered a continuously monitored multi-component system and use a generic algorithm for determining the optimal degradation level beyond which preventive maintenance to be performed while Jamali, Ait-Kadi, Cleroux, & Artiba (2005) evolved joint optimal periodic and conditional maintenance strategy. Luce (1999) selected the best maintenance method using Weibull Law by comparing corrective maintenance, systematic preventive maintenance and conditional preventive maintenance. Parida & Chattopadhyay (2007) presented a multi-criteria hierarchical maintenance performance measurement framework to resolve this issue; however their framework does not provide any guidance on the selection of business specific maintenance engineering methods. Knezevic & Knezevic (1993) described that the basic objectives of the maintenance activities are to deploy the minimum resources required to ensure that components perform their intended functions properly, to ensure system reliability and to recover from breakdowns. Arunraj & Maiti (2010) proposed an approach of maintenance policy selection based on risk of equipment failure and cost of maintenance using the analytic hierarchy process (AHP) and goal programming (GP). Tan, Li, Wu, Zheng, & He (2011) proposed a risk based inspection (RBI) methodology to evaluate the maintenance strategy through probability and consequence of accident or failure. They use the AHP to select the most practicable maintenance strategy for specific equipment. Bertolini & Bevilacqua (2006) present a combined AHP-GP model. The AHP prioritises different maintenance policies with respect to the classical Failure Mode Effect Analysis criteria (i.e. occurrence, severity and delectability) and the GP formulates a model that led to identification of the best set of maintenance type for the equipment failure modes considered. The QFD has been used by Kutucuoglu et al., (2001) to developed performance measurement system in maintenance. Carnero (2005) proposed a model that carries out the decision making in relation to the selection of the diagnostic techniques and instrumentation in the predictive maintenance programs. The model uses a combination of the analytic hierarchy process (AHP) and factor analysis (FA). It considers number of criteria that help to select the best alternative technique. Although this method considers both strategies, technical and managerial criteria, it doesn't build any relationship between management and technical requirements. A hybrid AHP-DEA approach has been also proposed for the risk assessment of bridges by Wang, Liu & Elhag (2008). In this

E_{ij}

approach, expert's opinions regarding the condition, the risk/safety and monetary criteria were ranked using DEA approach. The selection of a diesel parts cleaning system has been also proposed by Garcia-Gonzalo et al., (2013) where through a selection of financial, technical (efficiency, procuctivity and capacity) and harmful effects criteria, the best cleaning methodology is selected using AHP.

As reported above, although there are number of researches on maintenance method selection using operational research techniques, very few literatures link criteria for maintenance method selection with the strategic intents of the organisations. This study bridges this gap. Although maintenance method selection for any equipment, machinery and productive system is highly technical depending on their characteristics, cost of maintenance and production policy, linking them with organisational strategy in one hand enhances productivity of the system and on the other hand ensures organisational sustainability. This study proposes a holistic maintenance method selection method that combines both strategic intents of the organisation with technical requirements of the maintenance crew in an analytical framework.

4. Model development

4.1 Notation

Indices	
$i = 1,...,n$	Customer
$j = 1,...,m$	Technical requirement
Parameters	
R_{ij}	Relation between customer i and technical characteristic j
C_i	Importance weight for customer requirement i
Variables	
W_j	Degree of importance for the technical requirement j
W'_j	Normalized importance for the technical requirement j
E_{ij}	Eigenvector (importance) score of customer i corresponding to technical

	characteristic j
S_j	Overall score of technical requirement j

4.2 House of Quality (HoQ)

The concept of House of Quality (HoQ) is not new and has first introduced by Houser & Clausing (1988). This house – like diagram provides information regarding the relationship between the customers' needs and how the business/firm will facilitate these needs. HoQ diagram consists of two parts; the rows correspond to the customer requirements while the rows correspond to the technical requirements. The importance provided by HoQ is utilized by Quality Function Deployment (QFD) (Bicheno, 1994) and is used to identify the factors that are critical to customers.

4.3 The proposed QFD-AHP approach

In order to utilize the information provided by QFD and derive the degree of importance of customers' requirements towards tangible and intangible technical characteristics, a QFD-AHP approach is adopted in this paper. AHP is a multicriteria decision making (MCDM) technique, developed by Saaty (), where aiming at capturing the intra-relationships between criteria, both tangible and intangible. A graphical outline of the paper is presented in Figure 1; two Houses of Quality (HoQ) are presented (HoQ1 and HoQ2). In HoQ1 the rows represent strategic requirements while columns the technical requirements.

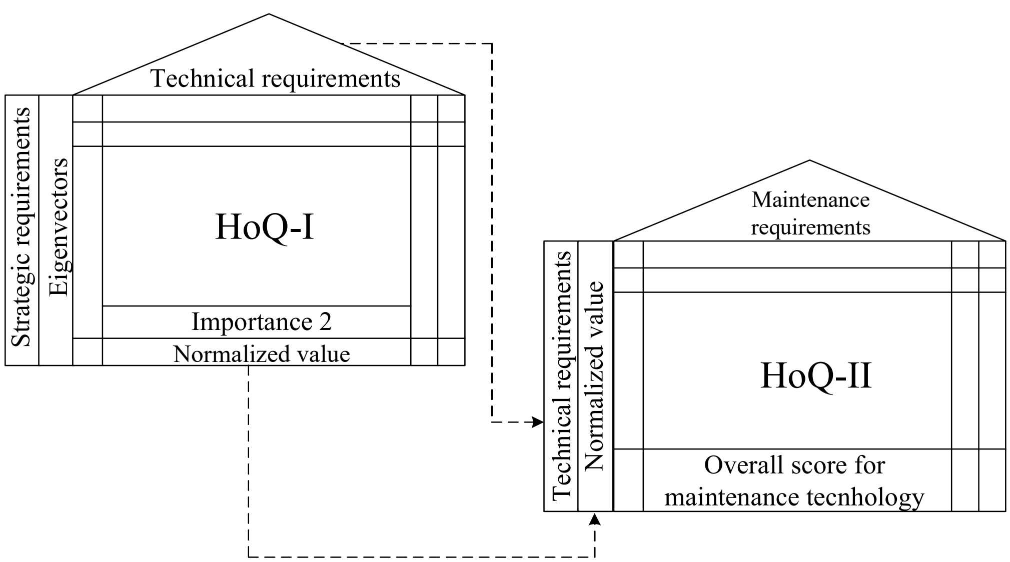

Figure 1: Graphical representation of QFD-AHP methodology

The proposed maintenance method selection model is depicted in Figure 1. The comparisons are made using a scale of absolute judgments that represents how much more one element dominates another with respect to a given attribute. Inconsistency is a major problem for AHP methodology (Saaty, 2008). The index that measures consistency in AHP is Consistency Ratio (*CR*). For the calculation of *CR*, Consistency Index (*CI*) which is calculated in (1) and Random Index (*RI*) must be provided; RI is a fixed number based on the dimensions of a pairwise comparison matrix A_{ij}.

$$CI = \frac{\lambda^{max} - n}{n-1} \tag{1}$$

In (1), λ^{max} stands for the largest eigenvalue of a pairwise comparison matrix A_{ij} of dimensions $n \times n$ while fixed values regarding RI are given in Table 1. Finally, Consistency Ratio (CR) which is the measure based on pairwise comparisons are consistent or not, is defined as the quotient of CI to RI.

$$\frac{CI}{RI} = CR \begin{cases} \leq 10\% \textit{ consistent} \\ > 10\% \text{ in}\textit{consistent} \end{cases} \tag{2}$$

Table 1: Values for Random Index (RI) based on the dimensions of pairwise matrix *A*.

n	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

QFD is tool which was developed by Japanese to meet customers' requirements throughout the design process, and also in the design of production systems. A matrix is used to present data and information (Evans & Lindsay, 1996). A full QFD application may make use of several HoQ diagrams, forming a sequence that gradually translate customer requirements into specific manufacturing steps and detailed manufacturing step requirements. Furthermore, QFD methodology is an overall concept that provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development and production (i.e. marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales) (Sullivan & Deployment, 1986).

In this study two HOQ have been used for the model development, linking the multiple criteria to form an effective decision making model. The generic model development has been explained below in steps.

1. The strategic managerial requirement were identified from the concerned expert group and also verified from the literature. This constructs/criteria are the "WHATs" of the HOQ-I. The importance of this constructs/ criteria were derived based on the AHP analysis.

2. The technical criteria were indentified based on the requirements of the maintenance group and the critical parts considered for the study. These constructs/criteria are the "HOWs" of the HOQ-I. The relationship rating based on a predefined scale 9,3,1,0 indicating strong relationship, medium relationship, weak relationship, no relationship respectively are obtained. These ratings were obtained from the same expert groups. This analysis yielded the degree of importance (importance-2) of each of the technical criteria by correlating with the managerial requirements. Assuming that there are $j = 1,...,n$ technical requirements and customer requirements, the computation of degree of importance is performed below:

   $$W_j = \sum_{i=1}^{m} R_{ij} \cdot C_i ,\ j = 1,...n \tag{3}$$

   In (2), W_j is a $n \times 1$ vector representing the degree of importance between technical requirement j and is defined as the product or quantified relationships between customer requirement i and technical requirement j (R_{ij}), and importance weighting of customer requirement i (C_i).

3. Degree of importance is further normalized by dividing each element w_j of vector W_j by the sum of all the elements. The resulting normalized score for each technical requirement j is denoted as W' and yields a value in the range of $[0,\ 100]\%$.

$$W'_j = \frac{w_j}{\sum_{j=1}^{n} W_j},\ j = 1,...n \tag{4}$$

4. The technologies available for the considered critical parts were identified from the literature and a HOQ-II was developed. The 'WHATs" part in HOQ-II relationship matrix are the technical criteria of the HOQ-I and the "HOWs" are the technologies considered for the critical parts.

5. Finally AHP analysis is applied for the examined technologies based on each and every maintenance group; constructs/criteria are used to obtain the importance/Eigen vector (E_{ij}) for each alternative technology. The overall score for each requirement j denoted as S_j is calculated by summing over index j the product of the normalized score for each technical requirement j with eigenvector score derived for each customer requirement i and technical requirement j .

$$S_j = \sum_{i=1}^{m} W'_j \cdot E_{ij},\ j = 1,...n \tag{5}$$

The ranking of the maintenance technology is based on the overall score as derived from step 5 (Bhattacharya, Sarkar*, & Mukherjee, 2005). The proposed methodology is graphically summarized in Figure 2.

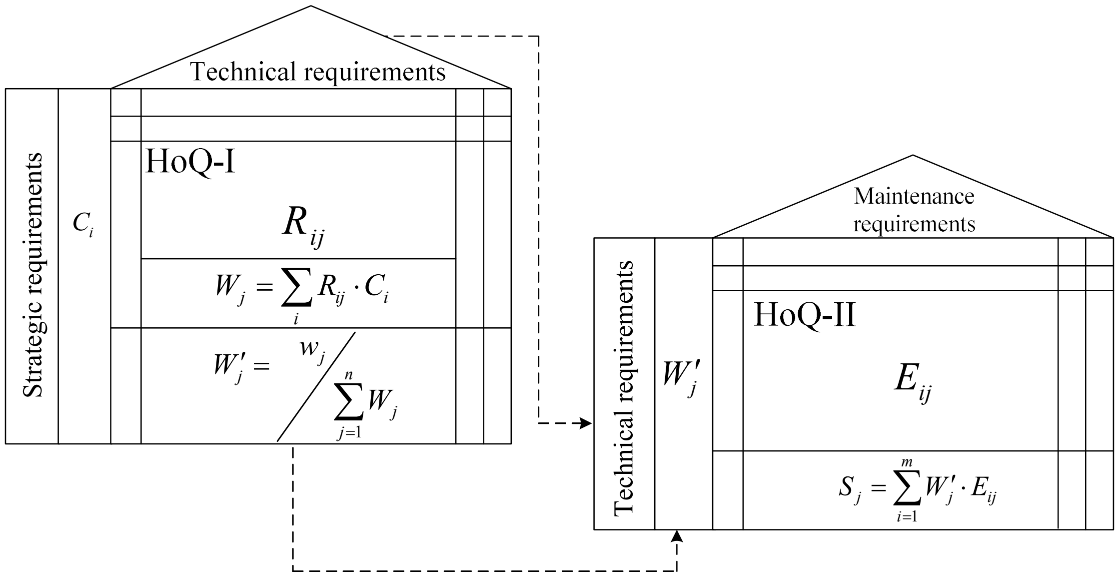

Figure 2: Graphical representation of the proposed QFD – AHP methodology.

5. Model Application on case study

The generic model that was presented Methodology section has been applied on a case study the detail application step and analysis of which is explained below.

***Step* 1**

The representatives of board of directors including the production directors of the concerned organization were selected for the case studies, in order to identify their requirements were derived through the voice of customer (VOC). In this case the requirement of the board members and the concerned stakeholders which were obtained from a focused group comprising of five representatives of board of directors including the production directors, general manager and production manager. These constructs/criteria which were validated from the literature, identified are based on (Zaim, Turkyilmaz, Acar, Al-Turki, & Demirel, 2012; Tsang, 1998) the following:

a) return on investment

b) running cost

c) reliability

d) operability

e) flexibility

f) machine availability

g) safety

h) resource utilization

i) energy consumption

The importance of each criterion was determined using AHP technique; these criteria are the "Whats" for the HoQ – I (that is the first QFD relationship matrix), while their rating was obtained from the same focused group with questionnaires using Saaty's scale. In order to find the degree of importance AHP technique was carried out and the ratings were standarized. A detailed aspect of AHP analysis is given in the following steps.

Table 2: Pair wise comparison matrix for degree of importance considering the managerial aspects

Major customer (managerial) aspects	Return on Investment	Running Cost	Reliability	Operability	Flexibility	Machine Availability	Safety	Resource Utilization	Energy Consumption	Eigen Vector	C.R
Return on Investment	1	3	0.333	3	3	1	0.333	5	1	0.12028	
Running Cost	0.333	1	1	1	3	3	0.333	3	1	0.1051	
Reliability	3	1	1	3	5	3	0.333	5	3	0.17522	
Operability	0.333	1	0.333	1	3	0.333	0.142	3	2	0.06666	
Flexibility	0.333	0.333	0.2	0.333	1	0.2	0.142	2	3	0.04578	0.09848
Machine Availability	1	0.333	0.333	3	5	1	0.333	3	2	0.10222	
Safety	3	3	3	7	7	3	1	7	5	0.30198	
Resource Utilization	0.2	0.333	0.2	0.333	0.5	0.333	0.142	1	0.333	0.02575	
Energy Consumption	1	1	0.333	0.5	0.333	0.5	0.2	3	1	0.05700	

***Step* 2**

The strategic maintenance requirement of the concerned organization were identified through brainstorming session with the selected focused maintenance group consisting of five of the top maintenance group board members and other stakeholder members, including R&D department engineers, chief maintenance engineer, chief plant engineer and production engineer. These requirements are the "Hows" for the HOQ – I. Afterwards, the three critical parts of the machines were identified based on the discussion with the focused group members based on the concerned organization chosen for the study. The available technology/technique for these three critical parts with respect to the predictive maintenance technology/technique was identified through the literature review and also from the primary research. The maintenance group requirements based on the available technology/technique used and other technology/technique available for those critical parts from the literature were also considered for the study. The aforementioned critical parts considered for these studies were: bearing system, gear system and lubrication system; the technologies considered for the parts namely for the bearing system and gear system was vibration analysis, acoustic emission, shock pulse method, oil analysis and for the lubrication system the alternatives was process parameter, performance monitoring, oil analysis. The requirement identified through brainstorming and from the primary research were: a) indicating cost of set up, b) number of probes required, c) maintenance time required, d) time to develop the setup, e) meets standards in maintenance system, f) break down/ corrective maintenance reduction, g) life cycle of the setup, h) frequency of equipment inspection, i) support equipments required, j) technical expertise required for maintenance, k) effectiveness of the set up, l) reparability of the set up. There was lots of literature available on the application of the predictive maintenance technology/technique and some of the related to the research has been given below.

Vibration analysis is used to analyze the vibration of the moving parts and still remains the most popular technology employed in wind turbine, especially for rotating equipment (Hameed, Hong, Cho, Ahn, & Song, 2009). Its applications have been presented for monitoring the gearbox (Caselitz & Giebhardt, 2003; Caselitz, Giebhardt, & Mevenkamp, 1994; Futter, 1995; Lin & McFadden, 1995; McFadden, 1987; Miller, 1999), the bearings (IGARASHI & HAMADA, 1982; (IGARASHI & HAMADA, 1982; Dyer & Stewart, 1978; Sun & Tang, 2002; Peter, Peng, & Yam, 2001). The measurement and interpretation of acoustic emissions (AE) parameters for fault detection in radially loaded ball bearings has been demonstrated at different speed ranges (Tandon & Nakra, 1990). In addition, the application of AE for the detection of bearing failures has been presented by Tan, (1990). Little or no vibration may be evident while faults are developing, but analysis of the oil can provide early warnings; a case study of a wind turbine gearbox was presented by Leske & Kitaljevich (2006). Shock pulse method (SPM) has been used as a quantitative method for condition monitoring of bearings, and works by detecting the mechanical shocks that are generated when a ball or roller in a bearing comes in contact with a damaged area of raceway or with debris (Butler, 1973). Signals are picked up by transducers and analysis gives an indication of system condition (Tandon & Nakra, 1992). Process parameters are the maintenance based on the detection of signals exceeding predefined control limits, control systems becoming increasingly sophisticated and diagnostic capabilities even better.

Transient and oscillatory stability were analyzed with different wind scenarios for electricity generation process (Muller, Poller, Basteck, Tilscher, & Pfister, 2006). Zaher & McArthur (2007) gave an explanation of the use of signals and trending for fault detection based on parameter estimation. Performance monitoring analysis the relationship between parameters such as power, wind speed, blade angle and rotor speed for an assessment of wind turbine condition and for the early detection of faults (Sørensen et al., 2002).

***Step* 3**

The managerial criteria and the maintenance group requirements relationship were correlated according to the requirements of the model on the basis of a predefined QFD scale. The ratings obtained was standardized using statistical analysis as the responses are of varying nature and for analyzing a single crisp value was required. Then these values were used to derive the overall importance of each of the maintenance group requirement based on (4).

The HOQ – I after analysis has been shown below considering the managerial voice and maintenance group voice.

Table 3: managerial criteria vs. maintenance group requirement relationship matrix.

		MAINTENANCE ENGINEERS REQUIREMENT											
Customer Requirement (Companies Managerial Perspective	Importance Using AHP	Cost Of Set Up	Number Of Probes Required	Maintenance Time Required	Time To Develop The Setup	Meets Standards In Maintenance System	Break Down/ Corrective Maintenance Reduction	Life Cycle Of The Setup	Frequency Of Equipment Inspection	Support Equipments Required	Technical Expertise Required For Maintenance	Effectiveness Of The Set Up	Reparability Of The Set Up
Return On Investment	0.12028	9	1	0	9	3	9	9	1	3	1	3	9
Running Cost	0.10510	1	3	1	0	9	9	3	9	3	3	0	9
Reliability	0.17522	3	9	1	0	3	9	0	3	3	9	9	0
Operability	0.06666	1	3	1	0	3	0	0	0	9	9	0	0
Flexibility	0.04578	1	3	3	0	3	0	0	0	3	0	1	0
Machine Availability	0.10222	0	0	9	0	0	9	0	9	0	0	0	3
Safety	0.30198	3	9	0	0	9	3	0	9	0	1	3	1
Resource Utilization	0.02575	0	1	1	0	9	9	3	3	9	3	0	3
Energy Consumption	0.05700	0	9	0	0	9	0	0	3	3	3	0	0
Degree Of Importance For Selection Criteria		2.73166	5.60645	1.43005	1.08252	5.63229	5.66307	1.47507	5.47789	2.34183	3.16273	2.88954	2.71431
Normalized Value		6.79	13.94	3.56	2.69	14.01	14.08	3.67	13.62	5.82	7.87	7.19	6.75
Rank		7	3	11	12	2	1	10	4	9	5	6	8

***Step* 4**

HOQ-I provides the normalized value of each of the maintenance group requirement; this normalized value was transferred to HOQ-II as a weight factor/importance for the maintenance group constructs and the technologies identified above were used as the 'Hows'. Furthermore, the maintenance group constructs as the "Whats" of the matrix and then another questioner was prepared for the AHP analysis of the alternative technology/technique in term of each and every maintenance group requirement. For this AHP analysis a response was obtained from the same focused maintenance expert group and an analyses was done accordingly. The rating obtained were normalized using statistical method as the value obtained were not crisp, the AHP analysis is given below.

Table 4: Pair wise comparison matrix at alternatives level based on cost of setup for bearing system.

Alternative for Cost of Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	0.333	0.26534	
Acoustic Emission	0.333	1	3	0.333	0.15118	0.07418
Shock Pulse Method	0.333	0.333	1	0.2	0.0752	
Oil Analysis	3	3	5	1	0.50829	

Table 5: Pair wise comparison matrix at alternatives level based on number of probes required for bearing system.

Alternative for Number of Probes Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	0.333	0.27624	
Acoustic Emission	0.333	1	1	0.333	0.11815	0.05787
Shock Pulse Method	0.333	1	1	0.333	0.11815	
Oil Analysis	3	3	3	1	0.48745	

Table 6: Pair wise comparison matrix at alternatives level based on maintenance time required for bearing system

Alternative for Maintenance Time Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.333	2	3	0.24725	
Acoustic Emission	3	1	3	3	0.48268	0.08062
Shock Pulse Method	0.5	0.333	1	3	0.17614	
Oil Analysis	0.333	0.333	0.333	1	0.09393	

Table 7: Pair wise comparison matrix at alternatives level based on maintenance time required for bearing system

Alternative for Time to Develop the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.333	0.333	2	0.15006	0.02271

Acoustic Emission	3	1	1	3	0.37218	
Shock Pulse Method	3	1	1	3	0.37218	
Oil Analysis	0.5	0.333	0.333	1	0.10558	

Table 8: Pair wise comparison matrix at alternatives level based on meets standards in maintenance system for bearing system.

Alternative for Meets Standards in Maintenance System	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.5	0.333	3	0.17130	
Acoustic Emission	2	1	1	5	0.35867	0.01279
Shock Pulse Method	3	1	1	5	0.40113	
Oil Analysis	0.333	0.2	0.2	1	0.06890	

Table 9: Pair wise comparison matrix at alternatives level based on break down/ corrective maintenance reduction for bearing system.

Alternative for Break Down/ Corrective Maintenance Reduction	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.333	0.333	3	0.14858	
Acoustic Emission	3	1	0.5	5	0.32485	0.03901
Shock Pulse Method	3	2	1	5	0.46005	
Oil Analysis	0.333	0.2	0.2	1	0.06653	

Table 10: Pair wise comparison matrix at alternatives level based on life cycle of the setup for bearing system.

Alternative for Life Cycle of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	2	0.5	0.26094	
Acoustic Emission	0.5	1	2	0.333	0.16893	0.02660
Shock Pulse Method	0.5	0.5	1	0.333	0.11896	
Oil Analysis	2	3	3	1	0.45117	

Table 11: Pair wise comparison matrix at alternatives level based on frequency of equipment inspection for bearing system.

Alternative for Frequency of Equipment Inspection	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	3	3	0.45086	
Acoustic Emission	0.5	1	0.5	3	0.19779	0.08062
Shock Pulse Method	0.333	2	1	3	0.25742	
Oil Analysis	0.333	0.333	0.333	1	0.09393	

Table 12: Pair wise comparison matrix at alternatives level based on support equipments required for bearing system.

Alternative for Support Equipments Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.5	0.333	2	0.16362	0.02660
Acoustic Emission	2	1	0.5	3	0.28290	

Shock Pulse Method	3	2	1	3	0.44755	
Oil Analysis	0.5	0.333	0.333	1	0.10592	

Table 13: Pair wise comparison matrix at alternatives level based on technical expertise required for maintenance for bearing system.

Alternative for Technical Expertise Required For Maintenance	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	2	0.5	0.26283	
Acoustic Emission	0.5	1	1	0.333	0.14088	0.00388
Shock Pulse Method	0.5	1	1	0.333	0.14088	
Oil Analysis	2	3	3	1	0.45541	

Table 14: Pair wise comparison matrix at alternatives level based on effectiveness of the setup for bearing system.

Alternative for Effectiveness of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.333	0.2	3	0.12218	
Acoustic Emission	3	1	0.5	5	0.29762	0.02567
Shock Pulse Method	5	2	1	7	0.52317	
Oil Analysis	0.333	0.2	0.142	1	0.05703	

Table 15: Pair wise comparison matrix at alternatives level based on reparability of the setup for bearing system.

Alternative for Reparability of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	2	0.333	0.25742	
Acoustic Emission	0.333	1	2	0.333	0.14697	0.08062
Shock Pulse Method	0.5	0.5	1	0.333	0.11293	
Oil Analysis	3	3	3	1	0.48268	

***Step* 5**

The importance/ Eigen vector (E_{ij}) for each alternative technology/technique obtained from the above step were used as the relationship rating for the HOQ – II. Then the overall score was computed for each of the technology/technique based on (5).

***Step* 6**

The ranking of the maintenance technology/technique on the basis of the overall score was obtained. This revealed the strategically most effective maintenance technology/technique for the considered critical parts based on the strategic intent of the organization. The HOQ-II analyzed based on the strategic model is shown below for the three critical parts considered.

Table 16: Bearing system framework for company.

OVER ALL IMPORTANCE OF THE MAINTENANCE TECHNLOGIES						
Technical Requirements	Weight	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	C.R
Cost Of Set Up	6.79392	0.26534	0.15118	0.0752	0.50829	0.07418
Number Of Probes Required	13.94383	0.27624	0.11815	0.11815	0.48745	0.05787
Maintenance Time Required	3.55668	0.24725	0.48268	0.17614	0.09393	0.08062
Time To Develop The Setup	2.69234	0.15006	0.37218	0.37218	0.10558	0.02271
Meets Standards In Maintenance System	14.00809	0.1713	0.35867	0.40113	0.0689	0.01279
Break Down/ Corrective Maintenance Reduction	14.08465	0.14858	0.32485	0.46005	0.06653	0.03901
Life Cycle Of The Setup	3.66865	0.26094	0.16893	0.11896	0.45117	0.0266
Frequency Of Equipment Inspection	13.62408	0.45086	0.19779	0.25742	0.09393	0.08062
Support Equipments Required	5.82438	0.16362	0.2829	0.44755	0.10592	0.0266
Technical Expertise Required For Maintenance	7.86604	0.26283	0.14088	0.14088	0.45541	0.00388
Effectiveness Of The Set Up	7.18659	0.12218	0.29762	0.52317	0.05703	0.02567
Reparability Of The Set Up	6.75077	0.25742	0.14697	0.11293	0.48268	0.08062
Over All Score		24.16633448	24.19439216	28.0661584	23.573146	
Rank		3	2	1	4	

Table 17: Gear system frame work for company.

OVER ALL IMPORTANCE OF THE MAINTENANCE TECHNLOGIES						
Technical Requirements	Weight	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	C.R
Cost Of Set Up	6.79392	0.24761	0.12926	0.07364	0.54949	0.07418
Number Of Probes Required	13.94383	0.48268	0.24725	0.17614	0.09393	0.08062
Maintenance Time Required	3.55668	0.15235	0.38986	0.38986	0.06792	0.01629
Time To Develop The Setup	2.69234	0.16864	0.3679	0.3679	0.09557	0.05787
Meets Standards In Maintenance System	14.00809	0.4258	0.30109	0.2129	0.06022	0.04544
Break Down/ Corrective Maintenance Reduction	14.08465	0.51095	0.26264	0.15997	0.06644	0.04923
Life Cycle Of The Setup	3.66865	0.39513	0.22146	0.31011	0.0733	0.09258
Frequency Of Equipment Inspection	13.62408	0.52224	0.19983	0.19983	0.07809	0.01629
Support Equipments Required	5.82438	0.32057	0.27801	0.31568	0.08574	0.0952
Technical Expertise Required For Maintenance	7.86604	0.52812	0.21	0.21	0.05188	0.02752
Effectiveness Of The Set Up	7.18659	0.52234	0.2498	0.17682	0.05103	0.05024
Reparability Of The Set Up	6.75077	0.25073	0.15749	0.10343	0.48835	0.05361
Over All Score		42.60217519	24.28425388	19.88859208	13.224922	
Rank		1	2	3	4	

Table 18: Lubrication system frame work for company.

OVER ALL IMPORTANCE OF THE MAINTENANCE TECHNLOGIES					
Technical Requirements	Weight	Process Parameters	Performance Monitoring	Oil Analysis	C.R
Cost Of Set Up	6.79392	0.52784	0.33252	0.13965	0.05156
Number Of Probes Required	13.94383	0.58155	0.309	0.10945	0.00355
Maintenance Time Required	3.55668	0.18517	0.15618	0.65864	0.02795
Time To Develop The Setup	2.69234	0.48064	0.40539	0.11397	0.02795
Meets Standards In Maintenance System	14.00809	0.15706	0.24931	0.59363	0.05156
Break Down/ Corrective Maintenance Reduction	14.08465	0.24931	0.15706	0.59363	0.05156
Life Cycle Of The Setup	3.66865	0.48064	0.40539	0.11397	0.02795
Frequency Of Equipment Inspection	13.62408	0.52784	0.33252	0.13965	0.05156
Support Equipments Required	5.82438	0.58155	0.309	0.10945	0.00355
Technical Expertise Required For Maintenance	7.86604	0.40539	0.48064	0.11397	0.02795
Effectiveness Of The Set Up	7.18659	0.17862	0.11252	0.70886	0.05156
Reparability Of The Set Up	6.75077	0.25828	0.10473	0.63699	0.03703
Over All Score		37.91	27.033	35.05	
Rank		1	3	2	

6. Case study results

The above analysis revealed results on the basis of the model, it can be concluded from table.1 that the degree of importance for managerial criteria, safety is the most important followed by reliability. The analysis of the model for the company reveals in term of maintenance group requirement “corrective maintenance reduction” with normalized value of 14.08 is the most important followed by “meets standard of a maintenance system” with normalized value of 14.01 as indicated in the table.2. The table.3-14 indicates the detail pairwise comparison matrix result with the Eigen vectors and the consistency ratio for bearing system. The analysis of the second relationship matrix provided the most effective technology/technique which meets most of the criteria and will be best for the maintenance regarding the company strategic managerial and the maintenance requirement. The analysis for bearing revealed that the Shock Pulse Method with overall score 28.07 is the best followed by acoustic emission with overall score of 24.19 and the worst was oil analysis with value of 23.57. In similar way the analysis of the gear system was done and it revealed that, vibration analysis was the most effective technologies followed by acoustic emission and on analyzing the lubrication system the most effective technology/technique was process parameters followed by the oil analysis. Finally, technologies with the least importance for all the system except for the lubrication analysis were found to be oil analysis, as demonstrated in Tables 15 – 17.

7. Findings.

From the above model analysis it was found that the organization is having different importance level of the managerial criteria and different strategies for maintenance technique from the one which they are using. A table was formulated using the overall score to rank all the alternatives below based on each critical parts. For gear, the vibration analysis is the best followed by the acoustic emission and for bearing systems shock pulse method is the best followed by acoustic emission. The analysis of the lubrication system also indicates the process parameter is the best which is a inbuilt system in any machinery this days hence it also helps address the cost factors, the company should exclude the oil analysis from the maintenance system unless the strategic maintenance requirement is changed as it showed the least importance in most of the analysis. The oil analysis for lubrication system can be used as secondary maintenance technology/technique as it is the most effective technologies for lubrication system analysis. Hence this study provided effective way of obtaining the most effective technology based on the strategic need of the organization .It has also been revealed from the cases study that none of the companies were using the appropriate technology/technique which can be more effective maintenance system rather the company were considering the technology/technique only on the cost basis and not on their sustainability issues, even though it may lead to financial gain in the long run thus the research presents an approach for an effective and sustainable maintenance system selection model. The model also provides an effective designing methodology for any company's maintenance needs the change of managerial criteria and there degree of importance or the maintenance group requirement can alter the result. Thus this model is versatile tool for designing an effective maintenance management system according to the need of the industries. The result for the case study is given in table.18.

Rank/Effectiveness	Lubrication system	Bearing system	Gear system
1	Process Parameter	Shock Pulse Method	Vibration Analysis
2	Oil Analysis	Acoustic Emission	Acoustic Emission
3	Performance Monitoring	Vibration Analysis	Shock Pulse Method
4	-	Oil Analysis	Oil Analysis

Table:18. Rank of the technologies of the critical parts

8. Discussion

Strategic maintenance framework based on both the technical and managerial requirement is hardly available in the literature. Thereby, this study provides a strategic maintenance management methodology which considers the managerial criteria and the maintenance group requirement of an organization and presents a model based on the organizational strategic importance. The case study result revealed that the company was not using the technology/technique which actually satisfies their strategic requirement. The primary research revealed that the main focus of the company was cost factor and in some cases considered the more modernized technology/technique for maintenance which may not be suitable according to strategic requirements. The presented model provides a versatile framework that can be applied to any requirement of the organization while the analysis is generic and can be extended to other areas of research.

9. Summary and Conclusions

This paper presents a comprehensive model QFD/AHP on the basis of maintenance strategy and maintenance group requirement. The methodology used, was based on a multiple case study approach with the active involvement of senior managers of the participating organizations. Initially, a few representatives of board of directors including the production directors were selected to identify their requirements and determine their importance using the AHP. Next step to the analysis was the identification of the requirements of maintenance group of the concerned organisation through brainstorming; the importance of maintenance group's requirements is derived through correlation with managerial requirement using the QFD principles. To this end, a few alternatives maintenance techniques/technologies for machineries of the case study organisation were identified. The priorities of the selected maintenance techniques/technologies with respect to each maintenance groups' requirement were derived using the AHP. Finally, the results of the aforementioned analysis were synthesized across the hierarchy to derive overall ranking of the maintenance techniques.

Although maintenance system technique/technology selection using multiple criteria decision making techniques has been researched extensively, very little work has been done to capture stakeholders' perspectives in maintenance decision-making models. This study bridges this gap by integrating stakeholders requirements in model building through a combined a QFD and AHP approach. Although AHP technique has been used in maintenance technique/technology selection based on a thorough literature the combination of QFD and AHP has not been deployed in maintenance engineering and management in prior research.

The developed methodology addresses one the most important aspects of maintenance procedure, the effectiveness of the technologies used in CBM and simultaneously meets the requirement of the managerial needs and the maintenance engineer needs. The model provided a detail methodology to exclude the unimportant or obsolete technologies from a particular company maintenance strategy so that the maintenance policy can be more profound and optimized. The validation of the proposed methodology was performed a real life case study and the results obtained on analyzing the data, proved the necessity of the model. Furthermore, the analysis of the results showed that the proposed model is suitable for the specific company strategy and its needs so as to predict the maintenance requirement properly. The proposed method could be easily implemented within any manufacturing system. The application of the proposed model in three case studies reveals that their current maintenance techniques are predominantly based on cost economics.

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Appendix- I

Company Profile

The company considered for the cases study is a gear manufacturer. It produces a wide variety of gears with turnover is of around INR 60 crore. The company has lots of modern machines in their production line up and all the maintenance is done by a dedicated maintenance department, though the latest machines brought are maintained by the OEMs. The experts consists of the board of directors including the production directors of the concerned organization who are in the company for more than 15 years and having overall experience on this field of more the 25 years. The maintenance group comprises of the similar profiles having huge experiences on this field and are head of the decision making bodies of their respective departments. The functional expertise is given below as pairwise comparison matrix ratings, used for the calculation of the case study for the organization.

Alternative for Cost of Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	0.333	0.24761	
Acoustic Emission	0.333	1	3	0.2	0.12926	0.07418
Shock Pulse Method	0.333	0.333	1	0.2	0.07364	
Oil Analysis	3	5	5	1	0.54949	

Table.1. Pair wise comparison matrix at alternatives level based on cost of setup for gear system

Alternative for Number of Probes Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	3	0.48268	
Acoustic Emission	0.333	1	2	3	0.24725	0.08062
Shock Pulse Method	0.333	0.5	1	3	0.17614	
Oil Analysis	0.333	0.333	0.333	1	0.09393	

Table.2. Pair wise comparison matrix at alternatives level based on number of probes required for gear system

Alternative for Maintenance Time Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	0.333	0.333	3	0.15235	
Acoustic Emission	3	1	1	5	0.38986	0.01629
Shock Pulse Method	3	1	1	5	0.38986	
Oil Analysis	0.333	0.2	0.2	1	0.06792	

Table.3. Pair wise comparison matrix at alternatives level based on maintenance time required for gear system

Alternative for Time	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen	C.R

to Develop the Setup					vector	
Vibration Analysis	1	0.333	0.333	3	0.16864	
Acoustic Emission	3	1	1	3	0.36790	0.05787
Shock Pulse Method	3	1	1	3	0.36790	
Oil Analysis	0.333	0.333	0.333	1	0.09557	

Table.4. Pair wise comparison matrix at alternatives level based on time to develop the setup for gear system

Alternative for Meets Standards in Maintenance System	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	2	5	0.42580	
Acoustic Emission	0.5	1	2	5	0.30109	0.04544
Shock Pulse Method	0.5	0.5	1	5	0.21290	
Oil Analysis	0.2	0.2	0.2	1	0.06022	

Table.5. Pair wise comparison matrix at alternatives level based on meets standards in maintenance system for gear system

Alternative for Break Down/ Corrective Maintenance Reduction	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	5	0.51095	
Acoustic Emission	0.333	1	2	5	0.26264	0.04923
Shock Pulse Method	0.333	0.5	1	3	0.15997	
Oil Analysis	0.2	0.2	0.333	1	0.06644	

Table.6. Pair wise comparison matrix at alternatives level based on break down/ corrective maintenance reduction for gear system

Alternative for Life Cycle of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	2	3	0.39513	
Acoustic Emission	0.5	1	0.5	5	0.22146	0.09258
Shock Pulse Method	0.5	2	1	5	0.31011	
Oil Analysis	0.333	0.2	0.2	1	0.07330	

Table.7. Pair wise comparison matrix at alternatives level based on life cycle of the setup for gear system

Alternative for Frequency of Equipment Inspection	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	5	0.52224	
Acoustic Emission	0.333	1	1	3	0.19983	0.01629
Shock Pulse Method	0.333	1	1	3	0.19983	
Oil Analysis	0.2	0.333	0.333	1	0.07809	

Table.8. Pair wise comparison matrix at alternatives level based on frequency of equipment inspection for gear system

Alternative for Support Equipments Required	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	1	2	0.32057	0.09520

Acoustic Emission	0.5	1	1	5	0.27801	
Shock Pulse Method	1	1	1	5	0.31568	
Oil Analysis	0.5	0.2	0.2	1	0.08574	

Table.9. Pair wise comparison matrix at alternatives level based on support equipments required for gear system

Alternative for Technical Expertise Required For Maintenance	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	7	0.52812	
Acoustic Emission	0.333	1	1	5	0.21000	0.02752
Shock Pulse Method	0.333	1	1	5	0.21000	
Oil Analysis	0.142	0.2	0.2	1	0.05188	

Table.10. Pair wise comparison matrix at alternatives level based on technical expertise required for maintenance for gear system

Alternative for Effectiveness of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	3	3	7	0.52234	
Acoustic Emission	0.333	1	2	5	0.24980	0.05024
Shock Pulse Method	0.333	0.5	1	5	0.17682	
Oil Analysis	0.142	0.2	0.2	1	0.05103	

Table.11. Pair wise comparison matrix at alternatives level based on effectiveness of the setup for gear system

Alternative for Reparability of the Setup	Vibration Analysis	Acoustic Emission	Shock Pulse Method	Oil Analysis	Eigen vector	C.R
Vibration Analysis	1	2	3	0.333	0.25073	
Acoustic Emission	0.5	1	2	0.333	0.15749	0.05361
Shock Pulse Method	0.333	0.5	1	0.333	0.10343	
Oil Analysis	3	3	3	1	0.48835	

Table.12. Pair wise comparison matrix at alternatives level based on reparability of the setup for gear system

Alternative for Cost of Setup	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	3	0.52784	0.05156
Performance Monitoring	0.5	1	3	0.33252	
Oil Analysis	0.333	0.333	1	0.13965	

Table.13. Pair wise comparison matrix at alternatives level based on cost of setup for lubrication system

Alternative for Number of Probes Required	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	5	0.58155	0.00355
Performance Monitoring	0.5	1	3	0.30900	
Oil Analysis	0.2	0.333	1	0.10945	

Table.14. Pair wise comparison matrix at alternatives level based on number of probes required for lubrication system

Alternative for Maintenance Time Required	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R

Process Parameter	1	1	0.333	0.18517	0.02795
Performance Monitoring	1	1	0.2	0.15618	
Oil Analysis	3	5	1	0.65864	

Table.15. Pair wise comparison matrix at alternatives level based on maintenance time required for lubrication system

Alternative for Time to Develop the Setup	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	1	5	0.48064	0.02795
Performance Monitoring	1	1	3	0.40539	
Oil Analysis	0.2	0.333	1	0.11397	

Table.16. Pair wise comparison matrix at alternatives level based on time to develop the setup for lubrication system

Alternative for Meets Standards in Maintenance System	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	0.5	0.333	0.15706	0.05156
Performance Monitoring	2	1	0.333	0.24931	
Oil Analysis	3	3	1	0.59363	

Table.17. Pair wise comparison matrix at alternatives level based on meets standards in maintenance system for lubrication system

Alternative for Break Down/ Corrective Maintenance Reduction	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	0.333	0.24931	0.05156
Performance Monitoring	0.5	1	0.333	0.15706	
Oil Analysis	3	3	1	0.59363	

Table.18. Pair wise comparison matrix at alternatives level based on break down/ corrective maintenance reduction for lubrication system

Alternative for Life Cycle of the Setup	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	1	5	0.48064	0.02795
Performance Monitoring	1	1	3	0.40539	
Oil Analysis	0.2	0.333	1	0.11397	

Table.19. Pair wise comparison matrix at alternatives level based on life cycle of the setup for lubrication system

Alternative for Frequency of Equipment Inspection	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	3	0.52784	0.05156
Performance Monitoring	0.5	1	3	0.33252	
Oil Analysis	0.333	0.333	1	0.13965	

Table.20. Pair wise comparison matrix at alternatives level based on frequency of equipment inspection for lubrication system

Alternative for Support Equipments Required	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	5	0.58155	0.00355
Performance Monitoring	0.5	1	3	0.30900	
Oil Analysis	0.2	0.333	1	0.10945	

Table.21. Pair wise comparison matrix at alternatives level based on support equipments required for lubrication system

Alternative for Technical Expertise Required For Maintenance	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	1	3	0.40539	0.02795
Performance Monitoring	1	1	5	0.48064	
Oil Analysis	0.333	0.2	1	0.11397	

Table.22. Pair wise comparison matrix at alternatives level based on technical expertise required for maintenance for lubrication system

Alternative for Effectiveness of the Setup	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	2	0.2	0.17862	0.05156
Performance Monitoring	0.5	1	0.2	0.11252	
Oil Analysis	5	5	1	0.70886	

Table.23. Pair wise comparison matrix at alternatives level based on effectiveness of the setup for lubrication system

Alternative for Reparability of the Setup	Process Parameter	Performance Monitoring	Oil Analysis	Eigen vector	C.R
Process Parameter	1	3	0.333	0.25828	0.03703
Performance Monitoring	0.333	1	0.2	0.10473	
Oil Analysis	3	5	1	0.63699	

Table.24. Pair wise comparison matrix at alternatives level based on reparability of the setup for lubrication system