A TWO-STEP DECISION MAKING APPROACH FOR IDENTIFICATION OF CRITICAL EQUIPMENT USING ANALYTICAL HIERARCHY PROCESS AND PREFERENCE RANKING ORGANIZATION METHOD FOR ENRICHMENT EVALUATIONS WITH IMPROVED NORMALIZATION

Ashish Khaira[1*] – Ravik Dwivedi[2]

[1]Mechanical Engineering, SATI, Vidisha, India
[2]Mechanical Engineering, MANIT, Bhopal, India

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Abstract:

Generally, numbers of shops are present in large-scale industries. Therefore, it is necessary to identify critical equipment's for ensuring lower failure rate. Multiple researchers' applied risk based analysis to select critical equipment's from one particular section of a plant; based on the feedback of industry personnel or of their own observations that increases the error probability. Apart from this, the decision making (DM) techniques usually provide the best alternatives, but in maintenance there is a need to identify critical or the worst performing equipment. Therefore, this research paper covers three parts: (1) a novel approach of two-step decision making for identifying critical section and then critical equipment in that section at an electrode graphite manufacturing plant; (2) an innovative methodology of normalization for the Analytic Hierarchy Process (AHP); (3) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method for validation. This work identified "utility" section n this heavy industry as a critical section and "screw compressor number 5" as critical equipment. From maintenance point of view, "critical" refers to the worst performing ones. Therefore, if this research followed a conventional methodology, then some other section could randomly be considered as "critical" and the best performing equipment would get the 1st ranking. Apart from this, PROMETHEE also provided the same result which validates the methodology.

1 Introduction

In general, numbers of shops or subsections are present in large-scale industries which may have hundreds of different types of equipment. It is a common practice in most industries to allocate a

[*] Corresponding author.
E-mail address: ashish_2285@yahoo.co.in

fewer amount for maintenance. Therefore, it is necessary to use available resources more efficiently and effectively. Such constraints raise the need to identify critical equipment to ensure maximum availability and high production rate. As large-scale industries have a lot of equipment, it is quite impractical to perform the conventional way of criticality analysis via Failure Mode & Effect Analysis (FMEA) or Failure Mode & Effect Criticality Analysis (FMECA) of all equipment.

Many researchers used the risk based analysis to identify the critical equipment. However, they have selected equipment from one particular section or subsection of an industrial setup after considering it critical, based on the feedback of industry personnel and observations of researchers which increases the possibility of error. Therefore, it is beneficial to compare different section/shops first in terms of their criticality and after that apply suitable decision making techniques to identify critical equipment in that particular section/shop. In simple words, narrowing down the target or following a reverse pyramid approach in a systematic manner.

The important point needs to be considered while applying these DM techniques in maintenance is that these techniques usually provide the best alternatives but the maintenance personnel needs to identify the critical or the worst performing equipment. Therefore, there is a need to make improvements in existing decision making techniques to cope-up this research gap.

This research dealt with the analysis of all the main equipment of an electrode graphite plant. This research attempted to show novel approach of a two-step decisions making to solve aforementioned flaw and identified critical equipment at an electrode graphite manufacturing plant. This work also addressed multiple criteria such as Energy Consumption, Mean Time between Failure (MTBF), and Mean Time to Repair (MTTR), etc. This research paper consists of: section 2, the review part of decision making, section 3, problems described, section 4, methodology adopted for the analysis, section 5, problem analysis, section 6, the result and discussion, and finally conclusion.

The contribution and significance of this study is of great importance. First, this is the first study that covered identification of a critical section prior to identification of the critical shop. Second, this work shows an innovative methodology for normalization in order to obtain the most critical or the worst performing section/equipment. If this research work followed conventional methodology, then some other section may randomly considered as critical and best performing equipment will get rank 1. Third, this work used two decision making techniques to cross validate the results. Fourth, this analysis is helpful for maintenance personnel to help them prepare a focused maintenance plan.

2 Literature Review

The equipment whose maximum availability is essential for a continuous running of the plant and failure of this equipment may result in a hefty financial loss or potential hazardous situation for both the atmosphere and humans. It is known as critical equipment. On the other hand, ref. [1] highlighted that industries wasted almost one-third of the total maintenance costs in unnecessary maintenance activities, which indiscriminately involve maintenance of almost all equipment with no or little consideration to its criticality. Therefore, there is a need to identify the most critical equipment first, and then plan the maintenance activities accordingly.

The ref. [2] showed a guideline to use key performance indicators (KPI's) like MTBF, MTTR, etc., in order to determine cumulative score of industrial equipment failure. The ref. [3] showed application of fuzzy AHP to identify a suitable maintenance strategy for it. All these authors have used a risk based method to identify an appropriate maintenance policy for critical equipment.

The ref. [4] highlighted the need of identifying critical equipment in their research work. The ref. [5] highlight the flaw in the risk based criticality analysis; multiplication of the severity, occurrence, and detection rankings may result in rank reversals, where a less serious failure mode receives a higher risk priority number (RPN) than a more serious failure mode. Apart from this, as per Carlson in [6], a severity of 1, occurrence of 8, and detection of 8 has the same RPN value as a severity of 8, occurrence of 4, and detection of 2. Clearly, there is a different risk level associated between these two examples. Identification of critical equipment is not an easy task as researchers has to deal with the multiple conflicting criteria's. Hence, multi criteria decision making (MCDM) processes used to bring the most appropriate decision.

As per ref. [7-8] one makes decisions in day to day life. Every action that a person takes is a result of this process. For example, eating is a result of feeling hungry, learning is a result of needing to know, walking is a result of a need, for physical activity, etc.

Different researchers have different views about MCDM, however the fundamental idea is same. It is explained as following:

- As per ref. [8-9], MCDM assists decision makers in situations where there are multiple alternatives with numerous and conflicting criteria.
- As per ref. [3], these are useful when there are no unambiguous and clear choices are available *i.e.*, every alternative scores higher in some criteria and not as high in some other criteria.

As per ref. [10-12], the MCDM methods could be divided in two categories, i.e. (a) Discrete MADM (multi attribute decision making), and (b) Continuous MODM (multi objective decision making). The MADM methods are generally considered discrete since there is a limited number of predetermined alternatives. As per ref. [13], the main application areas for the MCDM are environmental management, water management, business, and financial management, etc.

2.1 Analytic hierarchy process (AHP)

The analytic hierarchy process (AHP) consists of three levels [1,14]: 1) Goal - Top level, 2) Criteria/Sub criteria - Middle level and 3) Alternatives - Lower level

The ref. [1,8,14] outlined the following characteristics of the AHP that motivate the researchers to give more preference to the AHP -

- It is possible to include quantitative and qualitative criteria in large quantity in the decision making.
- A flexible hierarchy can be constructed which organizes the critical aspects of a problem into a hierarchical structure that makes decision process easier to handle.
- Also, it is the only method that can measure the consistency of decision maker's judgments.

The ref. [15] uses the AHP for effective priority ranking of the possible causes of failure. The ref. [16] covered research work about the criticality analysis of forming unit of a paper mill. The ref. [1] applied fuzzy AHP for identifying critical components in power distribution systems. The ref. [7] applied the AHP to rank the power plant equipment on the basis of selected multiple criterions and the normalized matrix containing values that are equal to division of every single element of attributes in a column with all of the attribute summation in that column. The ref. [8] showed the case study of the best equipment selection and conducts normalization for every criterion, sub criteria, and alternative. The ref. [3] applied integration of goal programming and fuzzy-AHP for selecting the optimal mix of maintenance approaches. The ref. [17] applied AHP for selecting a suitable maintenance strategy for heavy industry based in Morocco.

2.2 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

As per references [2,7,18,19] preference ranking tools are special types of the MCDM methods for a finite set of alternative actions; to be ranked and selected among conflicting criteria. The literature review revealed that researchers from around the globe prefer analytical hierarchy process (AHP) over other MCDM techniques, due to its simplicity and higher accuracy. It was also observed that researchers applied PROMETHEE to validate the results obtained with the AHP. All these references helped to understand the existing methodology of decision making and its practical uses. It also helped in identifying its flaws which were then taken as research objectives of this work.

3 Problem Description

In the context of maintenance of a plant, there are many independent variables that affect the likelihood of a machine failure. These variables are known as KPIs. Various researchers [2,9,20,21,22,23] outlined different KPIs. Generally, a different production system uses a different type of process and equipment. The attributes [2, 21, 22, 23] selected for this study are based on the two principal factors: viz. internal procedure deficiency and plant maintenance priorities. These attributes are proposed particularly to produce decision making tool to enable performance measuring and cost reducing for a maintenance department. The attributes are as following:

[A]. Critical Shop Identification - Unit Time: One Year (Jan-Dec 2015)

- Energy Consumption (EC) – Equipment energy consumption per unit time in Kilo Watt Hours
- Average Number of Failures (ANF) - Shows an average of failures occurred in a given time period in numbers
- Quantity of Spares (QOS) - Shows a quantity of spares that a mechanical maintenance

department issues in a given time period in numbers
- Spare Part Cost (SPC)– Cost of spares in Lac Indian rupees for a given time period

[B]. Critical Equipment Identification - Unit Time: One Year (Jan-Dec 2015)

- Availability - The probability that an item will be in an operable and committable state at the start of a mission when the mission is called for at a random time.

$$\text{Availability} = \frac{\text{MTBF}}{(\text{MTBF} + \text{MTTR})} \quad (1)$$

- Mean Time between Failures (MTBF) - It is an arithmetic average of how fast the system failes in hours. Up-time refers to a capability to perform the task, and downtime refers to not being able to perform the task.

$$\text{MTBF (Hrs)} = \\ = (\text{Total Up Time per unit Time}) - \\ - \frac{\text{Total Down Time per unit Time}}{\text{Total Number of Failures per unit Time}} \quad (2)$$

- Mean Time to Repair (MTTR) - It is an arithmetic average of how fast the system gets repaired in hours.
-

$$\text{MTTR (Hrs)} = \\ = \frac{\text{Total Down Time per unit Time}}{\text{Total Number of Failures per unit Time}} \quad (3)$$

- Failure Rate (FR) – The total number of failures within an item population, divided by the total time expended by that population, during a particular measurement interval expressed in failure per unit time.

$$\text{Failure Rate (FR)} = \frac{1}{\text{MTBF}} \quad (4)$$

- Total Number of Failures (TF) – Total failure occurred in a given time period, in numbers.

A survey of numerous literatures was conducted, however, any literature which discusses the critical ranking for the electrode manufacturing industry couldn't be found. Apart from this, the majority of the papers applied DM in identifying either criticality of some particular failure like cracking in some particular machinery, or critical equipment among multiple equipment of one particular section of a plant on the basis of feedback from industry people. Therefore, there is no provision of solid base. Few researchers applied FMECA in combination with the AHP, where they evaluated RPN subsequently conducting the ranking with the AHP. Apart from this, the majority of the papers did not take into consideration the key performance indicators like MTBF, MTTR, and availability for decision making. Keeping all these gaps in mind, the present work has been divided into three parts:

1. A modified two step DM approach to identify the critical section in a large-scale industry, then identifying the critical equipment in that particular section.
2. A modified AHP in which KPIs are taken as criteria for DM and for this purpose normalizing method is modified. In fact, if a lower value is considered for normalization, as in the case of non-beneficial attributes subsequently after DM, then it will provide the best alternative or best performing equipment which would need lesser maintenance as rank 1. However, from a maintenance point of view, there is a need to identify critical equipment or in simple words the worst performing equipment. By keeping this important fact in mind, this research work proposed an innovative methodology and corresponding equations for normalization, which are as following:

- For KPI's where higher value is critical

$$(n_{ij})_{nb} = \frac{x_{ij}}{\left(x_{ij}\right)_{cnb}} \quad (5)$$

- For KPI's where lower value is critical

$$(n_{ij})_{b} = \frac{\left(x_{ij}\right)_{cb}}{x_{ij}} \quad (6)$$

x_{ij} = Element of comparison matrix where i stands for alternatives (i = *1,2, ...* n) and j stands for criteria (j = 1,2, … m)
$(n_{ij})_{nb}$ = Normalized value of non-beneficial attribute

$\left(x_{ij}\right)_{cnb}$ = Most critical value of non-beneficial attribute

$(n_{ij})_b$ = Normalized value of beneficial attribute

$\left(x_{ij}\right)_{cb}$ = Most critical value of beneficial attribute

3. After that, PROMETHEE is applied, to validate the result obtained with the modified AHP.

4 Methodology

The current section covered the details about the basic steps of the AHP and the PROMETHEE which are necessary to reach the most appropriate decision regarding critical equipment.

4.1 Analytical Hierarchy Process (AHP) Procedure

Since the basic steps of the AHP are in a standard form, [24] this work has also incorporated the elaboration of each individual steps [7,11] that made details more graspable. The steps are as following:

Step 1: Decompose entire problem into three levels: goal or objective at the top level, attributes at the second level, and alternatives at the third level.
Step 2: To determine the weights of each attribute constructs a pair-wise comparison matrix using a scale of relative importance.
The below square matrix is named A_1

$$\begin{array}{c} \\ K_1 \\ K_2 \\ K_3 \\ - \\ K_M \end{array}\begin{array}{c} \begin{array}{cccccc} K_1 & K_2 & K_3 & - & - & K_M \end{array} \\ \begin{bmatrix} 1 & k_{12} & k_{13} & - & - & k_{1M} \\ k_{21} & 1 & k_{23} & - & - & k_{2M} \\ k_{31} & k_{32} & 1 & - & - & k_{3M} \\ - & - & - & - & - & - \\ k_{M1} & k_{M2} & k_{M3} & - & - & 1 \end{bmatrix} \end{array}$$

- Find the geometric mean of each row and add all the geometric means (As data in fractions are interrelated so a geometric mean is used).

$$\mathrm{GM_i} = \sqrt[M]{\left[\prod_{i=1}^{M} k_{ij}\right]\Pi} \qquad (7)$$

$$w_j = \frac{\mathrm{GM_i}}{\sum_{i=1}^{M}\mathrm{GM_i}} \qquad (8)$$

- The pair-wise comparison matrix is checked for consistency, and also weight of different criteria is calculated. Make A_2 with the help of w_j values.

$$A_2 = \begin{bmatrix} w_1 \\ w_2 \\ - \\ w_j \end{bmatrix}; \quad A_3 = A_1 \cdot A_2 \ ; \ \text{and} \ A_4 = \frac{A_3}{A_2}$$

- Determine the maximum Eigen value λ_{max} that is the average of the matrix A_4.The closer λ_{max} is to Eigen values, the more consistent it is with the comparison matrix A_1 or the more coherent will be the judgments provided.

- The consistency index (CI) is used as a measurement of consistency of data expressed. Calculate the consistency index CI = $(\lambda_{max}$- M$)$ / $($M - 1), where M is the order of matrix A_1.

Use the values of Random Index (Table 1) to calculate the consistency ratio (CR = CI/RI). If the consistency ratio (CR) value is less than 0.10 than the weights calculated are correct or considerable with maximum 10% of error.

Table 1. Random index (RI)

Attributes	3	4	5	6	7
RI	0.52	0.89	1.11	1.25	1.35

Step 4: After that, the comparison matrix is converted into a normalized matrix.

Step 5: By using the calculated weights and normalized values, it is possible to find the score of an alternative as

$$P_i = \sum_{i=1}^{M} w_j n_{ij} \qquad (9)$$

where
w_j = the weight of each attributes

n_{ij} = normalized value of alternative regarding to each attribute
P_i = overall or composite score of the alternative
The alternatives which have the highest value of P_i are considered as the best alternative.

4.2 PROMETHEE Procedure

In this innovative method, each alternative is compared to another alternative during the making of the matrix for a particular attribute. The basic steps [10,25] are as following:
Step 1: Calculate weights of the criteria using the AHP method

Step 2: The alternatives are pair-wise compared with respect to every single criterion, and the preference functions express results. The weights are assigned to each attribute to make an overall matrix. Suppose the decision maker have specified a preference function P_i and weight w_i for each criterion c_i (I = 1, 2…. M) of the problem. The multiple criteria preference index P_{a1a2} is subsequently defined as the weighted average of the preference functions P_i:

$$\Pi_{a1a2} = \sum_{i=1}^{M} w_i P_{i,a1,a2} \quad (10)$$

Π_{a1a2} shows the intensity of preference of the decision maker of alternative $a1$ over alternative $a2$, when considering simultaneously all the criteria. Its value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions.

Step 3: Find the sum of each row and each column in the overall matrix. The difference between the corresponding row and column provides the score for the alternatives.

$$\varphi^{+}(a) = \sum_{x \varepsilon A} \Pi_{xa} \quad (11)$$

$$\varphi^{-}(a) = \sum_{x \varepsilon A} \Pi_{ax} \quad (12)$$

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \quad (13)$$

$\varphi^{+}(a)$ is called the leaving flow, $\varphi^{-}(a)$ is called the entering flow, and $\varphi(a)$ is called the net flow.

Step 4: Arrange the score in the descending order.

5 The Problem Analysis

This section will analyze the industrial problem. A number of shops or subsections are available in this heavy industry as per activities associated with them. Therefore, the first step includes the use of AHP with the upgraded normalization method for identification of the most critical shops, furthermore, identification of the most critical equipment in that shop, and finally the application of the PROMETHEE method for validating the results obtained with the AHP.

5.1 Identification of critical shop with Analytical Hierarchy Process (AHP)

A number of shops or subsections are available in this heavy industry as per activities associated with them. In order to make a hierarchy diagram as presented in Figure 1, each shop has been assigned with a unique identification (IDs) (Table 2). The industrial data of one complete year were collected for all attributes (Table 3) including energy consumption, average number of failures per unit time, quantity of spares, and spare part cost for corresponding shops or subsections.
By using the methodology mentioned in the section 4.1, λ_{max} was obtained as 4.0340577, consistency index (CI) as 0.011352577, and the value of consistency ratio (CR) as 0.012755705. As CR is less than 0.1, the calculated weights: WEC = 0.56565, WANF = 0.09767, WQOS = 0.22858, and WSPC = 0.10809 are acceptable. Equations 5 and 6 are used for normalization, Equation 9 is used to evaluate the weighted score, and rank 1 is assigned to the shop with the highest weighted score (Table 4), here utility is obtained as the most critical shop or subsection of this heavy industrial setup.

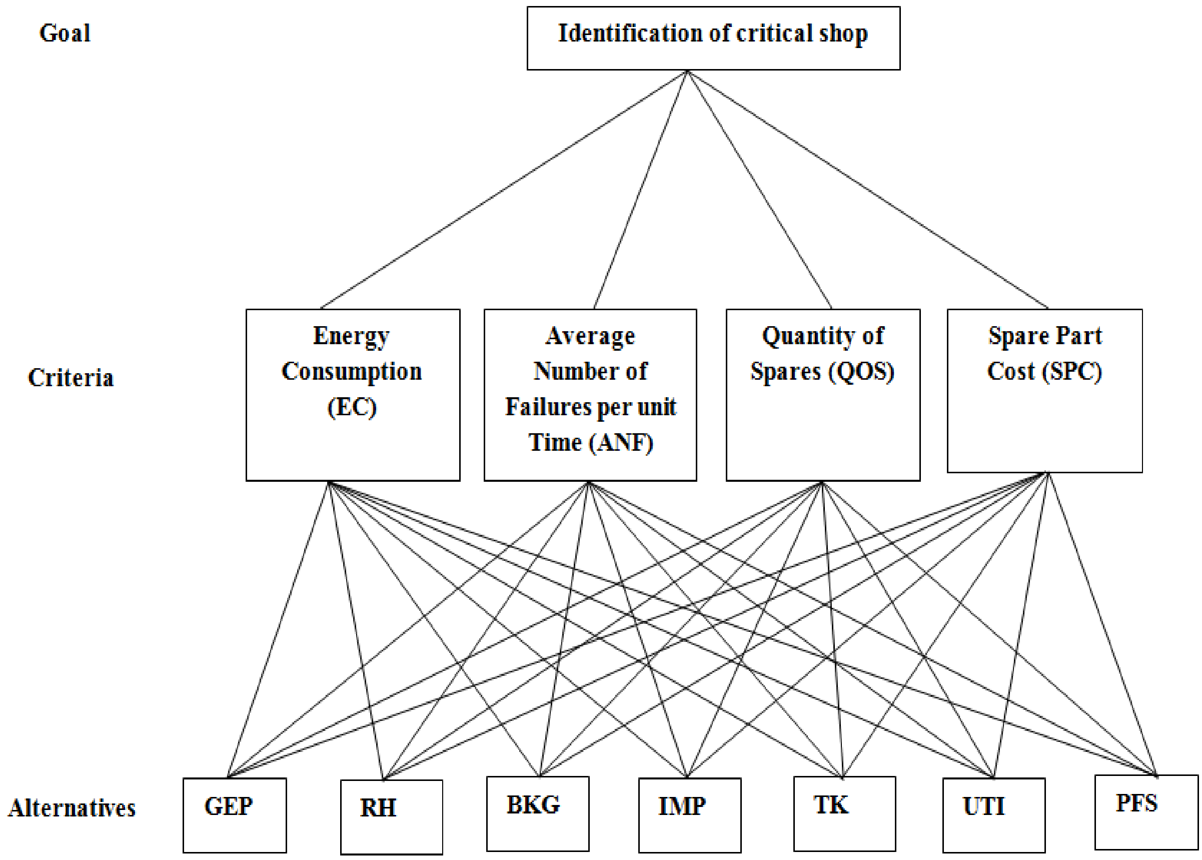

Figure 1. AHP Hierarchy Diagram of Shops.

Table 2. Nomenclature of Alternatives in AHP

Shop Name/Sub-Section	Graphite Electrode Production	Reid hammer Furnace	Baking	Impregnation	Tunnel Kiln	Utility	Product Finishing
ID	GEP	RH	BKG	IMP	TK	UTI	PFS

Table 3. Attributes and their values

Attributes/Shops	GEP	RH	BKG	IMP	TK	UTI	PFS
EC (KWH)	409924.2	288798.4	29635.66	273043.9	90966.38	490928.8	231593.2
ANF (In numbers)	509	115	616	291	269	582	487
QOS (In Numbers)	12462	9077	8468	4579	10459	16231	10655
SPC (Lac Indian Rupees)	179.39	64.97	131.87	80.97	117.83	80.38	50.39

Table 4. Weighted Score Using AHP

ID	GEP	RH	BKG	IMP	TK	UTI	PFS
Weighted Score	0.83661	0.51796	0.33052	0.47401	0.36575	**0.93494**	0.52447
Rank	2	4	7	5	6	**1**	3

5.2 Identification of critical shop using PROMETHEE

Here, the same weights as obtained during AHP procedure were used for rank evaluation. Equations 10, 11, 12, and 13 are used to calculate the net flow or domination. The rank 1 is assigned to the shop with the highest net domination.

Here utility shop (Table 5) came out as the most critical shop among other shops of this heavy industrial setup. The result obtained with PROMETHEE is same as the results obtained with AHP.

Table 5. Net Domination and Ranking

Shops	GEP	RH	BKG	IMP	TK	UTI	PFS
Net Domination	4.0208	-0.34424	-3.28984	-1.56682	-2.4371	4.93988	-1.32268
Rank	2	3	7	5	6	1	4

5.3 Identification of critical equipment using Analytical Hierarchy Process (AHP)

The utility shop came out as the most critical shop among other shops in this industrial setup. In order to make a hierarchy diagram (Figure2), unique IDs were assigned for each shop (Table 6). The utility contains a good deal of equipment. Therefore, collection of industrial data for one complete year were done and after that attributes including MTBF, MTTR, availability, failure rate, and TF corresponding to this multiple equipment were calculated using Equations1, 2, 3, and 4. The Table 7 shows attribute and their corresponding values. By using the methodology mentioned in section 4.1, λ_{max} was obtained as 5.065396, consistency index (CI) as 0.016349, and the value of consistency ratio (CR) as 0.014728829. As CR is less than 0.1, the calculated weights $W_{\text{MTBF}} = 0.491129515$, $W_{\text{MTTR}} = 0.08621161$, $W_{\text{Availability}} = 0.206685886$, $W_{\text{Failure Rate}} = 0.136636203$ and $W_{\text{TF}} = 0.07933678$ are acceptable. As our target is to identify most critical equipment, therefore, this work used the lowest MTBF, the highest MTTR, the lowest availability, high failure rate, and high total failures as our values for normalization. The proposed methodology applied to corresponding Equations 5 and 6 for normalization, Equation 10 was used to evaluate the weighted score, and the equipment with the highest weighted score was ranked 1. The analysis using the AHP shows the compressor number 5 from the utility section as the most critical equipment of this heavy industrial setup. The results are shown in Table 8

5.4 Identification of critical equipment using PROMETHEE

Here same weights were used as obtained with the AHP. After using Equations 10, 11, 12, and 13, rank 1 was assigned to equipment with the highest net domination. A compressor number 5 (Table 9) of utility section showed as the most critical among other equipments located in the same shop. The result obtained with the PROMETHEE is same as the results obtained with the AHP. Therefore, it validates the innovative methodology and corresponding equations applied in the AHP. It has already been discussed that a proper selection of critical equipment is mandatory for successful and economical implementation of maintenance planning. Therefore, giving priority to the least critical equipment may lead to waste of effort, man power, and associated costs.

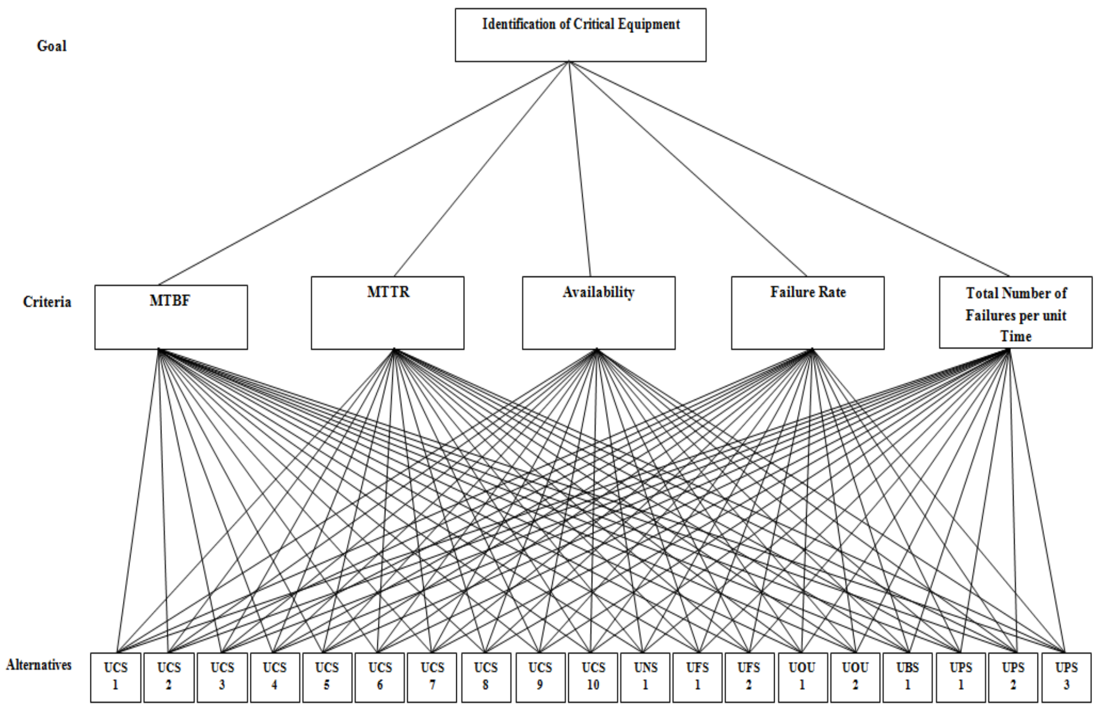

Figure 2. AHP Hierarchy Diagram of Equipment.

Table 6. Nomenclature of Equipment in AHP Diagram

Shop Name/Sub-Section	Shop Name/Sub-Section ID in AHP Diagram	Type of Equipment
Utility(U)/Compressor Section (CS)	UCS1	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS2	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS3	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS4	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS5	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS6	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS7	Centrifugal Compressor
Utility(U)/Compressor Section (CS)	UCS8	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS9	Screw Compressor
Utility(U)/Compressor Section (CS)	UCS10	Centrifugal Compressor
Utility(U)/Nitrogen Section (NS)	UNS1	Screw Compressor
Utility(U)/Furnace Section (FS)	UFS1	Screw Compressor
Utility(U)/Furnace Section (FS)	UFS2	Screw Compressor
Utility(U)/Old Utility (OU)	UOU1	Screw Compressor
Utility(U)/Old Utility (OU)	UOU2	Screw Compressor
Utility(U)/Boiler Section (BS)	UBS1	Boiler
Utility(U)/Pump Section (PS)	UPS1	Water Pump
Utility(U)/Pump Section (PS)	UPS2	Water Pump
Utility(U)/Pump Section (PS)	UPS3	Water Pump

Table 7. Attributes and their values

TF	Failure Rate	Availability	MTTR	MTBF	ID
125	0.027964	0.809783	8.4	35.76	UCS1
128	0.026885	0.809694	8.74218	37.19531	UCS2
58	0.023126	0.842742	8.06896	43.24137	UCS3
19	0.008724	0.916667	10.42105	114.6316	UCS4
92	0.037674	0.726786	9.97826	26.54347	UCS5
105	0.032639	0.797867	7.7619	30.63809	UCS6
35	0.006121	0.953	8.05714	163.3714	UCS7
83	0.037004	0.841967	5.07228	27.02409	UCS8
11	0.005854	0.954776	8.0909	170.8182	UCS9
75	0.023592	0.827865	8.81333	42.38666	UCS10
37	0.006544	0.949933	8.05405	152.8108	UNS1
49	0.011931	0.956006	3.85714	83.81632	UFS1
5	0.018248	0.878205	7.6	54.8	UFS2
12	0.016461	0.867857	9.25	60.75	UOU1
10	0.012136	0.903509	8.8	82.4	UOU2
22	0.020258	0.923469	4.0909	49.36363	UBS1
18	0.018947	0.989583	0.55555	52.77777	UPS1
17	0.015625	0.993464	0.42105	64	UPS2
12	0.007968	0.996032	0.5	125.5	UPS3

Table 8. Weighted Score (WS) using AHP

Rank	WS	ID
4	0.7984	**UCS1**
5	0.7851	**UCS2**
7	0.6663	**UCS3**
15	0.4072	**UCS4**
1	**0.9740**	**UCS5**
3	0.8614	**UCS6**
17	0.3479	**UCS7**
2	0.8884	**UCS8**
18	0.3286	**UCS9**
6	0.6939	**UCS10**
16	0.3567	**UNS1**
14	0.4182	**UFS1**
9	0.54109	**UFS2**
10	0.5313	**UOU1**
12	0.4474	**UOU2**
8	0.5477	**UBS1**
11	0.4832	**UPS1**
13	0.4255	**UPS2**
19	0.2951	**UPS3**

Table 9. Net Domination and Ranking

Rank	Net Dominatio	ID
3	11.09297	**UCS1**
5	10.58191	**UCS2**
7	5.154737	**UCS3**
14	-6.7121	**UCS4**
1	16.9618	**UCS5**
2	12.15446	**UCS6**
17	-9.82215	**UCS7**
4	10.76028	**UCS8**
18	-12.877	**UCS9**
6	8.130453	**UCS10**
16	-9.07995	**UNS1**
11	-3.11121	**UFS1**
10	-2.15973	**UFS2**
9	-0.7223	**UOU1**
13	-5.00832	**UOU2**
8	0.115101	**UBS1**
12	-3.94882	**UPS1**
15	-8.63231	**UPS2**
19	-12.8779	**UPS3**

6 Results & Discussion

The innovative methodology was applied in the AHP, and the same weights were used with the PROMETHEE method. The utility shop has come out to be as the most critical shop among other shops of this heavy industry. The results obtained (Figure 3) using the PROMETHEE are the same as the results obtained using the AHP. Therefore, the validation of innovative methodology and corresponding equations applied in the AHP was completed. Apart from this, if any of the researcher use conventional way of normalization, then the best alternative or the least critical shop i.e. baking shop will come out as rank 1 while in present case, it has rank 7.

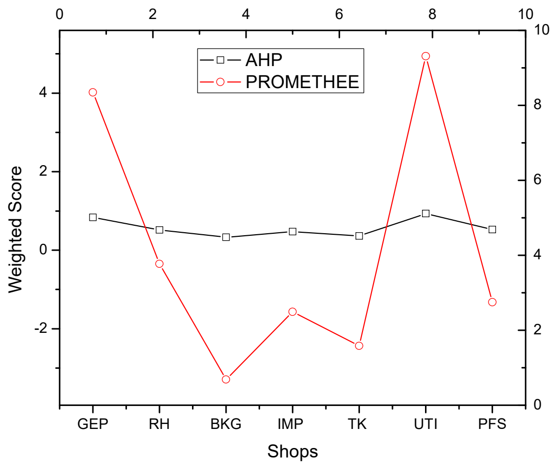

Figure 3. Ranking of Shops.

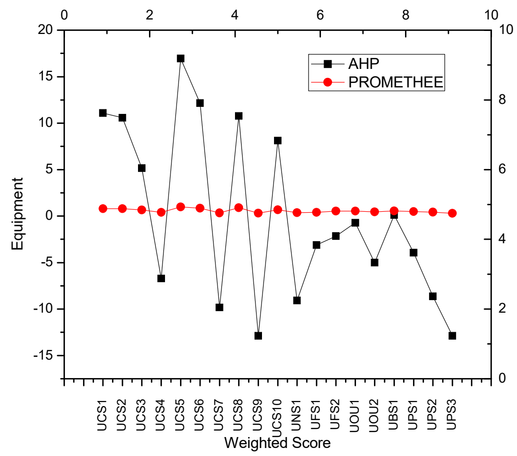

Figure 4. Ranking of Equipment .

Again, the innovative methodology was applied in the AHP, and the same weights were used with the PROMETHEE method. The UCS 5 (Figure 4) has come out to be the most critical equipment among other equipment in utility shop. The results obtained with the PROMETHEE are the same as the results obtained with the AHP. Therefore, the validation of innovative methodology and corresponding equations applied in the AHP was completed. Apart from this, if any of the researcher use conventional way of normalization then, the best alternative or least critical equipment i.e. utility pump section 3 (UPS 3) will come out as rank 1 while in present case, it has rank 19.

7 Conclusion

This research work firstly highlighted that multiplication of the severity, occurrence, and detection rankings may result in rank reversals. Many researchers used DM techniques to perform identification of critical equipment. However, they have taken equipment for ranking from one particular section or subsection of a plant by considering it critical based on feedback of industry personnel and observations of researchers which increases the possibility of error. Keeping all these gaps in mind the present work covered:

- A modified two-step DM approach.

- The KPIs used as criteria with this modified AHP and normalizing method modified accordingly, for maintenance point of view. In this part, the utility showed to be as critical section and a screw compressor number 5 as critical equipment.

- The validation of this innovative methodology and corresponding equations for normalization in the AHP was done using the PROMETHEE method and the results obtained were same as with the results obtained with the modified AHP.

- Furthermore, this is a generalized approach so other researchers may apply similar approach of decision making in other industries too, especially in heavy industries. It is possible to apply the same methodology of normalization with other DM techniques, to get more improved version of it.

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