

# Development of Equipment Maintenance Strategy for Critical Equipment.

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## ABSTRACT

This research presents the impact of maintenance as one of the competitive factors in an overall business strategy. Using the wrong maintenance techniques can waste time, money, and resources, and often has no effect on improving or maintaining availability of critical equipment. The strategy presented here incorporates cost effective maintenance management, fault and failure modes, parts and auxiliaries' criticality, and information management on the critical machine/equipment. The results of this study will be significant to manufacturing firms in minimizing incident stoppages not only on critical equipment but production facilities.

(Keywords: maintenance, strategy, industry, management, critical equipment)

## INTRODUCTION

Manufacturing industries and business organizations are set up primarily to meet the thirst or need for a particular commodity. Apart from this primary objective of societal satisfaction, the main aim of such organizations or manufacturing industries is to make profit, maximize profit, or minimize cost. In these cases, huge investments are been made in several aspects such as start-up capital, equipments, and machines. Future desired returns on investment do arouse certain concerns that can call for answers to several questions, including:

- How do we best preserve the investments made?
- What measures do we take to keep the units efficient, reliable, effective, and available?
- How do we accomplish our mission?

According to recent research on Effective Maintenance Implementation (EMI), it has been reported that the main problems faced by developing and under-developed countries is the lack of a proper maintenance culture<sup>[1]</sup>. There is no equipment that can operate with 100% efficiency and this buttresses the fact that any equipment, no matter its present or recent reliability status, can breakdown<sup>[2]</sup>. Maintenance is a system which requires investment and when properly implemented, it:

1. Provides reliable equipment that is safe, well configured and able to achieve timely delivery of orders to customers.
2. Minimizes equipments life cycle cost.

## MAINTENANCE

Though "maintenance" is a familiar word to most people, its meaning and interpretation can differ to people in different positions. Generally, people think of the maintenance man as that person in dirty overalls, carrying an oil can and wrenches, who is called upon to fix a damaged or a faulty system. In service and manufacturing industries, maintenance is regarded as shop-floor activities, such as tightening nuts and bolts, lubricating bearings, or repairing a machine parts when they break. Is this really what maintenance engineering all about? Is it because of this gloomy image that most young engineering graduates decline to pick up maintenance engineering jobs?

A popular definition of maintenance is: "A means to maintain and improve the quality of the elements involved in a production process, continuously and cost-effectively through detecting and controlling the deviations in the condition of a production process that is decided

by production costs, working environment and product quality in order to interfere when it is possible to arrest or reduce component/equipment deterioration rate before the process condition and product characteristics are intolerably affected and to perform the required action to restore the equipment/process or a part to as good as new”<sup>[3]</sup>.

The British Standards Institution; BS3811:1974 gave a generally accepted approach on maintenance and defines it as: “A combination of any actions carried out to retain an item in or restore it to acceptable operational standard”<sup>[4]</sup>. From the definition; “actions” are those of initiation, organization, and implementation.

Initiation activities may include the pre-purchase equipment appraisal, specification, installation, and commissioning of a facility. Once it has been commissioned and it is in operation, there must be an organized action to retain the equipment in service. If there is breakdown, swift actions must be taken to restore the equipment or facility to its “acceptable condition”.

Acceptable conditions will include those factors such as:

- Efficiency (fuel usage, power output, speed, etc.),
- Production of good quality product/ service,
- Safety of operations.

With this definition, it can be clearly seen that maintenance involves more than “fixing a broken system”. It involves the use of technical as well as management expertise. Such management expertise includes:

- Engineering (design and construction),
- Management (scheduling, cost, information collection/analysis),
- Accounting (profitability and investment in facilities).

The above factors were confirmed by an investigation carried out by the United Nations Industrial Development Organization (UNIDO). In investigating the possibility of improving upon maintenance and repair practices in developing countries, a UNIDO report revealed that:

“The actual maintenance problem does not lie only in the actual repair operations but also in the

planning and managerial activities at both the enterprise and the national levels”<sup>[5]</sup>.

## MAINTAINABILITY

The term “maintainability” as described in a layman’s language is the ease and speed with which a failed item can be repaired and brought back to service. However, maintainability has a precise definition as stated below:

“Maintainability is the probability that a unit or system will be restored to operational efficiency within a given period of time when the maintenance action is performed in accordance with prescribed procedures”<sup>[6]</sup>.

## RELIABILITY

Reliability is the probability that an item will survive a given operating period, under specified operating conditions, without failure. The *conditional probability of failure* measures the probability that an item entering a given age interval will fail during that interval. If the conditional probability of failure increases with age, the item shows wear-out characteristics. The conditional probability of failure reflects the overall adverse effect of age on reliability. It is not a measure of the change in an individual equipment item<sup>[7]</sup>.

## THE NEED FOR MAINTENANCE

Effective and efficient utilization of installed production facilities is a contributing factor to the promotion of industrial growth. One of the prerequisites to ensure the availability of installed production facilities for efficient use is to have an effective maintenance engineering system. With the advent of mechanization and automation coupled with the high cost of capital investment, this prerequisite seems to be claiming more attention than in the past when maintenance functions were something of a “Cinderella” activity. As a result of increasing the degree of mechanization and automation less people are involved in the direct production work.

Other factors which emphasize the need for effective maintenance systems are:<sup>[8]</sup>

- Increased production levels,
- Rigid production schedules,
- Increased machine utilization,
- Market competition.

Lack of an effective maintenance system in a manufacturing enterprise gives rise to several undesirable consequences some of which are:<sup>[8]</sup>

- Excessive machine breakdowns,
- Frequent emergency maintenance work,
- Shortened life-span of the facility,
- Poor utilization of maintenance staff,
- Lower quality of products,
- Delivery dates are not met,
- Panic operating changes,
- Disproportionate investment in spare parts and maintenance materials,
- Excessive overtime costs (both maintenance and production staff).

All these contribute to high costs of production and loss of profits.

### **AIM AND OBJECTIVES OF MAINTENANCE**

The aim is to achieve increased plant availability through better maintenance management but to do so at a low cost relative to the increased profit. Another aim is to maximize plant and equipment effectiveness in order to achieve targeted rates of return on investment. This attests to the fact that as organizations and equipment become more sophisticated, maintenance expectations begin to evolve. The principal objectives of maintenance can be stated as follows:

- To extend the useful life span of an item,
- To increase availability of installed equipment,
- To ensure operational readiness of all equipment required particularly for emergency purpose,
- To ensure the safety of people (personnel) using such equipment,
- To avoid exorbitant expenses on repair of equipment which might occur if the same equipment was not maintained and is allowed to fail.

### **MAINTENANCE STRATEGIES**

There are several maintenance strategies in existence for use in various fields and manufacturing industries across the world; each developed to suite a particular need but there are majorly two types of maintenance which can be classified under two broad practices. These are:

- Unplanned maintenance
- Planned maintenance

#### **Unplanned Maintenance**

Unplanned maintenance, as the name implies, is a practice carried out at equipment breakdowns. It involves an Unplanned Corrective Maintenance (UCM) or Operate To Failure (OTF) Strategy as a result of equipment breakdown.

#### **Planned Maintenance**

Simply waiting for machinery to fail before carrying out maintenance has now largely been replaced by more effective preventive maintenance programs. Due to the impact both during and beyond the immediate downtime, businesses have sought to prevent equipment breakdown by a process known as preventive maintenance. With preventive maintenance, equipment is routinely inspected and serviced in an effort to prevent breakdowns from occurring. Planned preventive maintenance exists in four forms;<sup>[6]</sup> these include:

- Scheduled or Fixed Time Maintenance (FTM): This is a Time Interval based maintenance practice; practices in this category include shut down maintenance which is pre-planned.
- Condition Based or Predictive Maintenance (CBM): This practice monitors Equipment condition. It involves inspections at equipment running conditions and during stoppage periods.
- Routine Asset Care (RAC): Requires regular running maintenance (e.g., servicing, adjustments, level checks).
- Replacement Maintenance: Requires a complete overhaul of the equipment or a full re-installment of such equipment which may be as a result of completed life span or total failure.

## FACTORS INFLUENCING MAINTENANCE STRATEGIC DEVELOPMENTS

The search to develop a maintenance strategy for critical equipment comes from a deep thirst for maintenance improvement. A good and worthwhile approach to maintenance improvement comes from the successful use and mastery of the key functions of these factors which entails:<sup>[9]</sup>

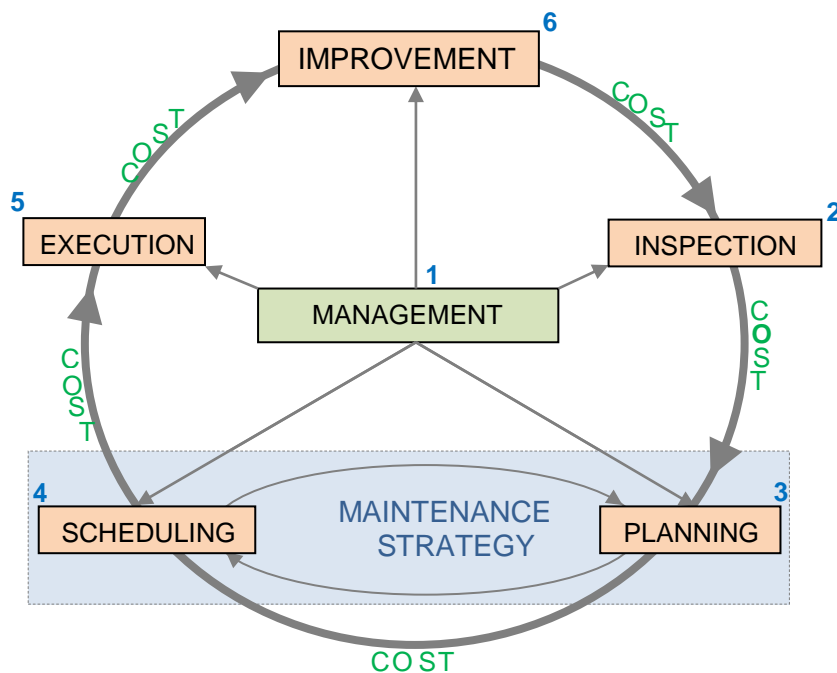
- a) Management
- b) Inspection
- c) Planning
- d) Scheduling
- e) Execution
- f) Improvement

These six key functions will form the foundation and backbone of any worthy maintenance strategy to be developed that will be universal and generally be accepted for use in any

manufacturing outfit. It worth noting that each of these entities relates to another and the management function comes as the common feature to any of these keys. All along the path of the maintenance strategy development methodology, cost factor is a vital “go ahead” to the next stage. Cost consideration is a key factor in any developed strategy as no key can function without cost input.

## METHODOLOGY

Development of an effective maintenance strategy for critical equipment requires a sound knowledge of the root causes of failure, its possible sources, modes of occurrence, and all related variables, as stated in the preceding sections. With this knowledge base, the methodology for the development of a maintenance strategy for critical equipment will be adjudged based on the following modules:<sup>[11]</sup>



**Figure 1:** Key Steps to successful Maintenance

- 1) Select equipment that is “critical” to plant operations,
- 2) Develop the best maintenance strategy for that equipment,
- 3) Develop a Critical Machine Maintenance Management Program (CMMP) that will plan and/or schedule this maintenance in concert with the load profile in order to:
  - i. Increase unit availability,
  - ii. Increase work productivity,
  - iii. Decrease maintenance frustrations.

Most manufacturing industries around the world have several processes involved before production can be actualized. They also tend to have several types of equipment for production. One of those types of equipment should be the critical equipment of the industry. Without its operation, production would be impacted in an enormous unpalatable way.

## SELECTING CRITICAL EQUIPMENT

Cement plants operate large equipment used in sequence for the production of cement. Identifying the critical equipment hence becomes problematic because the equipment works in link with each other especially in cases where the system operation is a closed circuit one. However, focusing on the selection of critical equipment for large plants and for any manufacturing/production firm is crucial to developing its maintenance strategy and begins with identification of critical equipment.

Critical equipment are machines that are vital to the plant or process and are a key part of a production process. Specifically, a critical machine is one in which all its processing time are part of its make-span. In order to select critical equipment, there are basic steps and principles to be applied which will be discussed below:

**Step1; Equipment Ranking:** Rank plant equipment based on its criticality to plant operation<sup>[11]</sup>. The first question any maintenance engineer developing a maintenance strategy should ask is: “Where to start?”<sup>[1]</sup>. Meanwhile the answer lies in the statement “What have you prioritized; are your issues known?” Any developed maintenance strategy will not be effective if the foundation of the equipment ranking is not taken seriously. For the purpose of

this work, ranking of equipment in “the plant” (any outfit) will be in 3 forms which are:

- High priority
- Medium priority
- Low priority

**Step2; Define Critical Nature:** After ranking the plant equipment as High, Medium, or Low, the next step is to define the critical nature of the “High” ranked equipment in step1 as either:<sup>[11]</sup>

- Tier 1,
- Tier 2,
- Tier 3, etc.

The emerging High – Tier 1 becomes the Critical Equipment of the plant.

Considering the different sections in a cement plant coded as: **A, B, C, D, E, F, G, and H**

Plant A – Limestone Crushing Plant

Plant B – Raw Material Store

Plant C – Vertical Roller Mill

Plant D – Gas Conditioning Tower

Plant E – Electrostatic Precipitator

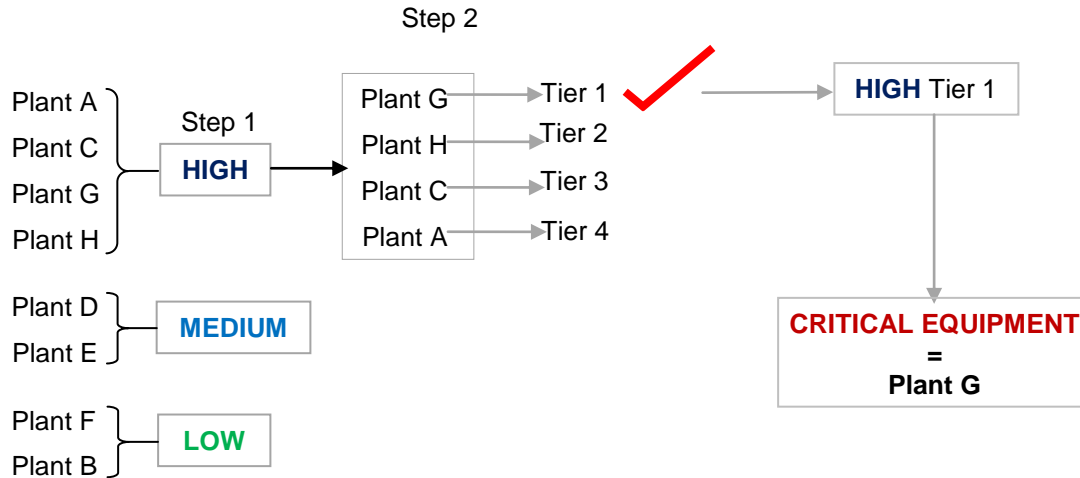
Plant F – CF Silo

Plant G – Clinker Kiln (+ Calciner)

Plant H – Clinker Cooler

Figure 2 represents an activity of ranking each equipment part and auxiliaries according to their criticality to plant operation and defining their critical natures.

After getting to know the critical equipment, the next step is to develop a maintenance strategy for such equipment; first, identifying basic maintenance strategies that can be adopted for use on any critical equipment such that there would be no maintenance action to be carried out on the equipment that will not fall within the basic maintenance strategies. Secondly, developing a “one” maintenance strategy from the identified basic maintenance strategies with a family name that can be generally adopted on any critical equipment.



**Figure 2:** Selecting Critical Equipment.

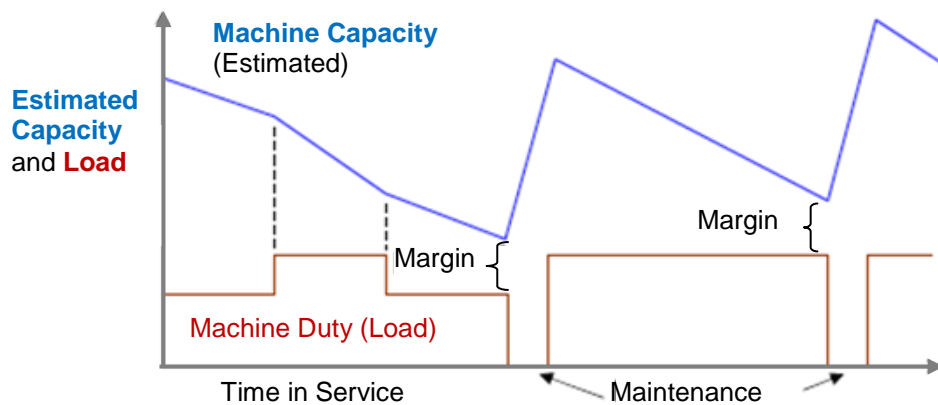
**DEVELOPING A MAINTENANCE STRATEGY FOR THAT EQUIPMENT**

**Identifying Basic Generalized/ Universal Maintenance Strategies**

Research has proven that there are some basic maintenance strategies that can be adopted for use on any critical equipment [12]. These will form the basis of the intended maintenance strategy to be developed as well as the planner package. Meanwhile, these basic maintenance strategies will be discussed in relation to the critical equipment.

**A. Fixed Time/ Scheduled Maintenance**

Fixed Time/Scheduled maintenance is an action that can be performed on any critical equipment. It entails specific maintenance tasks performed at set time intervals (or duty cycles). Significant margin between machine capacity and actual duty are maintained. The terms “Significant Margin” and “set Intervals” are the distinguishing differences between Fixed Time Maintenance and Routine Maintenance (to be discussed later). A simple example is an oil change in the car [12]. From Figure 3, it can be seen that the machine has its estimated capacity.



**Figure 3:** Scheduled Maintenance [12]

When on load over a particular period of time, it begins to drop in capacity gradually. The drop is shown by the broken lines and is not just sudden from the first degradation to the other. By estimation, the machine has to be maintained over this significant margin to avoid failure upon the application of additional load or continuous use; this is basically what Fixed Time

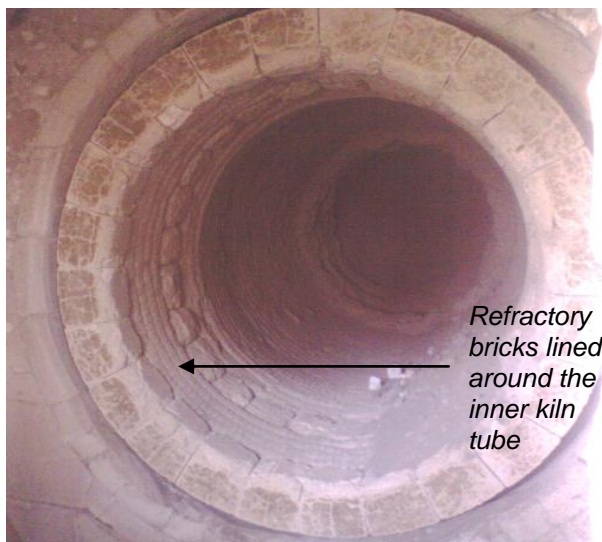
Maintenance entails. Considering the kiln of a cement plant, Fixed Time Maintenance can be embarked upon depending on the company's policy, by shutting the kiln down once or twice in a year for "Shut Down Maintenance". This can however, be a "tradition" in the plant; carrying out maintenance operations that could not be done during kiln running.



**Figure 4:** Cement Manufacturing Plant Clinker Producing Kiln.

Cases include changing of the refractory bricks in the kiln tube where there are hot spots; thereby, protecting the kiln shell, topping oil level in the girth gear, kiln rollers and verifying that the kiln inclination is still within  $16^\circ$  to the horizontal.

Centered Maintenance is a maintenance strategy that is employed when the actual condition of the machinery is to be assessed <sup>[12]</sup>. In this maintenance, the full integration of Inspection is needed. It requires on-line monitoring of the equipment without ceasing; both running and stoppage times. Consequently, data/ inspected information are used to optimally schedule maintenance. A major advantage of this kind of maintenance is that maximum production and avoidance of catastrophic failures is achieved.



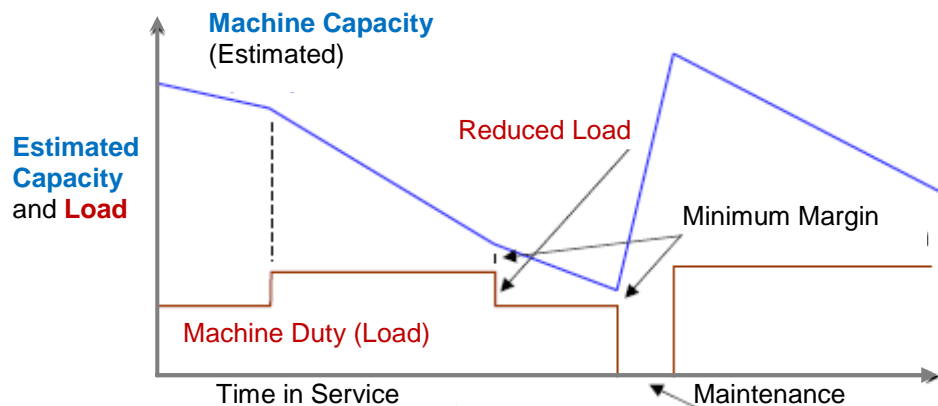
*Refractory bricks lined around the inner kiln tube*

**Figure 5:** Brick Lining in the Kiln Tube.

**B. Condition Based Maintenance**

Condition Based Maintenance also known as on-condition, predictive, pro-active, or reliability-

The schematic graph in Figure 6 addresses the benefit behind having an effective inspection system in place. The graph is almost similar to that of Fixed Time Maintenance except that there is no gradual degradation of the machine. The capacity drop is too sudden and tends towards failure. Maintenance action depicted in the figure is as a result of Online monitoring of the machine via Inspection. Hence, we can say an effective Inspection system saves machine failure and subsequently avoids its stoppage. Note that in Condition Based Maintenance the margin between duty and capacity is never allowed to reach zero; avoiding breakdown. Its resulting effect is that there is longer time between maintenance <sup>[12]</sup> tasks than for scheduled maintenance <sup>[12]</sup>.



**Figure 6:** Condition -Based Maintenance <sup>[12]</sup>

It should be noted that maintenance personnel should not joke with inspections; it will form the basis of their reports and explain the reasons why certain actions had to be taken without fear or favor if need be. A system that would not recognize Inspection as a vital key to success in maintenance actions is one breeding loss times. A simple example is changing the deflated tire of a car by inspection.

### **C. Routine Asset Care Maintenance**

The idea of bringing in Routine Asset Care Maintenance is to reduce the resulting effect from Condition Based Maintenance. It only takes dedicated maintenance personnel to bridge the gap between the time of inspection for quick, effective, and worthwhile maintenance and the time of such equipment failure/breakdown considering the little time available.

Consider a machine with a useful life  $N_n$  and at a particular year  $N_1$  loaded for use. If, say at year  $N_{1+i}$ , (where  $N_1 < N_{1+i} < N_n$ ), the equipment capacity drops suddenly such as depicted in Figure 8; by inspection and following the previous explanation, a Condition Based Maintenance plan may be proposed by the maintenance personnel in charge, and after maintenance, the equipment is restored to its functional state and loaded again.

Assuming at the same respective time, if a sudden drop in the equipment capacity occurs

again, likewise, a Condition Based Maintenance will be embarked upon following adequate inspections. By experience, the maintenance personnel in charge will not want to take chances in the coming year, he would rather consider embarking on a routine asset care maintenance done at specific intervals although not with a wide margin like that of Fixed Time maintenance.

With reference to Figure 6, from the period of machine capacity drop (first broken line) to the point of minimum capacity before failure (second broken line), routine maintenance can be carried out by keenly observing points along the slope at which maintenance can be carried out. With this, maintenance load is shared and equipment is regularly catered for. However, it should be noted that usually, uniform CBM tasks precedes Routine Asset Care Maintenance.

Assessing Figure 7 the personnel observing the slope of Figure 6 can uniformly decide points at which routine asset care should be carried out, this has a major advantage of quick restoration of the machine capacity and avoids excessive breakdown or failure as the case may be. The schematic graph of Figure 7 therefore results in that depicted in Figure 8.

Routine maintenance is a vital component of keeping company's equipment in safe operating condition. A machine that is not properly maintained could create potentially hazardous situations for maintenance staff.



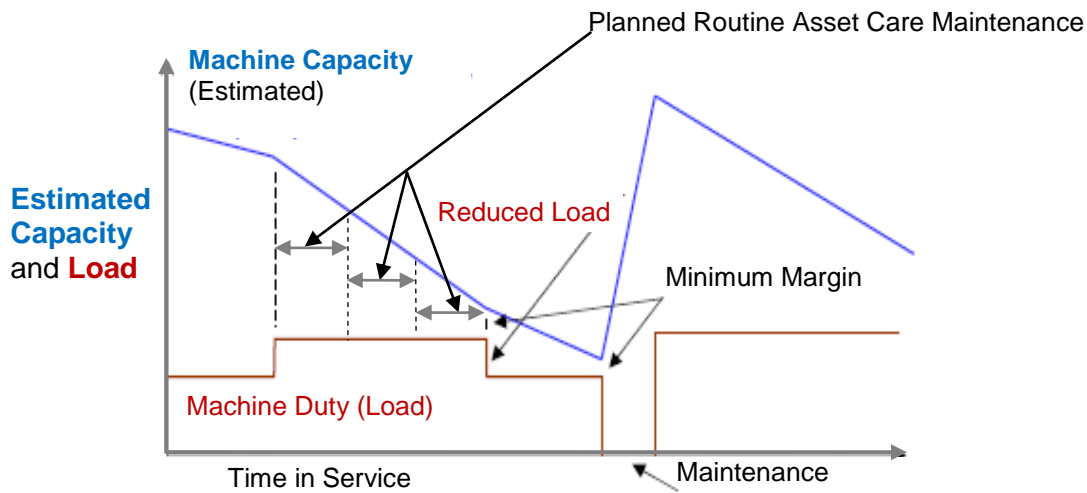


Figure 7: Routine Asset Care Maintenance

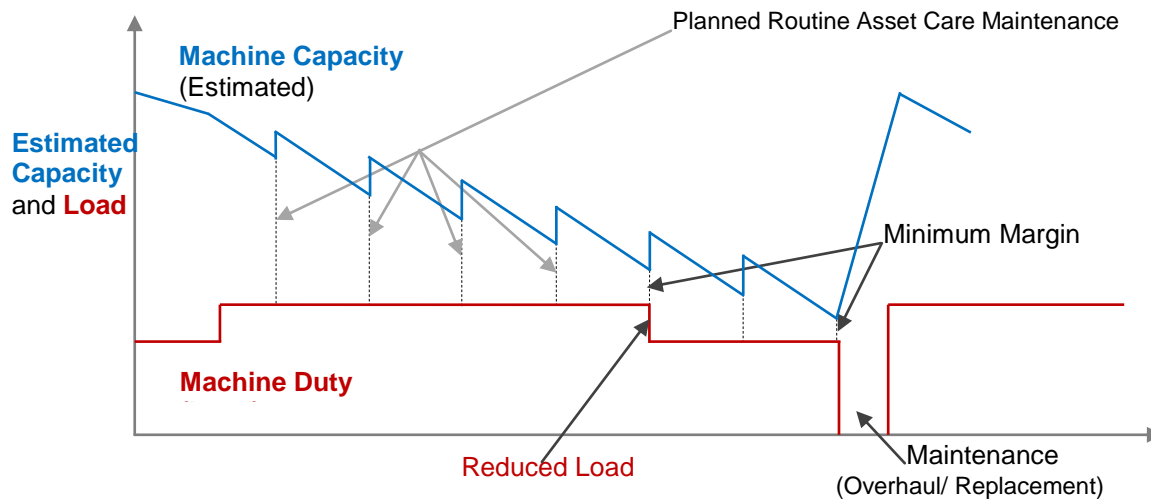
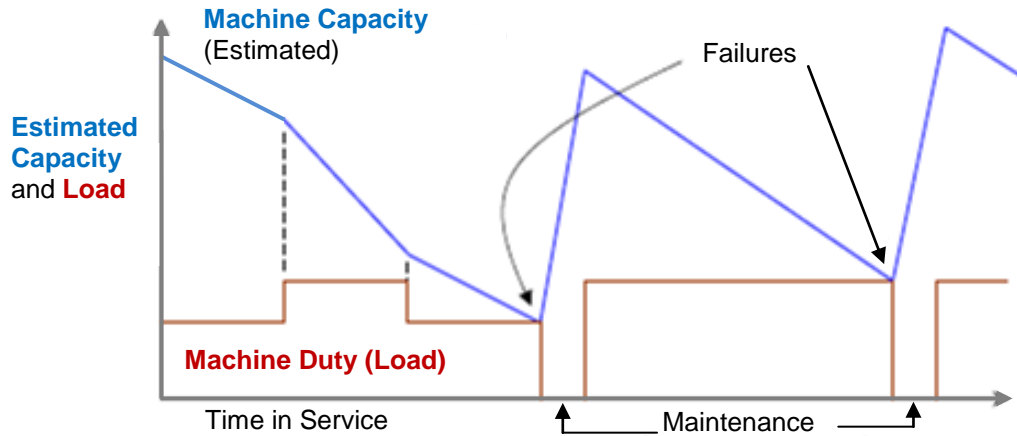


Figure 8: Planned Routine Asset Care Maintenance

#### D. Run-to-Failure Maintenance

Much of the maintenance literature describes Run-to-Failure Maintenance as a form of maintenance performed only when machinery has failed (i.e., a burned out light bulb) <sup>[12]</sup>. Run-to-Failure maintenance (Figure 9) has been taken as a form of unplanned maintenance in cases where

the machine breaks down at an unexpected time. This can be true in some cases but the scope of Run-to-Failure maintenance is far deeper than an unplanned maintenance; it can also be a form of planned maintenance. Run-to-failure maintenance is mostly common to some parts/auxiliary parts of a critical machine/equipment.



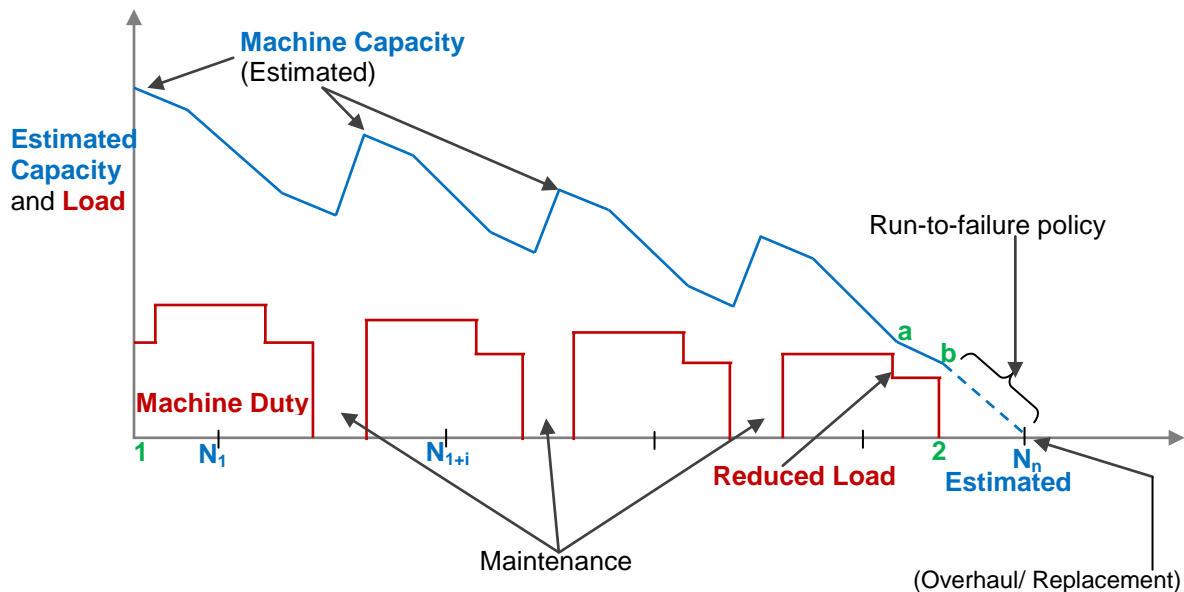
**Figure 9:** Run to Failure Maintenance <sup>[12]</sup>

There are some auxiliaries that by inspections, a Run-to-Failure policy is proposed especially in cases where the cost of maintenance is more than the cost of replacing it after failure.

Cost and age are the major determinants to proposing a Run-to-Failure maintenance policy. The cost of replacing an item; spare part coupled with the total maintenance cost (maintenance personnel cost, time cost, etc.) is compared with maintaining the working item taking note of its useful age in mind.

Another factor that determines the adoption of Run-to-failure maintenance strategy is age; for instance if the remaining useful life of the equipment after a scheduled/fixed maintenance action will just fall between the next planned-scheduled maintenance.

Referring to Figure 10 it can be seen that there have been series of maintenance actions that have been carried out from point "1" to point "2" but at specific point "a", the machine capacity cannot be increased even after the reduction of load and there is a uniform drop trend in the machine's capacity up to point "b".



**Figure 10:** Run-to-failure and Replacement Maintenance Policy.

After point “b”, there may be no need to carry out maintenance because there won’t be development in the machine’s capacity with respect to its remaining age estimated as “ $N_n$ ”. At this point, a Run-to-failure maintenance strategy will be proposed which will then be succeeded by a general overhaul or replacement.

### E. Replacement Maintenance

By replacement we mean a kind of strategy that delves into substitution. Usually replacement maintenance is adopted in unplanned cases where an item has failed (breakdown) and cannot be repaired or in planned situations where the item has been intentionally run to failure after its useful life just as represented in Figure 10.

Most firms perform overhaul as a means of replacement where major parts of a critical machine are substituted with spares/new ones. To buttress the function of replacement maintenance, this project will explicitly include planned-intentional, cost oriented replacement policy into its form of replacement maintenance strategy as discussed in the succeeding section; “Deciding a Maintenance Strategy”.

Considering the following example for such a case of planned-intentional cost oriented replacement policy.

A new bearing working as an auxiliary in a critical part on a critical machine with estimated life of say 8 months has just been installed during a planned shutdown maintenance of every 6 months. After the 6th month of installment which falls in another planned shutdown maintenance, the bearing still has 2 more months of useful life. Now considering and comparing cost implication of replacing the bearing after its useful life of 8 months to replacing it during the current shut down maintenance, the maintenance personnel may decide to replace the bearing during the current shut down maintenance and beat re-stopping the critical equipment after 2 months although the bearing has not failed (Figure 11a).

With this, he would have weighed the cost of immediate replacement with a spare bearing to risking the plant stoppage time and the cost of item spare after 2 months since he still has to replace because a bearing cannot be repaired and the plant has to be stopped because a bearing has to do with a moving part and moving parts must not be worked on (Figure 11b).

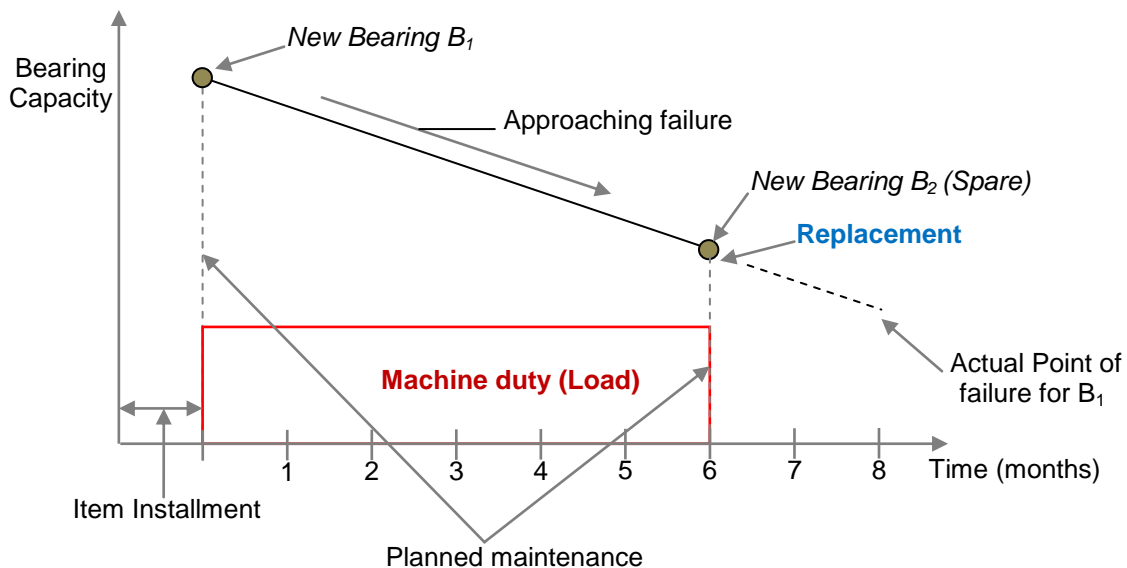


Figure 11a: Item Replacement before its Useful Life.

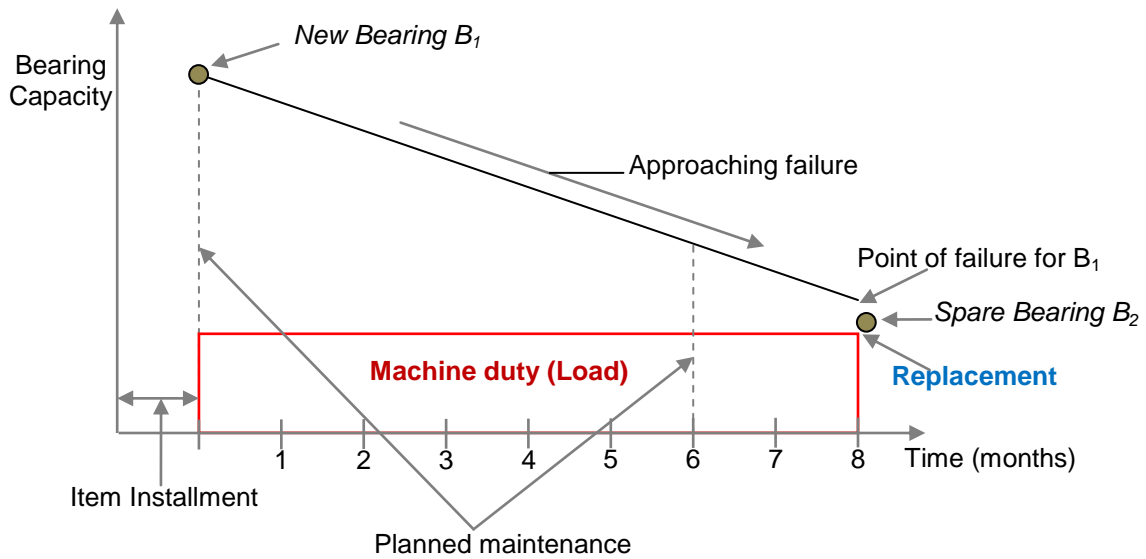


Figure 11b: Item Replacement after its Useful Life.

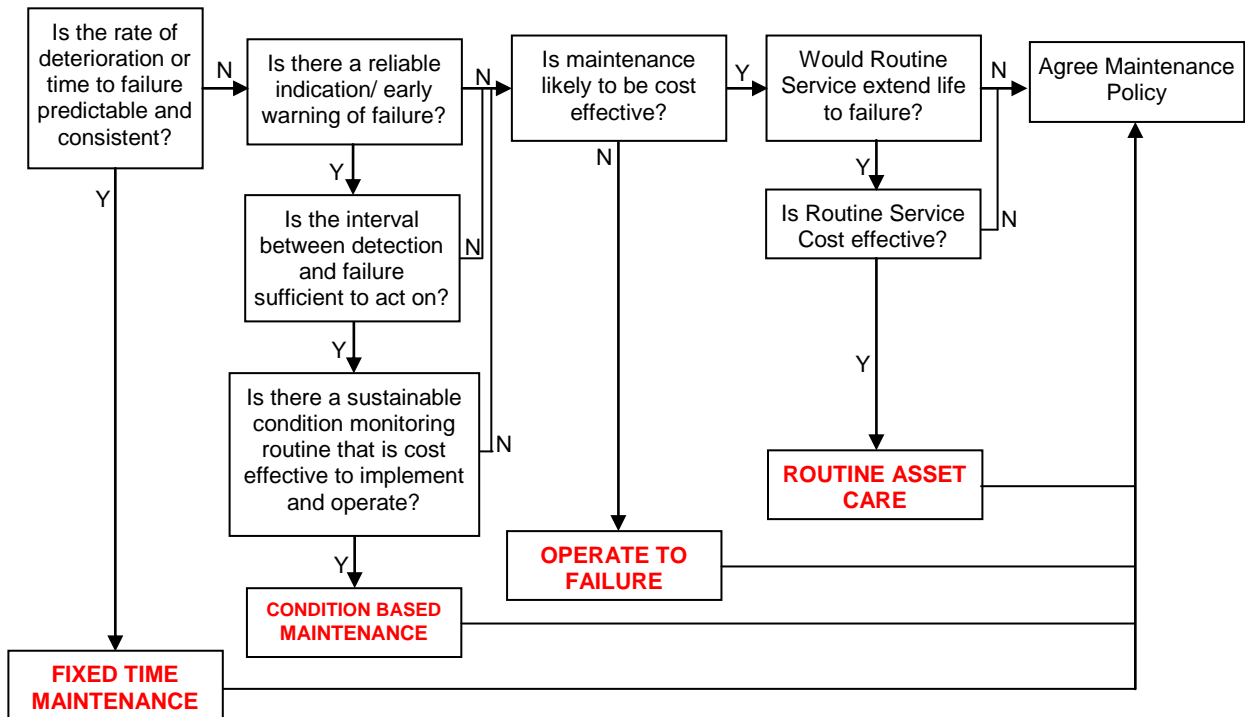
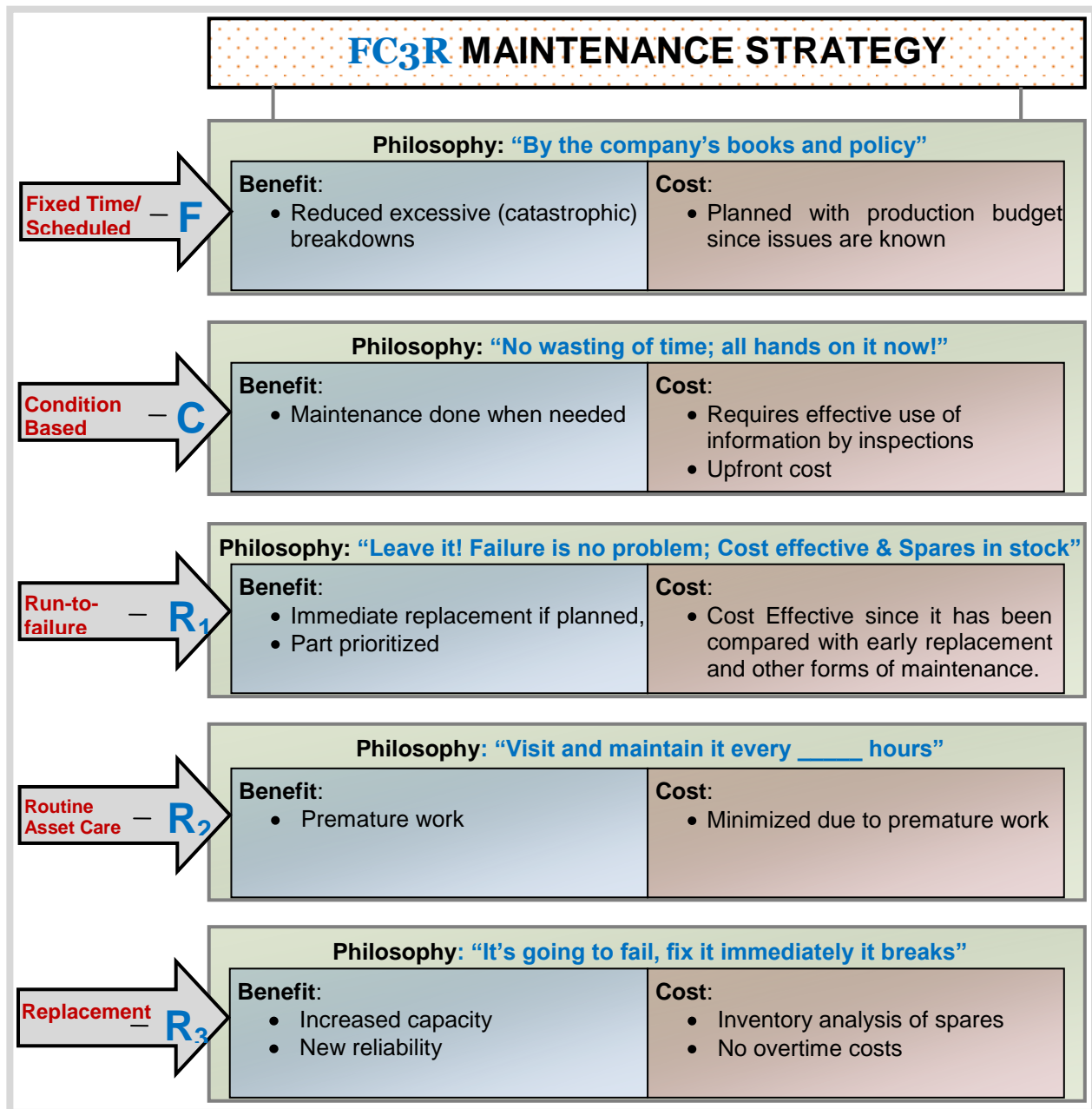


Figure 12: Maintenance Decision Diagram <sup>[1]</sup>

From the preceding basic maintenance strategies identification; there is no maintenance action that will minimize stoppages and avoid excessive downtimes on critical machines that will not fall within these five.

The logistics behind any maintenance strategy evolved from a flow diagram which when carefully studied, will pose no problem to any maintenance personnel. <sup>[1]</sup> He however, came up with a maintenance decision diagram as shown in Figure 12.



**Figure 13:** FC<sub>3</sub>R Maintenance Strategy – Summary Block of Functions.

The maintenance decision diagram above also incorporates four of the basic maintenance strategies except replacement. Most maintenance managers don't see "replacement" as a form of maintenance strategy but in the actual sense of it replacement is a maintenance action that precedes deterioration or failure so it should be chorused alongside with other maintenance strategies and this is what this project has been able to incorporate.

Following suite with the maintenance decision diagram and the basic maintenance strategies, the universal maintenance strategy can be developed from:

- Fixed Time/ Scheduled Maintenance – **F**;
- Condition Based Maintenance – **C**;
- Run-to-failure Strategic Maintenance – **R**;
- Routine Asset Care Maintenance – **R**;
- Replacement Maintenance – **R**

With the first letter notations; **F, C, R, R, R**, the family name; **FC3R** can be coined to serve as the generalized critical equipment maintenance strategy with the sole aim of transforming the world of maintenance and an objective of minimizing stoppages.

FC3R will be a form of maintenance strategy that will serve as a link to obtaining high equipment availability, lead to increased productivity, reduce excessive expenses such as overtime costs, aid technological improvements and provide reliability comfort when the sole aim of minimizing stoppages is achieved.

It will be worthy to note that FC3R maintenance strategy will give room for improvements especially updating parameters and inculcating possible strategic events in the Critical Machine Maintenance Program (Maintenance Planner) to be developed. Below in Figure 13 is a block diagram of the philosophies underlying the activities of FC3R; it can be referred to as the "Working Principal Functions of FC3R".

## CONCLUSION

Throughout this work, it has been shown that the reason behind the problem of untimely failure of equipment, their parts, and auxiliaries and undue replacement apart from radical designs, are poor and ineffective maintenance habits. A good and suitable part designed by an engineer should be worthwhile and serve till the end of its useful life but maintenance is due to anything subjected to continuous use; this work believes that with the developed maintenance strategy, undue equipment stoppage, untimely failure and undue replacement would be greatly minimized if not completely avoided.

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