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A PERIODICITY METRIC: A VERITABLE TOOL FOR EFFECTIVE PLANNED PREVENTIVE MAINTENANCE IN AN ENGINEERING FIRM

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ABSTRACT: The needs in the highly challenging environment for industrial competitiveness to keep the products quality within acceptable levels and on-time deliveries through optimum machine functionality called for maintenance culture in order to guarantee the system`s long-term reliability.The system`s long-term reliability, operating cost and useful life depend on the effectiveness of the preventive maintenance performed over the life cycle of the system. Consequently, in order to obtain an optimal preventive maintenance policy, there is a need for a metric to evaluate and quantify the amount of required periodicity to help design new and effective maintenance strategies. A novel metric to calculate the functional periodicity has been established using the complexity theory. This can be used for comparing the different maintenance policy alternatives. Finally, an industrial example is used to exemplify the application of the metric to verify the optimal policy of the proposed preventive maintenance model.
Keywords: Plans, preventive, maintenance, culture, failure, complexity, periodicity, virtual age, equivalent time, Computer Aided Design, strategy, frequency, level, rate, repair, virtual age, software

1. INTRODUCTION

A new system will not fail easily in the early stage of its life; as time passes, the system age and un-planned failures occur causing the system performance to drift away from its initial state.

Manufacturing systems are set up with the aim of supplying products with predetermined quality level and maximizing capacity utilization. However, it is deprived upkeep practice and bad Engineering ethics if the personnel in charge wait for machines or equipment to breakdown before he or she acts. The failure of most industries is due to lack of adequate maintenance practice and the outcome effect is that industries start to run at a huge loss. Meanwhile, for a worsening and repairable system, the application of up keeping culture can slow the aging haste or reduce the let-down rate and then restore the system to a “like new” state; hence, the need for adequate and modernized approach to maintenance culture in industrial firmto kept a manufacturing system in an acceptable condition throughout it useful life, Dekker (1996).

Maintenance is defined as a combination of any actions carried out to retain an item in, or restore it to, an acceptable condition, Azlan (2009). The needs in this extremely challenging environment for industrial competitiveness in term of cost; quality of services; prompt deliveries and proper management of available resources through the best plants and equipment performance called for this culture in order to guarantee system`s long-term stability and reliability. Therefore, with the application of maintenance culture to the plants and equipment; industrial firms can improve automation and operate more efficiently, produce quality products, minimize energy consumption and business loss due to production delays, and increase overall safety levels.

All over the world, industries have various modus operandi in organizing maintenance activities to sustain the life span of their plants and equipment. The classification of various maintenance activities are shown in Figure 1, Aurich (2006).

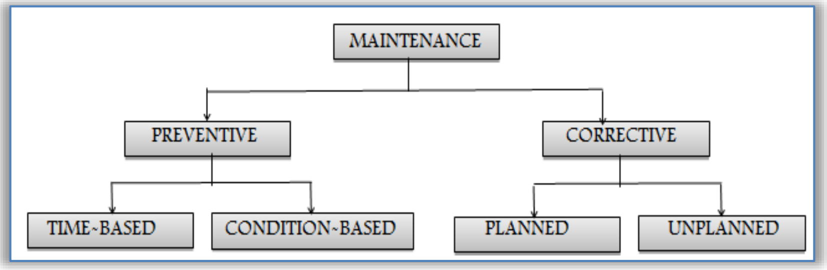

Figure 1: Classifications of Maintenance Activities

The corrective maintenance includes all actions performed as a result of failure to restore an item to a specified working condition. This class of maintenance culturesolves only the specific cause of failure and not all the status problems of the entity. In addition, it does not change the failure rate and does not increase the working life, Dhillon (1999).

The preventive maintenance (PM) includes all actions performed on operating equipment to restore it to a better condition, Dhillon (1999). It is not reduced only the proper operation but the failure probability as well as much as the number of maintenance works is increased.

Meanwhile, the most effective maintenance planning method is the preventive maintenance planning and this can be achieved through routine inspections. The preventive maintenance in the manufacturing system is the planned maintenance of plant infrastructure and equipment with the goal of improving equipment life by preventing excess depreciation and impairment. Besides, preventive maintenance measures can drastically reduce errors in day-to-day operations, as well as increase the overall preparedness of plants in the case of an emergency. This maintenance includes, but is not limited to, adjustments, cleaning, lubrication, repairs and replacements.

Due to the varying needs of different plants, the type and amount of preventive maintenance required varies from plant to plant. Hence, it is extremely difficult to establish a successful preventive maintenance program without the proper guidelines and instructions. The condition for a successful preventive maintenance is to decide the proper moment of its execution. One of the most used concepts is periodical preventive maintenance, which specifies the interventions following to be done at equal time elements of continuous operation [e.g. 670 Hr for ball mills], Vasiu (1996). Another concept is the so-called sequential preventive maintenance, consisting in planned interventions done on unequal time elements of continuous operation. The first concept is more convenient, but sequential preventive maintenance is more realistic because takes into account that an entity should to be recovered often with its ageing.

In this paper is presented a metric to evaluate and quantify function resetting to obtain an optimal preventive maintenance policy which takes into account several stochastic factors that influence the failure rate and working life of an entity in order to reduce the related costs. Hence, a novel metric for assessing the functional periodicity has been established using the complexity theory. The propose model will assess and compare the maintenance plans based on the periodicity of the maintenance plans, the virtual age and the equivalent time before full resetting for the maintenance plans.

2. THEORETICAL CONSIDERATION

Maintenance scheduling and assessment has been a topic of research for centuries where a few number of researchers have devoted their time to study the extent of righting, the maintenance occurrence or the virtual age of the maintained systems using Computer Aided Design with periodicity belief. As a result of rapid advances in modernization schemes during the past five decades, industrial maintenance has become so sophisticated since the number of functional requirements (FRs) continues to increase require many layers of decomposition; thus, fundamental principles to reduce complexity have to be conceived, Suh and Lee (2004).

The deterioration of manufacturing system performance is characterized by a time moving system range and may be considered as a time dependent complexity, Suh (1999). The complexity is defined as a measure of uncertainty in achieving the specified functional requirements Suh, (2005). Hence, the relationship between the design range and system range determines complexity Suh (1999, 2005).

Periodicity is important for the long-term sustainable system functionality. Periodicity re-initializes the system functionality to a “like new” state, which assures a high degree of functional certainty, Suh and Lee (2004). Hence, introducing periodicity reduces, if not eliminates, uncertainty and consequently decreases the complexity associated with combinatorial complexity. The notion of periodic resetting in the functional domain has been defined as a mechanism to reduce complexity and to restore the desired state of operation, Suh (2005).

Another important consideration is quantifying the level of periodicity that would result from adopting a certain maintenance regime and comparing it with the level of periodicity required to achieve the desired functionality goals, Meselhy (2005).

Therefore, a model to quantify the amount of required periodicity is needed to help design new and effective maintenance strategies and evaluate existing ones. The plan with higher periodicity will be preferred. This indicates that the preferred plan is much more capable of reducing the system complexity which makes it more stable and also an indication that the functional requirements will be satisfied. The durations with high complexities are possible failure time, David and Jim (1998).

3. MAINTENANCE MODELING

In this paper, periodicity equations were used to model a computer aided design (CAD) software for maintenance planning and evaluation in the functional domain. The program was written in Visual Basic because of its flexibility and ease of its accessibility in formulating the design to suit the desired objectives. The CAD assesses and compares the maintenance plans based on the periodicity, the virtual age and the equivalent time before full resetting of the maintenance plans.

4. MODELLING EQUATIONS

Preventive maintenance is the main source of periodicity when the maintenance strategy calls for minimal repair of failures whereby the machine is reset with each PM plan. The periodicity resulting from the PM of N classes can be expressed by Sub (1999):

$$Pr_{PM} = \sum_{i=1}^{n} \frac{PF_i}{[\frac{2}{PL_i}] - 1} \tag{1}$$

where, Pr_{PM} is the preventive maintenance periodicity, PF_i is the preventive maintenance frequency, PL_i is the preventive maintenance level, i is the number of resets and N is the number of preventive maintenance classes.

The failure repair periodicity can be expressed by Sub, (1999):

$$Pr_{repair} = \frac{\lambda}{\frac{2}{\mu} - 1} \tag{2}$$

where, λ is the failure rate, μ is the repair level and Pr_{repair} is the failure repair periodicity.

Since, the total maintenance plan periodicity is the sum of the failure repair periodicity and PM periodicity; thus,the total maintenance policy periodicity can be expressed as Suh, (2004):

$$Pr = \frac{\lambda}{\frac{2}{\mu} - 1} + \sum_{i=1}^{n} \frac{PF_i}{[\frac{2}{PL_i}] - 1} \tag{3}$$

The preventive maintenance frequency is expressed as;

$$PF = \frac{1}{D} \tag{4}$$

where, PF is preventive maintenance frequency and D is the number of days the machine operates per week.

Given the maintenance plan parameters; μ, λ, PL_i and PF_i; the maintenance plan periodicity can be determined which is a measure of the relative ability of the maintenance strategy to reset the machine's functionality.

The CAD software was utilized to predict the long-run future performance of maintained systems. The virtual age (V_a) concept will be utilized to develop this relationship. Virtual age is the accumulated age, such that after maintenance, the life time of a system will be reduced to a fraction repair level "μ" of the one immediately preceding maintenance.

Therefore, the average long-run virtual age ($V_{average}$) would be, Finkelstein (2009):

$$V_{average} = \frac{1}{2 \times Pr} \tag{5}$$

The Equation (5) shows the relationship between the system steady state average virtual age and the applied maintenance plan periodicity.

The equivalent time T_E before full resetting which is the time it will take the machine to behave as though it was new is given by, Finkelstein (2009):

$$T_E = 2 \times V_{average} \tag{6}$$

With reference to all these Equations, the formulated CAD software compares and evaluates the maintenance plans under consideration.

The logical arrangement to show steps by steps on how to determine each of the designed parameters used to compare the maintenance plans is as shown in fig. 2.

The policy with higher periodicity, less virtual age and equivalent time before full resetting is preferred. This indicates that it is more capable of reducing the system complexity, which makes it more stable and an indication that it will satisfy it functional requirement.

The formulated CAD software model for assessing maintenance strategies in the functional domain are general and can be applied to any other application that involve system resetting.

Since the failure is normally repaired when it happens, the failure repair periodicity is excluded from the proposed model; so, the periodicities of the maintenance plans were computed using equation:

$$Pr_{PM} = \sum_{i=1}^{n} \frac{PMF_i}{\left[\frac{2}{PL_i}\right] - 1} \qquad (7)$$

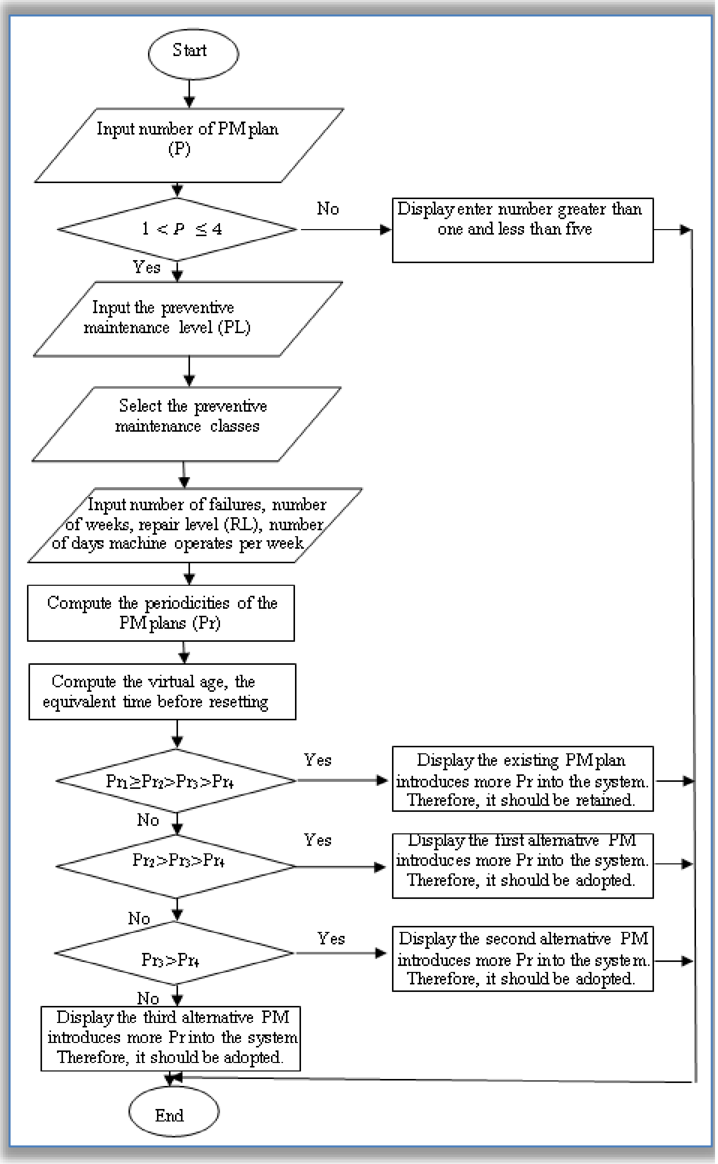

Figure 2. Logical arrangement of the designed package

5. NUMERICAL EXAMPLE

The maintenance plan adopted at one of a Construction Company in Nigeria was used to illustrate. The PM plan comprise of any four classes: weekly, fortnightly, monthly, quarterly and semi-annually. Each PM class has associated courses of action for each machine. This maintenance plan applies to all resource/machine in the plant. One of these resources is an articulated hauler with fleet number EG-198, which experiences random failures with an average of two failures per week. Using the proposed maintenance modelling approach, the plant maintenance strategy can by fully described by the following parameters, given in Table 1.

Table 1. Preventive maintenance plan

Existing maintenance plan								
	Classes					Results obtained for the maintenance plan		
Parameters	Weekly	Fortnightly	Monthly	Quarterly	Semi-Annually	Pr	$V_{average}$	T_E
PMF_i	0.1667	NIL	0.0417	0.0139	0.0069	0.0137	36.5	72.99
PML_i	0.0488	NIL	0.1839	0.3680	0.4750			
First alternative maintenance plan								
	Classes					Results obtained for the maintenance plan		
Parameters	Weekly	Fortnightly	Monthly	Quarterly	Semi-Annually	Pr	$V_{average}$	T_E
PF_i	0.1667	0.0833	0.0417	0.0139	NIL	0.0158	31.65	63.29
PL_i	0.0488	0.0976	0.1839	0.3680	NIL			
Second alternative maintenance plan								
	Classes					Results obtained for the maintenance plan		
Parameters	Weekly	Fortnightly	Monthly	Quarterly	Semi-Annually	Pr	$V_{average}$	T_E
PF_i	0.1667	0.0833	0.0417	NIL	0.0069	0.0148	33.78	67.57
PL_i	0.0488	0.0976	0.1839	NIL	0.4750			

» **The existing maintenance plan**

The articulated machine operates 6 days per week. Using the proposed maintenance modelling approach, the plant maintenance strategy can be fully described by the parameters shown in table 1.

» **Alternative maintenance plan**

The company is considering an alternative maintenance strategy, the assessment of alternatives under consideration is given in table 1. The table also described the parameters of the alternative maintenance plans.

6. RESULTS AND DISCURSION

The periodicities (Pr), virtual age ($V_{average}$) and equivalent time (T_E) before full resetting results obtained for the PM plans is as shown in table 1. From the table, the periodicity of the first alternative maintenance plan is greater than that of the existing and the second alternative preventive maintenance plan. The compares shows that the first alternative preventive maintenance plan introduces more periodicity into the system than other plans. Hence, it is more capable of reducing the system complexity.

In addition, the first alternative preventive plan results in less virtual age; so, the system performance is expected to be better as it takes less time to fully reset the machine. This is an indication that it is more stable, reliable and more capable of satisfying the functional requirement. Therefore, the first alternative preventive maintenance plan is preferred as it has the highest periodicity, less virtual age and less equivalent time before full resetting.

7. CONCLUSION

Preventive maintenance introduces periodicity, which is required to ensure the system functional stability throughout its life. The proposed periodicity metric for quantifying periodicity has been presented and this periodicity measures the relative ability of the maintenance plan to re-initialize the hauler's functionality. It can be said at this juncture that, if the first alternative PM plan was adopted, the failures would have been greatly reduced. The proposed metric is capable of computing the design parameters i.e. periodicities of the PM plans, the average long-run virtual age and equivalent time before full resetting for the maintenance plans. The proposed periodicity metric can be used to quantitatively compare the resetting ability of different maintenance plans, which can vastly enhance decision making in selecting appropriate maintenance plans.

Finally, it has been shown that the assessment and compares of preventive maintenance plans, using the computer-aided software, is quite simple which can be readily adopted in an industrial maintenance strategy.

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