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Prioritising Alternative Solutions to Power Generation Problems Using MCDM Techniques: Nigeria as Case Study

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Abstract: The engine that energizes industrialization and which invariably result to improved standard of living of nations' citizens is electric power. Hence a steady power supply is crucial for Nigeria to achieve her aim of becoming one of the most industrialised nation in the world. However the biggest challenge in Nigeria is electricity crisis, a crisis that had been without any visible end in sight. From the literature the problems of power generation in Nigeria ranges from improper maintenance of power generation infrastructure to militant activities. Although alternative solutions are available for addressing these problems but there is difficulty in selecting the optimal solution that will yield greater power output. This paper present a Multi-Criteria Decision Making (MCDM) tool for prioritising alternatives solutions to power generation problems. The tool uses a combination of entropy technique and Multi-Attribute Utility Theory (MAUT) method. To illustrate the suitability of the technique, two examples were utilised. Results of the analysis revealed that Reliability Centered Maintenance (RCM) and diplomatic approach are the optimal solutions for resolving problem of improper maintenance and militant activities respectively. The proposed tool will assist Government or electric power managers to use optimal solutions in solving power generation problems in order to maximise power plant output and consistently ameliorate power crisis.

Keywords: Alternative solutions, Power generation problems, MAUT method, Entropy method, decision criteria.

1. Introduction

Electricity production in Nigeria started in Lagos in 1896 after over a decade of it utilisation in England [1]. The total capacity of generators utilised was 60KW because the maximum demand as at 1896 was less than 60KW. In the year 1972 the different individual power generation company were merged to form National Electric Power Authority (NEPA) [2]. The body was entrusted by the Federal Government of Nigeria to generate, transmit and distribute electricity to consumers. However, as years gone by most of the generating assets became old and obsolete with an average life of 18 to 43 years and no new asset was added despite the ever increasing demand of power. The power sector was at the brim of total breakdown in 1999 with an average generation of 1,750MW daily.

In response to this challenges, there was substantial asset overhaul between 1999 and 2004 and asset expansion from 2004-2014 by the Federal Government of Nigeria. Additionally, in 2005 the ACT establishing NEPA was amended in order to break her monopoly and encourage private sector participation [3]. Notwithstanding all of these reforms and other concerted efforts made by Government to ameliorate energy crisis, Nigeria still remain the lowest electricity consumption per capita in Africa. For example between 2010 and 2014 Nigeria electricity consumption per capita stood at 149 KWH against that of Ghana which was more than 298 KWH [4].

Many reasons had been attributed to the energy crisis in Nigeria with focus on power generation problem in this paper. The focus is on power generation because it forms an important and integral part of the overall power system [5]. The major reason for the low power generation in Nigeria is the problem of improper maintenance which had caused substantial deterioration in power plant system output and has left most power stations in the state of disrepair. Another major challenge is the problem of gas supply pipeline vandalism by Militant in the Niger Delta region of Nigeria, since most of the power station are gas fired. Other challenges that had been attributed to poor power generation and invariably energy crisis in Nigeria are; corruption, lack of energy mix, inadequate funding and lack of adequate technical manpower.

There are different alternative solutions available for addressing each of the power generation problems. For example, in addressing maintenance problem different maintenance strategies such as Corrective maintenance (CM), Time based Preventive maintenance (TPM),

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Condition based preventive maintenance (CBM) and Reliability Centered maintenance (RCM) are available for maintenance of power generation infrastructure. The selection of the appropriate maintenance strategy for ameliorating power problem in order to maximum power plant output is always a challenge.

In literature, research work that have been carried out with respect to power generation in Nigeria were mainly on performance evaluation [8]. However in this paper a Multi-Criteria Decision Making (MCDM) tool is presented for selecting optimal solution from among different alternative solutions for each power generation problem. The tool uses MAUT technique in the ranking of the alternatives with respect to some decision criteria whilst applying entropy technique in decision criteria weightage. The MAUT method had been chosen because of its unique feature of incorporating decision makers risk perception into the decision making process which is lacking in other MCDM tools. Furthermore, the tool has been applied in resolving different multi-criteria decision problems in other industries. Emovon et al, (2016) [6] applied the MAUT method to select optimal inspection interval for marine machinery systems. The method was also used by Yang, Bonsall and Wang, (2009) [7] in selecting optimal mode of container transport in order to avoid service delivery delay.

2. Power Generation Problems

The Nigeria economic growth since independence have been slow which may be attributed to poor power generation and utilization. From previous research [8] the most dominant challenges facing power generation in Nigeria are presented in Table 1.

Tale 1: Power generation problems [8]

S/N	Power generation problem	Description
1	Lack of energy mix	Over dependent on hydro and fossil fuel rather than a mix of other sources such as solar, bio and wind energy
2	Improper or poor maintenance	The right maintenance approach are not use as in most cases the reactive technique are utilize.
3	Corruption	Resources allocated for power improvement are either embezzled or mismanaged by power managers.
4	Inadequate funding	Fund to purchase modern equipment and maintain existing infrastructure are grossly inadequate.
5	Militant activities	Gas Pipeline link to most thermal power stations are vandalized by militant in response to decades of marginalization.
6	Inadequate manpower	Lack or inadequate technical manpower for operating and maintenance of power equipment.
7	Wrong location	Power stations are wrongly sited either far from sources of energy or human capacity due to ethnicity.
8	Lack of policy continuity	Successive Government jettisoning good policies of their predecessors.

3. Solutions to Energy Crisis

The major factors affecting power generation in Nigeria had been described in Table 1. However from the work of Emovon and Samuel [8] the two most critical problems confronting the sector are poor maintenance of power generation infrastructure and militant activities. To address each challenge alternative solutions are available. For example, in solving improper maintenance problem different maintenance strategies such as corrective maintenance, time based preventive maintenance and Reliability Centered Maintenance (RCM) are applicable. The alternative solutions for addressing poor maintenance of power generation infrastructures and militant activities are presented in Tables 2 and 3 respectively. To select the optimal solution from the different alternatives, four decision criteria namely; cost, environmental friendliness, efficiency and ease of use are utilised. The decision criteria are briefly described in Table 4.

Table 2: Alternative solutions to improper maintenance

S/N	Alternative solutions	Description
1	Corrective maintenance (CM)	The principle behind this maintenance approach is that when an equipment or items fail then fixed it. An asset has to fail before repair or replacement is implemented
2	Time-based preventive maintenance (TPM)	This is a maintenance approach in which repair or replacement is performed on an asset at regular time interval. This interval is either based equipment on manufacturers' recommendations or based on the average industrial life of the asset.

3	Condition based Maintenance (CBM)	The repair or replacement time of an asset in this approach is based on the condition of the asset. Asset condition monitoring is either performed continually or at regular time interval.
4	Reliability Centered Maintenance (RCM)	The RCM philosophy uses a combination of corrective, time based preventive and condition based maintenance in preserving the functions of an asset. RCM determines the most effective approach for each items of the asset

Table 3: Alternative solutions to militant activities

S/N	Alternative solutions	Description
1	Diplomatic approach (DA)	Encouraging the Militant to drop arms against the state and integrating them to the society by proving them with formal education and subsequently gainful employment.
2	Military combat/drone technology (MD)	The use of the military to combat militants in combination with the use of drone technology.
3	Sensor network/ground patrol	In this approach pipelines are monitored using sensors network designed to detect fault such as leak along the pipeline in conjunction with ground patrol security team to vade off militants.

Table 4: Decision criteria

S/N	Decision criteria	Description
1	Cost (C)	The better solution is the one that is more cost effective.
2	Environmental friendliness (EF)	The solution that minimize environmental pollution better is the optimal alternative.
3	Efficiency (E)	The approach that will result to better power generation output is the optimal solution.
4	Ease of use (EU)	The approach that is easier to apply is the optimal technique.

4. Methodology

4.1 The ranking tool: Multi-Attribute Utility Theory (MAUT) technique

MAUT is a MCDM tool for reaching a definite decision when different alternatives with conflicting decision criteria are involved in the decision making process. The technique provides a logical means for arriving at optimal solution. MAUT method development can be traced to the utility theory established by Neumann and Morgenstern [9]. The theory was further extended by Keeney and Raiffa with the inclusion of the elicitation and specific assessment techniques [10]. With the blend of these two techniques, the decision criteria of most multi-criteria decision problem can firstly be represented as individual utility functions and then combined into a single function. The technique have been applied for solving different multi-criteria decision making problem in the literature. Zietsman (2008)[11] applied MAUT method in solving transportation corridor decision making problem. Emovon et al (2015)[6] utilised the methodology in addressing inspection decision making problem. Garmabaki et al (2016)[12] used the technique for optimal inspection determination.

The MAUT technique steps is as follows:

Step 1: Decision problem (matrix) formation: The decision problem is represented in the form of a matrix, as shown in Table 5. From the Table, B_i denotes decision criteria while A_j denotes the alternatives (alternative solutions to power generation problems). i and j are the number of decision criteria and the number of alternatives respectively. For this decision problem i is 4, meaning there are four decision criteria based on which alternative solutions to power generation problems are evaluated. The decision criteria are *C*, *EF*, *E* and *EU* and x_{ij} are the elements of the decision matrix.

Table 5: Decision matrix

Alternatives (Aj)	Decision criteria (Bi)			
	C	EF	E	EU
A_1	x_{11}	x_{12}	x_{13}	x_{14}
A_2	x_{21}	x_{22}	x_{23}	x_{24}
A_3	x_{31}	x_{32}	x_{33}	x_{34}
-	-	-	-	
-	-	-	-	
A_m	x_{m1}	x_{m2}	x_{m3}	x_{m4}

Step 2: Single utility functions determination: Decision maker's risk perception are embed into the decision making process with the aid of utility function. Utility functions are determined for each decision criteria which are then aggregated to form a multi-attribute utility function. The decision makers risk perceptions are of three types; risk neutral, risk prone and risk averse. The three risk perceptions with respect to the utility function are illustrated in Fig. 1

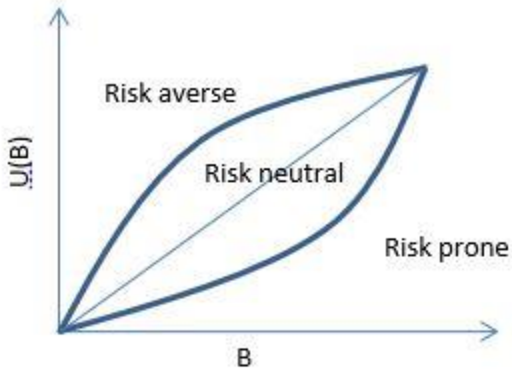

Figure 1: Utility function characteristics [6,13]

One prevalent utility function use in literature defining decision criteria is the power series function and is presented as follows [13]:

$$u(B_i) = \frac{(B_i - a)^z}{(b - a)^z} \quad (1)$$

Where z is defined as decision maker risk perception. For a risk-neutral decision maker, z is assigned with the value of 1 while for risk averse and risk prone decision makers the value of less and greater than 1 are given to z respectively. However for this research the decision makers risk perception is assumed to be neutral. The minimum and maximum values of the element of decision criteria B_i are b and a respectively in Eq. 1. The utility function of the four decision criteria; cost (C), environmental friendliness (EF), Efficiency (E) and Ease of use (EU) are as presented below in Eq. 2, 3, 4 and 5 respectively:

$$u(C) = \frac{\left(x_{1j} - a_1\right)^z}{(b_1 - a_1)^z} \quad (2)$$

$$u(EF) = \frac{\left(x_{2j} - a_2\right)^z}{(b_2 - a_2)^z} \quad (3)$$

$$u(E) = \frac{\left(x_{3j} - a_3\right)^z}{(b_3 - a_3)^z} \quad (4)$$

$$u(EU) = \frac{\left(x_{4j} - a_4\right)^z}{(b_4 - a_4)^z} \quad (5)$$

The maximum and minimum values of x_{1j}, are a_1, b_1 respectively and x_{1j} are the elements that belong to the criterion, C, in Table 5. The maximum and minimum values of x_{2j} are a_2, b_2 and x_{2j} are the elements that belong to criterion, EF. The minimum and maximum values of x_{3j} are b_3, a_3 and x_{3j} are the elements that belong to the criterion, E. Finally, the minimum and maximum values of x_{4j} are b_4, a_4 respectively and x_{4j} are the elements in Table 5 that belong to the criterion, EU. Since the risk preference of decision maker is assumed in this paper to be risk neutral, z in Eq. 2-5 will be assigned the value of 1.

Step 3: Multi-attribute utility functions Determination: Multi-attribute utility functions are then determined for each alternative solution to power generation problem as follows:

$$U(C, EF, E, EU) = w_C u(C) + w_{EF} u(EF) + w_E u(E) + w_{EU} u(EU) \quad (6)$$

Where w_C, w_{EF}, w_E and w_{EU}, are the weights of decision criteria; cost (C), environmental friendliness (EF), efficiency (E) and ease of use (EU) respectively as determined in this paper using the entropy method.

4.2 Criteria weighting technique: Entropy method

Criteria weights evaluation is a key factor in power problems alternative solutions prioritisation because of the impact of the criteria in the final ranking of the alternative solutions. One popular technique in the literature, for determining weights of criteria is the entropy method. Shemshadi (2011)[14] used the technique for objective weighting of decision criteria in supplier selection problem Wu (2011)[15] also used entropy method for criteria weights evaluation in a supplier selection problem.

The Entropy method steps are as follows [16, 17]:

(1) Normalisation of the decision matrix.

The decision matrix in Table 1 is normalised as follows:

$$y_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}, \quad i = 1,2,\dots,n; \quad j = 1,2,\dots,m \quad (7)$$

Where y_{ij} is the normalised matrix.

(3) Determination of entropy value e_i.

The entropy value for each decision criterion is calculated as follows:

$$e_i = -k \sum_{j=1}^{m} y_{ij} \ln(y_{ij}) \quad (8)$$

Where $k = \frac{1}{\ln(m)}$ is a constant which guarantees $0 \le e_i \le 1$

(4) The weight w_i of each decision criterion is estimated as follows:

$$w_i = \frac{1 - e_i}{\sum_{i=1}^{n} 1 - e_i} \quad (9)$$

5. Case Studies, Results and Discussion

Two examples are used in this paper to demonstrate the suitability and applicability of the proposed technique. The first example (case study 1) is a case of selecting optimal solution from among alternative solutions for solving the problem of improper maintenance of Nigeria power generation asset. The second example (case study 2) is a case of prioritising alternative solutions for solving the problem of militant activities which is another power generation problem militating against effective power supply in Nigeria. For both examples data used as input into the proposed solution technique were obtained relying on experts' opinions. The experts' evaluated alternative solutions using Likert scale. There are different Likert scale available for use, which include among others; 3, 5, 7 and 10 points scale. The commonly use type is the 5 points scale and was chosen for rating alternative solutions in this paper.

5.1 Example 1; Ranking of alternative solutions to improper maintenance

To demonstrate the applicability of this technique in the ranking of alternative solution to improper maintenance, data were obtained via experts' opinion due to lack of quantitative data. Two experts were used in the rating of alternative solutions with respect to decision criteria; *C*, *EF*, *E* and *EU* using 5 Likert scale. The average of the two experts' individual rating was computed and results obtained are presented in Table 6. Table 6 data is then used as input data into the MAUT method for the final ranking of the alternative solutions.

Table 6: Decision matrix

S/N	Alternative solutions to improper maintenance	C	EF	E	EU
1	CM	2	1.5	1	5
2	TPM	3	3	2.5	4
3	CBM	2	4.5	4	3
4	RCM	4	4.5	5	2.5

Prior to ranking of the alternatives solutions using the MAUT method, the weights of decision criteria were determined by the entropy method i.e. applying Eq. 7-9 on data in Table 6. From the analysis 0.1478, 0.2526, 0.4390 and 0.1606 were obtained as weights of *C*, *EF*, *E* and *EU* respectively.

The first step in the MAUT analysis is to determine the single utility functions of the decision criteria. On this basis Eq. 2-5 were applied on data in Table 6 and the results obtained are presented in Table 7. The multi-attribute utility functions value are then determined for each alternative solution using Eq. 6 on data in Table 7 together with the weights of decision criteria evaluated and the results obtained are presented in Table 8.

Table 7: Utility function of decision criteria

Alternative solutions to improper maintenance	U(C)	U(EF)	U(E)	U(EU)
CM	0	0	0	1
PM	0.5	0.5	0.375	0.6
CBM	0	1	0.75	0.2
RCM	1	1	1	0

Table 8: Multi-attribute utility function value for each alternative solutions

Alternative solutions to improper maintenance	U(C,EF,E,EU)	Rank
CM	0.16060	4
TPM	0.46119	3
CBM	0.61397	2
RCM	0.83940	1

From Table 8, the alternative solutions for addressing the problem of improper maintenance which has greatly affected power generation output in Nigeria is RCM having the highest Multi-attribute utility function value of 0.83940. This is closely followed by CBM having rank second position on the Table. The least option is the CM having the lowest value of Multi-attribute utility function of 0.16060. However the results are influenced by opinion of experts who assigned rating to the various alternative solutions with respect to decision criteria. Another important feature that may influence the outcome of the result is the weights of decision criteria. Furthermore the risk perception of the experts may also influence the outcome of the analysis. However the use of RCM methodology rather than the current practice of corrective maintenance and time-based preventive maintenance, will help in addressing maintenance problem that most power stations in Nigeria had suffered over the years. Nevertheless the success will depends, on proper implementation of the approach.

5.2 Example 2; Ranking of alternative solutions to militant activities

To further illustrate the applicability and suitability of the proposed technique, it was used in prioritising various alternative solutions to the problem of gas supply vandalism by militant (militant activities). Again in the absence of quantitative data, information for the analysis were obtained using experts' opinion. Two experts were used in the rating of each of the alternative solutions to militant activities with respect to decision criteria; *C*, *EF*, *E* and *EU* using 5 point Likert scale. The average of the two experts' individual rating was computed and results obtained are presented in Table 9. The data in Table 9 is then used as input data into the MAUT method for the final ranking of the alternative solutions to militant activities.

Table 9: Decision matrix

S/N	Alternative solutions to militant activities	C	EF	E	EU
1	Diplomatic Approach	5	5	3.5	2.5
2	Military combat/drone technology	1	1	3	2
3	Sensor network/ground patrol	2.5	3.5	2	4

Since criteria weights are needed in the MAUT analysis, the entropy technique was applied using Eq. 6-8 on data in Table 9 to determine them. From the entropy analysis 0.3213, 0.2867, 0.0464 and 0.3457 were obtained as weights of *C*, *EF*, *E* and *EU* respectively.

To rank the alternative solutions to militant activities using the MAUT approach the first step of the analysis were to determine the single utility functions of decision criteria. To achieve this aim Eq. 2-5 were applied on decision matrix in Table 9 and the results obtained are shown in Table 10. For each of the alternative solutions to militant activities the multi-attribute utility function values are evaluated using Eq. 6 on data in Table 10 together with the weights of decision criteria and the results obtained are shown in Table 11.

Table 10: Utility function of individual criterion

Alternative solutions to militant activities	C	EF	E	EU
Diplomatic Approach	1	1	1	0.25
Military combat/drone technology	0	0	0.667	0
Sensor network/ground patrol	0.375	0.625	0	1

From Table 11, it is obvious that the best alternative to address the militant activities in the Niger Delta region of Nigeria is diplomatic approach having the highest value of Multi-attribute utility functions of 0.74076. The least option is the Military combat/drone technology having rank in the last position. The results of the analysis can be influenced mainly by three factors namely; the weights of decision criteria, the risk perception of the decision makers and opinions of the experts that assign rating to alternatives. However the result obtained in this analysis is in line with the call on the Nigeria Government to use dialogue rather than the use of force in solving the menace of militant activities.

Table 11: Multi-attribute utility function value for each alternative solution

Alternative solution to militant activities	U(C,EF,E,EU)	Rank
Diplomatic Approach	0.74076	1
Military combat/drone technology	0.03092	3
Sensor network/ground patrol	0.64531	2

However other MCDM tools such as Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), Preference Ranking Organisation METHod for Enrichment Evaluation (PROMETHEE) and Compromise Programming (CP) has the capability to rank alternative solutions in a similar fashion, their individual use will depend on the decision makers' and/or analysts' choice which may be guided by ease of implementation (computational effort) and suitability [18]. However the choice of the MAUT method in this paper is its ability to incorporate decision makers risk perception into the decision making process, a feature missing in other MCDM tools. Additionally the technique can be implemented using hand calculation or excel spreadsheet with or without resorting to specialise software.

6. Conclusion

This paper presented an MCDM tool for prioritising alternatives solutions to various power generation problems in Nigeria. The tool is a combination of the MAUT technique and the entropy method. The entropy method was applied in decision criteria weightage whilst utilising the MAUT in the ranking of the alternative solutions. The purpose for the development of the tool was to ensure optimal solutions are applied in solving power generation problems in order to maximise power plant output and invariably ameliorate power crisis in Nigeria. Two examples were applied in demonstrating the applicability of the proposed technique. From the analysis of the first example, the RCM was ranked as the optimal solution for addressing the power generation maintenance related problem. The second example considered different alternative solutions for solving the problem of gas pipeline vandalism by militant. The result of the analysis revealed that diplomatic approach is the optimal solution. The MAUT method was chosen for ranking of alternative solutions because of its simplicity of application and its ability to incorporate decision makers risk perception into the decision making process which is lacking in other MCDM tools. The tool will guide power generation managers in Nigeria in making optimal choice from various alternative solutions to power problem for maximum power plant output and invariably minimise energy crisis. The technique will also help in solving other engineering multi-criteria decision problems with little modification.

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