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GENERAL CONCEPTS OF MAINTENANCE

Abstract:
Maintenance involves preventive (planned) and unplanned actions carried out to retain a system at or restore it to an acceptable operating condition. Optimal maintenance policies aim to provide optimum system reliability and safety performance at the lowest possible maintenance costs. Proper maintenance techniques have been emphasized in recent years due to the fact that the safety and reliability requirements of system, increased complexity and costs of material and labor are increasing.

Keywords:
maintenance, reliability, Preventive maintenance (PM), Corrective Maintenance (CM), Imperfect maintenance

INTRODUCTION

Maintenance has evolved from simple model that deals with machinery breakdowns, to time-based preventive maintenance, to today's condition-based maintenance. It is of great importance to avoid the failure of a system during its actual operation especially, when such failure is dangerous or costly. Time-based and condition-based maintenance are two major approaches for maintenance. In contrast, condition based maintenance can be more profitable in order to avoid failure occurrence at the lowest cost and to improve the availability and reliability of the maintained system.
The choices of the inspection schedule and preventive maintenance thresholds obviously have a great influence on the economic performance of the maintenance policy. The inspection dates and the preventive maintenance are main decision variables considered in many researches.

MAINTENANCE CLASSIFICATION

Maintenance can be classified by two major categories: corrective and preventive. Corrective Maintenance (CM) is the maintenance that is performed when the system fails. Corrective maintenance means all actions performed as the result of failure, to restore an item to a specified condition.
Preventive maintenance (PM) is the maintenance that happens when the system is operating and it means all actions performed in an attempt to retain an item in specified condition by providing systematic inspections, detection, and prevention on failures. Maintenance can also be classified according to the degree to which the operating condition of an item is restored by maintenance in the following way [1]:

1. Perfect repair: perfect maintenance is maintenance actions which restore a system operating condition to as „good as new”. That is, perfect maintenance and a system

has the same lifetime distribution and failure rate function as a new one. Generally, replacement of a failed system by a new one is a perfect repair.

2. *Minimal repair: minimal maintenance actions which restore a system to the same failure rate as it had when it failed. Minimal repair was first studied by Barlow [2]. The system operating state after the minimal repair is literally called „as bad as old".*
3. *Imperfect repair or imperfect maintenance: maintenance actions which do not make a system not „as good as new" but younger. Usually, it is assumed that imperfect*
4. *maintenance restores the system operating state to somewhere between „as good as new" and „as bad as old". Clearly, imperfect repair (maintenance) is a general repair (maintenance) which can include two extreme cases: minimal and perfect repairs (maintenance). Engine tune-up is an example of imperfect maintenance.*
5. *Worse repair or worse maintenance: maintenance actions which un-deliberately make the system failure rate or actual age increase but the system dose not breakdown. Thus, upon worse repairs a system operating condition became worse than that just prior to its failure.*
6. *Worst repair or worst maintenance: maintenance actions which un-deliberately make the system fail or break down.*

According to the above suggested classification, we can say that a PM can be a minimal, perfect, imperfect, worst or worse one. Similarly, a CM could be a minimal, perfect, imperfect, worst or worse CM. We will refer to imperfect CM and PM as imperfect maintenance later. The type and degree of maintenance used in practice depends on types of systems, their costs as well as reliability and safety requirements.

In the related literature, most studies assume that the system after CM or PM is „as good as new" (perfect maintenance) or „as bad as old" (minimal maintenance). In practice, the perfect maintenance assumption may be acceptable for system with one component which is structurally simple. On the other hand, the minimal repair assumption seems reasonable for failure behavior of systems when one of its components, non-dominating component, is replaced by a new one. However, many maintenance activities may not result in these two extreme situations but in a complicated intermediate one. Therefore, perfect maintenance and minimal maintenance are not practical in many actual instances and realistic imperfect maintenance should be modeled.

Recently, imperfect CM and PM have received more attention in reliability and maintenance literature. In fact, we can say that imperfect maintenance study indicates a significant breakthrough in maintenance and reliability and maintenance theory. In [3] the author mentioned that imperfectness of maintenance is related to the skill of the maintenance personnel, the quality of the maintenance procedure, and the maintainability of the system [3]. Obviously, maintenance expenditure and reliability requirement also have important effects on imperfectness of maintenance. Barlow and Proschan presented some possible causes for imperfect, worse or worst maintenance due to the maintenance performer [4]:

- *Repairing the wrong part.*
- *Only partially repairing the faulty part.*
- *Repairing (partially or completely) the faulty part.*
- *Incorrectly assessing the condition of the inspected units.*
- *Performing the maintenance action not when called for but at customer convenience.*
- *Nakagawa mentions three reasons causing worse or worst maintenance [5]:*
- *Hidden faults and failure which are not detected during maintenance.*
- *Human errors such as wrong adjustments and further damage done during maintenance.*
- *Replacement with faulty parts.*

According to Barlow and Proschan [4], maintenance policies based on planned inspections are „periodic inspection" and „inspection interval dependent on age". By periodic inspections, a failed unit is identified or it is determined whether the unit is functioning or not. With aging of the unit, the inspection interval may be shorter. These inspection methods are subject to imperfect maintenance caused by randomness in the actual time of inspection, in spite of the schedule, imperfect inspection and cost structure. Therefore, realistic and valid maintenance models must incorporate with random features of the inspection policy. So far only a small portion of literature *concerning to the stochastic behavior of the repairable systems and maintenance is involved in imperfect maintenance.*

MULTI COMPONENT SYSTEM'S MAINTENANCE

Currently, the interest for multi component maintenance models is increasing. In the beginning vast majority of the maintenance models were concerned about a single piece of equipment operating in a fixed environment, considered as an intrinsic barrier for allocations. Maintenance action of a multi component system differs from that one for a single-unit system; because these depend on some factors. One of the dependencies is economic dependence. Another one is failure dependence, or correlated failures. Economy dependency is a common term in most continuous operating systems. For this type of systems, the cost of system unavailability (one-time shut-down) may be much higher than component maintenance costs. Therefore, there is often great potential cost saving by implementing an opportunistic maintenance policy.

Obviously, the joint maintenance of two or more subsystems tends to spend less money and less time (economy dependency), and the failures of different subsystems in multicomponent system may not be independent (failure dependency). Thus, each subsystem may not be considered as a single-unit system, and to apply the existing optimum maintenance models of a single-unit system to each of such subsystems may not be practical.

Imperfect maintenance exists also in a repairable multi-component system. If one of its subsystems fails, it can be repaired by replacing some of its parts. Clearly, reliability measures of the repaired subsystems are improved after repair but it might not be as good as new (imperfect CM), and consequently the entire system will no longer function as well as a new one.

Realistic imperfect maintenance associated with individual subsystems and accordingly systems have to be modeled. According to [6], systems used in the production of goods and delivery of services constitute the vast majority of most industry's capital. These systems are subject to deterioration with usage and age. System deterioration is often in higher production costs and lower product quality, to keep production costs down while maintaining good quality. PM is often performed on such systems. It is obvious that these kinds of system are often composed by many subsystems whose maintenance is often imperfect or sometimes even worse. It is necessary to point out that considering the entire system as a single unit by a minimal repair model may not be suitable for large-scale systems. Such maintenance modeling is also too rough for complex systems due to the economy and failure dependencies. In practice, some subsystems are inspected and tested separately and their reliability performances are also evaluated individually.

Lifetime distributions of all new subsystems are known through reliability tests and statistical results before they will be used for such systems. As a result, we can evaluate whole system reliability measure and system maintenance cost based on failure information, maintenance costs, and maintenance degree of all subsystems. Therefore, we may say that a realistic method is to treat a system the same as one with many subsystems which are subjects to imperfect maintenance. We are, also able to model imperfect maintenance of the system through imperfect maintenance modeling of all subsystems and at the same time economical model and failure dependency of the system in order to obtain global optimum maintenance policies for the system.

CONCLUSION

The usual criteria of optimization of maintenance policies are based on maintenance cost measures, same as expected maintenance costs per unit of time and total discounted costs. Hence the optimal maintenance policies are the ones that minimize or maximize a given cost criterion

Reliability is the branch of quality assurance that deals specifically with the ability function upon demand. During the last decades many works have been devoted to the binary-state reliability analysis, where it is assumed that a system may experience only two possible states: one working state and one failure state.

However, in many real world situations a system or a component could experience more than two levels of performance varying from perfect functionality to complete failure; these systems are called multi-state systems. The evaluation of *maintenance, testing, and repair policies becomes more and more complex for multi-state systems that contain combinations of revealed and unrevealed failure [7].*

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