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Maintenance Strategy Selection as a Multiple Criteria Decision Making problem

Capstone Project / Fall '19
MENG 5980

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Abstract

Maintenance strategy selection (MSS) is one of the most critical decisions for safe and continuous operations. It is a key factor not only for reducing the maintenance cost, but also for achieving stable production rates without unplanned interruptions. There are different maintenance strategies implemented in the field and mentioned in the literature, each has both benefits and drawbacks for the production. Maintenance management have to make a decision of which strategy to follow. Such a decision need to be evaluated based on multiple criteria such as reliability, production loss, process safety, cost, environmental damage and others. The adoption of one maintenance strategy such as preventive maintenance for the whole plant can be seen as a proper solution to solve such a complex problem, but definitely not the most beneficial to the organization.

Multiple criteria decision making process (MCDM) offers different approaches to help in solving such a complex problem. The use of analytical hierarchy process (AHP), one of MCDM approaches, in solving maintenance strategy selection problem at a natural gas processing plant is presented in this report. The plant is currently adopting timely based preventive maintenance strategy for all of the equipment. Six Different equipment were studied in order to evaluate five different maintenance strategies against three main criteria which are cost, equipment damage and applicability. AHP results showed that significant changes should be made to the current followed maintenance strategy, which would have a huge impact on the company's resources and will generate cost savings in multiple areas as well as utilizing the company resources. AHP has proven to be an effective and flexible approach for solving complex decision making problems, as it helped the decision makers to simplify the problem into a hierarchy and prioritize the different criteria to reach an optimum solution for the proposed problem.

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List of Abbreviations

MCDM	Multiple Criteria Decision Making
MADM	Multi Attribute Decision Making
MODM	Multi Objective Decision Making
VMP	Vector Maximum Problem
WSM	Weighted sum Model
WPM	Weighted Product Model
AHP	Analytic hierarchy process
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
ELECTRE	Elimination and Choice Translating Reality
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
PM	Preventive Maintenance
CM	Corrective Maintenance
OM	Opportunistic Maintenance
RBM	Risk Based Maintenance
RCM	Reliability Centered Maintenance
PDM	Predictive Maintenance
CBM	Condition Based Maintenance
TBPM	Time Based Preventive Maintenance
DOM	Design Out Maintenance
MSS	Maintenance Strategy Selection
IEEFA	the Institute for Energy Economics and Financial Analysis
E&P	Exploration and Production
PHPC	Pharaonic Petroleum Company

BP	British Petroleum
EGAS	Egyptian Natural Gas Holding Company
IEOC	International Egyptian Oil Company
MMSCFD	Million Standard Cubic Feet per Day
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
DGS	Dry Gas Seal
N2 B/UP	Nitrogen Backup

1- Introduction

One of the main challenges that faces oil and gas industry nowadays around the globe is the sudden prices fluctuation. According to the Institute for Energy Economics and Financial Analysis (IEEFA), the oil and gas industry has hit rock bottom in financial terms compared to the previous decades. Not only is the industry currently suffering, but also, according to the IEEFA forecast, this financial stress will not be relieved anytime soon, actually it will increase due to three main factors. These factors are Fracking, renewable energy and the global climate movement. All of which will battle with the oil and gas industry[1].

The request for more effective operations is needed now more than ever, in order for the industry to survive this financial stress. Oil and gas industry is divided into three main streams, Upstream, Midstream and Downstream. Upstream includes Exploration and production (E&P), Midstream is for transportation of oil and gas , while downstream is the end market user which includes oil and gas refining, marketing and distributions.

Better maintenance management is one of the main keys to achieve optimal operations not only for its effect of reducing the operational cost, but also for lifetime extension of the current assets. As inadequate maintenance can result in equipment damage and loss of lives, an example is the piper alpha gas explosion back in 1988. Such an incident led to two billion euros estimated financial losses and the fatality of 167 men [2]. Y.Tang et al. found that most of the major incidents and financial losses in upstream oil and gas occurred due to equipment failures related to maintenance management and human mistakes[3]. The risk of catastrophic failure occurring always exists, but there is no doubt that effective maintenance techniques and practices can minimize that risk[4]. That is why maintenance strategy optimization is needed to reduce the maintenance cost without compromising safety or production.

Maintenance cost is believed to be the second largest portion of any operation budget[5], in some cases it reaches up to 70% of the production cost[6]. The cost of maintenance can be divided into two main categories, direct and indirect. Direct costs include work force, material, spare parts, and tools. Indirect costs are those incurred due to consequences associated with equipment failure and the unplanned downtime that cause production loss. Accidents cost, insurance policies and demurrages also counted as indirect maintenance cost[7].

Many maintenance strategies/techniques have been developed over time from run to fail “Naive” to the time based maintenance reaching to the condition based maintenance[8]. A. Garg and S.G. Deshmukh mentioned ten different techniques found in the literature till 2006[5]. Selection of which strategy to follow is a very critical and complex decision, as it will determine the maintenance cost, equipment availability, safety level and many other parameters.

Such a selection problem will have multiple and probably contradicting objectives as cost reduction, increasing availability, reducing unplanned downtime and meeting both safety and environment requirements. One constraint for this problem is the available resources, such as the maintenance budget limit per year, the number of workforce available (labor). Another constraint is equipment availability, for critical to production units, which can be measured in terms of Mean Time between failures (MTBF) and Mean Time To Repair (MTTR). The interdependency between the units and each other need to be considered also in the constraints, as an equipment shutdown may cause another equipment to stop. Safety requirements should also be addressed in the constraints, such as number of safety critical elements that failed or incidents occurred due to not following the safety procedures. The minimum production volume per month is also one of the important constraints.

Different optimization models for Maintenance strategies are found in the literature, it can be classified based on Certainty theory into three categories (Certainty-Risk-Uncertainty). Certainty theory measures the certainty degree based on the available information that affect the system under study as shown in figure (1). Under each category there are different models for maintenance policy/strategy optimization as shown in figure (2).[9].

Figure 1 Certainty Theory

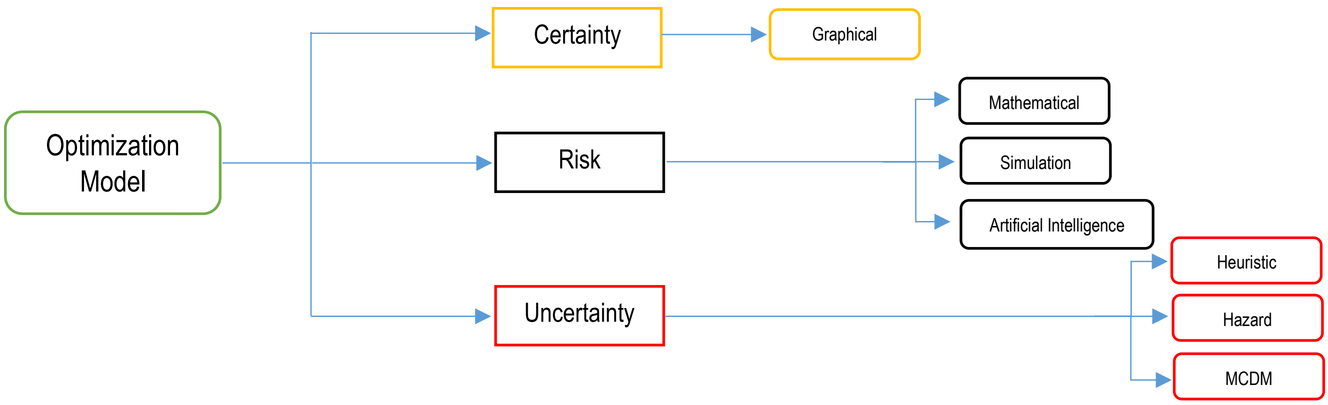

Figure 2 Optimization Model Classification

1.1 Problem Statement

The problem is to determine, which is the best maintenance strategy to be adopted for each equipment? Taking into consideration the effect of this strategy on safety requirements, production process, maintenance and operation cost, equipment availability and equipment lifetime.

1.2 Case Study system description

Pharaonic Petroleum Company (PHPC) is one of the leading natural gas production companies in Egypt since 2010. It is a Joint Venture between British Petroleum (BP), Egyptian Natural Gas holding Company (EGAS), and International Egyptian Oil Company (IEOC). PHPC processing and production plant is located at Ras el Bar concession at the Mediterranean Sea.

The company is currently operating five main wells' areas named Ha'py, Taurt, Seth, Akhen ad Atoll. Each area of them has a number of wells, as shown in figure (3). The total production of the company is 450 Million Standard Cubic Feet per Day (MMSCFD) of natural gas and 8800 Barrels per day of condensate. Generally speaking, all plant equipment can be divided into two categories. One is the production equipment, which are the equipment that are directly responsible for the gas production such as gas turbines, gas generators, low temperature separators (LTS), condensate pumps. The other category is the utility and supporting systems such as the air system, Nitrogen system, gas fuel skid and firefighting system.

The production of natural gas is basically a separation process for the well fluids. This separation process start from the offshore platforms 70 km north-west the onshore treatment plant, where the gas is extracted from the well. The extracted gas is then passed through a separation system, in which oily water is separated from the gas and directed to the waste water treatment system. Separated gas is transported to the onshore plant facilities via 30 inch pipeline for Ha'py Gas, and 20 inch pipeline for Taurt Wells. Both pipelines joints at the entrance of a finger type slug catcher. The slug catcher is a vessel with sufficient buffer volume to store the largest slugs expected from the upstream system. It is located between the outlet of offshore arrival pipelines and the inlet onshore processing equipment, to prevent overloading of the system.

Another separation process is carried inside the slug catcher in order to separate any water or hydrocarbon condensate from the gas before introducing the gas to the gas compressors. The compression stage is the main production stage for the gas, especially when the arrival pressure is below the network pressure, which is the case for Ha'py and Taurt gas. This stage consist of a seven stage centrifugal gas compressor with tandem dry gas seals, that is driven (connected by flexible coupling) by an eleven megawatt gas turbine figure (4).

Due to the criticality of this stage and the high cost associated with the assets in it, Gas turbine alone cost around two us million dollar, another separation process is done before introducing the gas to the compressor. The target of this process is to prevent compressor damage that may occur due to liquid or condensate carryover to the compressor. This is achieved by passing the gas through a suction scrubber vessel, in which any hydrocarbon condensate or free water entrained in the gas stream is knocked out. A mesh pad mist eliminator and a bank of cyclones inside the scrubber assures that 99% of all liquid droplets larger than 10 microns are removed from the gas stream. The knocked out liquids is then routed to condensate preheaters for more separation.

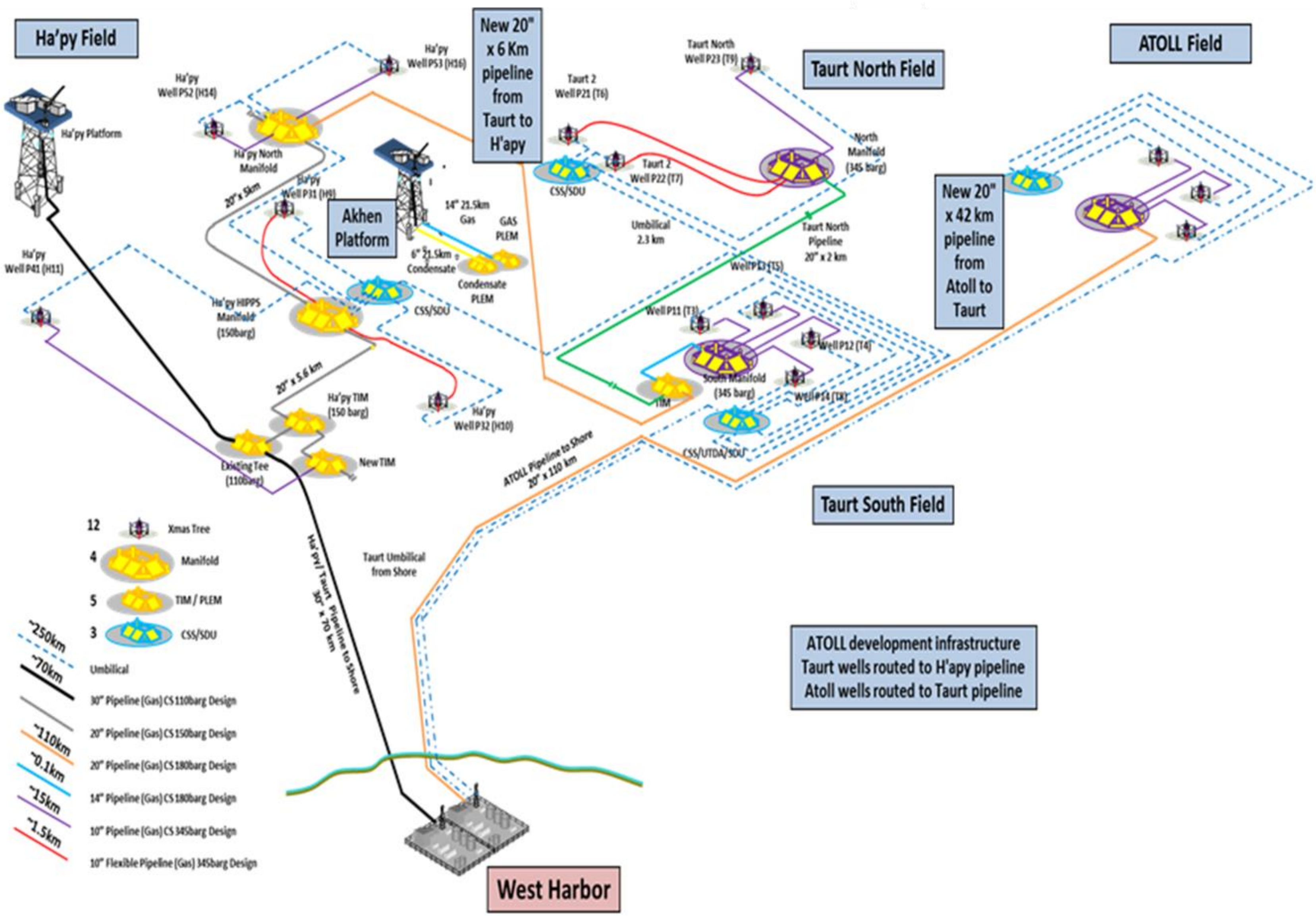

Figure 3: PHPC Wells schematic drawing

Figure 4 Gas Compression Stage

The separated gas at suction pressure of 24 barg is then routed to the compressor. The discharge gas from the compressor outlet has high pressure of 70 barg and high temperature of 135 degree Celsius. The high pressure is needed for gas transportation, while the temperature is a non-desirable side effect from the compression process. In order to reduce the gas temperature, the outlet discharged gas passes through a heat exchanger. This heat exchanger uses cold air to reduce the temperature to 45 degree Celsius, the cold air is introduced by the means of four fans (belt driven by four motors). Due to this cooling process, another separation process is required to remove any liquids that may have formed due to condensation. This separation is achieved using discharge knock-out drum, which is a vessel similar to the suction scrubber and this conclude the compression stage.

The outlet gas from the compression stage is then introduced to low temperature separators in order to condition the wet hydrocarbon gas to meet a hydrocarbon dew-point of 5c at any pressure below 70 barg and a water dew-point of 0 c at 70barg prior to being metered and exported to the network (sales gas).

Regarding the utility and support systems, it contains those systems which does not have a direct contact with the produced gas. The Compressed Air system, shown in figure (5), is one of those systems and has a function of providing dry, oil free compressed air for pneumatic instrument controllers, air actuated valves, gas power electrical generation packages, emergency electrical power generation package and nitrogen generation packages. The system consist of seven screw compressors working in parallel to maintain the air network system pressurized at 7 bar minimum. The discharge of all compressors is then directed to the air dryer package, shown in figure (6), for moisture removal. This process is done by introducing the filtered compressed air to the desiccant (activated alumina balls) inside the dryer tower. This activated alumina adsorb the moisture entrapped in the compressed air and then the dry air passes through post filters to remove any desiccant dust that may be attached to it.

Figure 6: Air Compressors

Figure 5: Air Dryers

The Nitrogen Generation system, another supporting system, shown in figure(7) uses the compressed dried air to provide a continuous supply of nitrogen gas with a purity of 95% at a nominal pressure of 5.5 barg. This supply is used for the gas compressors' dry gas seal (DGS) system and will be explained in detail on section three.

The Nitrogen compressor shown in figure (8) uses the Nitrogen gas produced from the Nitrogen system and compress it to 100 bar to be stored in horizontal vessel called the bullet, which is used a nitrogen gas supply in case of emergency, such as power failure.

The purpose of the above mentioned simplified process explanation is to give the reader an overview of the production process to be able to develop a proper understanding of the problem in hand. The next part of this report can be divided into four parts. The first part will present a general review on Multiple Criteria Decision Making (MCDM) and its methods, which can be used to solve the above-mentioned problem of maintenance strategy selection. Second part will be discussing the application of Analytical Hierarchy Process (AHP), one of MCDM Methods, on different equipment. The third part will present and discuss the results of AHP application. Final part will contain the conclusion and recommendations.

Figure 7: Nitrogen Generation Package

Figure 8: Nitrogen Reciprocating Compressor

2- Multiple Criteria Decision Making Methods' Review

Decision making is done every day in our life, and it's not always an easy task to do. Multiple Criteria a Decision Making or MCDM is an approach trying to simplify that task. MCDM can evaluate a number of alternatives against different/multiple (may be contradicting) criteria, attributes or goals. MCDM has been around as a discipline since 1950s, which indicates that it is relatively new. During the past decade, MCDM has been growing rapidly and in different research areas such as energy fuels, operations research, management science, economics, etc. [10]. Different case studies also were mentioned in the literature adopting MCDM approach for reaching the most suitable choice, action or policy. These studies were carried out in various industries such as power generation, manufacturing, automotive, oil and gas, etc. [11].

MCDM approach is perceived as an optimization technique, but with multiple objective functions. That is why MCDM can be categorized into two main categories; discrete multi attribute decision making problem (MADM) and continuous multi objective decision making (MODM) [10], or vector-maximum problem (VMP) as known in the literature[12]. Discrete or continuous is referring to the decision space. In this project both terms MADM and MCDM will be used interchangeably.

MADM methods can be categorized based on the data type into deterministic, fuzzy or stochastic. MADM can also be classified based on the information type & their prominent features into different methods such as weighted sum model (WSM), weighted product model (WPM), analytic hierarchy process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These are the most commonly used in the literature, but there are other methods and different classifications for MADM [12].

The Scope in this project will be focusing on MADM methods only. A quick review on some of MADM methods is carried on in the next section.

MADM Problems is usually translated into a decision matrix format as shown below in figure (9), where the columns represent the criteria (C_1,C_2,C_3…C_N) and the rows represent the alternatives (A_1, A_2, A_3…A_M) , and a_{ij} represent the performance of alternative (A_i). The weights of each criteria are represented by ($W_1, W_2, W_3, \ldots\ldots W_N$). The best or most suitable alternative is denoted (A^*).

		Criteria			
	C_1	C_2	C_3	…	C_N
Alt.	W_1	W_2	W_3	…	W_N
A_1	a_{11}	a_{12}	a_{13}	…	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	…	a_{3N}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_M	a_{M1}	a_{M2}	a_{M3}	…	a_{MN}

Figure 9: Decision Matrix

2.1 The Weighted Sum Model (WSM)

The weighted sum model, which also called simple additive weighting (SAW) is one of the most widely used approach in solving single dimension problems. WSM method uses the below simple equation 1-1 to determine the optimal alternative (in case of maximization problem)[13]. Limitation of such method appears when dealing with multidimensional problems. Single and multidimensional problems refers to the measuring units for the criteria being used to evaluate the alternatives. If all criteria have the same unit (dollar, hours, m3...) then it is called single dimension, different units mean multidimensional problems[12].

$$A^*_{WSM} = max \sum_{j=1}^{N} (W_j a_{ij}) \quad (1\text{-}1)$$

2.2 The Weighted Product Model (WPM)

The weighted product model (WPM) is very similar to WSM, except it uses the multiplication instead of summation as shown in equation 1-2, where A_K, A_L are the alternatives to be compared. N is the number of criteria, a_{kj} is the kth alternative value with respect to the jth criteria. w_j is the weight of the jth criteria. So if R($^{A_K}/_{A_L}$) is larger than 1, it mean that alternative A_K is better and more preferable than A_L .The advantage of using WPM over WSM is the ability to solve multidimensional problems, as it eliminates the measuring units and that is why sometimes it is referred to as dimensional analysis. Another advantage is the ability to use relative values instead of the actual ones[12], [13].

$$R\left(\frac{A_K}{A_L}\right) = \prod_{j=1}^{N} (a_{Kj}/a_{Lj})^{w_j} \quad (1\text{-}2)$$

2.3 The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is being used widely and it is highly evaluated. It was first developed by Prof. Thomas L. Saaty in 1980 [14], AHP is commonly used for the complicated decision making problems. It divides the problem into hierarchal systems that include any number of levels to fully characterize the problem. One advantage for using AHP method is the ability to deal with tangible and non-tangible criteria

AHP uses pairwise comparisons to derive comparison matrices (reciprocal matrices) and then compute the priority vector (matrix normalized eigenvector) and the largest eigenvalue (λ_{max}), then calculate both consistency index (CI) and the consistency ratio (CR) using the equations 1-3, 1-4, where (n) represents the number of factors or criteria and RI is the random consistency index that can be obtained from table (1). if the consistency ratio is less than 0.1, the judgment can be considered acceptable, otherwise (inconsistency greater than 0.1) a revision for the subjective judgment is needed[15]. Finally alternatives' overall composite weight can be calculated using equation 1-5, which is similar to the one used for the WSM. Note that AHP deals with relative values not actual ones, table (2) represents those standard values for judgment.[12], [13], [16].

$$\text{CI} = (\lambda_{max} - n)/n - 1 \quad (1\text{-}3)$$

$$\text{CR} = \text{CI/RI} \quad (1\text{-}4)$$

$$A^*_{AHP} = max \sum_{j=1}^{N} (W_j a_{ij}) \quad (1\text{-}5)$$

Table 1Random Consistency Index (RI) by R.W.Saaty [14]

n	1	2	3	4	5	6	7	8	9	10
Random Cosistencey Index (RI)	**0**	**0**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**

Table 2: Fundamental Scale By R.W.Saaty [14]

Importance Intensity	Definition	Explanation
1	Equally Important	2 activities contribute equally to the objective
3	Moderate importance of one over another	Experience & Judgment favor one activity over another
5	Essential or strong importance	Experience & Judgment strongly favor one activity over another
7	Very Strong Importance	An activity is strongly favored & its dominance demonstrated in practice
9	Extreme 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

2.4 The Revised Analytic Hierarchy Process (Revised AHP)

The Revised AHP was introduced in 1983 by Belton& Gear, as they found an inconsistency with the results of AHP method when introducing a similar/identical alternative to the existing ones. They found that the best alternative has changed, which does not make sense, Saaty argued that the addition of an identical alternative is not logical and should not be taken into account. They claimed that the inconsistency is resulted due to the summation of the relative values of each criteria which equals one, so they proposed to use the maximum value as the denominator of the relative values instead of the using the summation of the values. The result of this method, when introducing an identical alternative, was matching to the original problem result, i.e., the best alternative remains the same in both cases.

2.5 Elimination and Choice Translating Reality (ELECTRE)

ELECTRE was first introduced by Bernard Roy and his coworkers at a consultancy company called SIMA in 1966, it is known as an outranking method of decision making, that's why it can be used to rule out some of the less favorable alternatives first, then another MADM method is used to find the most suitable alternative of the remaining ones[12].

ELECTRE Method determine two sets called concordance set and discordance set, and then construct their matrices. The concordance set of any two alternatives can be defined as a set containing all criteria that prefer one alternative over the other. The discordance set is the complementary subset of the concordance set. A threshold value is introduced using equation 1-6 into concordance matrix to formulate the concordance dominance matrix (F), meaning that alternative (A_l) will be dominated by alternative (A_k) if the concordance index (C_{kl}) value is greater than the threshold value

($\underline{C}$), i.e. ($C_{kl} \geq \underline{C}$). Same is done for the discordance dominance matrix (G), with a threshold value named ($\underline{d}$) and is calculated using equation 1-7[12].

Next step is determining the “aggregate dominance matrix” (E) using equation 1-8 to get its elements, where $f_{kl}, g_{kl} = 1, if\ C_{kl} \geq \underline{C},\ d_{kl} \geq \underline{d}$, and$f_{kl}, g_{kl} = 0, if\ C_{kl} < \underline{C},\ d_{kl} < \underline{d}$. By checking the E matrix, it can be concluded which alternative is the dominant of all, and which is “ELECTREally” Dominated by others[12].

$$\underline{C} = \frac{1}{M(M-1)}\ X \sum_{k=1}^{M} \sum_{l=1}^{M} C_{kl} \qquad (1\text{-}6)$$

$$\underline{d} = \frac{1}{M(M-1)}\ X \sum_{k=1}^{M} \sum_{l=1}^{M} d_{kl} \qquad (1\text{-}7)$$

$$e_{kl} = f_{kl}\ x\ g_{kl} \qquad (1\text{-}8)$$

2.6 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS was developed in 1981, by Yoon and Hwang as a substitute for the ELECTRE approach. This method uses the distance to the ideal solution as the evaluation for the best alternative. It assumes that there is an ideal solution and a negative ideal one and the best alternative should be the closest in distance to the ideal solution and the farthest from the negative ideal one. It deploys the Euclidean distance method to measure how close the alternatives to the ideal solution[12].

The first two steps is the same as ELECTRE Method, first normalizing the decision matrix by using equation 1-9, then generating the weighted normalized decision matrix. The third step is finding both Ideal (A^{*}) & negative-Ideal (A^{-}) solutions using equations 1-10, 1-11.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{M} {x_{ij}}^{2}}} \qquad (1\text{-}9)$$

$$A_i^{*} = \{(max\ v_{ij} \mid j \in J), (\min v_{ij} \mid j \in J^{\backslash}) \mid i = 1,2,3, \dots, M\} \qquad (1\text{-}10)$$

$$A_i^- = \{(min\, v_{ij} | \, j \in J), (\max v_{ij} | \, j \in J^{\setminus}) | i = 1,2,3, \dots, M\} \quad (1\text{-}11)$$

Where: $J = \{ j = 1,2,3, \dots., N \mid j \; associated \; with \; benefit \; criteria\},$

$J^{\setminus} = \{ j = 1,2,3, \dots., N \mid j \; associated \; with \; cost \; criteria\}$

Using the Euclidean distance approach, the separation distances of each alternative from the ideal and negative ideal ones can be obtained by applying equations 1-12, 1-13, where (S_{i^*}) represents the separation measure from the ideal solution and (S_{i^-}) represents the separation measure from the negative ideal solution. Lastly is the relative closeness (C_{i^*}) calculation using equation 1-14, and then ranking the alternatives.

$$S_{i^*} = (\sum(v_{ij} - v_{j^*})^2)^{1/2}, i = 1,2,3, \dots., M \quad (1\text{-}12)$$

$$S_{i^-} = (\sum(v_{ij} - v_{j^-})^2)^{1/2}, i = 1,2,3, \dots., M \quad (1\text{-}13)$$

$$C_{i^*} = {S_{i^-}}/{(S_{i^*} + S_{i^-})}, 0 \le C_{i^*} \le 1, i = 1,2,3, \dots., M \quad (1\text{-}14)$$

It should be mentioned, that the above five methods of solving the MCDM/MADM problems are not the only ones that exists. There are many other methods used in the literature and in practical problems like VIKOR, PROMETHEE, ANP, MAUT, MACBETH….and many others. The diversity of the methods may be perceived as a strength point, but in the same time it creates confusion on which method is appropriate to use, which can be considered as a weakness[17].

It is really difficult to compare MADM methods in order to choose the best one, as a paradox will always appear. In order to find out which MADM method is the best, you have to use the best MADM method. Up till now, no one can precisely determine whether one method is making more sense than the other for the same problem[18].

Two evaluation criteria used by E. Triantaphyllou in a comparative analysis between some of MADM Methods. The first one is that if an MADM method is accurate in a multi-dimensional problems, it has to be accurate in a single dimensional problem as well. Triantaphyllou used the WSM method as the evaluation reference as it gives the best result in the single dimensional problems[18].

The second evaluation criteria is that the results of an effective MADM method should not change by adding a similar alternative or replacing one of the worse alternatives with another one that is more worse, as long as the relative importance of the decision criteria is fixed and doesn't change[18].

The results of Triantaphyllou comparative analysis between AHP, Revised AHP, and TOPSIS indicated that it is really difficult to determine which method is the best, although the revised AHP method appeared to give less contradictions rate percentage when compared to WSM results and low rate change percentages for the optimum alternative indication in the case of introducing worse or similar to non-best alternatives. That is why Triantaphyllou considered the revised AHP method as the best[18].

The selection of an appropriate MCDM approach for a certain problem can be made based on the required input data and the expected outcome results and their granularity. As mentioned by Ishizaka and Nemery (2013), AHP is in the middle between other approaches regarding the input effort and data required. The output of AHP is a complete ranking with scores for each alternative and criteria[19] .

Analytic Hierarchy Process is considered as an effective approach for solving complex decision making situations, as it helps the decision makers to simplify the problem into a hierarchy and prioritize the different criteria to reach an optimum solution. The use of pair wise comparisons is to convert the complicated decisions into a bunch of simple comparisons. AHP takes into account both objective and subjective criteria, which makes it more advance than the other MCDM approaches[20], and select the best trade-off among different criteria. Besides aiding the decision makers for reaching the best alternative, AHP provides a good and clear rationale regarding the selection and the rankings[14]. Due to its flexibility and suitability, AHP approach is chosen for the maintenance strategy selection problem

3- Using AHP for solving the Maintenance Strategy Selection (MSS) Problem at PHPC

Over the past 10 years, there has been a significant increase in the number of AHP Related publications. AHP approach is being used increasingly in different fields such as mechanical engineering, materials science, environmental science… etc.[20]. Bevilacqua and Braglia (2000) have used AHP for maintenance strategy selection problem at an oil refinery located in Italy. They proposed a model comparing five maintenance strategies alternatives against four main criteria, each has its own sub-criteria. They determined the best maintenance strategy for each cluster of equipment[15]. Bertolini and Bevilacqua (2006) proposed a similar model (only three alternatives) for a critical equipment (centrifugal pump) at an oil refinery, they combined AHP with Goal programming. They found that the predictive maintenance offers the optimum tradeoff between the usage of resources and failures reduction[21].

3.1 AHP Step by Step Procedures

First, we should construct the hierarchy starting from the top level, which is the goal (Maintenance Strategy Selection). The second level is defining the criteria that will be used to evaluate the alternatives, which is level two and three in case of existence of sub-criteria. Final level is to determine which alternatives (different maintenance strategies) we want to choose from.

Next step is performing the pairwise comparisons for each level using the importance level scale mentioned in table (2) at section (1), with respect to the upper level. After developing the judgment matrix, we can get the normalized eigenvector of the matrix, which is the priority vector. Finally, Judgment the evaluation using the inconsistency ratio is done (should be less than 0.1).

It should be noted that the selection of the personnel (Judges) who should answer the questions for the pairwise comparisons should not be random, in order to get accurate results. Those judges should have both practical and theoretical experience with the questioned system. As mentioned by Saaty and Özdemir (2015), some cases can be even evaluated by only one Judge, given that he is equipped with the proper knowledge and expertise[22].

A model similar to the one used by Bevilacqua and Braglia (2000) with a few modification according to PHPC maintenance staff is presented in figure (10). This model compare between five different maintenance strategies. First a brief background of different maintenance strategies is presented in the below section.

Maintenance strategies can be categorized in a classical way into two major categories, Preventive Maintenance (PM) and Corrective Maintenance (CM). PM's, which is the proactive approach, are done to prevent or reduce equipment's failures by replacing a component (at a fixed time interval) by new one in order to restore the equipment to an ideal situation , while CM's (also known as run to fail / reactive approach) are done after the failure occurrence to rectify the situation and get the equipment back online[11].

Modern classification for maintenance strategies include Risk Based Maintenance (RBM), Opportunistic Maintenance (OM), Reliability Centered Maintenance (RCM), Predictive Maintenance (PDM), Condition Based Maintenance (CBM) and Outsourcing Maintenance. A brief description for each strategy is to follow in the next section.

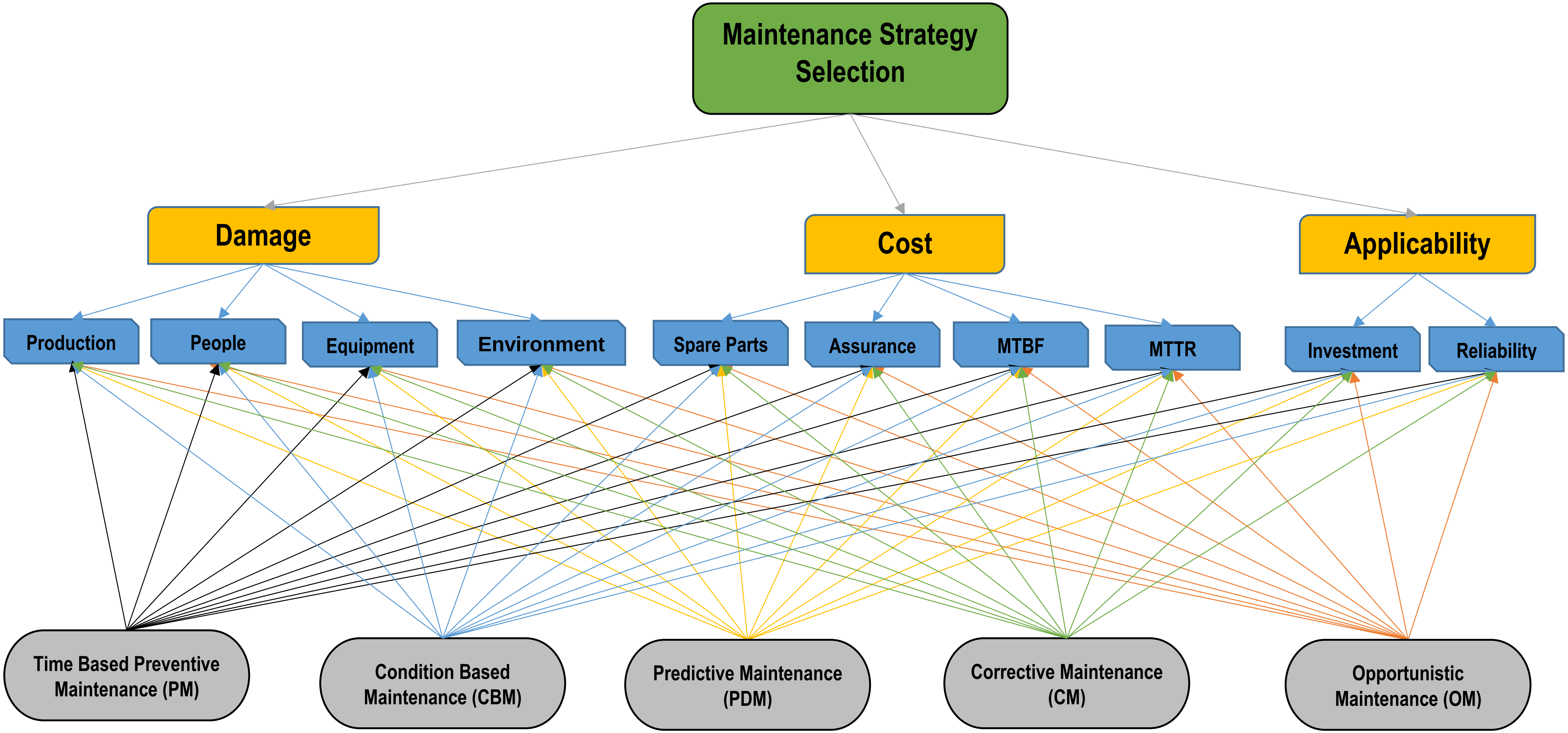

Figure 10 Hierarchal Structure for MSS problem

Timely Based Preventive Maintenance (TBPM): this maintenance strategy relies on the reliability characteristics of each component in the system. These characteristics are often defined by either the manufacturer of the component or the system packager. Maintenance personnel replace the component with a new one every fixed time interval, regardless of its condition.

Corrective Maintenance (CM): as the name implied, this maintenance strategy only takes action and intervene after the occurrence of the failure.

Condition Based Maintenance (CBM): It utilize the advanced technology like sensors to monitor the system onset conditions , and stop the equipment before the occurrence of failures and shutdowns, but it is not suitable for all systems due to economic reasons.

Predictive Maintenance (PDM): the different between PDM and CBM is that PDM collect the measured data from the field and analyze it in order to get an estimate for the exact time of failure and then take the necessary actions.

Design out Maintenance (DOM): This strategy is used for equipment with high failure rates and high maintenance cost, it aims to redesign the equipment’s critical parts, those who cause the frequent breakdowns.

Risk Based Maintenance (RBM): in this strategy assists are classified based on their risk values, high risk assets and low risk assets. The risk is quantified based on the consequences of unexpected failure to the equipment. Those with the high risk requires more inspection and close monitoring unlike the low risk assets.

Opportunistic Maintenance (OM): This strategy uses shutdown opportunities to perform maintenance activities, if equipment (A) fails, other equipment (B) might be affected and stopped until equipment (A) is restored. Then a maintenance opportunity (window) is available for equipment (B). This strategy is commonly used at continuous operation plants, which cannot afford to take some equipment out of service for routine maintenance.in case of equipment that have a whole equipment as a standby, this maintenance strategy should not be selected as it will not give any advantage.

As Shown in the above figure (10), five different maintenance strategies are chosen as alternatives. The difference between these maintenance strategies should be well defined before conducting the pairwise comparison. Especially CBM and PDM, as these two are very close in their definition. Both strategies are proactive with the aim of increasing the reliability and reducing the downtime. PDM depends on precise formulas supported by the data gathered from the sensors installed in the field. PDM aim is to predict the future, to know when the failure is going to happen and to act upon it. CBM on the other hand depends only on the data acquired by the sensor, in case of a parameter exceeds the acceptable level, maintenance action should be taken.

Opportunistic Maintenance (OM) is a preventive maintenance approach that aims to reduce the downtown by using planned and unplanned shutdowns for performing maintenance activities. This means that a part can be replaced earlier than it should or later than the original planned replacement time. This strategy is usually used with critical to production equipment, the ones that cause production loss in case of stoppage and do not have a standby equipment as mentioned earlier.

AHP hierarchy presented in figure (10) has the main objective of selecting the best suitable maintenance strategy, with respect to three main criteria; damage, cost and applicability. The sub criteria level in the damage criteria include the production damage (production loss), people fatalities or injuries, environmental damage and equipment damage. The Cost associated with each maintenance strategy is represented with four sub criteria. These are the cost of spare parts, the cost of the assurance spares, and Mean time between failures (MTBF) and Mean time to repair (MTTR). Assurance spares is a term used in the oil and gas industry representing spare parts with lower failure rate and higher cost than the normal spares (consumables). Assurance spares usually follow the minimum to maximum ratio of 0:1, and those spares are issued from the warehouse in case of failure or performance deterioration only. The Applicability criteria includes two sub criteria, the investment required to implement the strategy (hardware, software, etc.) and technique reliability, that can be measured by the failure detection capability and restoring the equipment condition to as new. It should be noted here that the investment required is a cost criteria, but it was not included under the criteria of cost as the investment required per machine is negligible when compared to the other cost factors.

3.2 Gas Compression Trains operation background:

Before performing the calculation, it's important to understand the criticality of each equipment and its production mode. As mentioned before, PHPC operates different wells. Only Atoll well can be processed directly to the low temperature separators without going through the compressor, as the receiving pressure of 80 barg is higher than the network pressure. Ha'py and Tuart gas must go through the compressor. In other words, there will be a production deferral of 200 MMSCFD in case of failure of the compression train.

PHPC operates three gas compression trains, the term compression train (figure 6) is used to refer to both the driver (Gas turbine) and the driven (Gas Compressor). All three can operate on H'apy&Taurt feed gas. Atoll Gas can only be introduced to compression Train “A” due to piping limitation. In case of unexpected failure/tripping of gas compression train “A”, Atoll gas can be processed as Free Flow without production loss. So, it can be considered that three gas compression trains are redundant to each other in the case of Ha’py and Taurt Gas. And for Atoll gas the free flow line is redundant to compression Train “A”. The current normal operation mode is to operate one gas turbine to process Ha’py and Taurt gas continuously (24hrs), and to process Atoll gas through compressor “A” if well pressure increased, due to pipe line blockage (seven days per month).

3.2.1 Gas Compression Train “A&B” AHP Calculation Example:

When performing the pairwise comparison between the criteria level. A question may be asked “how important is the damage factor (damage caused by adopting a certain maintenance strategy) compared to the cost factor (cost incurred by applying this strategy) with respect to maintenance strategy selection? The answer to such question is as shown in figure (11), the damage criteria has a very strong importance (value of 7) when compared to the cost criteria for gas turbine “A”. Also it can be said that the damage is seven times more important than the cost. Figure (12) represents the pairwise comparison for the sub criteria of Damage. It can be said that the equipment damage (caused by maintenance strategy) for gas turbine “A” has a moderate importance (value of 3) when compared to the production loss caused by the effect of implementing this strategy on gas turbine “A”. Detailed calculations can be found in Appendix “B”

In order to have a sense of the values shown in the calculations, one can think of it as follows. For example, the production loss caused by implementing PM strategy on Gas turbine “A” is seven times less than the loss caused when implementing CM strategy.

Gas Turbine "A"	Damage	Applicability	Cost
Damage	1.00	5.00	7.00
Applicability	0.20	1.00	3.00
Cost	0.14	0.33	1.00
Summ	1.34	6.33	11.00

Gas Turbine "A"	Damage	Applicability	Cost	Criteria Weight
Damage	0.74	0.79	0.64	0.723506057
Applicability	0.15	0.16	0.27	0.19318606
Cost	0.11	0.05	0.09	0.083307883

Gas Turbine "A"	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.72	0.97	0.58	2.27	0.723506057	3.141081563
Applicability	0.14	0.19	0.25	0.59	0.19318606	3.042719129
Cost	0.10	0.06	0.08	0.25	0.083307883	3.01365532
					λ_{max}	3.06581867
					CI	0.032909335
					CR	0.056740233

Figure 11: Level 1 Criteria comparison

Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	0.333333333	3	0.25
Equipment Damage	3	1	4	0.333333333
Environmental Damage	0.333333333	0.25	1	0.2
People Damage	4	3	5	1
Summ	8.333333333	4.583333333	13	1.783333333

Normalized Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.12	0.072727273	0.230769231	0.140186916	0.140920855
Equipment Damage	0.36	0.218181818	0.307692308	0.186915888	0.268197503
Environmental Damage	0.04	0.054545455	0.076923077	0.112149533	0.070904516
People Damage	0.48	0.654545455	0.384615385	0.560747664	0.519977126

Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.140920855	0.089399168	0.212713548	0.129994281	0.573027852	0.140920855	4.066309794
Equipment Damage	0.422762565	0.268197503	0.283618064	0.173325709	1.147903841	0.268197503	4.280069076
Environmental Damage	0.046973618	0.067049376	0.070904516	0.103995425	0.288922935	0.070904516	4.074817112
People Damage	0.563683419	0.80459251	0.35452258	0.519977126	2.242775636	0.519977126	4.313219803
						λ_{max}	4.183603946
						CI	0.061201315
						CR	0.068001462

Figure 12: Level 2: Sub-criteria Comparisons

One might ask, why PM is 7 times more important than CM when compared with respect to the production loss sub criteria, while it's only 4 times more important when compared with respect to the equipment damage?. The answer to such question is the core idea for AHP method that makes it flexible and suitable for a variety of situations. As AHP pairwise comparisons are done to simplify the complexity of such problems, so it is not wise to compare between the pairwise comparisons. That comparison is done by the consistency ratio check. Consistency Check detects any contradictions in the matrix. An example for these contradictions, let's assume we have three alternatives (A, B& C). (A) is two times more important than (B), while (B) is three times more important than (C). Can option (C) be more important than (A)? Of course not, as it will be inconsistent with the first two arguments. So it should be (A) is more important than (C).

For the sake of argument, the answer to the above mentioned question is that the difference in the values is related to both the nature of the sub criteria and the equipment itself. In other words, when implementing CM on gas turbine “A” the damage impact on the machine will not be as high as the production loss caused, due to the multi-layer protection installed to protect the turbine (temperature, pressure, vibration sensors), so the equipment will either trip or the performance will degrade (in case of compressor fouling), both will affect the production and cause production loss.

For the applicability criteria only has two sub-criteria, there is no need to do pairwise comparison. According to a survey done in site by maintenance personnel, it was agreed that investment required to apply the maintenance strategy has a weight of (0.4) compared to (0.6) for the reliability of the strategy regarding gas turbine “A”.

The final map with the global weights (shown in Appendix “B”) indicated that Predictive maintenance strategy is ranked as the first alternative to be followed, while the corrective maintenance strategy is the last. This map is only applicable for Gas Turbine “A” and for the current operation mode. Due to the difference in operation mode between gas turbine “A” and gas turbines “B&C”. Calculation was done for both separately. Gas turbine “B” calculation can be found in appendix “E”. However AHP ranking results for both systems are similar to each other, due to the similarity in many other aspects.

3.3 Nitrogen Generation Backup Compressors background:

As done in gas compression train "A", a brief introduction for the Nitrogen (N2) system criticality will be presented before the calculation. The only use of Nitrogen gas at PHPC Processing plant is to act as buffer gas in the Dry Gas Seal (DGS) (figure 13) installed on each gas compressor. The DGS plays an important role in preventing the compressed gas from escaping around the shaft and also prevents any possible mixing between lubrication oil for shaft bearings and compressed gas. Each compressor has two DGS's installed on its shaft, one at the turbine side (Drive End DE) and the other at the non-drive end side (NDE). It should be noted here that in case of failure of any of the DGS's installed on the compressor, the whole compression train is tripped immediately and considered out of service till the replacement of the failed DGS is performed by the maintenance team. One of the main reasons that can cause the DGS to fail is the absence of the Nitrogen gas.

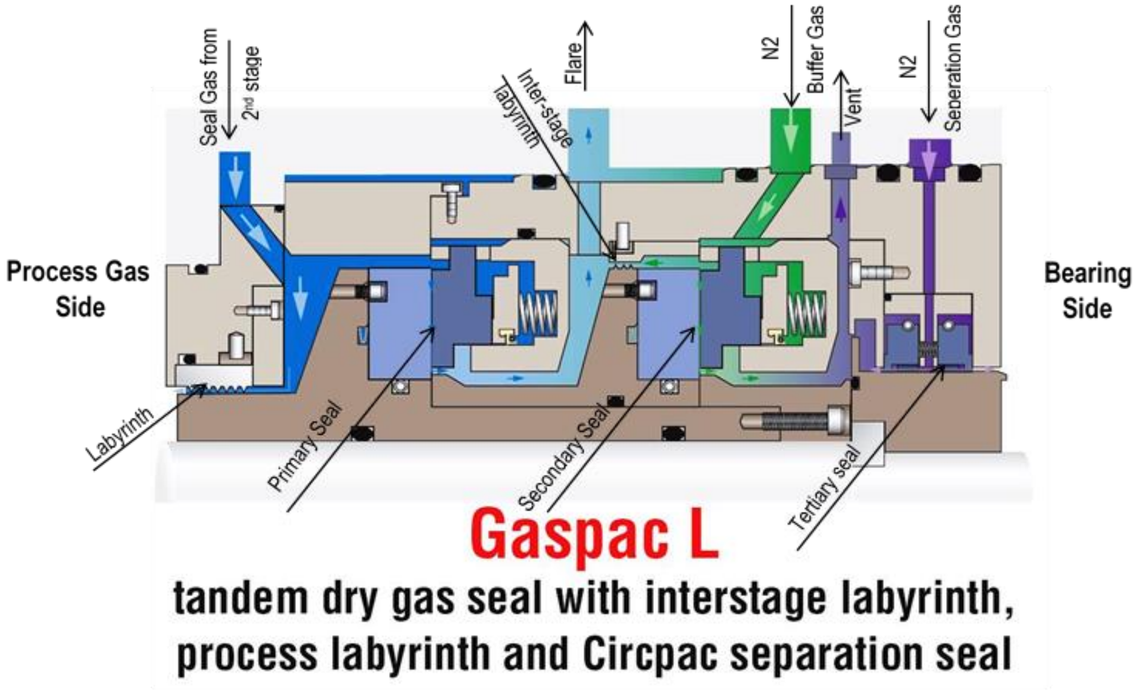

Figure 13: Dry Gas Seal (DGS) working Principle (courtesy of Flowserve Cooperation)

PHPC operates three Nitrogen generation packages (figure11), all of the three are working continuously to provide N2 to the DGS's, whether the compression train is running or standby. In case of Electricity blackout, all running gas turbines will be tripped as well as the N2 generation packages. The shaft of the gas turbine will not come to a complete stop after the shutdown immediately, it takes four hours running on slow roll mode to prevent bowing of the shaft. As the shaft is running, the lubrication is supplied by the means of the DC backup pump (running on Batteries). This means that there will be lubrication without N2 to buffer it. Such a case will cause the DGS to be damaged due to the lubrication oil going inside the seal, which will damage the seal faces.

For this emergency case, PHPC commissioned the N2 Backup compressor (N2 B/up). The N2 B/up Compressor main purpose, as mention earlier, is to compress N2 Gas generated by the N2 generation packages and store it at a pressure of 100 bar in the Bullet. In case of blackout, the DGS N2 supply is sourced from the bullet, which can supply the three compressors for the whole slow roll time period. After the black out, when the electricity is back, the N2 compressor is operated to charge the bullet. PHPC has two identical N2 compressors. Both are reciprocating diaphragm type. In normal operation, the bullet is fully charged, and the compressors are in standby mode. It should be noted here that the frequency of the black starts per year is from 1 to 2 times base on the last four years. Also, in case of black start two air compressors and two nitrogen packages are connected to port said national electricity grid and can be operated normally.

After performing the AHP calculation on N2 Backup compressor, it was found that the Corrective maintenance is the best to follow for such an equipment. Calculations can be found in Appendix "C"

3.4 Air Compressors & Dryers operational background:

PHPC currently have seven screw compressors, all the compressors are connected on a sequencer controller that is responsible for starting and stopping the compressors based on the compressed air network pressure. Normal Air consumption in the plant requires three to four compressors running, the remaining units are in standby.

As mentioned earlier, the use of air compressors in the plant is to provide the instrument air at 8 bar for all instrument devices such as Air actuated valves (Shut down valves SDV, Blowdown valves BDV,…etc.). This is very critical to continuous operation, as in case of air loss, each valve will take its failsafe action. For example the BDV on the gas turbine will open 100% releasing all compressed gas to the flare. And the SDV for the suction and discharge will be closed 100%, as well as the fuel supply SDV. Any of those situations will cause the compression train to be tripped immediately and will cause production deferral.

Also the failure of multiple air compressors might cause a failure to the N2 generation package, depending on the arrival air pressure to the package. Another usage for the instrument compressed air is the Huff& Puff System that is installed on the Air intake filters for the three Gas Turbines. The Huff & Puff system uses the instrument air to self-clean the air intake filters every day and is activated also in case of high differential pressure across the filters.

The Air Dryer assures the removal of any moisture or water existing in the air, to protect the instrument devices such as pressure regulators, oxygen sensors ...etc. PHPC operates four air dryers that uses adsorbent such as activated alumina or silica gel to remove any moisture from the compressed air. Normal operation requires only two dryers in operation, while the others two are in standby.

Although air dryer is very important to remove the moisture in air, in case of their failure operation team can bypass the dryers till the problem is rectified by maintenance team. Most of the application has its own filters that will reduce the amount of any moisture existing in the compressed air. Calculation for Air dryer and Air Compressors can be found in Appendix “D” and “F” respectively.

4- Results &Analysis

AHP approach showed that, predictive maintenance is the first alternative for both gas turbines, Air compressors and Nitrogen generation packages. Corrective maintenance was found to be the most suitable for the both Nitrogen compressor and air dryer. Figure (14) represents graphically the final results for the AHP. From the point of view of available resources, it does make sense that the available resources used to adopt PM for the six studied systems is almost the same for adopting PDM for four systems and CM for the other two systems. This is can be seen as resources allocation and utilization.

It was not a surprise that PDM is the most suitable for Gas turbines. As they are very critical to the production, and also due to their high asset cost. Any type of equipment damage cannot be tolerated for such an equipment, and PDM is the only strategy that can predict the failures and prevent them. Also, the cost of implementing such a system for the gas turbines will not be that costly, as the system infrastructure is already installed.

When comparing the value of the global weight of the PDM for all studied equipment, one can wonder why the nitrogen generation package has a higher value than the gas turbines? The answer to this question is the redundancy of the equipment and the implementation cost. One of the advantage of using AHP for this problem is integrating the redundancy into the final decision. Redundancy was represented inside the applicability criteria under the reliability sub-criteria, also integrated under the production loss sub criteria. Nitrogen generation package mode of operation is continuous for the three existing packages, so no redundancy at all, while gas turbines mode of operation is only one running continuously and the other two are in standby condition (For Ha'py gas) and in case of atoll gas, the free flow line represent a redundant production method. Also for such a small system as the N2 package, low investment is needed to adopt PDM unlike a huge system as the gas compression train. So predictive maintenance is highly favorable to be adopted regarding the N2 generation package.

Corrective maintenance was chosen by AHP for N2 backup compressor, which do make sense. As since the commissioning of the system back in 2016, it has only been used twice, given also the existence of standby compressor (redundancy) and also the fully charged bullet vessel. An extra redundancy for this system, is that even in cases of power failures, two Nitrogen generation packages can be operated by Port Said national electricity grid.

When checking the ranking generated by AHP for the N2 backup compressor, one can't help to notice that the second alternative is the predictive maintenance. The reason for favoring PDM over PM is that the implementation cost for PDM is much lower than PM spare parts cost. Also, the complexity of the system associated with its high asset cost compared to the N2 Package.

Air dryer was actually expected to have the preventive maintenance as the first alternative, while AHP selection was the corrective maintenance. One of the reasons behind such a selection is related to the weight of the cost criteria (0.54) when compared to the weight of the damage criteria (0.3). For such a simple system (low asset cost) with no rotating parts, and with two units standby (redundancy), the damage to production, people or environment is highly unlikely.

Although air dryers is connected to the air compressors (process wise), and both are considered utility facilities, not production, air compressor results recommended the adoption of predictive maintenance. This can be explained by the different nature of each equipment, as the compressor contains rotating parts, which make the equipment damage expensive.

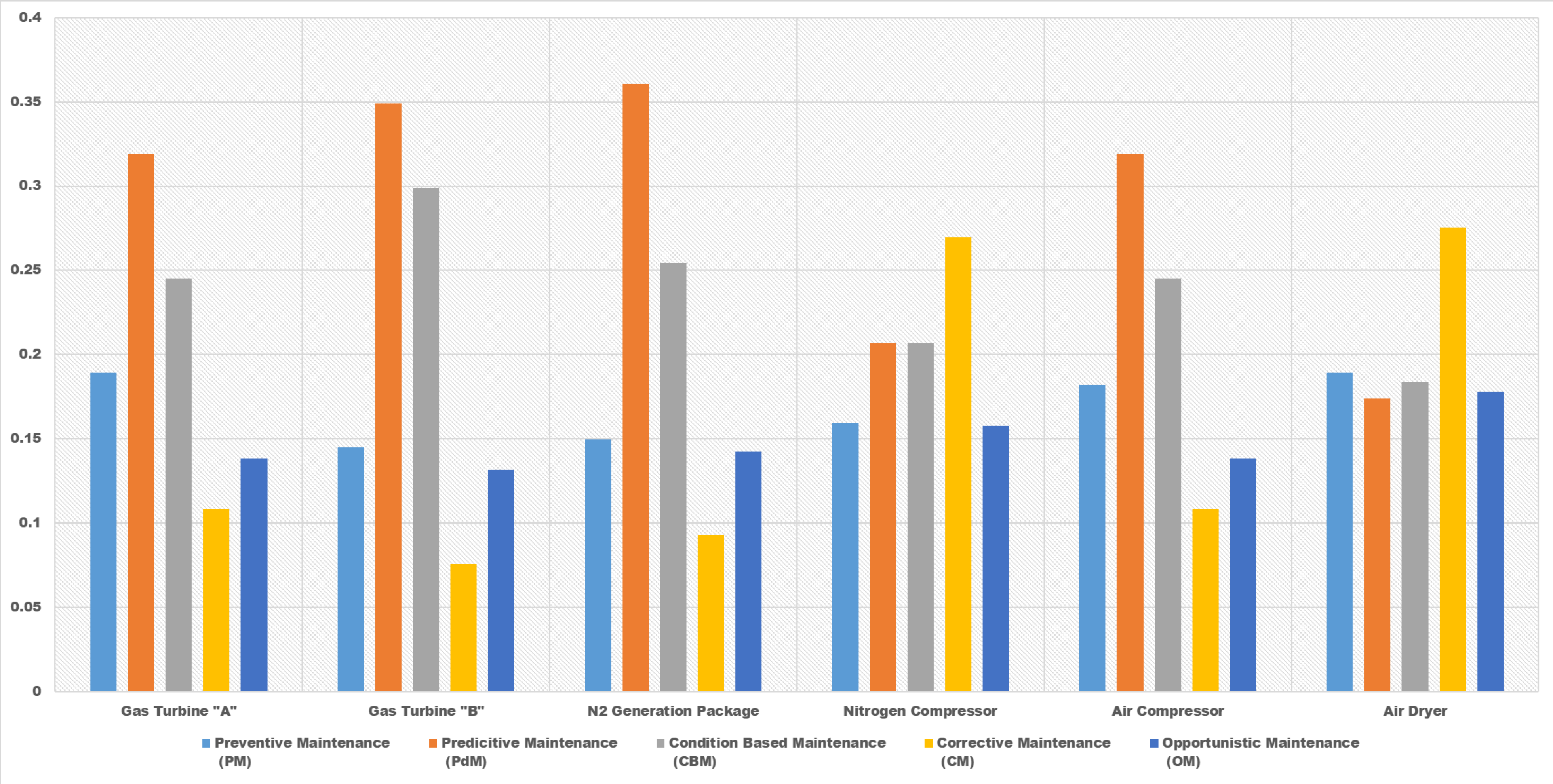

Figure 14: AHP Final Results

5- Conclusion

The definition of the best maintenance strategy for an oil and gas company such as PHPC requires developing a well-defined decision support systems. The selection of the maintenance strategy and the maintenance plan for each equipment can be very confusing, due to the complexity of such a problem. This complexity is due to Data collection difficulties, how many factors to be taken into account? And how to measure and judge each factor?

The Analytic hierarchy process (AHP), showed a great flexibility and robustness in solving such a complex problem. Not only that the Mathematical optimization models' creation would be very difficult in such a problem, but also it will not be able to account for all factors especially the qualitative ones. AHP shows a perfect integration between both qualitative and quantitative data.

In this project report, AHP was used to help maintenance managers at PHPC to select the best maintenance strategy for each equipment. The decision was based on criticality to production, redundancy existence, safety compliance, applicability of the proposed strategy, cost associated with the implementation and the equipment availability. AHP results indicated that the current followed strategy is not the best, and recommended the adoption of predictive maintenance strategy for gas turbines, air compressors and nitrogen packages, while recommended corrective maintenance strategy for the air dryer and nitrogen compressor.

Following the recommendation of AHP analysis would have a huge impact not only on the total maintenance cost but also on the production rates as well as process safety. Cost savings can be represented in spare parts inventory reduction, also it can be sensed in utilizing company's resources. As the current followed system (TBPM) generates unnecessary maintenance work for all factory equipment. The production rates will increase as the unplanned shutdowns decrease due to shifting to the proposed strategies.

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7- Appendices

7-1 Appendix "A" Nitrogen Generation Package Calculations

N2 Gen	Damage	Applicability	Cost
Damage	1.00	3.00	5.00
Applicability	0.33	1.00	2.00
Cost	0.20	0.50	1.00
Summ	1.53	4.50	8.00

with respect to MS applied on N2 Generation Package , how important is Damage when compared to cost?

N2 Gen	Damage	Applicability	Cost	Criteria Weight
Damage	0.65	0.67	0.63	0.64794686
Applicability	0.22	0.22	0.25	0.229871176
Cost	0.13	0.11	0.13	0.122181965

N2 Gen	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.647947	0.689614	0.610910	1.95	0.64794686	3.007145
Applicability	0.215982	0.229871	0.244364	0.69	0.229871176	3.002627
Cost	0.129589	0.114936	0.122182	0.37	0.122181965	3.001318
					λ_{max}	3.003697
					CI	0.001848
					CR	0.003187

N2 Gen	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	5	8	9
Equipment Damage	0.2	1	4	5
Environmental Damage	0.125	0.25	1	2
People Damage	0.111111111	0.2	0.5	1
Summ	1.436111111	6.45	13.5	17

with respect to the damage criteria, how important is the production losswhen compared to the people damage for the N2 generation package? Environmental damage& people damage are highly unlikely with such an equipment, while the production loss can be caused due to DGS

Normalized N2 Gen	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.696324952	0.775193798	0.592592593	0.529411765	0.648380777
Equipment Damage	0.13926499	0.15503876	0.296296296	0.294117647	0.221179423
Environmental Damage	0.087040619	0.03875969	0.074074074	0.117647059	0.07938036
People Damage	0.077369439	0.031007752	0.037037037	0.058823529	0.051059439

N2 Gen	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.648380777	1.105897117	0.635042884	0.459534954	2.848855731	0.648380777	4.393800423
Equipment Damage	0.129676155	0.221179423	0.317521442	0.255297197	0.923674217	0.221179423	4.176130869
Environmental Damage	0.081047597	0.055294856	0.07938036	0.102118879	0.317841692	0.07938036	4.004034377
People Damage	0.072042309	0.044235885	0.03969018	0.051059439	0.207027813	0.051059439	4.054643282
						λ_{max}	4.157152238
						CI	0.052384079
						CR	0.058204532

Production Loss/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	5.00	1.00
PDM	3.00	1.00	2.00	7.00	3.00
CBM	2.00	0.50	1.00	5.00	2.00
CM	0.20	0.14	0.20	1.00	0.20
OM	1.00	0.33	0.50	5.00	1.00
	7.20	2.31	4.20	23.00	7.20

Ex: with respect to the production loss sub-criteria, how important is PM when compared to CM? which one can reduce the production loss, the decsion is based from previous failures of the N2 packages, when the PM strategy was followed. For example, if pm was not carried on inlet filters (cm) by replacing them every 6 months, the unit can be tripped due to clogged filters. pdm monitor the dp across the filter and decide the optimum replacement type (plan the downtime for maint)

Production Loss/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.138889	0.144330	0.119048	0.217391	0.138889	0.151709
PDM	0.416667	0.432990	0.476190	0.304348	0.416667	0.409372
CBM	0.277778	0.216495	0.238095	0.217391	0.277778	0.245507
CM	0.027778	0.061856	0.047619	0.043478	0.027778	0.041702
OM	0.138889	0.144330	0.119048	0.217391	0.138889	0.151709

Production Loss/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.151709	0.136457	0.122754	0.208509	0.151709	0.771138	0.151709	5.0829988
PDM	0.455128	0.409372	0.491015	0.291912	0.455128	2.102555	0.409372	5.1360463
CBM	0.303419	0.204686	0.245507	0.208509	0.303419	1.265539	0.245507	5.15479123
CM	0.030342	0.058482	0.049101	0.041702	0.030342	0.209969	0.041702	5.03501369
OM	0.151709	0.136457	0.122754	0.208509	0.151709	0.771138	0.151709	5.0829988
							λ_{max}	5.09836976
							CI	0.02459244
							CR	0.02195754

Equipment Damage/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	4.00	1.00
PDM	2.00	1.00	1.00	5.00	2.00
CBM	2.00	1.00	1.00	5.00	2.00
CM	0.25	0.20	0.20	1.00	0.25
OM	1.00	0.50	0.50	4.00	1.00
	6.25	3.20	3.20	19.00	6.25

with respect to sub-criteria of equipment damage, how important is PM when compared to CM? which can cause less damage to equipment when implemeted ? Due to the protection on the package the difference between the alternatives is not high. Ex: in case of liuid buildup in the filters drain , there is a level switch that signals a solenoid to open to empty the drain. if solenoid malfunctioned due to following (cm) the level switch will trigger high level alarm and trip the equipment, in case of level swich also malfunctioning, the logic it self open the drain every fixed time interval (15 min). when both fail a liquid will be introduced to the packge which will be drained from the carbon filter drain. so thers is multiple barrier to protec the equipment with low probability of similtenaeous failure of them all.

Equipment Damage/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.160000	0.156250	0.156250	0.210526	0.160000	0.168605
PDM	0.320000	0.312500	0.312500	0.263158	0.320000	0.305632
CBM	0.320000	0.312500	0.312500	0.263158	0.320000	0.305632
CM	0.040000	0.062500	0.062500	0.052632	0.040000	0.051526
OM	0.160000	0.156250	0.156250	0.210526	0.160000	0.168605

Equipment Damage/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.168605	0.152816	0.152816	0.206105	0.168605	0.848947	0.168605	5.03511784
PDM	0.337211	0.305632	0.305632	0.257632	0.337211	1.543316	0.305632	5.04959532
CBM	0.337211	0.305632	0.305632	0.257632	0.337211	1.543316	0.305632	5.04959532
CM	0.042151	0.061126	0.061126	0.051526	0.042151	0.258082	0.051526	5.0087334
OM	0.168605	0.152816	0.152816	0.206105	0.168605	0.848947	0.168605	5.03511784
							λ_{max}	5.03563194
							CI	0.00890799
							CR	0.00795356

Environmental Damage/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	3.00	1.00
PDM	2.00	1.00	1.00	4.00	2.00
CBM	2.00	1.00	1.00	4.00	2.00
CM	0.33	0.25	0.25	1.00	0.33
OM	1.00	0.50	0.50	3.00	1.00
	6.33	3.25	3.25	15.00	6.33

the environmental damage caused by implementing or adobting any maintenence policy , for the N2 generation system the impact on the environment can be the release of N2 gas to the atmosphere due to malfunction of the discharge three way valve, which also can affect nearby personnel as the vent is 3m hieht from the ground.

Environmental Damage/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.157895	0.153846	0.153846	0.200000	0.157895	0.164696
PDM	0.315789	0.307692	0.307692	0.266667	0.315789	0.302726
CBM	0.315789	0.307692	0.307692	0.266667	0.315789	0.302726
CM	0.052632	0.076923	0.076923	0.066667	0.052632	0.065155
OM	0.157895	0.153846	0.153846	0.200000	0.157895	0.164696

Environmental Damage/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.164696	0.151363	0.151363	0.195466	0.164696	0.827584	0.164696	5.02490987
PDM	0.329393	0.302726	0.302726	0.260621	0.329393	1.524858	0.302726	5.03708987
CBM	0.329393	0.302726	0.302726	0.260621	0.329393	1.524858	0.302726	5.03708987
CM	0.054899	0.075682	0.075682	0.065155	0.054899	0.326316	0.065155	5.008285
OM	0.164696	0.151363	0.151363	0.195466	0.164696	0.827584	0.164696	5.02490987
							λ_{max}	5.0264569
							CI	0.00661422
							CR	0.00590556

People Damage/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	2.00	1.00
PDM	1.00	1.00	1.00	2.00	1.00
CBM	1.00	1.00	1.00	2.00	1.00
CM	0.50	0.50	0.50	1.00	0.50
OM	1.00	1.00	1.00	2.00	1.00
	4.50	4.50	4.50	9.00	4.50

the generation package doesn’t include any rotating element ad does not operate under high pressure to propose risk on humans, the greatest risk is leakage of N2 gas to atmosphere or venting to atmosphere due to malfunfunction of logic, valve , sensor,...

People Damage/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.222222	0.222222	0.222222	0.222222	0.222222	0.222222
PDM	0.222222	0.222222	0.222222	0.222222	0.222222	0.222222
CBM	0.222222	0.222222	0.222222	0.222222	0.222222	0.222222
CM	0.111111	0.111111	0.111111	0.111111	0.111111	0.111111
OM	0.222222	0.222222	0.222222	0.222222	0.222222	0.222222

People Damage/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.222222	0.222222	0.222222	0.222222	0.222222	1.111111	0.222222	5
PDM	0.222222	0.222222	0.222222	0.222222	0.222222	1.111111	0.222222	5
CBM	0.222222	0.222222	0.222222	0.222222	0.222222	1.111111	0.222222	5
CM	0.111111	0.111111	0.111111	0.111111	0.111111	0.555556	0.111111	5
OM	0.222222	0.222222	0.222222	0.222222	0.222222	1.111111	0.222222	5
							λ_{max}	5
							CI	0
							CR	0

Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.648380777	0.221179423	0.07938036	0.051059439	1
PM	0.151709	0.168605	0.164696	0.222222	0.16007762
PDM	0.409372	0.305632	0.302726	0.222222	0.368405568
CBM	0.245507	0.305632	0.302726	0.222222	0.262158732
CM	0.041702	0.051526	0.065155	0.111111	0.04928046
OM	0.151709	0.168605	0.164696	0.222222	0.16007762

	Production Loss	Equipment Damage	Environmental Damage	People Damage
map weight	0.420116288	0.143312513	0.051434255	0.033083803

N2 Gen	MTBF	MTTR	Spare Parts	Assurance Spare
MTBF	1	4	6	5
MTTR	0.25	1	5	4
Spare Parts	0.166666667	0.2	1	0.5
Assurance Spares	0.2	0.25	2	1
Summ	1.616666667	5.45	14	10.5

with respect to cost criteria , how important is spare parts cost when compared with assurance spares cost for the N2 Generation package?
For the N2 generation package, the assurance spares cost is not much higher than the regular spares due to the simplicity of the equipment? not like gas tubine. the assurance for this equipmet is the controller, the 3 way valve and the heater.

Normalized N2 Gen	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight
MTBF	0.618556701	0.733944954	0.428571429	0.476190476	0.56431589
MTTR	0.154639175	0.183486239	0.357142857	0.380952381	0.269055163
Spare Parts	0.103092784	0.036697248	0.071428571	0.047619048	0.064709413
Assurance Spares	0.12371134	0.04587156	0.142857143	0.095238095	0.101919534

N2 Gen	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.56431589	1.076220652	0.388256475	0.509597672	2.53839069	0.56431589	4.498173336
MTTR	0.141078972	0.269055163	0.323547063	0.407678138	1.141359336	0.269055163	4.242101596
Spare Parts	0.094052648	0.053811033	0.064709413	0.050959767	0.263532861	0.064709413	4.072558385
Assurance Spares	0.112863178	0.067263791	0.129418825	0.101919534	0.411465328	0.101919534	4.037158631
						λ_{max}	4.212497987
						CI	0.070832662
						CR	0.078702958

MTBF/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	6.00	1.00
PDM	3.00	1.00	2.00	9.00	3.00
CBM	2.00	0.50	1.00	8.00	2.00
CM	0.17	0.11	0.13	1.00	0.17
OM	1.00	0.33	0.50	6.00	1.00
	7.17	2.28	4.13	30.00	7.17

with respect to cost sub-criteria MTBF, how important is PM, when compared to cm? which will generate cost reduction or incresae the MTBF's? PDM will increase the MTBF , as it will predict the failure of the equipment, also the CBM will intervene before the failure occurs. while the CM will reduce the MTBF and increase the cost aasociated.

MTBF/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.139535	0.146341	0.121212	0.200000	0.139535	0.149325
PDM	0.418605	0.439024	0.484848	0.300000	0.418605	0.412216
CBM	0.279070	0.219512	0.242424	0.266667	0.279070	0.257349
CM	0.023256	0.048780	0.030303	0.033333	0.023256	0.031786
OM	0.139535	0.146341	0.121212	0.200000	0.139535	0.149325

MTBF/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.149325	0.137405	0.128674	0.190714	0.149325	0.755443	0.149325	5.0590653
PDM	0.447974	0.412216	0.514697	0.286071	0.447974	2.108933	0.412216	5.11608125
CBM	0.298649	0.206108	0.257349	0.254286	0.298649	1.315041	0.257349	5.10996121
CM	0.024887	0.045802	0.032169	0.031786	0.024887	0.159531	0.031786	5.01895503
OM	0.149325	0.137405	0.128674	0.190714	0.149325	0.755443	0.149325	5.0590653
							λ_{max}	5.07262562
							CI	0.0181564
							CR	0.01621108

MTTR/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.25	7.00	1.00
PDM	5.00	1.00	2.00	9.00	5.00
CBM	4.00	0.50	1.00	8.00	4.00
CM	0.14	0.11	0.13	1.00	0.14
OM	1.00	0.20	0.25	7.00	1.00
	11.14	2.01	3.63	32.00	11.14

with respect to cost sub-criteria MTTR, how important is PM, when compared to cm? which will generate cost reduction or reduce the MTTR? PDM will reduce the MTTR , as it will plan the downtime and prepare the maintenance plan along with spares required before the machine stopped, while the CM will increase the MTTR and increase the cost aasociated, as its need time for troubleshotting the problem and invistigate the failure and prepare material, manpower, plan. all of which is done while the equipment is under failuer.

MTTR/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.089744	0.099448	0.068966	0.218750	0.089744	0.113330
PDM	0.448718	0.497238	0.551724	0.281250	0.448718	0.445530
CBM	0.358974	0.248619	0.275862	0.250000	0.358974	0.298486
CM	0.012821	0.055249	0.034483	0.031250	0.012821	0.029324
OM	0.089744	0.099448	0.068966	0.218750	0.089744	0.113330

MTTR/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.113330	0.089106	0.074621	0.205271	0.113330	0.595659	0.113330	5.25596585
PDM	0.566650	0.445530	0.596972	0.263920	0.566650	2.439722	0.445530	5.47600548
CBM	0.453320	0.222765	0.298486	0.234596	0.453320	1.662487	0.298486	5.56973303
CM	0.016190	0.049503	0.037311	0.029324	0.016190	0.148519	0.029324	5.06465959
OM	0.113330	0.089106	0.074621	0.205271	0.113330	0.595659	0.113330	5.25596585
							λ_{max}	5.32446596
							CI	0.08111649
							CR	0.07242544

Spare Parts/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.25	0.33	0.14	1.00
PDM	4.00	1.00	2.00	0.25	4.00
CBM	3.00	0.50	1.00	0.20	3.00
CM	7.00	4.00	5.00	1.00	7.00
OM	1.00	0.25	0.33	0.14	1.00
	16.00	6.00	8.67	1.74	16.00

with respect to the subcriteria of spare parts cost, how important is PM when compared to CM? which will generate more savings in the spare parts cost. As the PM is timely based, it requires huge inventory to be instock especially with long lead times for procuring the spares. so PHPC should have the spares for two upcoming years in the

Spare Parts/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.062500	0.041667	0.038462	0.082305	0.062500	0.057487
PDM	0.250000	0.166667	0.230769	0.144033	0.250000	0.208294
CBM	0.187500	0.083333	0.115385	0.115226	0.187500	0.137789
CM	0.437500	0.666667	0.576923	0.576132	0.437500	0.538944
OM	0.062500	0.041667	0.038462	0.082305	0.062500	0.057487

Spare Parts/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.057487	0.052073	0.045930	0.076992	0.057487	0.289968	0.057487	5.04410531
PDM	0.229946	0.208294	0.275578	0.134736	0.229946	1.078500	0.208294	5.17778305
CBM	0.172460	0.104147	0.137789	0.107789	0.172460	0.694644	0.137789	5.04136465
CM	0.402406	0.833175	0.688944	0.538944	0.402406	2.865875	0.538944	5.31757243
OM	0.057487	0.052073	0.045930	0.076992	0.057487	0.289968	0.057487	5.04410531
							λ_{max}	5.12498615
							CI	0.03124654
							CR	0.02789869

Assurance Spares/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	4.00	1.00
PDM	2.00	1.00	1.00	5.00	2.00
CBM	2.00	1.00	1.00	5.00	2.00
CM	0.25	0.20	0.20	1.00	0.25
OM	1.00	0.50	0.50	4.00	1.00
	6.25	3.20	3.20	19.00	6.25

with respect to subcriteria of assurance spare parts cost, how important is PM when compared to CM for the N2 Generation package? Which will generate savings in the cost of assurance spares. It shoud be noted here that in any maintenance stratgies PHPC will purchase intially all assurance, so the comparison here is for the cosumption of assurance. ex: by adopting CM strategy, a liquid may be introduced to the membrane system , and over long period of time, this membrane will need to be changed.

Assurance Spares/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.160000	0.156250	0.156250	0.210526	0.160000	0.168605
PDM	0.320000	0.312500	0.312500	0.263158	0.320000	0.305632
CBM	0.320000	0.312500	0.312500	0.263158	0.320000	0.305632
CM	0.040000	0.062500	0.062500	0.052632	0.040000	0.051526
OM	0.160000	0.156250	0.156250	0.210526	0.160000	0.168605

Assurance Spares/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.168605	0.152816	0.152816	0.206105	0.168605	0.848947	0.168605	5.03511784
PDM	0.337211	0.305632	0.305632	0.257632	0.337211	1.543316	0.305632	5.04959532
CBM	0.337211	0.305632	0.305632	0.257632	0.337211	1.543316	0.305632	5.04959532
CM	0.042151	0.061126	0.061126	0.051526	0.042151	0.258082	0.051526	5.0087334
OM	0.168605	0.152816	0.152816	0.206105	0.168605	0.848947	0.168605	5.03511784
							λ_{max}	5.03563194
							CI	0.00890799
							CR	0.00795356

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.56431589	0.269055163	0.064709413	0.101919534	1
PM	0.149325	0.113330	0.057487	0.168605	**0.135662408**
PDM	0.412216	0.445530	0.208294	0.305632	**0.397120698**
CBM	0.257349	0.298486	0.137789	0.305632	**0.265601104**
CM	0.031786	0.029324	0.538944	0.051526	**0.065953382**
OM	0.149325	0.113330	0.057487	0.168605	**0.135662408**

	MTBF	MTTR	Spare Parts	Assurance Spare
Map weight	0.068949224	0.032873688	0.007906323	0.012452729

Investment/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	3.00	1.00	0.17	1.00
PDM	0.33	1.00	0.33	0.13	0.33
CBM	1.00	3.00	1.00	0.17	1.00
CM	6.00	8.00	6.00	1.00	6.00
OM	1.00	3.00	1.00	0.17	1.00
	9.33	18.00	9.33	1.63	9.33

with respect to sub criteria of investment required, how important is PM compared to Cm? which will require less investment ? It should be noted here that for this equipment there is Differntial pressure gauges installed on all filters, pressure relief valves on the carbon filter vessel temperature sensors and pressure gauges oxygen sensor. Also there is no rotating parts, so there is no need for oil analysis or vibration analysis. that is why cbm investment is the same for PM, while PDM is higher as it need a software to analyze the data and predict the failure.

Investment/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.107143	0.166667	0.107143	0.102564	0.107143	0.118132
PDM	0.035714	0.055556	0.035714	0.076923	0.035714	0.047924
CBM	0.107143	0.166667	0.107143	0.102564	0.107143	0.118132
CM	0.642857	0.444444	0.642857	0.615385	0.642857	0.597680
OM	0.107143	0.166667	0.107143	0.102564	0.107143	0.118132

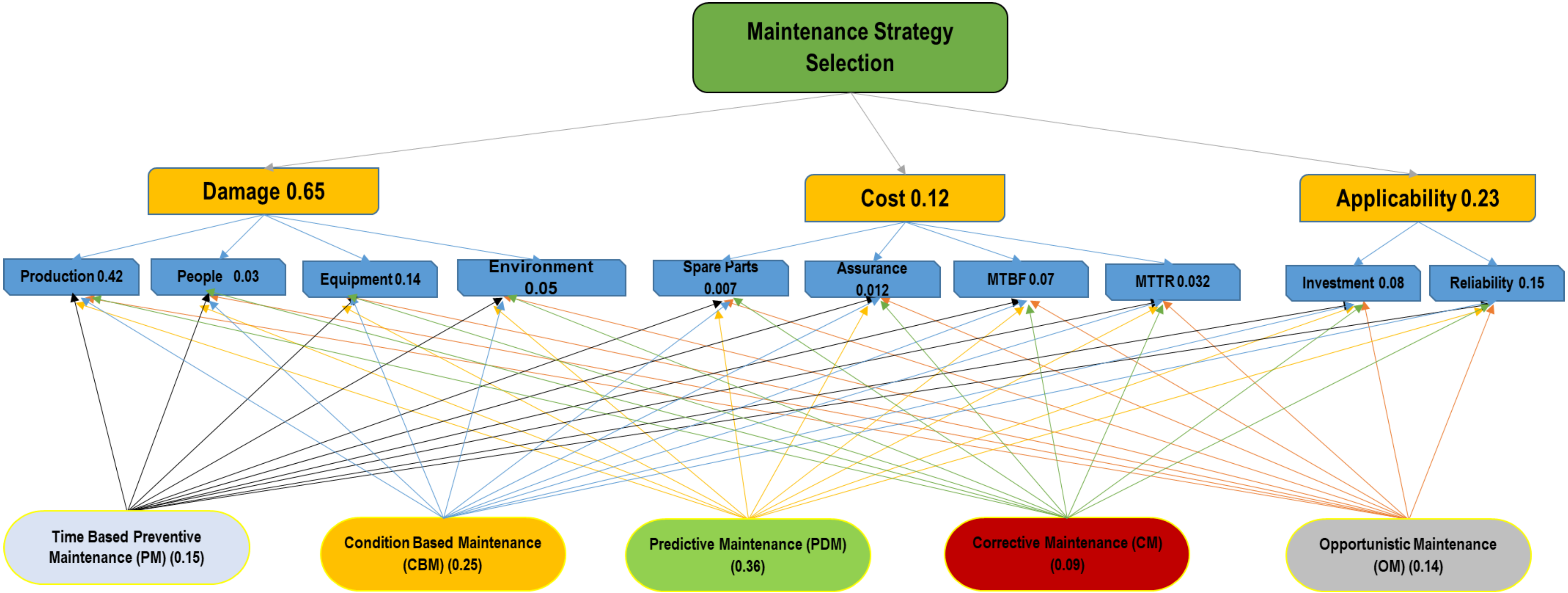
Investment/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.118132	0.143773	0.118132	0.099613	0.118132	0.597782	0.118132	5.06029285
PDM	0.039377	0.047924	0.039377	0.074710	0.039377	0.240766	0.047924	5.02388535
CBM	0.118132	0.143773	0.118132	0.099613	0.118132	0.597782	0.118132	5.06029285
CM	0.708791	0.383394	0.708791	0.597680	0.708791	3.107448	0.597680	5.19918284
OM	0.118132	0.143773	0.118132	0.099613	0.118132	0.597782	0.118132	5.06029285
							λ_{max}	5.08078935
							CI	0.02019734
							CR	0.01803334

Reliability/N2 Gen	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.33	6.00	2.00
PDM	5.00	1.00	2.00	9.00	6.00
CBM	3.00	0.50	1.00	8.00	4.00
CM	0.17	0.11	0.13	1.00	0.25
OM	0.50	0.17	0.25	4.00	1.00
	9.67	1.98	3.71	28.00	13.25

Reliability/N2 Gen	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.103448	0.101124	0.089888	0.214286	0.150943	0.131938
PDM	0.517241	0.505618	0.539326	0.321429	0.452830	0.467289
CBM	0.310345	0.252809	0.269663	0.285714	0.301887	0.284084
CM	0.017241	0.056180	0.033708	0.035714	0.018868	0.032342
OM	0.051724	0.084270	0.067416	0.142857	0.075472	0.084348

Reliability/N2 Gen	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.131938	0.093458	0.094695	0.194053	0.168695	0.682839	0.131938	5.17546313
PDM	0.659689	0.467289	0.568167	0.291080	0.506086	2.492311	0.467289	5.3335557
CBM	0.395813	0.233644	0.284084	0.258738	0.337391	1.509670	0.284084	5.3141751
CM	0.021990	0.051921	0.035510	0.032342	0.021087	0.162850	0.032342	5.0352164
OM	0.065969	0.077881	0.071021	0.129369	0.084348	0.428588	0.084348	5.08120561
							λ_{max}	5.18792319
							CI	0.0469808
							CR	0.04194714

Criteria / Alternative	Invest	Reliability	Final Score
	0.35	0.65	1
PM	0.118132	0.131938	0.127105675
PDM	0.047924	0.467289	0.320511219
CBM	0.118132	0.284084	0.22600047
CM	0.597680	0.032342	0.230210494
OM	0.118132	0.084348	0.096172142
	Invest	Reliability	
Map weight	0.080454911	0.149416264	



Alternative \ Criteria	Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final Weights
	0.420116288	0.143312513	0.051434255	0.033083803	0.068949	0.032874	0.007906323	0.012452729	0.080455	0.149416	
PM	0.15170932	0.168605263	0.164696356	0.222222222	0.149325	0.11333	0.057486546	0.168605263	0.118132	0.131938	0.149515
PDM	0.409372265	0.305631579	0.302726046	0.222222222	0.412216	0.44553	0.208293764	0.305631579	0.047924	0.467289	0.360905
CBM	0.245507389	0.305631579	0.302726046	0.222222222	0.257349	0.298486	0.137788857	0.305631579	0.118132	0.284084	0.254268
CM	0.041701707	0.051526316	0.065155196	0.111111111	0.031786	0.029324	0.538944286	0.051526316	0.59768	0.032342	0.092908
OM	0.15170932	0.168605263	0.164696356	0.222222222	0.149325	0.11333	0.057486546	0.168605263	0.118132	0.084348	0.142404

7-2 Appendix "B" Gas Turbine "A" Calculations

Gas Turbine "A"	Damage	Applicability	Cost
Damage	1.00	5.00	7.00
Applicability	0.20	1.00	3.00
Cost	0.14	0.33	1.00
Summ	1.34	6.33	11.00

Gas Turbine "A"	Damage	Applicability	Cost	Criteria Weight
Damage	0.74	0.79	0.64	0.723506057
Applicability	0.15	0.16	0.27	0.19318606
Cost	0.11	0.05	0.09	0.083307883

Gas Turbine "A"	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.72	0.97	0.58	2.27	0.723506057	3.141081563
Applicability	0.14	0.19	0.25	0.59	0.19318606	3.042719129
Cost	0.10	0.06	0.08	0.25	0.083307883	3.01365532
					λ_{max}	3.06581867
					CI	0.032909335
					CR	0.056740233

Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	0.333333333	3	0.25
Equipment Damage	3	1	4	0.333333333
Environmental Damage	0.333333333	0.25	1	0.2
People Damage	4	3	5	1
Summ	8.333333333	4.583333333	13	1.783333333

Normalized Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.12	0.072727273	0.230769231	0.140186916	0.140920855
Equipment Damage	0.36	0.218181818	0.307692308	0.186915888	0.268197503
Environmental Damage	0.04	0.054545455	0.076923077	0.112149533	0.070904516
People Damage	0.48	0.654545455	0.384615385	0.560747664	0.519977126

Gas Turbine "A"	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.140920855	0.089399168	0.212713548	0.129994281	0.573027852	0.140920855	4.066309794
Equipment Damage	0.422762565	0.268197503	0.283618064	0.173325709	1.147903841	0.268197503	4.280069076
Environmental Damage	0.046973618	0.067049376	0.070904516	0.103995425	0.288922935	0.070904516	4.074817112
People Damage	0.563683419	0.80459251	0.35452258	0.519977126	2.242775636	0.519977126	4.313219803
						λ_{max}	4.183603946
						CI	0.061201315
						CR	0.068001462

Production Loss/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.25	7.00	4.00
PDM	5.00	1.00	2.00	9.00	6.00
CBM	4.00	0.50	1.00	8.00	5.00
CM	0.14	0.11	0.13	1.00	0.25
OM	0.25	0.17	0.20	4.00	1.00
	10.39	1.98	3.58	29.00	16.25

Production Loss/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.10	0.10	0.07	0.24	0.25	0.15
PDM	0.48	0.51	0.56	0.31	0.37	0.45
CBM	0.38	0.25	0.28	0.28	0.31	0.30
CM	0.01	0.06	0.03	0.03	0.02	0.03
OM	0.02	0.08	0.06	0.14	0.06	0.07

Production Loss/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.15	0.09	0.08	0.22	0.29	0.82	0.15	5.44967616
PDM	0.75	0.45	0.60	0.28	0.44	2.52	0.45	5.65069576
CBM	0.60	0.22	0.30	0.25	0.36	1.74	0.30	5.7894893
CM	0.02	0.05	0.04	0.03	0.02	0.16	0.03	5.09470733
OM	0.04	0.07	0.06	0.12	0.07	0.37	0.07	5.06578566
							λ_{max}	5.41007084
							CI	0.10251771
							CR	0.09153367

Equipment Damage/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	4.00	2.00
PDM	3.00	1.00	2.00	5.00	4.00
CBM	2.00	0.50	1.00	5.00	3.00
CM	0.25	0.20	0.20	1.00	0.50
OM	0.50	0.25	0.33	2.00	1.00
	6.75	2.28	4.03	17.00	10.50

Equipment Damage/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.15	0.15	0.12	0.24	0.19	0.17
PDM	0.44	0.44	0.50	0.29	0.38	0.41
CBM	0.30	0.22	0.25	0.29	0.29	0.27
CM	0.04	0.09	0.05	0.06	0.05	0.06
OM	0.07	0.11	0.08	0.12	0.10	0.10

Equipment Damage/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.17	0.14	0.13	0.22	0.19	0.86	0.17	5.07264074
PDM	0.51	0.41	0.54	0.28	0.38	2.12	0.41	5.15779125
CBM	0.34	0.21	0.27	0.28	0.29	1.38	0.27	5.13612164
CM	0.04	0.08	0.05	0.06	0.05	0.28	0.06	5.02550922
OM	0.08	0.10	0.09	0.11	0.10	0.48	0.10	5.05822194
							λ_{max}	5.09005696
							CI	0.02251424
							CR	0.020102

Environmental Damage/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	3.00	1.00
PDM	2.00	1.00	1.00	3.00	2.00
CBM	2.00	1.00	1.00	2.00	2.00
CM	0.33	0.33	0.50	1.00	0.50
OM	1.00	0.50	0.50	2.00	1.00
	6.33	3.33	3.50	11.00	6.50

Environmental Damage/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.10	0.25	0.14	0.10	0.06	0.13
PDM	0.19	0.51	0.28	0.10	0.12	0.24
CBM	0.19	0.51	0.28	0.07	0.12	0.23
CM	0.03	0.17	0.14	0.03	0.03	0.08
OM	0.10	0.25	0.14	0.07	0.06	0.12

Environmental Damage/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.15	0.22	0.15	0.09	0.07	0.69	0.13	5.27036971
PDM	0.30	0.45	0.30	0.09	0.15	1.29	0.24	5.3375762
CBM	0.30	0.45	0.30	0.06	0.15	1.25	0.23	5.36261975
CM	0.05	0.15	0.15	0.03	0.04	0.42	0.08	5.12816166
OM	0.15	0.22	0.15	0.06	0.07	0.66	0.12	5.31392687
							λ_{max}	5.28253084
							CI	0.07063271
							CR	0.06306492

People Damage/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	4.00	2.00
PDM	3.00	1.00	2.00	3.00	2.00
CBM	2.00	0.50	1.00	2.00	2.00
CM	0.25	0.33	0.50	1.00	0.50
OM	0.50	0.50	0.50	2.00	1.00
	6.75	2.67	4.50	12.00	7.50

People Damage/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.15	0.13	0.11	0.33	0.27	0.20
PDM	0.44	0.38	0.44	0.25	0.27	0.36
CBM	0.30	0.19	0.22	0.17	0.27	0.23
CM	0.04	0.13	0.11	0.08	0.07	0.08
OM	0.07	0.19	0.11	0.17	0.13	0.13

People Damage/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.20	0.12	0.11	0.34	0.27	1.04	0.20	5.26834431
PDM	0.59	0.36	0.46	0.25	0.27	1.93	0.36	5.40665627
CBM	0.39	0.18	0.23	0.17	0.27	1.24	0.23	5.43275091
CM	0.05	0.12	0.11	0.08	0.07	0.43	0.08	5.12527352
OM	0.10	0.18	0.11	0.17	0.13	0.69	0.13	5.16001376
							λ_{max}	5.27860776
							CI	0.06965194
							CR	0.06218923

Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.100246404	0.277449467	0.057537416	0.564766713	1
PM	0.150961351	0.16877416	0.175465061	0.196851852	0.183230813
PDM	0.445146758	0.410667689	0.296384668	0.356111111	0.376736803
CBM	0.300192674	0.268608043	0.27820285	0.22787037	0.249319068
CM	0.030951578	0.056131526	0.092664178	0.08462963	0.071804102
OM	0.07274764	0.095818581	0.157283243	0.134537037	0.118909215
	Production Loss	Equipment Damage	Environmental Damage	People Damage	
map weight	0.072528881	0.20073637	0.041628669	0.408612138	

Gas Turbine "A"	MTBF	MTTR	Spare Parts	Assurance Spare
MTBF	1	2	4	3
MTTR	0.5	1	3	0.5
Spare Parts	0.25	0.333333333	1	0.25
Assurance Spares	0.333333333	2	4	1
Summ	2.083333333	5.333333333	12	4.75

Normalized Gas Turbine "A"	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight
MTBF	0.48	0.375	0.333333333	0.631578947	0.45497807
MTTR	0.24	0.1875	0.25	0.105263158	0.195690789
Spare Parts	0.12	0.0625	0.083333333	0.052631579	0.079616228
Assurance Spares	0.16	0.375	0.333333333	0.210526316	0.269714912

Gas Turbine "A"	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.45497807	0.391381579	0.318464912	0.809144737	1.973969298	0.45497807	4.338603172
MTTR	0.227489035	0.195690789	0.238848684	0.134857456	0.796885965	0.195690789	4.072168992
Spare Parts	0.113744518	0.065230263	0.079616228	0.067428728	0.326019737	0.079616228	4.094890511
Assurance Spares	0.151659357	0.391381579	0.318464912	0.269714912	1.13122076	0.269714912	4.194135025
						λ_{max}	4.174949425
						CI	0.058316475
						CR	0.064796083

MTBF/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	5.00	0.50
PDM	3.00	1.00	3.00	7.00	4.00
CBM	2.00	0.33	1.00	6.00	3.00
CM	0.20	0.14	0.17	1.00	0.33
OM	2.00	0.25	0.33	3.00	1.00
	8.20	2.06	5.00	22.00	8.83

MTBF/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.12	0.16	0.10	0.23	0.06	0.13
PDM	0.37	0.49	0.60	0.32	0.45	0.44
CBM	0.24	0.16	0.20	0.27	0.34	0.24
CM	0.02	0.07	0.03	0.05	0.04	0.04
OM	0.24	0.12	0.07	0.14	0.11	0.14

MTBF/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.13	0.15	0.12	0.21	0.07	0.68	0.13	5.10678913
PDM	0.40	0.44	0.73	0.29	0.55	2.42	0.44	5.43454378
CBM	0.27	0.15	0.24	0.25	0.41	1.32	0.24	5.41868664
CM	0.03	0.06	0.04	0.04	0.05	0.22	0.04	5.19071716
OM	0.27	0.11	0.08	0.13	0.14	0.72	0.14	5.29597731
							λ_{max}	5.2893428
							CI	0.0723357
							CR	0.06458545

MTTR/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	5.00	1.00
PDM	3.00	1.00	2.00	6.00	2.00
CBM	2.00	0.50	1.00	5.00	3.00
CM	0.20	0.17	0.20	1.00	0.25
OM	1.00	0.50	0.33	4.00	1.00
	7.20	2.50	4.03	21.00	7.25

MTTR/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.14	0.13	0.12	0.24	0.14	0.15
PDM	0.42	0.40	0.50	0.29	0.28	0.37
CBM	0.28	0.20	0.25	0.24	0.41	0.28
CM	0.03	0.07	0.05	0.05	0.03	0.05
OM	0.14	0.20	0.08	0.19	0.14	0.15

MTTR/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.15	0.12	0.14	0.23	0.15	0.79	0.15	5.13629322
PDM	0.46	0.37	0.55	0.27	0.30	1.96	0.37	5.2305535
CBM	0.31	0.19	0.28	0.23	0.45	1.45	0.28	5.25520733
CM	0.03	0.06	0.06	0.05	0.04	0.23	0.05	5.11173937
OM	0.15	0.19	0.09	0.18	0.15	0.76	0.15	5.09766102
							λ_{max}	5.16629089
							CI	0.04157272
							CR	0.0371185

Spare Parts/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.17	0.20	0.13	3.00
PDM	6.00	1.00	2.00	0.25	6.00
CBM	5.00	0.50	1.00	0.20	5.00
CM	8.00	4.00	5.00	1.00	9.00
OM	0.33	0.17	0.20	0.11	1.00
	20.33	5.83	8.40	1.69	24.00

Spare Parts/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.05	0.03	0.02	0.07	0.13	0.06
PDM	0.30	0.17	0.24	0.15	0.25	0.22
CBM	0.25	0.09	0.12	0.12	0.21	0.16
CM	0.39	0.69	0.60	0.59	0.38	0.53
OM	0.02	0.03	0.02	0.07	0.04	0.04

Spare Parts/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.06	0.04	0.03	0.07	0.11	0.30	0.06	4.98628519
PDM	0.36	0.22	0.31	0.13	0.21	1.24	0.22	5.60437702
CBM	0.30	0.11	0.16	0.11	0.18	0.85	0.16	5.45608481
CM	0.48	0.88	0.78	0.53	0.32	2.99	0.53	5.65177033
OM	0.02	0.04	0.03	0.06	0.04	0.18	0.04	5.15776507
							λ_{max}	5.37125649
							CI	0.09281412
							CR	0.08286975

Assurance Spares/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	4.00	1.00
PDM	3.00	1.00	2.00	5.00	3.00
CBM	2.00	0.50	1.00	5.00	2.00
CM	0.25	0.20	0.20	1.00	0.25
OM	1.00	0.33	0.50	4.00	1.00
	7.25	2.37	4.20	19.00	7.25

Assurance Spares/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.14	0.14	0.12	0.21	0.14	0.15
PDM	0.41	0.42	0.48	0.26	0.41	0.40
CBM	0.28	0.21	0.24	0.26	0.28	0.25
CM	0.03	0.08	0.05	0.05	0.03	0.05
OM	0.14	0.14	0.12	0.21	0.14	0.15

Assurance Spares/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.15	0.13	0.13	0.20	0.15	0.76	0.15	5.09557867
PDM	0.45	0.40	0.51	0.25	0.45	2.05	0.40	5.15929519
CBM	0.30	0.20	0.25	0.25	0.30	1.30	0.25	5.15147035
CM	0.04	0.08	0.05	0.05	0.04	0.26	0.05	5.03543518
OM	0.15	0.13	0.13	0.20	0.15	0.76	0.15	5.09557867
							λ_{max}	5.10747161
							CI	0.0268679
							CR	0.0239892

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.445917065	0.180155502	0.077627592	0.296299841	1
PM	0.133535486	0.154443087	0.060139274	0.088208308	**0.118174099**
PDM	0.44448296	0.374822158	0.220575192	0.232095685	**0.351621446**
CBM	0.243620413	0.275520001	0.155522604	0.215429018	**0.234175373**
CM	0.042055627	0.045226606	0.528495146	0.358635814	**0.174190683**
OM	0.136305514	0.149988148	0.035267784	0.105631176	**0.121838399**

	MTBF	MTTR	Spare Parts	Assurance Spare	
Map weight	0.037148407	0.015008373	0.00646699	0.024684112	

Investment/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	4.00	3.00	0.50	1.00
PDM	0.25	1.00	0.50	0.20	0.25
CBM	0.33	2.00	1.00	0.25	0.33
CM	2.00	5.00	4.00	1.00	3.00
OM	1.00	4.00	3.00	0.33	1.00
	4.58	16.00	11.50	2.28	5.58

Investment/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.22	0.25	0.26	0.22	0.18	0.23
PDM	0.05	0.06	0.04	0.09	0.04	0.06
CBM	0.07	0.13	0.09	0.11	0.06	0.09
CM	0.44	0.31	0.35	0.44	0.54	0.41
OM	0.22	0.25	0.26	0.15	0.18	0.21

Investment/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.23	0.23	0.27	0.21	0.21	1.15	0.23	5.10182677
PDM	0.06	0.06	0.05	0.08	0.05	0.30	0.06	5.05149882
CBM	0.08	0.12	0.09	0.10	0.07	0.46	0.09	5.03385603
CM	0.45	0.29	0.36	0.41	0.63	2.15	0.41	5.19730455
OM	0.23	0.23	0.27	0.14	0.21	1.08	0.21	5.12750601
							λ_{max}	5.10239843
							CI	0.02559961
							CR	0.02285679

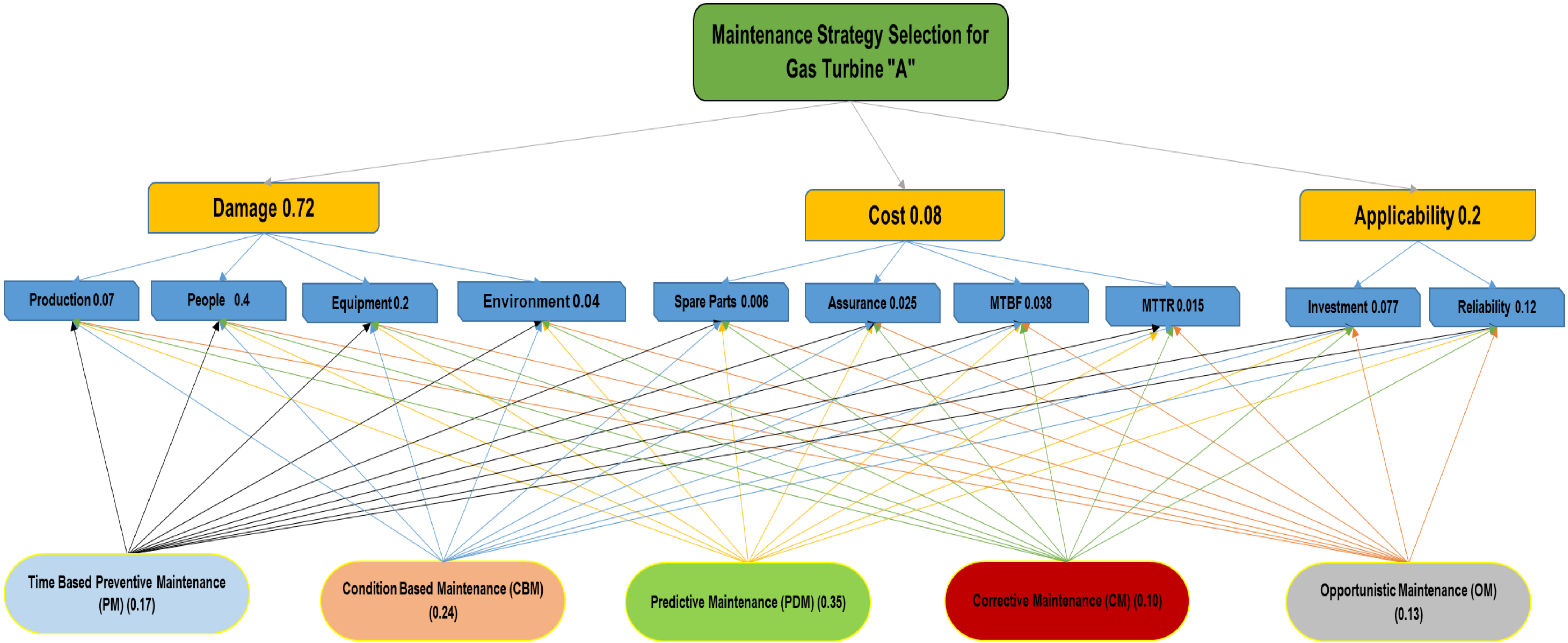
Reliability/GT "A"	PM	PDM	CBM	CM	OM
PM	1.00	0.25	0.33	6.00	2.00
PDM	4.00	1.00	2.00	7.00	4.00
CBM	3.00	0.50	1.00	6.00	3.00
CM	0.17	0.14	0.17	1.00	0.17
OM	0.50	0.25	0.33	6.00	1.00
	8.67	2.14	3.83	26.00	10.17

Reliability/GT "A"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.12	0.12	0.09	0.23	0.20	0.15
PDM	0.46	0.47	0.52	0.27	0.39	0.42
CBM	0.35	0.23	0.26	0.23	0.30	0.27
CM	0.02	0.07	0.04	0.04	0.02	0.04
OM	0.06	0.12	0.09	0.23	0.10	0.12

Reliability/GT "A"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.15	0.11	0.09	0.22	0.24	0.80	0.15	5.38022657
PDM	0.60	0.42	0.55	0.26	0.47	2.30	0.42	5.4351639
CBM	0.45	0.21	0.27	0.22	0.35	1.51	0.27	5.51799751
CM	0.02	0.06	0.05	0.04	0.02	0.19	0.04	5.08361848
OM	0.07	0.11	0.09	0.22	0.12	0.61	0.12	5.17005598
							λ_{max}	5.31741249
							CI	0.07935312
							CR	0.070851

Criteria / Alternative	Invest	Reliability	Final Score
	0.4	0.6	1
PM	0.225426793	0.129469458	**0.167852392**
PDM	0.058578215	0.404935682	**0.266392695**
CBM	0.090774868	0.253186151	**0.188221638**
CM	0.414391872	0.040549072	**0.190086192**
OM	0.210828252	0.171859638	**0.187447084**

	Invest	Reliability	
Map weight	0.077274424	0.115911636	



Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final
	0.066212425	0.145357492	0.038814437	0.293368189	0.024664742	0.057301172	0.081089182	0.18289525	0.071693122	0.038603989	
PM	0.171152285	0.141796368	0.164696356	0.170465757	0.162148557	0.366047803	0.058016454	0.274013042	0.195296564	0.18215697	0.189173316
PDM	0.307521961	0.463658546	0.302726046	0.412715901	0.426085837	0.256887538	0.180606761	0.213196997	0.056345953	0.404440426	0.319105734
CBM	0.307521961	0.270682048	0.302726046	0.267888871	0.274197218	0.23340269	0.119314724	0.264489233	0.089349139	0.269227016	0.245032817
CM	0.04265151	0.034057708	0.065155196	0.03663373	0.040387175	0.03952445	0.555331385	0.045966883	0.405775906	0.044669288	0.108565919
OM	0.171152285	0.089805329	0.164696356	0.112295742	0.097181214	0.104137519	0.086730676	0.202333844	0.253232439	0.0995063	0.138122214

7-3 Appendix "C" Nitrogen Backup Diaphragm Compressor

N2 B/Up Compressor	Damage	Applicability	Cost
Damage	1.00	4.00	2.00
Applicability	0.25	1.00	0.20
Cost	0.50	5.00	1.00
Summ	1.75	10.00	3.20

N2 B/Up Compressor	Damage	Applicability	Cost	Criteria Weight
Damage	0.57	0.40	0.63	0.532142857
Applicability	0.14	0.10	0.06	0.101785714
Cost	0.29	0.50	0.31	0.366071429

N2 B/Up Compressor	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.53	0.41	0.73	1.67	0.532142857	3.14094
Applicability	0.13	0.10	0.07	0.31	0.101785714	3.026316
Cost	0.27	0.51	0.37	1.14	0.366071429	3.117073
					λ_{max}	3.094776
					CI	0.047388
					CR	0.081704

N2 B/Up Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	0.333333333	4	0.111111111
Equipment Damage	3	1	6	0.125
Environmental Damage	0.25	0.166666667	1	0.166666667
People Damage	9	8	6	1
Summ	13.25	9.5	17	1.402777778

Normalized N2 B/Up Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.075471698	0.035087719	0.235294118	0.079207921	0.106265364
Equipment Damage	0.226415094	0.105263158	0.352941176	0.089108911	0.193432085
Environmental Damage	0.018867925	0.01754386	0.058823529	0.118811881	0.053511799
People Damage	0.679245283	0.842105263	0.352941176	0.712871287	0.646790752

N2 B/Up Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.106265364	0.064477362	0.214047195	0.071865639	0.45665556	0.106265364	4.297313278
Equipment Damage	0.318796092	0.193432085	0.321070792	0.024179011	0.85747798	0.193432085	4.432966641
Environmental Damage	0.026566341	0.032238681	0.053511799	0.032238681	0.144555501	0.053511799	2.701376236
People Damage	0.956388276	1.547456679	0.321070792	0.193432085	3.018347832	0.646790752	4.666652732
						λ_{max}	4.024577222
						CI	0.008192407
						CR	0.009102675

Production Loss/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	2.00	1.00
PDM	1.00	1.00	1.00	2.00	1.00
CBM	1.00	1.00	1.00	2.00	1.00
CM	0.50	0.50	0.50	1.00	1.00
OM	1.00	1.00	1.00	1.00	1.00
	4.50	4.50	4.50	8.00	5.00

Production Loss/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.22	0.22	0.22	0.25	0.20	0.22
PDM	0.22	0.22	0.22	0.25	0.20	0.22
CBM	0.22	0.22	0.22	0.25	0.20	0.22
CM	0.11	0.11	0.11	0.13	0.20	0.13
OM	0.22	0.22	0.22	0.13	0.20	0.20

Production Loss/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.22	0.22	0.22	0.26	0.20	1.13	0.22	5.06716418
PDM	0.22	0.22	0.22	0.26	0.20	1.13	0.22	5.06716418
CBM	0.22	0.22	0.22	0.26	0.20	1.13	0.22	5.06716418
CM	0.11	0.11	0.11	0.13	0.20	0.67	0.13	5.05063291
OM	0.22	0.22	0.22	0.13	0.20	1.00	0.20	5.04201681
							λ_{max}	5.05882845
							CI	0.01470711
							CR	0.01313135

Equipment Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	3.00	1.00
PDM	2.00	1.00	1.00	4.00	2.00
CBM	2.00	1.00	1.00	4.00	2.00
CM	0.33	0.25	0.25	1.00	0.33
OM	1.00	0.50	0.50	3.00	1.00
	6.33	3.25	3.25	15.00	6.33

Equipment Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.16	0.15	0.15	0.20	0.16	0.16
PDM	0.32	0.31	0.31	0.27	0.32	0.30
CBM	0.32	0.31	0.31	0.27	0.32	0.30
CM	0.05	0.08	0.08	0.07	0.05	0.07
OM	0.16	0.15	0.15	0.20	0.16	0.16

Equipment Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.16	0.15	0.15	0.20	0.16	0.83	0.16	5.02490987
PDM	0.33	0.30	0.30	0.26	0.33	1.52	0.30	5.03708987
CBM	0.33	0.30	0.30	0.26	0.33	1.52	0.30	5.03708987
CM	0.05	0.08	0.08	0.07	0.05	0.33	0.07	5.008285
OM	0.16	0.15	0.15	0.20	0.16	0.83	0.16	5.02490987
							λ_{max}	5.0264569
							CI	0.00661422
							CR	0.00590556

Environmental Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	2.00	1.00
PDM	1.00	1.00	1.00	2.00	1.00
CBM	1.00	1.00	1.00	2.00	1.00
CM	0.50	0.50	0.50	1.00	0.50
OM	1.00	1.00	1.00	2.00	1.00
	4.50	4.50	4.50	9.00	4.50

Environmental Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.22	0.22	0.22	0.22	0.22	0.22
PDM	0.22	0.22	0.22	0.22	0.22	0.22
CBM	0.22	0.22	0.22	0.22	0.22	0.22
CM	0.11	0.11	0.11	0.11	0.11	0.11
OM	0.22	0.22	0.22	0.22	0.22	0.22

Environmental Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
PDM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
CBM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
CM	0.11	0.11	0.11	0.11	0.11	0.56	0.11	5
OM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
							λ_{max}	5
							CI	0
							CR	0

People Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	2.00	1.00
PDM	1.00	1.00	1.00	2.00	1.00
CBM	1.00	1.00	1.00	2.00	1.00
CM	0.50	0.50	0.50	1.00	0.50
OM	1.00	1.00	1.00	2.00	1.00
	4.50	4.50	4.50	9.00	4.50

People Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.22	0.22	0.22	0.22	0.22	0.22
PDM	0.22	0.22	0.22	0.22	0.22	0.22
CBM	0.22	0.22	0.22	0.22	0.22	0.22
CM	0.11	0.11	0.11	0.11	0.11	0.11
OM	0.22	0.22	0.22	0.22	0.22	0.22

People Damage/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
PDM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
CBM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
CM	0.11	0.11	0.11	0.11	0.11	0.56	0.11	5
OM	0.22	0.22	0.22	0.22	0.22	1.11	0.22	5
							λ_{max}	5
							CI	0
							CR	0

Alternative \ Criteria	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.106265364	0.193432085	0.053511799	0.646790752	1
PM	0.22	0.16	0.22	0.22	0.211212947
PDM	0.22	0.30	0.22	0.22	0.237912317
CBM	0.22	0.30	0.22	0.22	0.237912317
CM	0.13	0.07	0.11	0.11	0.104406106
OM	0.20	0.16	0.22	0.22	0.208556313
	Production Loss	Equipment Damage	Environmental Damage	People Damage	
map weight	0.056548354	0.102933502	0.028475921	0.344185079	

N2 B.Up Comp	MTBF	MTTR	Spare Parts	Assurance Spare			
MTBF	1	0.5	0.25	0.2			
MTTR	2	1	0.2	0.166666667			
Spare Parts	4	5	1	0.25			
Assurance Spares	5	6	4	1			
Summ	12	12.5	5.45	1.616666667			
Normalized N2 B.Up Comp	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight		
MTBF	0.083333333	0.04	0.04587156	0.12371134	0.073229058		
MTTR	0.166666667	0.08	0.036697248	0.103092784	0.096614174		
Spare Parts	0.333333333	0.4	0.183486239	0.154639175	0.267864687		
Assurance Spares	0.416666667	0.48	0.733944954	0.618556701	0.56229208		
N2 B.Up Comp	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.073229058	0.048307087	0.066966172	0.112458416	0.300960733	0.073229058	4.109853934
MTTR	0.146458117	0.096614174	0.053572937	0.016102362	0.312747591	0.096614174	3.237077712
Spare Parts	0.292916233	0.483070872	0.267864687	0.024153544	1.068005336	0.267864687	3.987107628
Assurance Spares	0.366145291	0.579685047	1.071458747	0.096614174	2.11390326	0.56229208	3.759439859
						λ_{max}	3.773369783
						CI	-0.075543406
						CR	-0.083937117

MTBF/N2 B.Up Comp	PM	PDM	CBM	CM	OM			
PM	1.00	0.50	0.50	2.00	1.00			
PDM	2.00	1.00	1.00	3.00	2.00			
CBM	2.00	1.00	1.00	3.00	2.00			
CM	0.50	0.33	0.33	1.00	0.50			
OM	1.00	0.50	0.50	2.00	1.00			
	6.50	3.33	3.33	11.00	6.50			
MTBF/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight		
PM	0.15	0.15	0.15	0.18	0.15	0.16		
PDM	0.31	0.30	0.30	0.27	0.31	0.30		
CBM	0.31	0.30	0.30	0.27	0.31	0.30		
CM	0.08	0.10	0.10	0.09	0.08	0.09		
OM	0.15	0.15	0.15	0.18	0.15	0.16		
MTBF/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
PDM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CBM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CM	0.08	0.10	0.10	0.09	0.08	0.45	0.09	5.0057652
OM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
							λ_{max}	5.01327768
							CI	0.00331942
							CR	0.00296377

MTTR/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	2.00	1.00
PDM	2.00	1.00	1.00	3.00	2.00
CBM	2.00	1.00	1.00	3.00	2.00
CM	0.50	0.33	0.33	1.00	0.50
OM	1.00	0.50	0.50	2.00	1.00
	6.50	3.33	3.33	11.00	6.50

MTTR/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.15	0.15	0.15	0.18	0.15	0.16
PDM	0.31	0.30	0.30	0.27	0.31	0.30
CBM	0.31	0.30	0.30	0.27	0.31	0.30
CM	0.08	0.10	0.10	0.09	0.08	0.09
OM	0.15	0.15	0.15	0.18	0.15	0.16

MTTR/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
PDM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CBM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CM	0.08	0.10	0.10	0.09	0.08	0.45	0.09	5.0057652
OM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
							λ_{max}	5.01327768
							CI	0.00331942
							CR	0.00296377

Spare Parts/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	0.25	0.25	0.13	1.00
PDM	4.00	1.00	1.00	0.25	4.00
CBM	4.00	1.00	1.00	0.25	4.00
CM	8.00	4.00	4.00	1.00	8.00
OM	1.00	0.25	0.25	0.13	1.00
	18.00	6.50	6.50	1.75	18.00

Spare Parts/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.06	0.04	0.04	0.07	0.06	0.05
PDM	0.22	0.15	0.15	0.14	0.22	0.18
CBM	0.22	0.15	0.15	0.14	0.22	0.18
CM	0.44	0.62	0.62	0.57	0.44	0.54
OM	0.06	0.04	0.04	0.07	0.06	0.05

Spare Parts/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.05	0.04	0.04	0.07	0.05	0.26	0.05	5.02117647
PDM	0.21	0.18	0.18	0.13	0.21	0.91	0.18	5.07094134
CBM	0.21	0.18	0.18	0.13	0.21	0.91	0.18	5.07094134
CM	0.42	0.72	0.72	0.54	0.42	2.80	0.54	5.20326679
OM	0.05	0.04	0.04	0.07	0.05	0.26	0.05	5.02117647
							λ_{max}	5.07750048
							CI	0.01937512
							CR	0.01729921

Assurance Spares/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	0.20	1.00
PDM	2.00	1.00	1.00	0.25	2.00
CBM	2.00	1.00	1.00	0.25	2.00
CM	5.00	4.00	4.00	1.00	5.00
OM	1.00	0.50	0.50	0.20	1.00
	11.00	7.00	7.00	1.90	11.00

Assurance Spares/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.09	0.07	0.07	0.11	0.09	0.09
PDM	0.18	0.14	0.14	0.13	0.18	0.16
CBM	0.18	0.14	0.14	0.13	0.18	0.16
CM	0.45	0.57	0.57	0.53	0.45	0.52
OM	0.09	0.07	0.07	0.11	0.09	0.09

Assurance Spares/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.09	0.08	0.08	0.10	0.09	0.43	0.09	5.01573927
PDM	0.17	0.16	0.16	0.13	0.17	0.79	0.16	5.02757112
CBM	0.17	0.16	0.16	0.13	0.17	0.79	0.16	5.02757112
CM	0.43	0.62	0.62	0.52	0.43	2.63	0.52	5.09066808
OM	0.09	0.08	0.08	0.10	0.09	0.43	0.09	5.01573927
							λ_{max}	5.03545777
							CI	0.00886444
							CR	0.00791468

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.073229058	0.096614174	0.267864687	0.56229208	1
PM	0.16	0.16	0.05	0.09	**0.089068986**
PDM	0.30	0.30	0.18	0.16	**0.186318704**
CBM	0.30	0.30	0.18	0.16	**0.186318704**
CM	0.09	0.09	0.54	0.52	**0.44922462**
OM	0.16	0.16	0.05	0.09	**0.089068986**

	MTBF	MTTR	Spare Parts	Assurance Spare	
Map weight	0.026807066	0.035367689	0.098057609	0.205839065	

Investment/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	2.00	2.00	0.20	1.00
PDM	0.50	1.00	1.00	0.14	0.50
CBM	0.50	1.00	1.00	0.14	0.50
CM	5.00	7.00	7.00	1.00	5.00
OM	1.00	2.00	2.00	0.20	1.00
	8.00	13.00	13.00	1.69	8.00

Investment/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.13	0.15	0.15	0.12	0.13	0.14
PDM	0.06	0.08	0.08	0.08	0.06	0.07
CBM	0.06	0.08	0.08	0.08	0.06	0.07
CM	0.63	0.54	0.54	0.59	0.63	0.58
OM	0.13	0.15	0.15	0.12	0.13	0.14

Investment/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.14	0.15	0.15	0.12	0.14	0.68	0.14	5.01387952
PDM	0.07	0.07	0.07	0.08	0.07	0.36	0.07	5.00749184
CBM	0.07	0.07	0.07	0.08	0.07	0.36	0.07	5.00749184
CM	0.68	0.51	0.51	0.58	0.68	2.95	0.58	5.05927001
OM	0.14	0.15	0.15	0.12	0.14	0.68	0.14	5.01387952
							λ_{max}	5.02040254
							CI	0.00510064
							CR	0.00455414

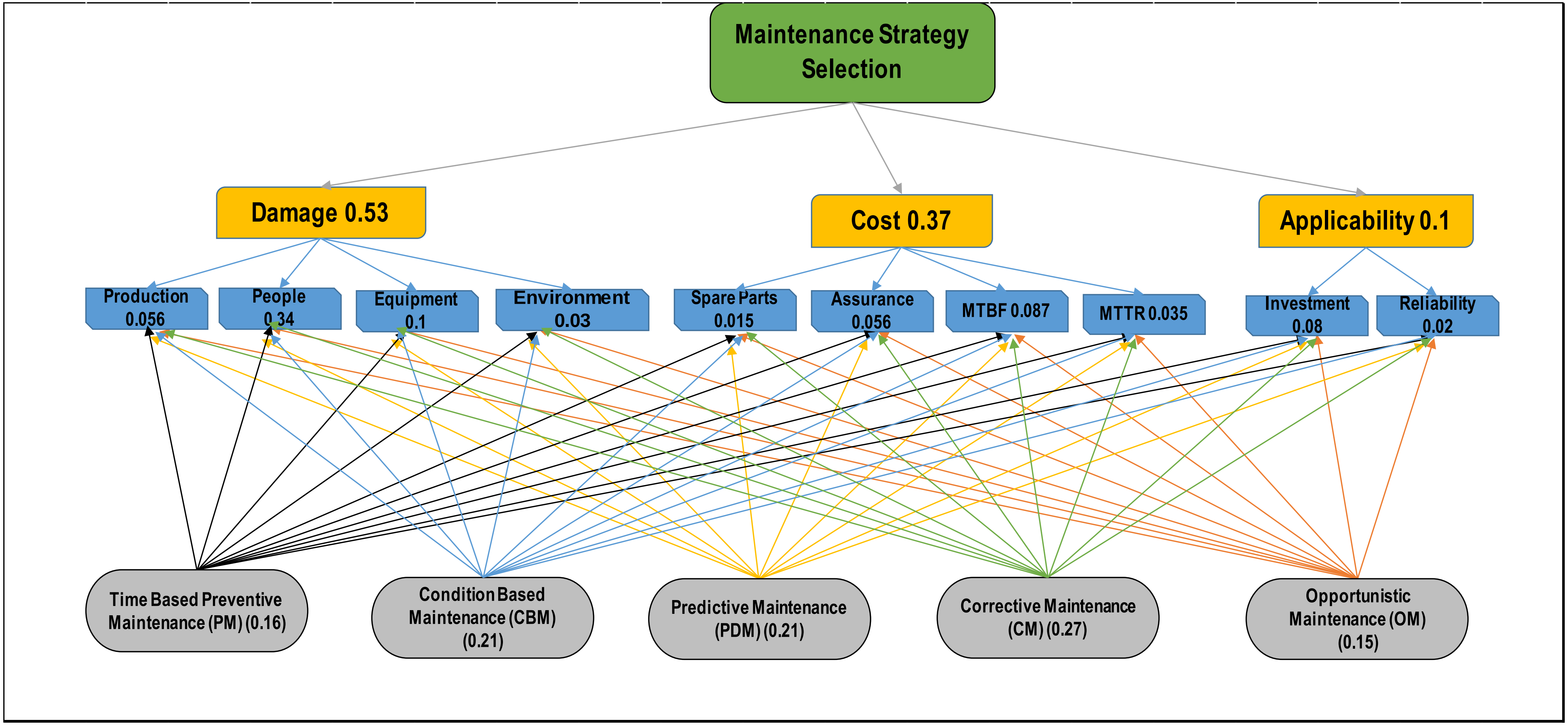
Reliability/N2 B.Up Comp	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	2.00	1.00
PDM	2.00	1.00	1.00	3.00	2.00
CBM	2.00	1.00	1.00	3.00	2.00
CM	0.50	0.33	0.33	1.00	0.50
OM	1.00	0.50	0.50	2.00	1.00
	6.50	3.33	3.33	11.00	6.50

Reliability/N2 B.Up Comp	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.15	0.15	0.15	0.18	0.15	0.16
PDM	0.31	0.30	0.30	0.27	0.31	0.30
CBM	0.31	0.30	0.30	0.27	0.31	0.30
CM	0.08	0.10	0.10	0.09	0.08	0.09
OM	0.15	0.15	0.15	0.18	0.15	0.16

Reliability/N2 B.Up Comp	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
PDM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CBM	0.32	0.30	0.30	0.27	0.32	1.49	0.30	5.01879699
CM	0.08	0.10	0.10	0.09	0.08	0.45	0.09	5.0057652
OM	0.16	0.15	0.15	0.18	0.16	0.79	0.16	5.01151461
							λ_{max}	5.01327768
							CI	0.00331942
							CR	0.00296377

Alternative \ Criteria	Invest	Reliability	Final Score
	0.8	0.2	1
PM	0.14	0.16	0.13979424
PDM	0.07	0.30	0.117699182
CBM	0.07	0.30	0.117699182
CM	0.58	0.09	0.485013156
OM	0.14	0.16	0.13979424

	Invest	Reliability	
Map weight	0.081428571	0.020357143	



Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final
	0.056548354	0.102933502	0.028475921	0.344185079	0.026807066	0.035367689	0.098057609	0.205839065	0.081428571	0.020357143	
PM	0.223333333	0.164696356	0.222222222	0.222222222	0.157902098	0.157902098	0.051892552	0.085987697	0.135267275	0.157902098	0.159230128
PDM	0.223333333	0.302726046	0.222222222	0.222222222	0.297622378	0.297622378	0.178998779	0.156185919	0.072718383	0.297622378	0.20678939
CBM	0.223333333	0.302726046	0.222222222	0.222222222	0.297622378	0.297622378	0.178998779	0.156185919	0.072718383	0.297622378	0.20678939
CM	0.131666667	0.065155196	0.111111111	0.111111111	0.088951049	0.088951049	0.538217338	0.515652768	0.584028683	0.088951049	0.269374673
OM	0.198333333	0.164696356	0.222222222	0.222222222	0.157902098	0.157902098	0.051892552	0.085987697	0.135267275	0.157902098	0.157816419

7-4 Appendix “D” Air Dryer Package Calculation

Air Dryer	Damage	Applicability	Cost
Damage	1.00	2.00	0.50
Applicability	0.50	1.00	0.33
Cost	2.00	3.00	1.00
Summ	3.50	6.00	1.83

with respect to MS applied on air dryer Package , how important is Damage when compared to cost?

Air Dryer	Damage	Applicability	Cost	Criteria Weight
Damage	0.29	0.33	0.27	0.297258297
Applicability	0.14	0.17	0.18	0.163780664
Cost	0.57	0.50	0.55	0.538961039

Air Dryer	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.297258	0.327561	0.269481	0.89	0.297258297	3.008495
Applicability	0.148629	0.163781	0.179654	0.49	0.163780664	3.004405
Cost	0.594517	0.491342	0.538961	1.62	0.538961039	3.014726
					λ_{max}	3.009209
					CI	0.004604
					CR	0.007939

Air Dryer	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	2	5	4
Equipment Damage	0.5	1	4	3
Environmental Damage	0.2	0.25	1	0.333333333
People Damage	0.25	0.333333333	3	1
Summ	1.95	3.583333333	13	8.333333333

with respect to the damage criteria, how important is the production loss when compared to the people damage for the air deyer? Environmental damage& people damage are highly unlikely with such an equipment, while the production loss can be caused in case of moisture introduction & accumlation in the regulators installed on Shutdown valves. but the redunduncy of the dryer (2 dryers in operation and 2 dryers standby) reduce the probability of production loss.

Normalized Air Dryer	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.512820513	0.558139535	0.384615385	0.48	0.483893858
Equipment Damage	0.256410256	0.279069767	0.307692308	0.36	0.300793083
Environmental Damage	0.102564103	0.069767442	0.076923077	0.04	0.072313655
People Damage	0.128205128	0.093023256	0.230769231	0.12	0.142999404

Air Dryer	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.483893858	0.601586166	0.361568277	0.571997615	2.019045915	0.483893858	4.172497505
Equipment Damage	0.241946929	0.300793083	0.289254621	0.428998211	1.260992844	0.300793083	4.19222687
Environmental Damage	0.096778772	0.075198271	0.072313655	0.047666468	0.291957166	0.072313655	4.03737253
People Damage	0.120973465	0.100264361	0.216940966	0.142999404	0.581178195	0.142999404	4.064200131
						λ_{max}	4.116574259
						CI	0.038858086
						CR	0.043175651

Production Loss/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	3.00	1.00
PDM	1.00	1.00	1.00	3.00	1.00
CBM	1.00	1.00	1.00	3.00	1.00
CM	0.33	0.33	0.33	1.00	0.33
OM	1.00	1.00	1.00	3.00	1.00
	4.33	4.33	4.33	13.00	4.33

Ex: with respect to the production loss sub-criteria, how important is PM when compared to CM? which one can reduce the production loss, the decsion is based from previous failures of the air dryers package, when the PM strategy was followed.
For example, if pm was not carried on replacing the dessicant, which adsorb the moisture (cm) by replacing them every 3-5 years , the efficiency of the dryer will be affected greatly, as if it is not working.

Production Loss/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.230769	0.230769	0.230769	0.230769	0.230769	0.230769
PDM	0.230769	0.230769	0.230769	0.230769	0.230769	0.230769
CBM	0.230769	0.230769	0.230769	0.230769	0.230769	0.230769
CM	0.076923	0.076923	0.076923	0.076923	0.076923	0.076923
OM	0.230769	0.230769	0.230769	0.230769	0.230769	0.230769

Production Loss/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.230769	0.230769	0.230769	0.230769	0.230769	1.153846	0.230769	5
PDM	0.230769	0.230769	0.230769	0.230769	0.230769	1.153846	0.230769	5
CBM	0.230769	0.230769	0.230769	0.230769	0.230769	1.153846	0.230769	5
CM	0.076923	0.076923	0.076923	0.076923	0.076923	0.384615	0.076923	5
OM	0.230769	0.230769	0.230769	0.230769	0.230769	1.153846	0.230769	5
							λ_{max}	5
							CI	0
							CR	0

Equipment Damage/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	3.00	1.00
PDM	1.00	1.00	1.00	1.00	1.00
CBM	1.00	1.00	1.00	1.00	1.00
CM	0.33	1.00	1.00	1.00	1.00
OM	1.00	1.00	1.00	1.00	1.00
	4.33	5.00	5.00	7.00	5.00

with respect to sub-criteria of equipment damage, how important is PM when compared to CM? which can cause less damage to equipment when implemented ? Due to the simplicity if the equipment, it is basically pipes with filters & desiccant with a simple controller to switch between the towers. so there will be no equipment damage when adopting any maintenance strategy. maybe on the long run, corrosion inside the filter housing, or desiccant housing can be introduced due to adopting CM strategy. and it is repairable. also, due to the pressurized system (8bar), in case of over pressure and failure of the barrier (safety valve) the desiccant towers may be ruptured. in this case PDM doesn't have an effect on safety valve , as the regular PM is to calibrate the valve each year.

Equipment Damage/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.230769	0.200000	0.200000	0.428571	0.200000	0.251868
PDM	0.230769	0.200000	0.200000	0.142857	0.200000	0.194725
CBM	0.230769	0.200000	0.200000	0.142857	0.200000	0.194725
CM	0.076923	0.200000	0.200000	0.142857	0.200000	0.163956
OM	0.230769	0.200000	0.200000	0.142857	0.200000	0.194725

Equipment Damage/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.251868	0.194725	0.194725	0.491868	0.194725	1.327912	0.251868	5.27225131
PDM	0.251868	0.194725	0.194725	0.163956	0.194725	1.000000	0.194725	5.13544018
CBM	0.251868	0.194725	0.194725	0.163956	0.194725	1.000000	0.194725	5.13544018
CM	0.083956	0.194725	0.194725	0.163956	0.194725	0.832088	0.163956	5.07506702
OM	0.251868	0.194725	0.194725	0.163956	0.194725	1.000000	0.194725	5.13544018
							λ_{max}	5.15072777
							CI	0.03768194
							CR	0.03364459

Environmental Damage/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	1.00	1.00
PDM	1.00	1.00	1.00	1.00	1.00
CBM	1.00	1.00	1.00	1.00	1.00
CM	1.00	1.00	1.00	1.00	1.00
OM	1.00	1.00	1.00	1.00	1.00
	5.00	5.00	5.00	5.00	5.00

there is no environmental damage caused by implementing or adobting any maintenance policy all have the same values

Environmental Damage/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
PDM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
CBM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
CM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
OM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000

Environmental Damage/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
PDM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
CBM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
CM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
OM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
							λ_{max}	5
							CI	0
							CR	0

People Damage/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	5.00	1.00
PDM	1.00	1.00	1.00	2.00	1.00
CBM	1.00	1.00	1.00	2.00	1.00
CM	0.20	0.50	0.50	1.00	0.33
OM	1.00	1.00	1.00	3.00	1.00
	4.20	4.50	4.50	13.00	4.33

as this is a pressurized system up to 8 bar , and also the desicant vapor is toxic for human being. And finally the high noise generated from the regeneration tower, all can affect the people. PDM will inspect the desicant each year to detemine its condition and suitability, which will increase the probability of people damage, while PM recommend changinf evey 4 years.

People Damage/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.238095	0.222222	0.222222	0.384615	0.230769	0.259585
PDM	0.238095	0.222222	0.222222	0.153846	0.230769	0.213431
CBM	0.238095	0.222222	0.222222	0.153846	0.230769	0.213431
CM	0.047619	0.111111	0.111111	0.076923	0.076923	0.084737
OM	0.238095	0.222222	0.222222	0.230769	0.230769	0.228816

People Damage/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.259585	0.213431	0.213431	0.423687	0.228816	1.338950	0.259585	5.15804327
PDM	0.259585	0.213431	0.213431	0.169475	0.228816	1.084737	0.213431	5.08237986
CBM	0.259585	0.213431	0.213431	0.169475	0.228816	1.084737	0.213431	5.08237986
CM	0.051917	0.106716	0.106716	0.084737	0.076272	0.426357	0.084737	5.03150817
OM	0.259585	0.213431	0.213431	0.254212	0.228816	1.169475	0.228816	5.11099253
							λ_{max}	5.09306074
							CI	0.02326518
							CR	0.02077249

Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.483893858	0.300793083	0.072313655	0.142999404	1
PM	0.230769	0.251868	0.200000	0.259585	0.239011216
PDM	0.230769	0.194725	0.200000	0.213431	0.215223068
CBM	0.230769	0.194725	0.200000	0.213431	0.215223068
CM	0.076923	0.163956	0.200000	0.084737	0.113119589
OM	0.230769	0.194725	0.200000	0.228816	0.217423059

	Production Loss	Equipment Damage	Environmental Damage	People Damage
map weight	0.143841464	0.08941324	0.021495834	0.042507759

Air Dryer	MTBF	MTTR	Spare Parts	Assurance Spare
MTBF	1	0.5	0.2	2
MTTR	2	1	0.25	4
Spare Parts	5	4	1	6
Assurance Spares	0.5	0.25	0.166666667	1
Summ	8.5	5.75	1.616666667	13

with respect to cost criteria , how important is spare parts cost when compared with assurance spares cost for the air dryer?
For the air dryer package, the assurance spares cost is less than the regular spares cost, due to the simplicity of the equipment? not like gas turbine. the assurance for this equipment is only the controller, while the spares is the inlet filters, outlet filters, desiccant, solenoid, power supply, gaskets, humidity sensor.

Normalized Air Dryer	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight
MTBF	0.117647059	0.086956522	0.12371134	0.153846154	0.120540269
MTTR	0.235294118	0.173913043	0.154639175	0.307692308	0.217884661
Spare Parts	0.588235294	0.695652174	0.618556701	0.461538462	0.590995658
Assurance Spares	0.058823529	0.043478261	0.103092784	0.076923077	0.070579413

Air Dryer	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.120540269	0.108942331	0.118199132	0.141158825	0.488840556	0.120540269	4.055412863
MTTR	0.241080537	0.217884661	0.147748914	0.282317651	0.889031763	0.217884661	4.080286144
Spare Parts	0.602701343	0.871538644	0.590995658	0.423476476	2.488712121	0.590995658	4.211049758
Assurance Spares	0.060270134	0.054471165	0.098499276	0.070579413	0.283819989	0.070579413	4.02128578
						λ_{max}	4.092008636
						CI	0.030669545
						CR	0.034077273

MTBF/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	3.00	2.00	5.00	1.00
PDM	0.33	1.00	0.50	2.00	0.33
CBM	0.50	2.00	1.00	3.00	0.50
CM	0.20	0.50	0.33	1.00	0.25
OM	1.00	3.00	2.00	4.00	1.00
	3.03	9.50	5.83	15.00	3.08

with respect to cost sub-criteria MTBF, how important is PM, when compared to cm? which will generate cost reduction i.e., increase the MTBF's? the definition of failure for the air dryer is not tripping the equipment, it is the failure of doing its function. meaning that stopping the machine for maintenance is considered a failure at that time, or in case of adopting cm, which affect the outlet dried air (increase moisture)

MTBF/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.329670	0.315789	0.342857	0.333333	0.324324	0.329195
PDM	0.109890	0.105263	0.085714	0.133333	0.108108	0.108462
CBM	0.164835	0.210526	0.171429	0.200000	0.162162	0.181790
CM	0.065934	0.052632	0.057143	0.066667	0.081081	0.064691
OM	0.329670	0.315789	0.342857	0.266667	0.324324	0.315862

MTBF/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.329195	0.325385	0.363581	0.323456	0.315862	1.657479	0.329195	5.03494719
PDM	0.109732	0.108462	0.090895	0.129382	0.105287	0.543758	0.108462	5.01336287
CBM	0.164597	0.216924	0.181790	0.194074	0.157931	0.915316	0.181790	5.03500641
CM	0.065839	0.054231	0.060597	0.064691	0.078965	0.324323	0.064691	5.01340359
OM	0.329195	0.325385	0.363581	0.258765	0.315862	1.592788	0.315862	5.04267646
							λ_{max}	5.0278793
							CI	0.00696983
							CR	0.00622306

MTTR/Air Dryer	PM	PDM	CBM	CM	OM	with respect to cost sub-criteria MTTR, how important is PM, when compared to cm? which will generate cost reduction i.e., reduce the MTTR? Adopting cm can cause rupture to the desiccant pressure vessel, which can take large time to repair, while other strategy will not be different with respect to the MTTR due to the nature of the equipment
PM	1.00	1.00	1.00	6.00	1.00	
PDM	1.00	1.00	1.00	6.00	1.00	
CBM	1.00	1.00	1.00	6.00	1.00	
CM	0.17	0.17	0.17	1.00	0.17	
OM	1.00	1.00	1.00	6.00	1.00	
	4.17	4.17	4.17	25.00	4.17	

MTTR/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.240000	0.240000	0.240000	0.240000	0.240000	0.240000
PDM	0.240000	0.240000	0.240000	0.240000	0.240000	0.240000
CBM	0.240000	0.240000	0.240000	0.240000	0.240000	0.240000
CM	0.040000	0.040000	0.040000	0.040000	0.040000	0.040000
OM	0.240000	0.240000	0.240000	0.240000	0.240000	0.240000

MTTR/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.240000	0.240000	0.240000	0.240000	0.240000	1.200000	0.240000	5
PDM	0.240000	0.240000	0.240000	0.240000	0.240000	1.200000	0.240000	5
CBM	0.240000	0.240000	0.240000	0.240000	0.240000	1.200000	0.240000	5
CM	0.040000	0.040000	0.040000	0.040000	0.040000	0.200000	0.040000	5
OM	0.240000	0.240000	0.240000	0.240000	0.240000	1.200000	0.240000	5
							λ_{max}	5
							CI	0
							CR	0

Spare Parts/Air Dryer	PM	PDM	CBM	CM	OM	with respect to the sub criteria of spare parts cost, how important is PM when compared to CM? which will generate more savings in the spare parts cost. As the PM is timely based, it requires huge inventory to be in stock especially with long lead times for procuring the spares. so PHPC should have the spares for two upcoming years in the
PM	1.00	0.50	1.00	0.14	1.00	
PDM	2.00	1.00	0.50	0.25	2.00	
CBM	1.00	2.00	1.00	0.17	1.00	
CM	7.00	4.00	6.00	1.00	7.00	
OM	1.00	0.50	1.00	0.14	1.00	
	12.00	8.00	9.50	1.70	12.00	

Spare Parts/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.083333	0.062500	0.105263	0.083916	0.083333	0.083669
PDM	0.166667	0.125000	0.052632	0.146853	0.166667	0.131564
CBM	0.083333	0.250000	0.105263	0.097902	0.083333	0.123966
CM	0.583333	0.500000	0.631579	0.587413	0.583333	0.577132
OM	0.083333	0.062500	0.105263	0.083916	0.083333	0.083669

Spare Parts/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.083669	0.065782	0.123966	0.082447	0.083669	0.439534	0.083669	5.25323568
PDM	0.167338	0.131564	0.061983	0.144283	0.167338	0.672506	0.131564	5.11164471
CBM	0.083669	0.263127	0.123966	0.096189	0.083669	0.650621	0.123966	5.24836294
CM	0.585684	0.526254	0.743798	0.577132	0.585684	3.018553	0.577132	5.23026763
OM	0.083669	0.065782	0.123966	0.082447	0.083669	0.439534	0.083669	5.25323568
							λ_{max}	5.21934933
							CI	0.05483733
							CR	0.0489619

Assurance Spares/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	1.00	1.00
PDM	1.00	1.00	1.00	1.00	1.00
CBM	1.00	1.00	1.00	1.00	1.00
CM	1.00	1.00	1.00	1.00	1.00
OM	1.00	1.00	1.00	1.00	1.00
	5.00	5.00	5.00	5.00	5.00

with respect to sub criteria of assurance spare parts cost, how important is PM when compared to CM for the air dryer? Which will generate savings in the cost of assurance spares. as mentioned the only assurance spares is the controller, which will not be affected by adopting any maint strategy, even the CM, As it is already doesn't have any preventive maintenance done on it

Assurance Spares/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
PDM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
CBM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
CM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000
OM	0.200000	0.200000	0.200000	0.200000	0.200000	0.200000

Assurance Spares/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
PDM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
CBM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
CM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
OM	0.200000	0.200000	0.200000	0.200000	0.200000	1.000000	0.200000	5
							λ_{max}	5
							CI	0
							CR	0

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.120540269	0.217884661	0.590995658	0.070579413	1
PM	0.329195	0.240000	0.083669	0.200000	**0.155537568**
PDM	0.108462	0.240000	0.131564	0.200000	**0.157235739**
CBM	0.181790	0.240000	0.123966	0.200000	**0.161584865**
CM	0.064691	0.040000	0.577132	0.200000	**0.371711463**
OM	0.315862	0.240000	0.083669	0.200000	**0.153930365**

	MTBF	MTTR	Spare Parts	Assurance Spare
Map weight	0.064966508	0.117431343	0.318523634	0.038039554

Investment/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	4.00	2.00	0.33	1.00
PDM	0.25	1.00	0.25	0.14	0.25
CBM	0.50	4.00	1.00	0.25	2.00
CM	3.00	7.00	4.00	1.00	7.00
OM	1.00	4.00	0.50	0.14	1.00
	5.75	20.00	7.75	1.87	11.25

with respect to sub criteria of investment required, how important is PM compared to Cm? which will require less investment ? It should be noted here that for this equipment there is Differential pressure gauges installed on all filters, pressure relief valves on the desiccant tower, humidity sensor on the outlet air and pressure gauges on desiccant tower. Also there is no rotating parts, so there is no need for oil analysis or vibration analysis. that is why cbm investment is the same for PM, while PDM is higher as it need a software to analyze the data and predict the failure.

Investment/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.173913	0.200000	0.258065	0.178344	0.088889	0.179842
PDM	0.043478	0.050000	0.032258	0.076433	0.022222	0.044878
CBM	0.086957	0.200000	0.129032	0.133758	0.177778	0.145505
CM	0.521739	0.350000	0.516129	0.535032	0.622222	0.509024
OM	0.173913	0.200000	0.064516	0.076433	0.088889	0.120750

Investment/Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.179842	0.179513	0.291010	0.169675	0.120750	0.940790	0.179842	5.23120216
PDM	0.044961	0.044878	0.036376	0.072718	0.030188	0.229120	0.044878	5.10536818
CBM	0.089921	0.179513	0.145505	0.127256	0.241500	0.783696	0.145505	5.38604433
CM	0.539526	0.314148	0.582020	0.509024	0.845252	2.789970	0.509024	5.48101434
OM	0.179842	0.179513	0.072752	0.072718	0.120750	0.625576	0.120750	5.18074249
							λ_{max}	5.2768743
							CI	0.06921857
							CR	0.0618023

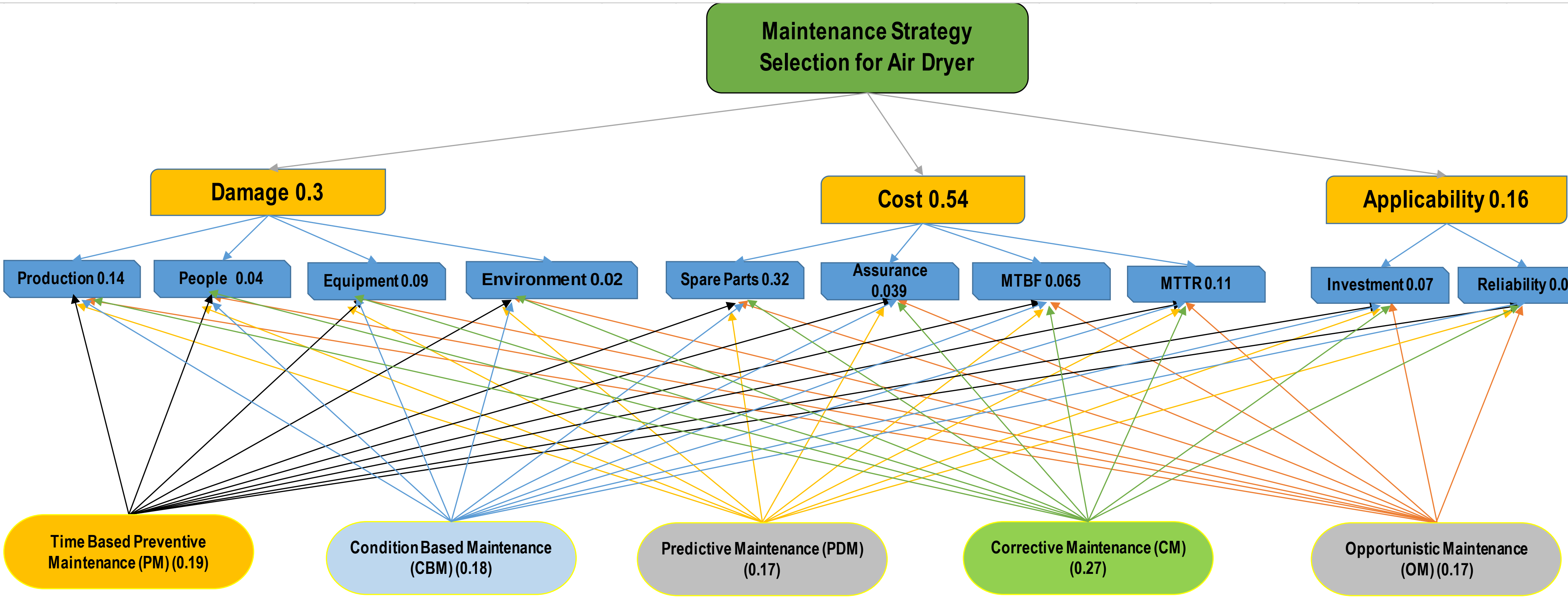
Reliability/Air Dryer	PM	PDM	CBM	CM	OM
PM	1.00	1.00	1.00	5.00	1.00
PDM	1.00	1.00	1.00	6.00	1.00
CBM	1.00	1.00	1.00	6.00	1.00
CM	0.20	0.17	0.17	1.00	0.20
OM	1.00	1.00	1.00	5.00	1.00
	4.20	4.17	4.17	23.00	4.20

Reliability/Air Dryer	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.238095	0.240000	0.240000	0.217391	0.238095	0.234716
PDM	0.238095	0.240000	0.240000	0.260870	0.238095	0.243412
CBM	0.238095	0.240000	0.240000	0.260870	0.238095	0.243412
CM	0.047619	0.040000	0.040000	0.043478	0.047619	0.043743
OM	0.238095	0.240000	0.240000	0.217391	0.238095	0.234716

Reliability Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.234716	0.243412	0.243412	0.218716	0.234716	1.174973	0.234716	5.0059276
PDM	0.234716	0.243412	0.243412	0.262460	0.234716	1.218716	0.243412	5.00680457
CBM	0.234716	0.243412	0.243412	0.262460	0.234716	1.218716	0.243412	5.00680457
CM	0.046943	0.040569	0.040569	0.043743	0.046943	0.218767	0.043743	5.00116118
OM	0.234716	0.243412	0.243412	0.218716	0.234716	1.174973	0.234716	5.0059276
							λ_{max}	5.0053251
							CI	0.00133128
							CR	0.00118864

Criteria / Alternative	Invest	Reliability	Final Score
	0.45	0.55	1
PM	0.179842	0.234716	0.210022932
PDM	0.044878	0.243412	0.154071855
CBM	0.145505	0.243412	0.199353811
CM	0.509024	0.043743	0.2531198
OM	0.120750	0.234716	0.183431602

	Invest	Reliability	
Map weight	0.073701299	0.090079365	



Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final
	0.143841464	0.08941324	0.021495834	0.042507759	0.064967	0.117431	0.318523634	0.038039554	0.073701	0.090079	
PM	0.230769231	0.251868132	0.2	0.25958486	0.329195	0.24	0.083669182	0.2	0.179842	0.234716	0.189274452
PDM	0.230769231	0.194725275	0.2	0.213431013	0.108462	0.24	0.131563612	0.2	0.044878	0.243412	0.17395477
CBM	0.230769231	0.194725275	0.2	0.213431013	0.18179	0.24	0.123966384	0.2	0.145505	0.243412	0.183715089
CM	0.076923077	0.163956044	0.2	0.084737485	0.064691	0.04	0.57713164	0.2	0.509024	0.043743	0.275419862
OM	0.230769231	0.194725275	0.2	0.228815629	0.315862	0.24	0.083669182	0.2	0.12075	0.234716	0.177635827

7-5 Appendix "E" Gas Turbine "B" Calculations

GT "B"	Damage	Applicability	Cost
Damage	1.00	4.00	8.00
Applicability	0.25	1.00	5.00
Cost	0.13	0.20	1.00
Summ	1.38	5.20	14.00

with respect to MS applied on Gas Turbine "B" , how important is Damage when compared to cost?

GT "B"	Damage	Applicability	Cost	Criteria Weight
Damage	0.73	0.77	0.57	0.689310689
Applicability	0.18	0.19	0.36	0.243756244
Cost	0.09	0.04	0.07	0.066933067

GT "B"	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.689311	0.975025	0.535465	2.20	0.689310689	3.191304
Applicability	0.172328	0.243756	0.334665	0.75	0.243756244	3.079918
Cost	0.086164	0.048751	0.066933	0.20	0.066933067	3.015672
					λ_{max}	3.095631
					CI	0.047816
					CR	0.082441

GT "B"	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	0.333333333	5	0.142857
Equipment Damage	3	1	7	0.25000
Environmental Damage	0.2	0.142857143	1	0.111111111
People Damage	7	4	9	1
Summ	11.2	5.476190476	22	1.503968254

with respect to the damage criteria, how important is the production loss when compared to the people damage for the gas turbine?

Normalized GT "B"	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.089285714	0.060869565	0.227272727	0.094986807	0.118103704
Equipment Damage	0.267857143	0.182608696	0.318181818	0.166226913	0.233718642
Environmental Damage	0.017857143	0.026086957	0.045454545	0.073878628	0.040819318
People Damage	0.625	0.730434783	0.409090909	0.664907652	0.607358336

GT "B"	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.118103704	0.077906214	0.204096591	0.086765477	0.486871985	0.118103704	4.122410819
Equipment Damage	0.354311111	0.233718642	0.285735227	0.151839584	1.025604564	0.233718642	4.388201788
Environmental Damage	0.023620741	0.033388377	0.040819318	0.06748426	0.165312696	0.040819318	4.049864212
People Damage	0.826725925	0.93487457	0.367373864	0.607358336	2.736332694	0.607358336	4.505301949
						λ_{max}	4.266444692
						CI	0.088814897
						CR	0.098683219

Production Loss/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.25	6.00	0.50
PDM	5.00	1.00	2.00	8.00	4.00
CBM	4.00	0.50	1.00	7.00	3.00
CM	0.17	0.13	0.14	1.00	0.17
OM	2.00	0.25	0.33	6.00	1.00
	12.17	2.08	3.73	28.00	8.67

Ex: with respect to the production loss sub-criteria, how important is PM when compared to CM? which one can reduce the production loss

Production Loss/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.082192	0.096386	0.067093	0.214286	0.057692	0.103530
PDM	0.410959	0.481928	0.536741	0.285714	0.461538	0.435376
CBM	0.328767	0.240964	0.268371	0.250000	0.346154	0.286851
CM	0.013699	0.060241	0.038339	0.035714	0.019231	0.033445
OM	0.164384	0.120482	0.089457	0.214286	0.115385	0.140799

Production Loss/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.103530	0.087075	0.071713	0.200668	0.070399	0.533385	0.103530	5.15200324
PDM	0.517648	0.435376	0.573702	0.267557	0.563194	2.357478	0.435376	5.41480721
CBM	0.414118	0.217688	0.286851	0.234113	0.422396	1.575166	0.286851	5.49123172
CM	0.017255	0.054422	0.040979	0.033445	0.023466	0.169567	0.033445	5.07006952
OM	0.207059	0.108844	0.095617	0.200668	0.140799	0.752987	0.140799	5.34797289
							λ_{max}	5.29521692
							CI	0.07380423
							CR	0.06589663

Equipment Damage/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	7.00	2.00
PDM	3.00	1.00	1.00	8.00	3.00
CBM	2.00	1.00	1.00	8.00	3.00
CM	0.14	0.13	0.13	1.00	0.17
OM	0.50	0.33	0.33	6.00	1.00
	6.64	2.79	2.96	30.00	9.17

with respect to sub-criteria of equipment damage, how important is PM when compared to CM? which can cause less damage to equipment when implemented ?

Equipment Damage/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.150538	0.119403	0.169014	0.233333	0.218182	0.178094
PDM	0.451613	0.358209	0.338028	0.266667	0.327273	0.348358
CBM	0.301075	0.358209	0.338028	0.266667	0.327273	0.318250
CM	0.021505	0.044776	0.042254	0.033333	0.018182	0.032010
OM	0.075269	0.119403	0.112676	0.200000	0.109091	0.123288

Equipment Damage/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.178094	0.116119	0.159125	0.224070	0.246576	0.923984	0.178094	5.18818342
PDM	0.534282	0.348358	0.318250	0.256080	0.369863	1.826834	0.348358	5.244129
CBM	0.356188	0.348358	0.318250	0.256080	0.369863	1.648740	0.318250	5.18063743
CM	0.025442	0.043545	0.039781	0.032010	0.020548	0.161326	0.032010	5.03985782
OM	0.089047	0.116119	0.106083	0.192060	0.123288	0.626598	0.123288	5.08240008
							λ_{max}	5.14704155
							CI	0.03676039
							CR	0.03282177

Environmental Damage/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	6.00	1.00
PDM	2.00	1.00	1.00	7.00	2.00
CBM	2.00	1.00	1.00	7.00	2.00
CM	0.17	0.14	0.14	1.00	0.17
OM	1.00	0.50	0.50	6.00	1.00
	6.17	3.14	3.14	27.00	6.17

there is no environmental damage caused by implementing or adobting any maintenance policy all have the same values

Environmental Damage/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.162162	0.159091	0.159091	0.222222	0.162162	0.172946
PDM	0.324324	0.318182	0.318182	0.259259	0.324324	0.308854
CBM	0.324324	0.318182	0.318182	0.259259	0.324324	0.308854
CM	0.027027	0.045455	0.045455	0.037037	0.027027	0.036400
OM	0.162162	0.159091	0.159091	0.222222	0.162162	0.172946

Environmental Damage/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.172946	0.154427	0.154427	0.218400	0.172946	0.873146	0.172946	5.0486714
PDM	0.345891	0.308854	0.308854	0.254800	0.345891	1.564292	0.308854	5.06482027
CBM	0.345891	0.308854	0.308854	0.254800	0.345891	1.564292	0.308854	5.06482027
CM	0.028824	0.044122	0.044122	0.036400	0.028824	0.182293	0.036400	5.00803571
OM	0.172946	0.154427	0.154427	0.218400	0.172946	0.873146	0.172946	5.0486714
							λ_{max}	5.04700381
							CI	0.01175095
							CR	0.01049192

People Damage/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.33	7.00	1.00
PDM	3.00	1.00	1.00	8.00	3.00
CBM	3.00	1.00	1.00	8.00	3.00
CM	0.14	0.13	0.13	1.00	0.14
OM	1.00	0.33	0.33	7.00	1.00
	8.14	2.79	2.79	31.00	8.14

People Damage/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.122807	0.119403	0.119403	0.225806	0.122807	0.142045
PDM	0.368421	0.358209	0.358209	0.258065	0.368421	0.342265
CBM	0.368421	0.358209	0.358209	0.258065	0.368421	0.342265
CM	0.017544	0.044776	0.044776	0.032258	0.017544	0.031380
OM	0.122807	0.119403	0.119403	0.225806	0.122807	0.142045

People Damage/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.142045	0.114088	0.114088	0.219657	0.142045	0.731924	0.142045	5.15275383
PDM	0.426136	0.342265	0.342265	0.251037	0.426136	1.787838	0.342265	5.22355159
CBM	0.426136	0.342265	0.342265	0.251037	0.426136	1.787838	0.342265	5.22355159
CM	0.020292	0.042783	0.042783	0.031380	0.020292	0.157530	0.031380	5.02014613
OM	0.142045	0.114088	0.114088	0.219657	0.142045	0.731924	0.142045	5.15275383
							λ_{max}	5.15455139
							CI	0.03863785
							CR	0.03449808

Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.118103704	0.233718642	0.040819318	0.607358336	1
PM	0.103530	0.178094	0.172946	0.142045	**0.147183026**
PDM	0.435376	0.348358	0.308854	0.342265	**0.35332193**
CBM	0.286851	0.318250	0.308854	0.342265	**0.328743883**
CM	0.033445	0.032010	0.036400	0.031380	**0.031975769**
OM	0.140799	0.123288	0.172946	0.142045	**0.138775391**

	Production Loss	Equipment Damage	Environmental Damage	People Damage
map weight	0.081410145	0.161104759	0.028137192	0.418658593

GT "B"	MTBF	MTTR	Spare Parts	Assurance Spare
MTBF	1	3	5	4
MTTR	0.333333333	1	4	3
Spare Parts	0.2	0.25	1	0.25
Assurance Spares	0.25	0.333333333	4	1
Summ	1.783333333	4.583333333	14	8.25

with respect to cost criteria , how important is spare parts cost when compared with assurance spares cost for gas turbine "B"?
Forthe gas turbine, the assurance spares cost is way higher than the regular spares cost

Normalized GT "B"	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight
MTBF	0.560747664	0.654545455	0.357142857	0.484848485	0.514321115
MTTR	0.186915888	0.218181818	0.285714286	0.363636364	0.263612089
Spare Parts	0.112149533	0.054545455	0.071428571	0.03030303	0.067106647
Assurance Spares	0.140186916	0.072727273	0.285714286	0.121212121	0.154960149

GT "B"	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.514321115	0.790836267	0.335533236	0.619840596	2.260531213	0.514321115	4.395174818
MTTR	0.171440372	0.263612089	0.268426589	0.464880447	1.168359496	0.263612089	4.432116529
Spare Parts	0.102864223	0.065903022	0.067106647	0.038740037	0.27461393	0.067106647	4.092201607
Assurance Spares	0.128580279	0.087870696	0.268426589	0.154960149	0.639837713	0.154960149	4.129046839
						λ_{max}	4.262134948
						CI	0.087378316
						CR	0.097087018

MTBF/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.33	8.00	2.00
PDM	5.00	1.00	2.00	9.00	6.00
CBM	3.00	0.50	1.00	8.00	5.00
CM	0.13	0.11	0.13	1.00	0.17
OM	0.50	0.17	0.20	6.00	1.00
	9.63	1.98	3.66	32.00	14.17

with respect to cost sub-criteria MTBF, how important is PM, when compared to cm? which will generate cost reduction i.e., increase the MTBF's?

MTBF/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.103896	0.101124	0.091116	0.250000	0.141176	0.137462
PDM	0.519481	0.505618	0.546697	0.281250	0.423529	0.455315
CBM	0.311688	0.252809	0.273349	0.250000	0.352941	0.288157
CM	0.012987	0.056180	0.034169	0.031250	0.011765	0.029270
OM	0.051948	0.084270	0.054670	0.187500	0.070588	0.089795

MTBF/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.137462	0.091063	0.096052	0.234160	0.179590	0.738328	0.137462	5.37112636
PDM	0.687312	0.455315	0.576315	0.263430	0.538771	2.521143	0.455315	5.5371404
CBM	0.412387	0.227657	0.288157	0.234160	0.448976	1.611338	0.288157	5.59186768
CM	0.017183	0.050591	0.036020	0.029270	0.014966	0.148029	0.029270	5.05735719
OM	0.068731	0.075886	0.057631	0.175620	0.089795	0.467664	0.089795	5.20811923
							λ_{max}	5.35312217
							CI	0.08828054
							CR	0.07882191

MTTR/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	6.00	2.00
PDM	2.00	1.00	2.00	7.00	4.00
CBM	2.00	0.50	1.00	7.00	3.00
CM	0.17	0.14	0.14	1.00	0.17
OM	0.50	0.25	0.33	6.00	1.00
	5.67	2.39	3.98	27.00	10.17

with respect to cost sub-criteria MTTR, how important is PM, when compared to cm? which will generate cost reduction i.e., reduce the MTTR?

MTTR/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.176471	0.208955	0.125749	0.222222	0.196721	0.186024
PDM	0.352941	0.417910	0.502994	0.259259	0.393443	0.385310
CBM	0.352941	0.208955	0.251497	0.259259	0.295082	0.273547
CM	0.029412	0.059701	0.035928	0.037037	0.016393	0.035694
OM	0.088235	0.104478	0.083832	0.222222	0.098361	0.119426

MTTR/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.186024	0.192655	0.136773	0.214166	0.238851	0.968469	0.186024	5.20616442
PDM	0.372047	0.385310	0.547094	0.249861	0.477702	2.032014	0.385310	5.27371789
CBM	0.372047	0.192655	0.273547	0.249861	0.358277	1.446386	0.273547	5.2875254
CM	0.031004	0.055044	0.039078	0.035694	0.019904	0.180725	0.035694	5.06312035
OM	0.093012	0.096327	0.091182	0.214166	0.119426	0.614113	0.119426	5.14222434
							λ_{max}	5.19455048
							CI	0.04863762
							CR	0.04342645

Spare Parts/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.33	0.14	0.50
PDM	5.00	1.00	2.00	0.20	3.00
CBM	3.00	0.50	1.00	0.17	2.00
CM	7.00	5.00	6.00	1.00	5.00
OM	2.00	0.33	0.50	0.20	1.00
	18.00	7.03	9.83	1.71	11.50

with respect to the sub criteria of spare parts cost, how important is PM when compared to CM? which will generate more savings in the spare parts cost. As the PM is timely based, it requires huge inventory to be in stock especially with long lead times for procuring the spares. so PHPC should have the spares for two upcoming years in the

Spare Parts/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.055556	0.028436	0.033898	0.083565	0.043478	0.048987
PDM	0.277778	0.142180	0.203390	0.116992	0.260870	0.200242
CBM	0.166667	0.071090	0.101695	0.097493	0.173913	0.122172
CM	0.388889	0.710900	0.610169	0.584958	0.434783	0.545940
OM	0.111111	0.047393	0.050847	0.116992	0.086957	0.082660

Spare Parts/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.048987	0.040048	0.040724	0.077991	0.041330	0.249080	0.048987	5.08465055
PDM	0.244934	0.200242	0.244343	0.109188	0.247980	1.046687	0.200242	5.22711344
CBM	0.146960	0.100121	0.122172	0.090990	0.165320	0.625563	0.122172	5.12036283
CM	0.342907	1.001209	0.733029	0.545940	0.413300	3.036385	0.545940	5.56175696
OM	0.097973	0.066747	0.061086	0.109188	0.082660	0.417654	0.082660	5.05267819
							λ_{max}	5.20931239
							CI	0.0523281
							CR	0.04672152

Assurance Spares/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	3.00	1.00
PDM	2.00	1.00	1.00	4.00	2.00
CBM	2.00	1.00	1.00	4.00	2.00
CM	0.33	0.25	0.25	1.00	0.50
OM	1.00	0.50	0.50	2.00	1.00
	6.33	3.25	3.25	14.00	6.50

with respect to sub criteria of assurance spare parts cost, how important is PM when compared to CM? Which will generate savings in the cost of assurance spares. For example adopting cm strategy means no oil analysis, which can cause wear to the gearbox and the pumps as well as bearings, while PDM can save these costs. PM will change the oil at fixed interval times, while PDM will only change based on lube oil analysis carried quarterly. so both will save in the assurance. but the major save of PDM strongly appears in Spares cost all Ms's will purschase assurance intially, except CM. while CM will consume more assurance than others.

Assurance Spares/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.157895	0.153846	0.153846	0.214286	0.153846	0.166744
PDM	0.315789	0.307692	0.307692	0.285714	0.307692	0.304916
CBM	0.315789	0.307692	0.307692	0.285714	0.307692	0.304916
CM	0.052632	0.076923	0.076923	0.071429	0.076923	0.070966
OM	0.157895	0.153846	0.153846	0.142857	0.153846	0.152458

Assurance Spares/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.166744	0.152458	0.152458	0.212898	0.152458	0.837016	0.166744	5.01977107
PDM	0.333488	0.304916	0.304916	0.283864	0.304916	1.532099	0.304916	5.02465857
CBM	0.333488	0.304916	0.304916	0.283864	0.304916	1.532099	0.304916	5.02465857
CM	0.055581	0.076229	0.076229	0.070966	0.076229	0.355234	0.070966	5.00570497
OM	0.166744	0.152458	0.152458	0.141932	0.152458	0.766050	0.152458	5.02465857
							λ_{max}	5.01989035
							CI	0.00497259
							CR	0.00443981

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.514321115	0.263612089	0.067106647	0.154960149	1
PM	0.137462	0.186024	0.048987	0.166744	**0.148863888**
PDM	0.455315	0.385310	0.200242	0.304916	**0.396437761**
CBM	0.288157	0.273547	0.122172	0.304916	**0.275764084**
CM	0.029270	0.035694	0.545940	0.070966	**0.072096736**
OM	0.089795	0.119426	0.082660	0.152458	**0.106837532**

	MTBF	MTTR	Spare Parts	Assurance Spare	
Map weight	0.03442509	0.017644366	0.004491654	0.010371958	

Investment/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	4.00	2.00	0.17	1.00
PDM	0.25	1.00	0.50	0.13	0.25
CBM	0.50	2.00	1.00	0.14	0.20
CM	6.00	8.00	7.00	1.00	6.00
OM	1.00	4.00	5.00	0.17	1.00
	8.75	19.00	15.50	1.60	8.45

with respect to sub criteria of investment required, how important is PM compared to Cm? which will require less investment ?

Investment/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.114286	0.210526	0.129032	0.104089	0.118343	0.135255
PDM	0.028571	0.052632	0.032258	0.078067	0.029586	0.044223
CBM	0.057143	0.105263	0.064516	0.089219	0.023669	0.067962
CM	0.685714	0.421053	0.451613	0.624535	0.710059	0.578595
OM	0.114286	0.210526	0.322581	0.104089	0.118343	0.173965

Investment/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.135255	0.176891	0.135924	0.096432	0.173965	0.718468	0.135255	5.31193745
PDM	0.033814	0.044223	0.033981	0.072324	0.043491	0.227833	0.044223	5.15194508
CBM	0.067628	0.088446	0.067962	0.082656	0.034793	0.341485	0.067962	5.02463884
CM	0.811532	0.353782	0.475734	0.578595	1.043790	3.263433	0.578595	5.64027344
OM	0.135255	0.176891	0.339810	0.096432	0.173965	0.922354	0.173965	5.30195087
							λ_{max}	5.28614914
							CI	0.07153728
							CR	0.06387258

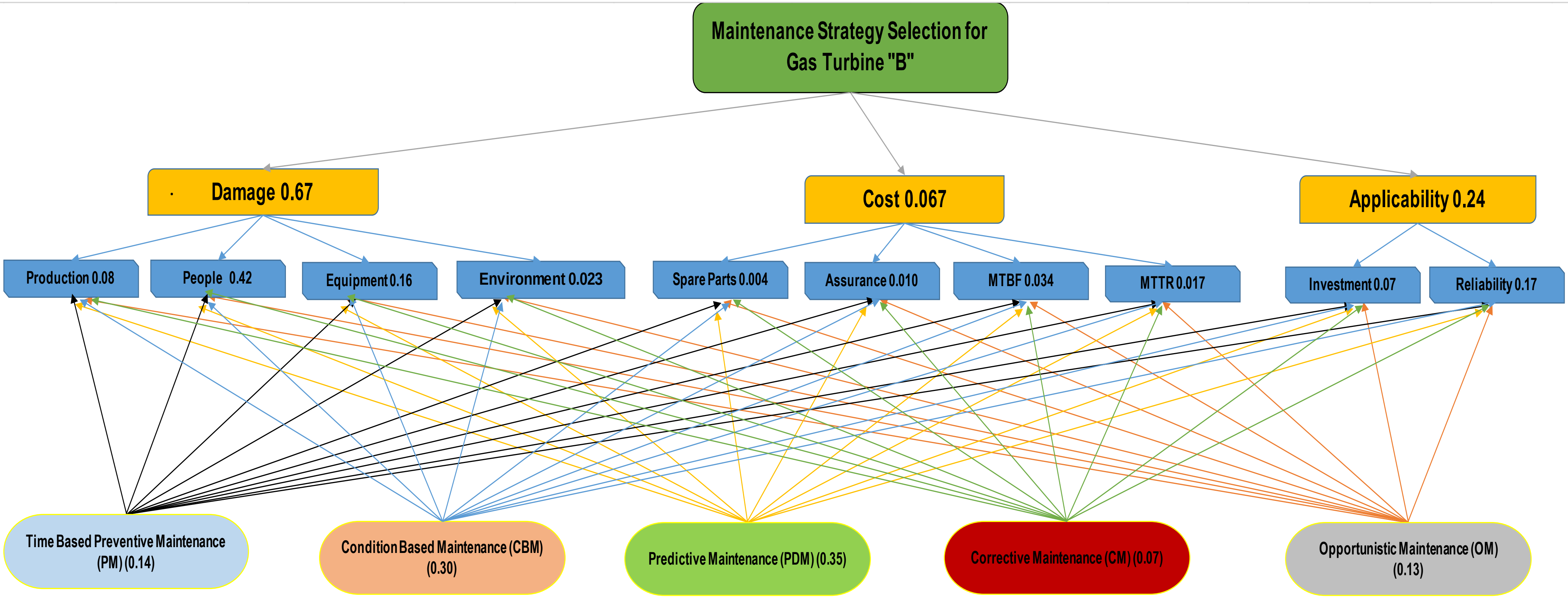
Reliability/GT "B"	PM	PDM	CBM	CM	OM
PM	1.00	0.25	0.33	5.00	2.00
PDM	4.00	1.00	2.00	8.00	5.00
CBM	3.00	0.50	1.00	6.00	4.00
CM	0.20	0.13	0.17	1.00	0.25
OM	0.50	0.20	0.25	4.00	1.00
	8.70	2.08	3.75	24.00	12.25

Reliability/GT "B"	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.114943	0.120482	0.088889	0.208333	0.163265	0.139182
PDM	0.459770	0.481928	0.533333	0.333333	0.408163	0.443306
CBM	0.344828	0.240964	0.266667	0.250000	0.326531	0.285798
CM	0.022989	0.060241	0.044444	0.041667	0.020408	0.037950
OM	0.057471	0.096386	0.066667	0.166667	0.081633	0.093765

Reliability Air Dryer	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.139182	0.110826	0.095266	0.189749	0.187529	0.722553	0.139182	5.19140765
PDM	0.556730	0.443306	0.571595	0.303598	0.468823	2.344051	0.443306	5.28766536
CBM	0.417547	0.221653	0.285798	0.227698	0.375058	1.527754	0.285798	5.34557907
CM	0.027836	0.055413	0.047633	0.037950	0.023441	0.192274	0.037950	5.06652943
OM	0.069591	0.088661	0.071449	0.151799	0.093765	0.475265	0.093765	5.06870939
							λ_{max}	5.19197818
							CI	0.04799455
							CR	0.04285227

Criteria / **Alternative**	Invest	Reliability	Final Score
	0.3	0.7	1
PM	0.135255	0.139182	**0.13800428**
PDM	0.044223	0.443306	**0.323580713**
CBM	0.067962	0.285798	**0.220447028**
CM	0.578595	0.037950	**0.200143283**
OM	0.173965	0.093765	**0.117824696**

	Invest	Reliability
Map weight	0.073126873	0.170629371



Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final
0.081410145	0.161104759	0.028137192	0.418658593	0.03442509	0.017644366	0.004491654	0.010371958	0.073126873	0.170629371	
0.103529599	0.178093971	0.172945673	0.142045291	0.137462469	0.18602357	0.04898672	0.166743783	0.135255341	0.139182397	0.145058155
0.435376115	0.348357884	0.308854309	0.342264906	0.455314989	0.385309504	0.200241782	0.304916136	0.044222757	0.443305552	0.348958197
0.286851086	0.318250357	0.308854309	0.342264906	0.288157399	0.273546927	0.122171542	0.304916136	0.067962023	0.285797744	0.298799748
0.033444661	0.032010034	0.036400036	0.031379605	0.029270012	0.035694376	0.545939936	0.070965876	0.578594862	0.037949749	0.07565307
0.140798538	0.123287754	0.172945673	0.142045291	0.089795131	0.119425624	0.08266002	0.152458068	0.173965018	0.093764559	0.13153083

7-6 Appendix "F" Air Compressor Calculations:

Air Compressor	Damage	Applicability	Cost
Damage	1.00	4.00	2.00
Applicability	0.25	1.00	0.25
Cost	0.50	4.00	1.00
Summ	1.75	9.00	3.25

with respect to MS applied onAir Compressor , how important is Damage when compared to cost?

Normalized Air Compressor	Damage	Applicability	Cost	Criteria Weight
Damage	0.57	0.44	0.62	0.543752544
Applicability	0.14	0.11	0.08	0.11029711
Cost	0.29	0.44	0.31	0.345950346

Air Compressor	Damage	Applicability	Cost	WSV	Criteria Weight	WSV/CW
Damage	0.543753	0.441188	0.691901	1.68	0.543752544	3.083832
Applicability	0.135938	0.110297	0.086488	0.33	0.11029711	3.016605
Cost	0.271876	0.441188	0.345950	1.06	0.345950346	3.061176
					λ_{max}	3.053871
					CI	0.026936
					CR	0.046441

Air Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage
Production Loss	1	0.333333333	2	0.250000
Equipment Damage	3	1	4	0.33333
Environmental Damage	0.5	0.25	1	0.16667
People Damage	4	3	6	1
Summ	8.5	4.583333333	13	1.75

with respect to the damage criteria, how important is the production loss when compared to the people damage for the Air Compressor? Due to the redunduncy, the production will not be affected by the failuer of one compressor, that's why the weight of the equipment damage is higher

Normalized Air Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage	Criteria Weight
Production Loss	0.117647059	0.072727273	0.153846154	0.142857143	0.121769407
Equipment Damage	0.352941176	0.218181818	0.307692308	0.19047619	0.267322873
Environmental Damage	0.058823529	0.054545455	0.076923077	0.095238095	0.071382539
People Damage	0.470588235	0.654545455	0.461538462	0.571428571	0.539525181

Air Compressor	Production Loss	Equipment Damage	Environmental Damage	People Damage	WSV	Criteria Weight	WSV/CW
Production Loss	0.121769407	0.089107624	0.142765078	0.134881295	0.488523405	0.121769407	4.011873068
Equipment Damage	0.365308221	0.267322873	0.285530156	0.179841727	1.098002977	0.267322873	4.107403771
Environmental Damage	0.060884704	0.066830718	0.071382539	0.089920863	0.289018824	0.071382539	4.048872851
People Damage	0.487077628	0.80196862	0.428295234	0.539525181	2.256866663	0.539525181	4.183060853
						λ_{max}	4.087802636
						CI	0.029267545
						CR	0.032519495

Production Loss/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	5.00	1.00
PDM	2.00	1.00	1.00	6.00	2.00
CBM	2.00	1.00	1.00	6.00	2.00
CM	0.20	0.17	0.17	1.00	0.20
OM	1.00	0.50	0.50	5.00	1.00
	6.20	3.17	3.17	23.00	6.20

Ex: with respect to the production loss sub-criteria, how important is PM when compared to CM? which one can reduce the production loss

Production Loss/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.161290	0.157895	0.157895	0.217391	0.161290	0.171152
PDM	0.322581	0.315789	0.315789	0.260870	0.322581	0.307522
CBM	0.322581	0.315789	0.315789	0.260870	0.322581	0.307522
CM	0.032258	0.052632	0.052632	0.043478	0.032258	0.042652
OM	0.161290	0.157895	0.157895	0.217391	0.161290	0.171152

Production Loss/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.171152	0.153761	0.153761	0.213258	0.171152	0.863084	0.171152	5.04278444
PDM	0.342305	0.307522	0.307522	0.255909	0.342305	1.555562	0.307522	5.05837734
CBM	0.342305	0.307522	0.307522	0.255909	0.342305	1.555562	0.307522	5.05837734
CM	0.034230	0.051254	0.051254	0.042652	0.034230	0.213620	0.042652	5.00849198
OM	0.171152	0.153761	0.153761	0.213258	0.171152	0.863084	0.171152	5.04278444
							λ_{max}	5.04216311
							CI	0.01054078
							CR	0.00941141

Equipment DamageAir Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.20	0.50	6.00	2.00
PDM	5.00	1.00	2.00	8.00	6.00
CBM	2.00	0.50	1.00	7.00	5.00
CM	0.17	0.13	0.14	1.00	0.20
OM	0.50	0.17	0.20	5.00	1.00
	8.67	1.99	3.84	27.00	14.20

with respect to sub-criteria of equipment damage, how important is PM when compared to CM? which can cause less damage to equipment when implemented ?

Equipment DamageAir Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.115385	0.100418	0.130112	0.222222	0.140845	0.141796
PDM	0.576923	0.502092	0.520446	0.296296	0.422535	0.463659
CBM	0.230769	0.251046	0.260223	0.259259	0.352113	0.270682
CM	0.019231	0.062762	0.037175	0.037037	0.014085	0.034058
OM	0.057692	0.083682	0.052045	0.185185	0.070423	0.089805

Equipment Damage/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.141796	0.092732	0.135341	0.204346	0.179611	0.753826	0.141796	5.31625751
PDM	0.708982	0.463659	0.541364	0.272462	0.538832	2.525298	0.463659	5.44646086
CBM	0.283593	0.231829	0.270682	0.238404	0.449027	1.473535	0.270682	5.44378422
CM	0.023633	0.057957	0.038669	0.034058	0.017961	0.172278	0.034058	5.05840509
OM	0.070898	0.077276	0.054136	0.170289	0.089805	0.462405	0.089805	5.14896936
							λ_{max}	5.28277541
							CI	0.07069385
							CR	0.06311951

Environmental Damage/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.50	0.50	3.00	1.00
PDM	2.00	1.00	1.00	4.00	2.00
CBM	2.00	1.00	1.00	4.00	2.00
CM	0.33	0.25	0.25	1.00	0.33
OM	1.00	0.50	0.50	3.00	1.00
	6.33	3.25	3.25	15.00	6.33

there is no environmental damage caused by implementing or adobting any maintenance policy

Environmental Damage/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.157895	0.153846	0.153846	0.200000	0.157895	0.164696
PDM	0.315789	0.307692	0.307692	0.266667	0.315789	0.302726
CBM	0.315789	0.307692	0.307692	0.266667	0.315789	0.302726
CM	0.052632	0.076923	0.076923	0.066667	0.052632	0.065155
OM	0.157895	0.153846	0.153846	0.200000	0.157895	0.164696

Environmental Damage/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.164696	0.151363	0.151363	0.195466	0.164696	0.827584	0.164696	5.02490987
PDM	0.329393	0.302726	0.302726	0.260621	0.329393	1.524858	0.302726	5.03708987
CBM	0.329393	0.302726	0.302726	0.260621	0.329393	1.524858	0.302726	5.03708987
CM	0.054899	0.075682	0.075682	0.065155	0.054899	0.326316	0.065155	5.008285
OM	0.164696	0.151363	0.151363	0.195466	0.164696	0.827584	0.164696	5.02490987
							λ_{max}	5.0264569
							CI	0.00661422
							CR	0.00590556

People Damage/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	6.00	2.00
PDM	3.00	1.00	2.00	7.00	4.00
CBM	2.00	0.50	1.00	7.00	3.00
CM	0.17	0.14	0.14	1.00	0.20
OM	0.50	0.25	0.33	5.00	1.00
	6.67	2.23	3.98	26.00	10.20

People Damage/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.150000	0.149733	0.125749	0.230769	0.196078	0.170466
PDM	0.450000	0.449198	0.502994	0.269231	0.392157	0.412716
CBM	0.300000	0.224599	0.251497	0.269231	0.294118	0.267889
CM	0.025000	0.064171	0.035928	0.038462	0.019608	0.036634
OM	0.075000	0.112299	0.083832	0.192308	0.098039	0.112296

People Damage/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.170466	0.137572	0.133944	0.219802	0.224591	0.886376	0.170466	5.19973064
PDM	0.511397	0.412716	0.535778	0.256436	0.449183	2.165510	0.412716	5.24697494
CBM	0.340932	0.206358	0.267889	0.256436	0.336887	1.408502	0.267889	5.25778344
CM	0.028411	0.058959	0.038270	0.036634	0.022459	0.184733	0.036634	5.04270497
OM	0.085233	0.103179	0.089296	0.183169	0.112296	0.573173	0.112296	5.10413418
							λ_{max}	5.17026563
							CI	0.04256641
							CR	0.03800572

Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	Final Score
	0.121769407	0.267322873	0.071382539	0.539525181	1
PM	0.171152	0.141796	0.164696	0.170466	**0.162473537**
PDM	0.307522	0.463659	0.302726	0.412716	**0.405673276**
CBM	0.307522	0.270682	0.302726	0.267889	**0.275948415**
CM	0.042652	0.034058	0.065155	0.036634	**0.038713816**
OM	0.171152	0.089805	0.164696	0.112296	**0.117190955**

	Production Loss	Equipment Damage	Environmental Damage	People Damage
map weight	0.066212425	0.145357492	0.038814437	0.293368189

Air Compressor	MTBF	MTTR	Spare Parts	Assurance Spare
MTBF	1	0.333333333	0.25	0.2
MTTR	3	1	0.5	0.333333333
Spare Parts	4	2	1	0.25
Assurance Spares	5	3	4	1
Summ	13	6.333333333	5.75	1.783333333

with respect to cost criteria , how important is spare parts cost when compared with assurance spares cost for air compressor"? For the air compressor , assurance cost is high as manin motor, air cooler, controller, compressor rotor and bearings, lube oil pump, while spares include air filters, lubrication oils, oil breather, gaskets , orings, transmitter, hoses

Normalized Air Compressor	MTBF	MTTR	Spare Parts	Assurance Spare	Criteria Weight
MTBF	0.076923077	0.052631579	0.043478261	0.112149533	0.071295612
MTTR	0.230769231	0.157894737	0.086956522	0.186915888	0.165634094
Spare Parts	0.307692308	0.315789474	0.173913043	0.140186916	0.234395435
Assurance Spares	0.384615385	0.473684211	0.695652174	0.560747664	0.528674858

Air Compressor	MTBF	MTTR	Spare Parts	Assurance Spare	WSV	Criteria Weight	WSV/CW
MTBF	0.071295612	0.055211365	0.058598859	0.105734972	0.290840808	0.071295612	4.079364745
MTTR	0.213886837	0.165634094	0.117197718	0.176224953	0.672943602	0.165634094	4.062832622
Spare Parts	0.285182449	0.331268189	0.234395435	0.132168715	0.983014788	0.234395435	4.193830767
Assurance Spares	0.356478062	0.496902283	0.937581741	0.528674858	2.319636944	0.528674858	4.387643762
						λ_{max}	4.180917974
						CI	0.060305991
						CR	0.067006657

MTBF/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	5.00	2.00
PDM	3.00	1.00	2.00	7.00	5.00
CBM	2.00	0.50	1.00	6.00	4.00
CM	0.20	0.14	0.17	1.00	0.25
OM	0.50	0.20	0.25	4.00	1.00
	6.70	2.18	3.92	23.00	12.25

with respect to cost sub-criteria MTBF, how important is PM, when compared to cm? which will generate cost reduction i.e., increase the MTBF's?

MTBF/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.149254	0.153173	0.127660	0.217391	0.163265	0.162149
PDM	0.447761	0.459519	0.510638	0.304348	0.408163	0.426086
CBM	0.298507	0.229759	0.255319	0.260870	0.326531	0.274197
CM	0.029851	0.065646	0.042553	0.043478	0.020408	0.040387
OM	0.074627	0.091904	0.063830	0.173913	0.081633	0.097181

MTBF/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.162149	0.142029	0.137099	0.201936	0.194362	0.837574	0.162149	5.16547356
PDM	0.486446	0.426086	0.548394	0.282710	0.485906	2.229542	0.426086	5.23261288
CBM	0.324297	0.213043	0.274197	0.242323	0.388725	1.442585	0.274197	5.26112252
CM	0.032430	0.060869	0.045700	0.040387	0.024295	0.203681	0.040387	5.04321311
OM	0.081074	0.085217	0.068549	0.161549	0.097181	0.493571	0.097181	5.07886911
							λ_{max}	5.15625823
							CI	0.03906456
							CR	0.03487907

MTTR/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	2.00	2.00	7.00	3.00
PDM	0.50	1.00	1.00	6.00	5.00
CBM	0.50	1.00	1.00	5.00	4.00
CM	0.14	0.17	0.20	1.00	0.20
OM	0.33	0.20	0.25	5.00	1.00
	2.48	4.37	4.45	24.00	13.20

with respect to cost sub-criteria MTTR, how important is PM, when compared to cm? which will generate cost reduction i.e., reduce the MTTR?

MTTR/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.403846	0.458015	0.449438	0.291667	0.227273	0.366048
PDM	0.201923	0.229008	0.224719	0.250000	0.378788	0.256888
CBM	0.201923	0.229008	0.224719	0.208333	0.303030	0.233403
CM	0.057692	0.038168	0.044944	0.041667	0.015152	0.039524
OM	0.134615	0.045802	0.056180	0.208333	0.075758	0.104138

MTTR/GT "B"	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.366048	0.513775	0.466805	0.276671	0.312413	1.935712	0.366048	5.28813982
PDM	0.183024	0.256888	0.233403	0.237147	0.520688	1.431148	0.256888	5.5711088
CBM	0.183024	0.256888	0.233403	0.197622	0.416550	1.287486	0.233403	5.51615946
CM	0.052293	0.042815	0.046681	0.039524	0.020828	0.202140	0.039524	5.1142932
OM	0.122016	0.051378	0.058351	0.197622	0.104138	0.533504	0.104138	5.12307079
							λ_{max}	5.32255441
							CI	0.0806386
							CR	0.07199875

Spare Parts/ Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	0.14	0.50
PDM	3.00	1.00	2.00	0.17	3.00
CBM	2.00	0.50	1.00	0.20	2.00
CM	7.00	6.00	5.00	1.00	5.00
OM	2.00	0.33	0.50	0.20	1.00
	15.00	8.17	9.00	1.71	11.50

with respect to the sub criteria of spare parts cost, how important is PM when compared to CM? which will generate more savings in the spare parts cost. As the PM is timely based, it requires huge inventory to be in stock especially with long lead times for procuring the spares. so PHPC should have the spares for two upcoming years in the

Spare Parts/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.066667	0.040816	0.055556	0.083565	0.043478	0.058016
PDM	0.200000	0.122449	0.222222	0.097493	0.260870	0.180607
CBM	0.133333	0.061224	0.111111	0.116992	0.173913	0.119315
CM	0.466667	0.734694	0.555556	0.584958	0.434783	0.555331
OM	0.133333	0.040816	0.055556	0.116992	0.086957	0.086731

Spare Parts/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.058016	0.060202	0.059657	0.079333	0.043365	0.300574	0.058016	5.18084858
PDM	0.174049	0.180607	0.238629	0.092555	0.260192	0.946033	0.180607	5.23808094
CBM	0.116033	0.090303	0.119315	0.111066	0.173461	0.610179	0.119315	5.11402633
CM	0.406115	1.083641	0.596574	0.555331	0.433653	3.075314	0.555331	5.53779997
OM	0.116033	0.060202	0.059657	0.111066	0.086731	0.433689	0.086731	5.00041618
							λ_{max}	5.2142344
							CI	0.0535586
							CR	0.04782018

Assurance Spares/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	2.00	1.00	6.00	1.00
PDM	0.50	1.00	0.50	5.00	2.00
CBM	1.00	2.00	1.00	5.00	1.00
CM	0.17	0.20	0.20	1.00	0.25
OM	1.00	0.50	1.00	4.00	1.00
	3.67	5.70	3.70	21.00	5.25

with respect to sub criteria of assurance spare parts cost, how important is PM when compared to CM? Which will generate savings in the cost of assurance spares.

Assurance Spares/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.272727	0.350877	0.270270	0.285714	0.190476	0.274013
PDM	0.136364	0.175439	0.135135	0.238095	0.380952	0.213197
CBM	0.272727	0.350877	0.270270	0.238095	0.190476	0.264489
CM	0.045455	0.035088	0.054054	0.047619	0.047619	0.045967
OM	0.272727	0.087719	0.270270	0.190476	0.190476	0.202334

Assurance Spares/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.274013	0.426394	0.264489	0.275801	0.202334	1.443031	0.274013	5.26628732
PDM	0.137007	0.213197	0.132245	0.229834	0.404668	1.116950	0.213197	5.23905239
CBM	0.274013	0.426394	0.264489	0.229834	0.202334	1.397065	0.264489	5.2821225
CM	0.045669	0.042639	0.052898	0.045967	0.050583	0.237756	0.045967	5.17234182
OM	0.274013	0.106598	0.264489	0.183868	0.202334	1.031302	0.202334	5.09703235
							λ_{max}	5.21136728
							CI	0.05284182
							CR	0.0471802

Criteria / Alternative	MTBF	MTTR	Spare Parts	Assurance Spare	Final Score
	0.071295612	0.165634094	0.234395435	0.528674858	1
PM	0.162149	0.366048	0.058016	0.274013	**0.230653075**
PDM	0.426086	0.256888	0.180607	0.213197	**0.227972678**
CBM	0.274197	0.233403	0.119315	0.264489	**0.226004136**
CM	0.040387	0.039524	0.555331	0.045967	**0.163894702**
OM	0.097181	0.104138	0.086731	0.202334	**0.151475409**

	MTBF	MTTR	Spare Parts	Assurance Spare
Map weight	0.024664742	0.057301172	0.081089182	0.18289525

Investment/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	5.00	3.00	0.33	0.50
PDM	0.20	1.00	0.50	0.20	0.25
CBM	0.33	2.00	1.00	0.25	0.33
CM	3.00	5.00	4.00	1.00	2.00
OM	2.00	4.00	3.00	0.50	1.00
	6.53	17.00	11.50	2.28	4.08

with respect to sub criteria of investment required, how important is PM compared to Cm? which will require less investment ?

Investment/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.153061	0.294118	0.260870	0.145985	0.122449	0.195297
PDM	0.030612	0.058824	0.043478	0.087591	0.061224	0.056346
CBM	0.051020	0.117647	0.086957	0.109489	0.081633	0.089349
CM	0.459184	0.294118	0.347826	0.437956	0.489796	0.405776
OM	0.306122	0.235294	0.260870	0.218978	0.244898	0.253232

Investment/Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.195297	0.281730	0.268047	0.135259	0.126616	1.006949	0.195297	5.15599753
PDM	0.039059	0.056346	0.044675	0.081155	0.063308	0.284543	0.056346	5.04993012
CBM	0.065099	0.112692	0.089349	0.101444	0.084411	0.452995	0.089349	5.06993907
CM	0.585890	0.281730	0.357397	0.405776	0.506465	2.137257	0.405776	5.26708649
OM	0.390593	0.225384	0.268047	0.202888	0.253232	1.340145	0.253232	5.29215275
							λ_{max}	5.16702119
							CI	0.0417553
							CR	0.03728152

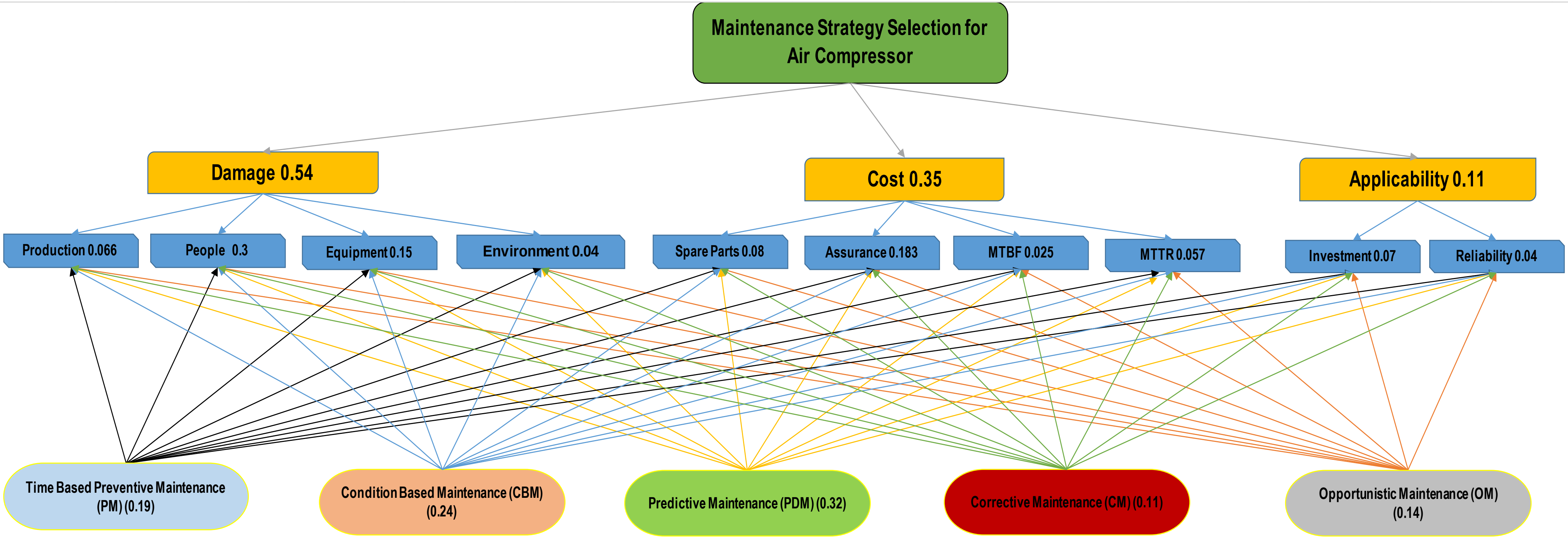
Reliability/Air Compressor	PM	PDM	CBM	CM	OM
PM	1.00	0.33	0.50	5.00	3.00
PDM	3.00	1.00	2.00	6.00	4.00
CBM	2.00	0.50	1.00	5.00	4.00
CM	0.20	0.17	0.20	1.00	0.25
OM	0.33	0.25	0.25	4.00	1.00
	6.53	2.25	3.95	21.00	12.25

Reliability/Air Compressor	PM	PDM	CBM	CM	OM	Alternative Weight
PM	0.153061	0.148148	0.126582	0.238095	0.244898	0.182157
PDM	0.459184	0.444444	0.506329	0.285714	0.326531	0.404440
CBM	0.306122	0.222222	0.253165	0.238095	0.326531	0.269227
CM	0.030612	0.074074	0.050633	0.047619	0.020408	0.044669
OM	0.051020	0.111111	0.063291	0.190476	0.081633	0.099506

Reliability Air Compressor	PM	PDM	CBM	CM	OM	WSV	Alternative Weight	WSV/CW
PM	0.182157	0.134813	0.134614	0.223346	0.298519	0.973449	0.182157	5.34401345
PDM	0.546471	0.404440	0.538454	0.268016	0.398025	2.155406	0.404440	5.32935424
CBM	0.364314	0.202220	0.269227	0.223346	0.398025	1.457133	0.269227	5.41228304
CM	0.036431	0.067407	0.053845	0.044669	0.024877	0.227229	0.044669	5.08692677
OM	0.060719	0.101110	0.067307	0.178677	0.099506	0.507319	0.099506	5.09836364
							λ_{max}	5.25418823
							CI	0.06354706
							CR	0.05673844

Criteria / Alternative	Invest	Reliability	Final Score
	0.65	0.35	1
PM	0.195297	0.182157	0.190697706
PDM	0.056346	0.404440	0.178179019
CBM	0.089349	0.269227	0.152306396
CM	0.405776	0.044669	0.27938859
OM	0.253232	0.099506	0.19942829

	Invest	Reliability	
Map weight	0.071693122	0.038603989	



Criteria / Alternative	Production Loss	Equipment Damage	Environmental Damage	People Damage	MTBF	MTTR	Spare Parts	Assurance Spare	Invest	Reliability	Final
	0.066212425	0.145357492	0.038814437	0.293368189	0.024664742	0.057301172	0.081089182	0.18289525	0.071693122	0.038603989	
PM	0.171152285	0.141796368	0.164696356	0.170465757	0.162148557	0.366047803	0.058016454	0.274013042	0.195296564	0.18215697	0.189173316
PDM	0.307521961	0.463658546	0.302726046	0.412715901	0.426085837	0.256887538	0.180606761	0.213196997	0.056345953	0.404440426	0.319105734
CBM	0.307521961	0.270682048	0.302726046	0.267888871	0.274197218	0.23340269	0.119314724	0.264489233	0.089349139	0.269227016	0.245032817
CM	0.04265151	0.034057708	0.065155196	0.03663373	0.040387175	0.03952445	0.555331385	0.045966883	0.405775906	0.044669288	0.108565919
OM	0.171152285	0.089805329	0.164696356	0.112295742	0.097181214	0.104137519	0.086730676	0.202333844	0.253232439	0.0995063	0.138122214