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A Topsis-Based Methodology for Prioritizing Maintenance Activities Suitable for A Municipal Water Works

Case Study: Chanchaga Water Works, Minna

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ABSTRACT

Maintenance is performed in the industry to ensure that physical assets continue to function to designed capacity. In most instances, scheduled maintenances are hardly fully implemented owing to maintenance budget fluctuations/constraints. Budget shortage has negative impact on maintenance strategies and results in the undesirable deterioration of production plant's components and increasing risk of accidents and downtimes. In most traditional practices, the choice, of which maintenance location that should be addressed urgently and which to delay, to the subjective discretion of the maintenance manager. One of the dangers of such discretional judgment in maintenance is that the risk of delayed maintenance is different for different components even for the same plant: a low-risk component could be chosen ahead of a high-risk one which jeopardized the overarching objectives of conducting the maintenance activities. The paper developed and implemented a methodology to minimize the impact of budget fluctuation by quantifying the risk of not performing a maintenance activity and identifying the priority of maintenance activities based on the quantified risk. TOPSIS algorithm uses a value system to estimate the risks that are not only relevant to failure of the system but also concern with the repair of the various sub- system of the plant under various criteria and to integrate the scores to arrive at a prioritization metric as an alternative to risk priority number of the traditional failure mode and effect analysis (FMEA). The framework is implemented on a real case study of Municipal water works and the conclusions proved well for wider applications in varied and allied industrial settings. Last, From the result obtained, the alternative A4 (reservoir) has the highest relative coefficient of 0.904049 which shows that it suffers most criticality than the other Alternatives, this occur as a result of abandonment of this component over dedicates because it has not been develop any fault and for that reason much attention were been diverted to those components like; pumping machine and others, since they always develop faults. The Alternative A5which is fire hydrant with relative closeness of 0.704793 becomes the second component that suffers high criticality due to the unavailability of this component across the metropolis; there is a need for the management to build more of it across the metropolis that will help reduce the loads on this existing one. Follow by valve with closeness coefficient of 0.483325, pipe with 0.47755 and finally pumping machine with 0.061847.

KEYWORDS: *Maintenance, TOPSIS, Delayed Maintenance, Water Supply and Decision Making*

1. INTRODUCTION

Water is life: adequate supply of water is central to life and civilization. The five basic human needs namely air, water, food, light, and heat. Water is common factor to other four. It is therefore not an understatement to say water is life, because it forms an appreciable proportion of all living things including man. In fact, water is very critical to human life. Water constitutes about 80% of animal cells. The human body by weight consists of about 70% water and several body functions depend on water (United Nations report, 2006).According to the popular Nigerian musician Fela Kuti who in his song "water no get enemy" reiterated that all human activities cling on water and that man will go to any length to search for water in times of scarcity and this has proven the slogan "water is life" right. In the third world countries of the world with Nigeria inclusive, the problem of portable water supply in Minna metropolis have poised a lot of challenges with task of collecting water falling largely on women and children and their journey to collect water is long, tiring and often dangerous, it prevents millions of mothers from working and lifting their families out of poverty. It keeps millions of children out school and from playing, depriving them of the wellbeing and education necessary to become healthy adults.

According to United Nations Report, (2012), 783 million people, or 11% of the global population, remain without access to an improved source of portable water supply. Water is fundamental to our way of life at whatever point in the socio-economic spectrum a community may be situated. The essential paradox of water supply in developing countries is that, in one sense, everyone has a water supply, in another sense, most people have not. Water is essential for life and all human communities must have some kind of water source. It may be dirty, it may be in adequate in volume and it may be several hours walk away but, nevertheless some water must be available. However, if reasonable criterion of adequacy in term of the quantity, quality and availability of water then most people in developing countries do not have an adequate supply (Cairncross and Feachem,1988) More so, delivery of safe reliable supply of drinking water to consumers tap depends on the integrity of the distribution system. The pipe networks, extending over large areas encompasses multiple connections and points of access typically constituting the bulk of water utility assets. Proper management of water system is crucial for ensuring sustainability of a given water resource, maintaining high quality water resources, and maximizing the utility's ability to respond to profound operating conditions (punmia et al, 2001). To survive in the modern economy, water production companies must be careful in making decisions. Improper decisions increase companies' costs in terms of resource wastage as well affect the consumers' satisfaction. Modern water production companies are now facing some great problems like budget deficient as a result of modern economy, time consumption and lack of advanced knowledge as well experience. The difficulty of the component's evaluation problem has driven the researcher to develop a model for helping decision makers/maintenance managers. The specific objective of this research model is to help decision maker in dealing with difficulty arising from maintenance significant in components criticality problem. The strategic decision, backed by the company is to be implemented effectively to increase water production capacity and safety as a whole. The identification of most critical component among eligible alternatives is a very powerful decision. As decisions regarding components are crucial elements in a company's quality success or failure. In order to identify the most critical component among the various alternatives the decision maker must consider meaningful criteria and possess special knowledge of the components properties. But those criteria should be considered those maximize the water production capacity. A thorough evaluation and identification of the component that suffers the must criticality among the existing components will be carried out and the most critical component would be suggested to the Niger State Water works which will help the management to find a lasting solution to the problem of inadequate water supply in Minna metropolis. In this study, the evaluation criteria for the identification of component's criticality decision ware selected from the studies and the discussions with the company's workers in deferent areas. To evaluate the component criticality, deferent methods have been widely applied in the literature: Simple Additive Weighting Method (SAW), Simple Multi-Attribute Rating Technique (SMART), Elimination and Choice Translation Reality (ELECTHRE) and The Analytical Hierarchy Process (AHP) are some of these methods.

In this research work a prototype frame work using TOPSIS method has been employed to evaluate the component criticality to prompt the water production capacity.

2.0 METHODOLOGY

TOPSIS: Means Technique for order of preference by similarity to ideal solution. This is one of the multiple – criteria decision making technique that deals with the selection of the best alternative usually have the closest distance to the ideal solution and farthest distance from the negative ideal solution.

TOPSIS allows trade-offs between criterions, where a poor result in one criterion can be negated by good result in another criterion. This provides a more realistic form of modeling than non-compensatory methods. TOPSIS Technique has been commonly used to solve decision making problems. This technique is based on the comparison between all the alternatives included in the problem. This proposed technique is highly useful in large-scale decision-making problems found in water quality assessment, disaster risk assessment, real estate management, sustainability assessment, environmental risk assessment, supplier selection.

TOPSIS also has the following advantages:

i. Simplicity
ii. Rationality
iii. Good computational efficiency and has ability to measure relative performance for each alternative in a simple mathematical form (Chen and Hwang,1992).

2.1. ANALYSIS PROCEDURES BY THE USES OF THE TOPSIS METHOD

In the TOPSIS method, the process of rating particular alternatives and comparing them with others, there is a distance expressed in the n-dimensional, Euclidean distance (n- number of criteria) between the value vectors describing particular alternatives and vectors responding to ideal and negative-ideal variants. The most reasonable alternative is the one with the value vector of simultaneously the shortest distance from the vector of negative-ideal solution.

The decisive steps, covered by the analysis of TOPSIS method are followed:

i. Creation of a decision matrix,
ii. Creation of normalized decision matrix
iii. Creation of weight, normalized decision matrix
iv. Indication of the ideal and negative-ideal solution
v. Calculation of the distance of each alternative for ideal and negative ideal solution.
vi. Calculation of the similarity indicators of particular alternatives for the ideal solution
vii. Creation of the final alternatives, ranking in the decreasing order of the similarity value indicator (Jahanshahloo et al ,2006).

2.2 CLASSICAL VERSION OF THE TOPSIS METHOD

As it was mentioned in the previous part of the paper, the foundations of the TOPSIS method were presented in the work of (Hwang andYoon, 1981). The basis of the analysis is the decision matrix Qm, n including ratings of considered alternatives i = 1, 2, ..., m in the context of the accepted criteria j = 1, 2, ..., n: On the basis of which there have been calculated normalized ratings of particular alternatives.

$$\mathbf{Q}_{m,n} = \begin{bmatrix} Q_{1,1} & Q_{1,2} & \cdots & Q_{1,n} \\ Q_{2,1} & Q_{2,2} & \cdots & Q_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ Q_{m,1} & Q_{m,2} & \cdots & Q_{m,n} \end{bmatrix} \quad (1)$$

$$n_{i,j} = \frac{Q_{i,j}}{\sqrt{\sum_{i=1}^{m} Q_{i,j}^2}} \quad (2)$$

In the phase of normalized rating, it is possible to use the formulas (Ishizaka, Nemery, 2013):

$$n_{i,j} = \frac{Q_{i,j}}{Q_{\max}} \quad (3)$$

----- for the criterion

$$n_i = \frac{Q_{\min}}{Q_{i,j}} \quad (4)$$

Then, there is an identification of the ideal solution conducted (V+) and negative-ideal solution (V–) with the use of corrected assessments. The ideal solution is defined as:

$$V^{+} = \{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\} \quad (6)$$

$$V^{-} = \{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\} \quad (7)$$

In the above equations

j v+ and j v− are the values defining ideal and

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{i,j} - v_j^{+})^2} \quad (8)$$

negative ideal solutions in the context of criterion(j), however, Cbenefits, Ccosts are respectively benefits and costs criteria subsets.After indication of the ideal and negative ideal solution there are the distances calculated di + and di − between them and consecutive alternatives:

On the basis of di+ and di − there is a ranking the coefficient of the particular alternatives indicated:

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{i,j} - v_j^{-})^2} \quad (9)$$

$$R_i = \frac{d_i^{-}}{d_i^{-} + d_i^{+}} \quad (10)$$

The procedure ends with the establishment of the alternatives ranking in the decreasing order of the Ri value rating (Hwang and Yoon, 1981).

2.3 ENTROPY METHOD

The entropy method is the method used for assessing the weight in a given problem because with this method, the decision matrix for a set of candidate materials contains a certain amount of information. The entropy works based on a predefined decision matrix. Entropy in information theory is a criterion for the amount of uncertainty represented by a discrete probability distribution, in which there is agreement that a broad distribution represents more uncertainty than does a sharply packed one (Dong et al. 2005). The entropy method for assessing the relative importance of criteria is calculated using material data for each criterion, the entropy of the set of normalized outcomes of the jth criterion is given by

$$E_j = -\left[\sum_{i=1}^{m} p_{ij} \ln(p_{ij})\right] / \ln(m) \; ; \; j = 1, 2,$$

....n and i=1,2 ...m (11)

The pij form the normalized decision matrix and is given by

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \; ; \; i = 1, 2, \ldots, and; \; j = 1,$$

2,. . . , n (12)

$$w_j = \frac{1 - E_j}{\sum_{j=i}^{n} (1 - E_j)}$$

Where rij is an element of the decision matrix, k is a constant of the entropy equation and j E as the information entropy value for jth criteria. Hence, the criteria weights, j w is obtained using the following expression

$$w_j = \frac{1 - E_j}{\sum_{j=i}^{n} (1 - E_j)}$$

J=1,2,………….. (13)

Whereby (1-Ej) is the degree of diversity of the information involved in the outcomes of the Jth criterion (Dong et all.2005)

2.4 FIGURES AND TABLES

The following components are to be consider in this research work

i. Pumping machines
ii. Pipes lines
iii. Valves
iv. Power source
v. Reservoir

(i) PUMPING MACHINE

Pumps are used to increase the energy in a water distribution system (Mays, 2006). There are many different types of pumps. They include positive displacement pumps, kinetic pumps, turbine pumps, horizontal centrifugal pumps, vertical centrifugal pumps. However, the most commonly used type of pumps in water distribution system is the centrifugal pumps. This is because of their low cost, system piping consists of the transmission system which are the raising mains and the distribution system which are the distribution mains. The transmission system consists of components that are designed to convey large quantity of water over a great distance from water works to the service reservoirs. simplicity, and reliability in the range of flows and head encountered.

Plate I A centrifugal pump of 355kw

(ii) PIPE LINES

The water system piping consists of the transmission system which are the raising mains and the distribution system which are the distribution mains. The transmission system consists of components that are designed to convey large quantity of water over a great distance from water works to the service reservoirs.

Plate II an asbestos cement pipe

(iii) VALVES

Valves are used for various purposes in water distribution systems, including isolation, air release, drainage, and checking and pressure reduction.

The valves were air release valves, sluice valve and butterfly valves. Sluice and gate valves are extensively used in the distribution to shut off the supplies whenever desired.

Plate III. A Butterfly valve

(vi). STORAGE AND DISTRIBUTION RESERVOIRS

Punmia et al., (2001) described storage and distribution reservoirs as important units in a modern distribution system. Clear water storage is required for storage of filtered water until it is pumped into the service reservoirs or distribution reservoirs. Bhargava and Gupta (2004) gave the functions and economic benefits of service reservoir to include:

The service reservoirs absorb the hourly fluctuation in and allow the pumps to operate at a constant rate. This improves the efficiency and reduces the cost of operation;

Plate IV. A clear water storage reservoir

(iv) Hydrants

There is only one functional hydrant throughout the distribution system. A fire hydrant which is an active protection measure and a source of water provided in most urban, suburban and rural areas with municipal water service to enable fire-fighters to tap into the municipal water supply to assist in extinguishing a fire. Looking at the importance of fire hydrant, there is the need for the Water Board to install more fire hydrants at strategic positions in the water distribution system.

Plate V: fire Hydrant

2.5 THE EXISTING CRITERIA FOR THIS RESEARCH WORK

Scoring Scheme for Maintenance Significant Factors

A number of issues are related to the failure of an item, its repair and subsequent use. The factors linked to failure of an item are identified as occurrence of failure, Severity, and reliability respectively. The issue of repair can be identified to have closer association with service time and the ability to organize the resources for repair, which are classified as maintainability and lead time to get spares. When the equipment is put to use, a measure of safety and economic loss can be relevant. This concern can be taken care of by measures like economic safety factor. Thus, the five factors that are to be considered in this research work are as follows: chance of failure (occurrence), reliability importance measure, maintainability, lead time for spare parts, economic safety factor.

The evaluation of each attribute is obtained in different ways by defining a rational method to quantify the single criterion for each cause of fault, based on a series of tables. In particular, every factor is divided into several classes that are assigned a different score (in the range from 1 to 9) to take into account the different criticality levels. The scores have then been defined in accordance with the experiences of the maintenance personnel. A technical data used to assign the different scores is discussed below (marivappan, 2004).

a. CHANCE OF FAILURE (O)

It is concerned with the frequency with which a failure mode occurs; higher value indicates higher criticality of the item. Probability of occurrence of failure was evaluated as a function of Mean Time Between Failures (MTBF).

TABLE 1: CHANCE OF FAILURE (O

Occurrence	MTBF	Score
Almost never	>2 years	1
Rare	2-3 years	2
Very few	2-3 years	3
Few	3/4- 1 years	4
Medium	6-9 months	5
Moderately high	4-6 months	6
High	2-4 months	7
Very high	1-2 months	8
Extremely high	<30 days	9

Adapted from (marivappan, 2004).

b. RELIABILITY IMPORTANCE MEASURE (RI)

Here, the Biranbaum's measure of Reliability Importance (RI) is used to assess the change in top event occurrence for a given change in the probability of occurrence of input event. Birnbaum's measure of a component represents the probability that a system will be in a critical state due to the failure of that component at time t. The guidelines to assign the score for reliability importance of a component are presented in Table 2.

Table 2: Reliability Importance Measure(RI)

Criteria %	Criteria for Reliability importance	Score
Less than 10	Negligible	1
10-20	Slight	2
20-30	Little	3
30-40	Minor	4
40-50	Moderate	5
50-60	Significant	6
60-70	High	7
70-80	Very high	8
More than 80	Extremely high	9

Adapted from (marivappan, 2004).

c. MAINTAINABILITY (M)

Maintainability is defined as the probability that an equipment/ component/ system can be restored back to its original/desired condition within the specified time interval. A low value of this index indicates lower chance of putting the equipment back to its original/desired condition. Thus, higher maintenance criticality index is associated with lower maintainability value. The scores assigned to different levels of maintainability index are listed in Table 3.3

Table 3: Maintainability (M)

Criteria	Maintainability	Score
$Mt > 0.8$	Almost certain	1
$0.7 < Mt \leq 0.8$	Very high	2
$0.6 < Mt \leq 0.7$	High	3
$0.5 < Mt \leq 0.6$	Moderately high	4
$0.4 < Mt \leq 0.5$	Medium	5
$0.3 < Mt \leq 0.4$	Low	6
$0.2 < Mt \leq 0.3$	Very low	7
$0.1 < Mt \leq 0.2$	Slight	8
$Mt < 0.1$	Extremely low	9

Adapted from (marivappan, 2004).

d. SPARE PARTS (SP)

A large number of spare parts are required for maintenance. Their chances of availability and importance level for the functioning of the equipment have substantial effect on the maintenance criticality of that equipment. The scoring scheme for their combinations is shown in Table 4 below.

Table 4: Spare parts score (SP)

Criteria	Availability		
	Easv	Difficult	scarce
Desirable	1	4	7
Essential	2	5	8
Vital	3	6	9

Adapted from (marivappan, 2004).

e. ECONOMIC SAFETY LOSS (ES)

The economics of safety also need to be considered while defining the maintenance criticality of a component. Table 5 below.

Table 5: Economic safety loss (ES)score

Status of the equipment/ sub system	Score
With no moving parts	3
With one moving part/critical category	6
With more than one moving parts/critical category	9

Adapted from (marivappan, 2004).

Table 6: The collected Data

Components (Alternatives)	Chance of failure (O)	Reliability importance Measure (RI)	Maintainability (M)	Spare Part (SP)	Economy safety loss (ES)
Pump	5	5	5	6	6
Pipe	3	4	5	6	3
Valve	4	3	5	6	3
Reservoir	2	1	5	3	3
Fire Hydrant	1	1	5	5	3

The Table 6 above describes the details of five different components data collected from Niger state water works Minna. The components: pump, pipe, valve, reservoir and fire Hydrant are the alternatives and represented as A1, A2, A3, A4 and A5 respectively WHILE the criteria are: chance of failure, Reliability importance measure, Maintainability, spare parts and Economic loss functions are represented as C1, C2, C3, C4 and C5 respectively. Therefore, the Table 6 will result to the Table 7 below.

TABLE 7: DECISION MATRIX

Components	**Criteria**	**Criteria**	**Criteria**	**Criteria**	**Criteria**
Alternative	C1	C2	C3	C4	C5
A1	5	5	5	6	6
A2	3	4	5	6	3
A3	4	3	5	6	3
A4	2	1	5	3	3
A5	1	1	5	6	3

TABLE 8: NORMALIZED DECISION MATRIX

	C1	**C2**	**C3**	**C4**	**C5**
A1	0.6742	0.693375	0.447214	0.503509	0.70710678
A2	0.40452	0.5547	0.447214	0.503509	0.35355339
A3	0.53936	0.416025	0.447214	0.503509	0.35355339
A4	0.26968	0.138675	0.447214	0.251754	0.35355339
A5	0.182574	0.19245	0.5	0.485643	0.5

TABLE 9: ENTROPY VALUE EJ

	C1	C2	C3	C4	C5
Ej	-3.19651	-3.08055	-3.5339	-3.4707	-3.50134

TABLE 10: WEGTHS CRITERIA VALUES WJ

	C1	C2	C3	C4	C5
Wj	0.192651	0.187327	0.208139	0.205238	0.206645

Table 11: WEIGHTED NORMALIZED DECISION MATRIX

	C1	**C2**	**C3**	**C4**	**C5**
A1	0.129885	0.129888	0.093083	0.103339	0.14612008
A2	0.077931	0.10391	0.093083	0.103339	0.07306004
A3	0.103908	0.077933	0.093083	0.103339	0.07306004
A4	0.051954	0.025978	0.093083	0.05167	0.07306004
A5	0.035173	0.036051	0.10407	0.099672	0.1033225

TABLE 12: IDEAL SOLUTION AND NEGATIVE IDEAL SOLUTION

A+	0.035173	0.025978	0.093083	0.05167	0.07306004
A-	0.129885	0.129888	0.10407	0.103339	0.14612008

TABLE 13: SEPARATION FROM POSITIVE AND NEGATIVE IDEAL SOLUTION

	S+	S-
A1	0.166659	0.010987
A2	0.102818	0.093982
A3	0.100467	0.093982
A4	0.016781	0.15811
A5	0.058671	0.140074

TABLE 14: RELATIVE CLOSENESS TO THE IDEAL SOLUTION

	CI	RANK
A1	0.061847	5
A2	0.47755	4
A3	0.483325	3
A4	0.904049	1
A5	0.704793	2

3. RESULT AND DISCUSSION

This research work is a case study of Niger State Chanchaga water works, Minna, therefore, the company need to prioritise the existing components in order to treat the most critical components before those with less criticality should be treated last. From the result obtained, the alternative A4 is the reservoir has the highest relative coefficient of 0.904049 which shows that it suffers most criticality than the other Alternatives, this occur as a result of abandonment of this component over dedicates because it has not been develop any fault and for that reason much attention were been diverted to those components like; pumping machine and others, since they always develop faults.

The Alternative A5 which is fire hydrant with relative closeness of 0.704793 becomes the second component that suffers high criticality due to the unavailability of this component across the metropolis; there is a need for the management to build more of it across the metropolis that will help reduce the loads on this existing one. The Alternative A3 which is valve, it has the relative closeness coefficient of 0.483325 and that make it to be the third Alternative that suffers much criticality. This incident occurs as a result of lack of proper attention because most of the parts in this component need repair and replacements.

The Alternative A2 which is pipe has relative closeness coefficient of 0.47755 which has become the fourth Alternative which shows that it has less criticality since this particular component is a fixed component and the leakages can easily be detected and repaired. the Alternative which is pumping machine has the most least relative closeness coefficient of 0.061847 which shows that special attention always been giving to this particular component simply because of the awareness of its functionality therefore, as a result of this constants attention to pumping machine had made it to suffers the least criticality.

Finally, the Alternatives, A4, A5 andA3 which are reservoir, fire hydrant and valve are suffering highest criticality which needs to be treated first before these Alternatives, A2 and A3 which are pipe and pump have less criticality and should be treated last.

4. CONCLUSION

This study describes the role of maintenance as a support function and its impact on production efficiency with respect to the life length and performance of production equipments which is fundamental in achieving production profitability.

Maintenance is performed to ensure that physical assets continue to function to the capacity for which they were designed. The benefits of a well-maintained plant include a lower rate of failures and downtime, cost efficiency and higher productivity. This proper decision paves way for the company to deliver its service to the consumers effectively. Several factors are considered in other to identify the component that suffers the highest criticality. But the consideration of this several criteria makes the process of selecting of the most critical component more difficult. for that reason, this paper has presented a prototype frame work using the TOPSIS classical interval version method as an effective tool for supporting component's criticality selection decision.

In this research, the weights of the different criteria are calculated using ENTROPY method of determining the weighted criteria values under the objective weighting method and for identifying the most critical component one of the well-known MCDM methods namely TOPSIS method has been used. For both methods, the results are calculated by using Microsoft office Excel.

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