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A FUZZY LINGUISTIC APPROACH OF PREVENTIVE MAINTENANCE SCHEDULING COST OPTIMISATION

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ABSTRACT

The simultaneous scheduling of resource-constrained maintenance and operations is an emerging theory that is attracting the attention of both researchers and practitioners. The purpose of this paper is to capture the uncertainty in the development of a model that schedules both preventive maintenance and operational activities. Fuzzy logic is employed to transform the human expertise into IF-THEN rules. The approach has the advantage of revealing semantic uncertainty with the associated non-specifying measures. The methodology applied tracks the error values in terms of results in linguistic variable. The result obtained indicates the feasibility of tracking the uncertain measures in the model discussed. Thus, the study may be applicable to both production system and transportation organizations that are engaged in both maintenance and operational activities. The research has serious implication in terms of the ability to monitor the imprecision that were introduced in the previous models. This obviously provides a more reliable framework for researchers and practitioners interested in maintenance scheduling operation. The paper is new in that, it demonstrates the application of fuzzy logic in a form that was never documented.

INTRODUCTION

Many organization worldwide are shifting their focus from the traditional way of running the business to a modern and pro-active approach that guarantees the continued existence of the business. Traditionally, businesses are managed with the sole aim of making profit. This viewpoint is fading away in view of the emerging business improvement concepts that has dominated organizational practices worldwide. Such concepts include business process re-engineering, total quality management, etc. As such the customer is at the central focus of the company's objective with the aim of satisfying and exceeding customers' requirements.

This condition has created intense competition among rival organizations. Therefore, for businesses to stay afloat, customer satisfaction should be the central focus. While satisfying the customer, the profit maximization objective of company would automatically be achieved since an increased customer patronage is envisaged. In an effort to continue in business, company managers are re-engineering their processes for efficiency and effectiveness. The maintenance culture is one of the subsystems of the organization that has received an increased attention in recent times. Fortunately the viewpoint of the maintenance function as a "bottomless pit of expenses" is fading away. Maintenance is now viewed as a "value adding activity" to the organization. In other to improve efficiency of operations, proper scheduling of facilities should be done. In scheduling facilities, optimal approaches are sought for such that minimum cost is expended on activities and maximum results obtained. Until recently most approaches utilized in maintenance scheduling are near optimal (see Anily et al., 1998, 1999). This is largely due to the non-polynomial problem that usually exists in problem formulation.

Fortunately, Charles Owaba (2002) has recently proposed a breakthrough methodology that uses the basic principles of Gantt Charting. Since the development of the original model numerous efforts have been made by authors in extending its framework. Such extensions have incorporated a reviewed cost dimensions, and alternative consideration without the use of Gantt charting principles. Unfortunately, none of the articles have considered the uncertain nature of the problem semantic uncertainty in the model framework is an important concern that is worthy of analytical investigation (Oke, 2004a,b). This important gap in the maintenance scheduling literature is addressed in the current work.

In particular, the fuzzy logic concept is applied to the simultaneous scheduling of resource-constrained maintenance and operations. The linguistic variables are used to substitute for the key-parameters and variable of the Gantt charting model. The model that evolves from the current research is of immense benefits both to the academic community and the industry. With the model, the real value of measure could be easily captured while the decisions based on the modeling information will be more reliable than the former model that does not contain fuzzy logic concepts.

Literature review: The maintenance scheduling literature has a variety of applications (Zurn and Quintana, 1975; Wang et al., 2002; Walker et al., 2001a,b). These diverse applications include aircraft maintenance, process industry, vehicle fleet maintenance, railway track maintenance, power generation, pavement maintenance, highway maintenance, refinery and production facilities (Alfares, 1999; Ashayeri, et al., 1996; de Campos and Belhot, 1994; Gunn and Lee, 1991; Lee, 1991; Lake et al., 2000, 2001; Lake and Ferreira, 2001; Creemers et al., 1994). An attempt to codify the maintenance scheduling literature portrays a line of inquiry that has grown in volume and in depth. Despite the immense resources allocated to the study of maintenance scheduling during the past 30 years, a more intensive study into some deep structures is still required.

Subsequently, a number of theoreticians proposed models for scheduling maintenance (Zurn and Quintana, 1977; Stremel and Jenkins, 1981; Stremel, 1981; Ram and Olumolade, 1987; Duffuaa and Al-Sltan, 1997). Duffuaa and Ben-Daya (1994) proposed a model, which is similar to that of Hariga in that it focused on non-identical production units (Duffuaa and Ben-Daya, 1994). The model is developed for the joint overhaul problem by incorporating the cost of production, and the cost of coordination. The model obtains lower costs of two examples. Among the deficiencies of these models is the fact that no evidence of machine dominance concept is considered.

Cheung and Hui (2004) investigated a chemical production site from the perspective of loss minimization. The paper proposes a multi-period mixed integer linear programming (MILP) model as an aid to optimize short-term maintenance schedule. In a study by El-Sharkh and El-keib (2003), the concept of a fuzzy evolutionary programming-based solution methodology for security-constrained generator maintenance scheduling was explored. The paper presents the fuzzy model with uncertainties in the load and fuel and maintenance costs. The technique results are fuzzy optimal cost range that reflects the problem uncertainties. It solves a decomposed maintenance model of two interrelated subproblems, namely the maintenance and the security-constrained economic dispatch problem. Dieulle et. al. (2003) focused on the development of a new probabilistic method based on the semi-regenerative property of the evolution process. In order to calculate the long-time expected cost per unit of time, the authors use a recent result generalizing the well-known theorem that expresses the cost criterion as equal to the ratio of the expected cost on renewal cycle over the expected cycle duration. Numerical experiments show that there exists a set of parameters (the critical threshold and the parameters of maintenance scheduling function) which lead to a minimal cost.

El-Sharkh and El-Keib (2000) considered an evolutionary programming (EP) based technique to the unified model of the maintenance scheduling (MS) problem of power generation and transmission systems. The Hill-climbing technique (HCT) is used in conjunction with the EP to find a feasible solution in the neighbourhood of the new feasible solutions during the solution process.

The work by Kobbacy et al. (1997) is concerned with the development of a realistic preventive maintenance (PM) scheduling model. A heuristic approach for implementing the semi-parametric proportional hazard model (PHM) to schedule the next preventive maintenance interval on the basis of the equipment’s full condition history was introduced. These models are then used within a simulation framework to schedule the next preventive maintenance interval. The results indicate a higher availability for the recommended schedule than the availability resulting from applying the optimal PM intervals as suggested by using the conventional stationary models.

Olorunniwo and Izuchukwu (1991) applied the concept of maintenance improvement factors to preventive and overhaul maintenance. The authors developed mathematical models that are used to generate preventive and overhaul maintenance schedules. Examples are provided to demonstrate the sensitivity of the schedules to model parameters.

Ashayeri et al. (1996) reported on simultaneous planning of preventive maintenance and production in a process industry environment. The authors developed a mixed integer linear programming model. The model scheduling production jobs and preventive jobs, while minimizing costs associated with production back orders, corrective maintenance and preventive maintenance. The model takes into account the probability of a breakdown given by the last maintenance period. The formulation of the model is flexible so that it can be adapted for several production situations. However, the deterministic model discussed does not afford insight into the nature of deterioration of machines. A common form of machine deterioration is stochastic but many studies have assumed linear deterioration for ease of modeling.

Model framework: From the original proposal by Charles-Owaba (2002) the problem is defined as follows:

Given a set of machines for preventive maintenance and operations in T contiguous periods, limited periodic maintenance capacity (A_j), limited budgetary allocation (B_a); limited manpower resources (M_r); duration (B_{ir}) per maintenance visit, arrival period K_{ij}); and the number of visits per machine (N_i); select the periods for alternative preventive maintenance and operations under conditions of inflation, such that the total preventive maintenance cost is minimum (see figure 1).

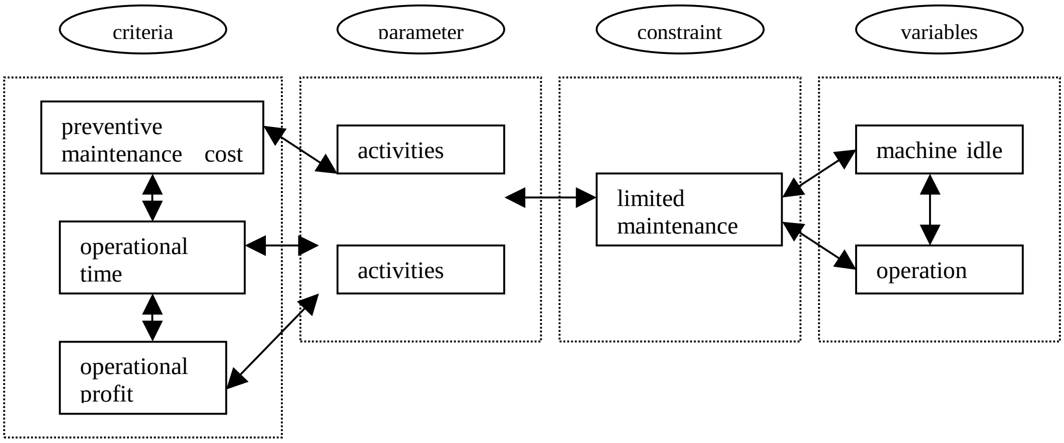


Figure 1: Structural Model of Charles-Owaba's OGC Model

The following assumptions, adopted from Charles-Owaba (2002) are used in generating fuzzy logic model.

i. Time for corrective and preventive maintenance is considered.
ii. Cycle of activities occurs in the following order: Operation – maintenance.
iii. Total number operation – maintenance periods are not fixed.
iv. Maintenance periods are known.
v. An arriving machine has its maintenance activities commenced only when resources are available. Otherwise, it waits.
vi. A machine is either operating or in for maintenance at any moment.
vii. Arrivals occur and maintenance of operation activities commences at the beginning of a period while completion is at the end of a period.
viii. Arrival periods for planned preventive maintenance are pre-scheduled.
ix. The span of a period maybe one or more seconds, minutes, hours, days, weeks, month etc.
x. All assumptions are ensured to work together for the common objective of maximizing profit by cost minimization.

Parameters used in fuzzy logic model

i. Operation cost → (OPC)
ii. Maintenance cost → (MC)
iii. Projected cost→ (PRC)

These parameters constitute the fuzzy logic variables used to generate the fuzzy logic model. The following error terms of the model are thus defined.

Error terms

PRC – (Σ OPC / MC) = Z, "Zero – error" term (No change in projected cost)
PRC – (Σ OPC / MC) = N, "Negative – error" term (Greater than projected cost)
PRC – (Σ OPC / MC) = P. "Positive – error" term (Less than projected cost)

Considering the model over length of time, we have:

d{PRC – (Σ OPC / MC)}/dt = $\dot{Z}$, “Zero-error-dot” (No change in projected cost overtime)
d{PRC – (Σ OPC / MC)}/dt = $\dot{N}$, “Negative-error-dot” (Greater than projected cost overtime)
d{PRC – (Σ OPC / MC)}/dt = $\dot{P}$, “Positive-error-dot” (Less than projected cost overtime)

It is reasonable to consider conditions of the model as changing or varying to a large degree overtime, hence, the following additional terms are generated for more effective control of the fuzzy logic model.

d{PRC – (Σ OPC/MC)}/dt = R$\dot{Z}$, “Zero-error-dot” remains (No change condition remains overtime)
d{PRC–(ΣOPC/MC)}/dt= CR$\dot{Z}$,“Negative-error-dot”(No change remains continuous overtime)
d{PRC–(ΣOPC/MC)}/dt= >> $\dot{N}$, “Positive-error-dot” (Grreater than projected cost overtime)
d{PRC–(ΣOPC/MC)}/dt= >>> $\dot{N}$, very, very large “Negative-error-dot” (Very, very greater than projected cost overtime)
d(PRC–{ΣOPC/MC)}/dt = >> $\dot{P}$, “very, very large positive -error-dot” (Very, very Less than projected cost overtime)
d{PRC–(ΣOPC/MC)}/dt = >>> $\dot{P}$, “very, very large positive -error-dot” (Very, very Less than projected cost overtime)

The next step in the fuzzy model is to generate rule matrix for the varying conditions, so as to come up with effective rules structure for the model.

Rule – matrix

	Error		
Error - dot	1 NC	2 GC	3 LC
	4 NCR	5 NCC	6 LGC
	7 VLGC	8 LLG	9 VLLG

From the rule-matrix, a rule structure can thus be generated for the fuzzy logic model as follows:

Rule structure
IF PRC – (∑OPC/MC) = Z AND d{PRC-(∑OPC/MC)}/dt = $\dot{Z}$ THEN Output = NC
IF PRC – (∑OPC/MC) = N AND d{PRC-(∑OPC/MC)}/dt = $\dot{N}$ THEN Output = GC
IF PRC – (∑OPC/MC) = P AND d{PRC-(∑OPC/MC)}/dt = $\dot{P}$ THEN Output = LC
IF PRC – (∑OPC/MC) = Z AND d{PRC-(∑OPC/MC)}/dt = R$\dot{Z}$ THEN Output = NCR
IF PRC – (∑OPC/MC) = Z AND d{PRC-(∑OPC/MC)}/dt = CR$\dot{Z}$ THEN Output = NCC
IF PRC – (∑OPC/MC) = N AND d{PRC-(∑OPC/MC)}/dt = >> $\dot{N}$ THEN Output = LGC

IF PRC – (∑OPC/MC) = N AND d{PRC-(∑OPC/MC)}/dt = >>> $\dot{N}$ THEN Output = VLGC
IF PRC – (∑OPC/MC) = P AND d{PRC-(∑OPC/MC)}/dt = >> $\dot{P}$ THEN Output = LLC
IF PRC – (∑OPC/MC) = P AND d{PRC-(∑OPC/MC)}/dt = >>> $\dot{P}$ THEN Output = VLLC

Note

Notations	**Meaning**
∑	Summation sign
>	Greater than
>>	Very greater than
>>>	Very very greater than
NC	No change
GC	Greater changer in projected cost
LC	Lower/lesser change in projected cost
NCR	No change remains
NCC	No change continues
LGC	Large greater change
VLGC	Very large greater change
VLLG	Very large lesser change
LLG	Large lesser change

System operating rules: A System Operating rule based on the rule structure in the previous section can thus be generated for the control of the fuzzy logic model. The operating rule is as follows:

INPUT #1: (“Error”, Zero (Z), Negative (N), Positive (P))
INPUT #2: (“Error-dot”, Zero ($\dot{Z}$), Negative ($\dot{N}$), Positive ($\dot{P}$))

CONCLUSION: (“Output”, No change (NC), Greater change (GC), Lesser change (LC),
No change remains (NCR), No change continues (NCC),
Large greater change (LGC), Very large greater change (VLGC),
Large lesser change (LLC), Very large lesser change (VLLC))

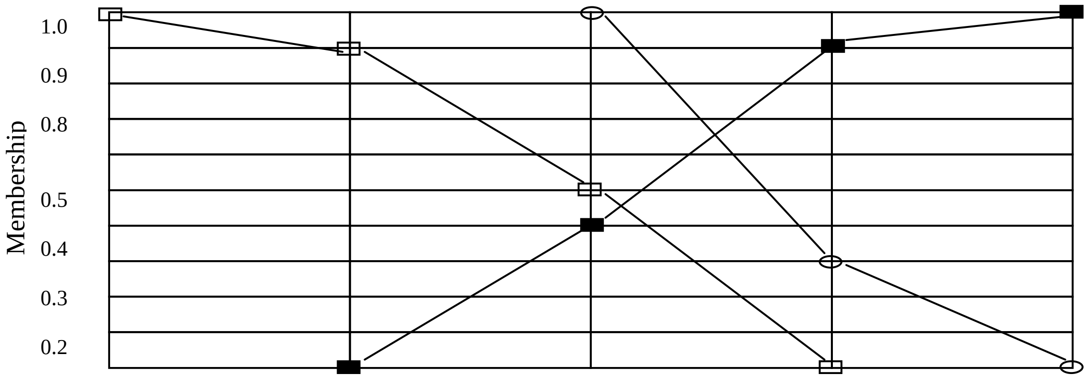
INPUT #1: System Status
Error: PRC – (∑OPC/MC)
Z = No, N = Greater, P = Less
INPUT #1: System Status
Error-dot: d(Error)/dt
$\dot{Z}$ = Not changing, $\dot{N}$ = Getting greater, $\dot{P}$ = Getting lesser
OUTPUT: Conclusion and system response
Output: N = No response, G = Greater response, L = Low response

Application: Representing the components of the fuzzy logic control model of the Gantt charting multiple machines' preventive maintenance activities with membership functions, we have the following table:

Table 1: Showing relationship between fuzzy output and membership function

Level No.	**Interpretation**	**Fuzzy Output**	**Linguistic Variables**
1.	Optimistic	Negative	$\{(\sum M_cO_c) – (TP)_c\}$
2.	Most Likely	Zero	$\{(\sum M_cO_c) – (TP)_c\}$
3.	Pessimistic	Positive	$\{(\sum M_cO_c) – (TP)_c\}$

where degree of relationship between fuzzy output and membership function ranges from 0 – 1.0. Illustrating the above table graphically, we have:



Note: ■ denotes positive
□ denotes negative
○ denotes zero

The interpretation of the graph shows that:

(i) When the sum of maintenance and operating costs is higher than the total minimum preventive maintenance cost $(TP)_c$, the fuzzy model prompts positive.
(ii) When the sum of maintenance and operating costs are lower than $(TP)_c$, the fuzzy model prompts negative (optimistic output).
(iii) When the sum of maintenance and operating costs are equal to the $(TP)_c$, the fuzzy model prompts zero and 0 is the weakest relationship while 1.0 is the strongest relationship.

Representing the fuzzy logic model relationship by the use of direct graph we have:

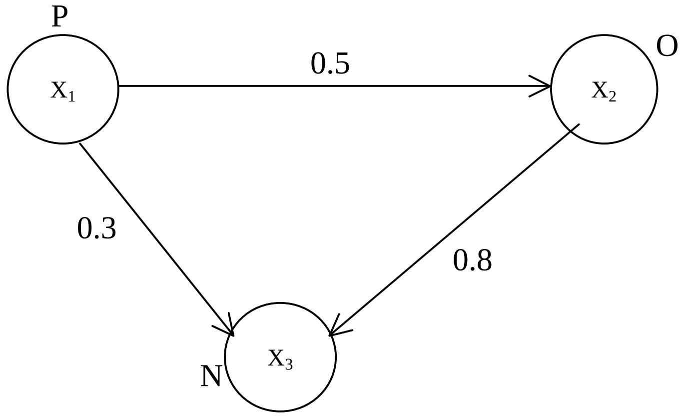
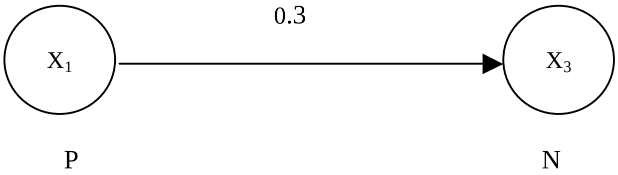


Fig. 2: shows the strength of relationship within the fuzzy logic outputs: positive, zero and negative.

Note:

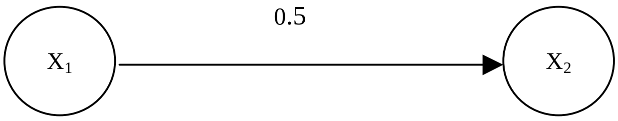
X_1 = Positive (High costs of maintenance and operation) (pessimistic output)
X_2 = Zero (Maintenance and operating costs = minimum total production cost)
X_3 = Negative (Maintenance and operating costs lower than minimum total production cost) (optimistic output)
0.8 = Strong relationship
0.5 = Weak relationship
0.3 = Weaker relationship

This implies that it is not likely that the industry will run at high cost when sum of maintenance and operating costs are lower than minimum total production cost i.e.



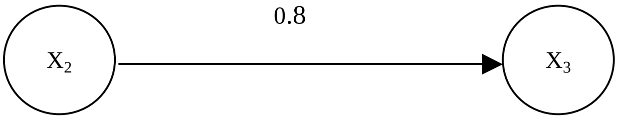
= Weaker relationship

Also, when the sum of maintenance and operating costs is equal to the minimum total production cost, it is easier to run at high cost compared to when the sum of maintenance and operating cost is lower. Hence,



= Weak relationship

Finally, the graph implies that it is very easy to run at a costs of maintenance and operation equal minimum total cost even though the sum of maintenance and operation costs are lower than minimum total production costs, if care is not taken. This is illustrated from relationship between X_2 and X_3 given by:



= Strong relationship

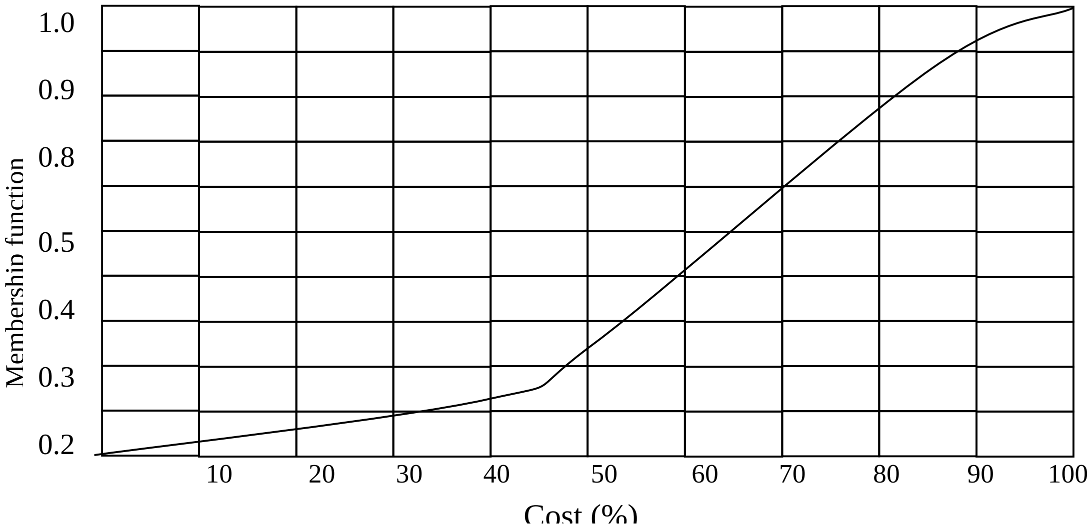
For more simplified graphical illustration, the following table of membership function, cost level and cost percentage is given:

Table 2: Showing relationship between the cost level and membership function

Membership	Cost Level	Cost (%)
0 – 2	Low cost	0 – 40
2.5 – 4.5	Medium cost	41 – 50
5 – 8.5	High cost	51 – 80

9 – 1.0	Maximum cost	80 – 100

Fig. 3: Graphical Illustration of Table 2



To define the fuzzy logic model more clearly, a term is used to represent the procedure followed. This term is known as "defuzzification".

Defuzzification

Defuzzification is the term used for the procedure followed in an attempt to convert the fuzzy set having overall conclusions to a single conclusion or value. There are various methods used in defuzzification, the common one being the "center-of-gravity defuzzification" method, in which the center of gravity of the overall fuzzy set conclusions is determined to represent the desired conclusion. If a fuzzy set is represented by Z, defined over the interval [a, b], the center-of-gravity defuzzification c is given by:

$$c = \frac{\int_a^b xz(x)dx}{\int_a^b z(x)dx}$$

Based on this idea of defuzzification, an extension of fuzzy logic model is thought of in looking into how more specific output can be achieved. This leads to further research into neuro-fuzzy model, which intends to combine both fuzzy logic and neural networks.

A case study

TEM-D Mechanical Components Manufacturing Company (Nigeria): The above named firm is an hypothetical organization that specializes in manufacturing of mechanical components like bolts, nuts, screws and the likes. The major manufacturing machine is lathe machine amongst others. A study was carried out in 2002 concerning the costs of operating and maintaining the lathe machine in relation to the total production cost of components produced by the machine over a period of two years. It was found that one thousand pieces each of both bolts and nuts were produced over a period of one month at the production cost of N200 per piece. This production cost estimate per piece when calculated over a month amounted to N200,000 for each components, giving total production cost of N400,000. It was also discovered that some costs were incurred in maintaining the machine prior to production and also during production. These costs are termed maintenance and operating costs respectively. To maximize profit – TEM-D intends to sell the products at the price double the total cost of production which implies that any extra costs (maintenance and operating costs) on total production cost must be less than the total production cost for TEM-D to make profit. This objective necessitates the use of a control model like fuzzy-logic control model.

Application of fuzzy-logic control model: The major parameters in the Gantt Charting Multiple Machines' Preventive Maintenance Activities as identified in the case study of TEM-D manufacturing company are: Maintenance Cost, Operating Cost and Total Production Cost. Defining these parameters in terms of fuzzy logic model, we have:

(i) Input Parameters: (a) Maintenance Cost (X)
(b) Operating Cost (Y)
(c) Total Production Cost (N400,000)
(ii) Linguistic Variables (∑XY – N400,000)
(iii) Output Parameters
Errors
(a) (∑XY – N400,000) = Positive = (Pessimistic) (P_e)
(b) (∑XY – N400,000) = Zero = (Most Likely) (M_L)
(c) (∑XY – N400,000) = Negative = (Optimistic) (O_p)

(d) d/(∑XY – N400,000)/dt = Positive = $(\dot{P}_e)$
(e) d/(∑XY – N400,000)/dt = Zero = $(\dot{M}_L)$
(f) d/(∑XY – N400,000)/dt = Negative = $(\dot{O}_p)$
Error-dot

Note:
Errors are output parameters within a month. Error-dot are output parameters over the period of 2 years during which the research was completed.

A rule-matrix is thus generated from the output parameters in order to formulate a rule structure for the fuzzy logic model given as follows:

Rule Matrix

(Error)

	P	Z	N
(Error-dot)	1 P_e	2 M_L	3 O_p

Now formulating rule structure we have:

IF (∑XY – N400,000) = P, AND d(∑XY – N400,000)/dt = $\dot{P}$, THEN output = P_e
IF (∑XY – N400,000) = Z, AND d(∑XY – N400,000)/dt = $\dot{Z}$, THEN output = M_L
IF (∑XY – N400,000) = Z, AND d(∑XY – N400,000)/dt = $\dot{N}$, THEN output = O_p

Note: The main objective of TEM-D manufacturing company is to reach out for the condition of optimistic (Op) where (∑XY – N400,000) = Negative. A situation where the sum of the costs of maintenance and operation are lesser than the total production cost (N400,000).

From the rule-structure, system operating rules for the sake of computation are generated as follows:

System Operating Rules

INPUT # 1: (“Error,” Positive (P), Zero (Z), Negative (N))
INPUT # 2: (Error-dot,” Positive ($\dot{P}$), Zero ($\dot{Z}$), Negative ($\dot{N}$))
CONCLUSION: (“Output”, Optimistic (O_p), Pessimistic (P_e), Most Likely (M_L))
INPUT #1: System Status
Error = (∑XY – N400,000)
P = Pessimistic, N = Optimistic, Z = Most Likely
Error-dot = d(∑XY – N400,000)/dt
$\dot{P}$ = Getting Pessimistic, $\dot{N}$ = Getting Optimistic, $\dot{Z}$ = Getting Most Likely
OUTPUT Conclusion & System Response
Output O_p = Optimistic, P_e = Pessimistic, M_L = Most Likely

CONCLUSIONS

As the engineering community considers approaches and models that would improve the existing scheduling tools for both operations and maintenance, a strong case is made for the use of fuzzy logic control model in this work. In particular, we express the mathematical expression in the mathematical model developed by Charles-Owaba (2002) in linguistic variables, taking in account the “error” and “error.dot” concepts in an uncertain environment. The following observations are made in an attempt to develop and apply the fuzzy-based model:

- The system is most desirable to operate under the condition of “Less Change” (LC) in projected Cost (PRC) of operation and maintenance of machines, since the ultimate desire of the industry is to minimize to the bearest minimum the costs of operation and maintenance to achieve maximum profit.

- The fuzzy logic model gives allowance for variations in conditions, hence it is effective in controlling the costs of operation and maintenance of machine, no matter the variations. This accommodation of varying changes in conditions is enhanced by the fuzziness of fuzzy logic model.

- The fuzzy logic model effectively takes care to different time periods within which operation-maintenance activities are carried out (arrival time and post arrival time) since it controls “error” due to changes over time.

- It, however, recommends that the operation-maintenance condition should be targeted at achieving the least change possible PRC – (∑OPC/MC) = LC. LC – implying less change where (∑OPC/MC) is very small. According to the fuzzy logic model, the error at this condition is positive (P) indicating a safe condition.

In this work, four important questions readily come to the mind of a potential reader of this article. These questions are addressed here (i) what are we going to learn from the article that we do not know now? (ii) why is it worth knowing? (iii) how will we know that all conclusions are valid? (iv) what does the future hold in reformulating and developing the model?

Till date, all the articles reviewed in this work relevant to the simultaneous scheduling of maintenance and operations have largely ignored the application of soft computing tools. Since uncertainty exist in model application, the omission of fuzzy logic in the modeling effort is a serious gap. This is a new dimension of treating the simultaneous scheduling of resource-constrained maintenance and operations. It is therefore a new contribution to knowledge in the area, and it is worthy of future extension. Since imprecision exist in real-life measurement using the previously defined models by other authors, these uncertainties could be tracked with a level of confidence. This is the main reason the technique is what knowing. Based on the empirical analysis made in this paper, the results are pointers to the validity of our conclusions. This is obviously a strong support for the conclusion made in this work. In considering what the future holds in reformulating the model, a number of application tools in other fields readily comes to mind. Some of the tools that will be applied includes genetic algorithms, artificial neural network, fuzzy, neuro-genetic and a host of statistical tools.

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