591 (Prudence)

ENGINEER SMART

ADEBIYI EMMANUEL O.

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INTRODUCTION TO RELIABILITY AND MAINTAINABILITY

The concept of reliability as it relates to engineering practice focuses on the costs of failure caused by system downtime which include the cost of spare parts, equipments, repair, equipment overhaul, personnel and equipment warranty. There is a discipline in engineering that addresses issues surrounding the reliability of components used for general engineering designs. It is called Reliability Engineering.

Reliability engineering is used to apply scientific know-how to a component, product, plant or process in order to ensure that it performs its intended function, without failure, for the required time duration in a specified environment. It emphasizes dependability in the life cycle management of a product, which is the ability of a system or component to function under stated conditions for a specified period of time. Reliability has two significant dimensions, which are the time and the stress. A product or component is expected to endure for several years of its life and also perform its desired function, despite all the threatening stresses applied to it, such as temperature, vibration, shock, voltage, and other environmental factors. Reliability plays a key role in sustaining the quality of a product or component, as such an increase in the complexity of the product or component as well as in the equipment will lead to an increasing demand for higher reliability. Reliability engineering as an engineering framework enables the definition of a complete production regime which

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deals with the study of the ability of the product to perform its required functions, under stated conditions for a specified period of time. It characterizes measures and analyzes the failure and repair of the system components in order to improve their use by increasing their design life, mitigating defect risks and reducing the likelihood of failures.

Maintainability can be defined as the degree of facility with which an equipment or system is capable of being retained in, or restored to, serviceable operation. In order to achieve a satisfactory maintainability for an equipment or system, the following factors must be considered carefully:

1. The equipment or machine could fail at some time or another.
2. The positioning of maintenance displays, check points, gauges, meters and the position of one assembly with respect to another.
3. The limitations imposed by the human frame.
4. The environment in which maintenance or repairs will be carried out.
5. The design of test equipment
6. The presentation of information in the maintenance and repair manual.

The purpose of obtaining a satisfactory maintainability is to improve the effectiveness and efficiency of maintenance.

* A less complex definition of maintainability is that it is the ease with which a product can be maintained in order to:
  - correct defects or their causes,
  - repair or replace faulty or worn-out components

without having to replace still working parts.
- prevent unexpected working conditions.
- Maximize a product's useful life.
- Maximize efficiency, reliability, and safety.
- meet new requirements.
- make future maintenance easier or
- cope with a changed environment.

RELIABILITY SPECIFICATION AND METRICS

Reliability is defined as the probability that an item is able to perform its intended function(s) without any form of failure for a specified period of time under stated conditions. it is used to measure whether or not an item functions properly when used by the targeted users within the specified operating conditions or environment. During the design and specification of reliability, it is important to identify the operating conditions of the item(s) or component(s) as well as to identify what truly constitute proper functioning of the said item or component (that is to say, what is a failure or failure). The breakdown of a system may be as a result of a failure of component or an item which can be repaired or replaced. for the former, the rate of recurrence of the problem is an important characteristics when considering its reliability. while for the latter, the lifetime of the component is very important. Analyzing the recurrence data obtained from reparable systems and the lifetime data for components and non-reparable units usually require the use of different statistical models and methods of analysis. Whatever the case may be, component and system reliability should be defined with respect to a well-defined mission and conditions of use.

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* Condition of use are presented in 2 wa
- Narrative: Brief descriptn of the anti operational condition under whi system will be used.
- Specific: Itemized list of known or anti upa ranges of environments & conditions

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Reliability is a function of the environment where the component / system is been operated and the stress it exerts on the system. The conditions of use include but are not limited to the environment of operation (such as temperature, season of the year, operating time, dust, vibration, acoustic environment, geographic location), maintenance as specified, and operation within the design specifications. As an example, if a user consistently operate a system outside the design specifications like operating at a speed higher than the specified speed limit, such operation will result to reliability problems wherever the system is been operated. Hence, an operational perspective must be presented as early as possible in the design reviews. A reliability specification requires a clear description of what constitutes mission success or failure for a system when it is operational. The essential elements of a reliability specification are:

1. A quantitative statement of the reliability requirement.
2. A full description of the environment in which the system / equipment will be stored, transported operated and maintained.
3. The time measure or mission profile
4. A clear definition of what constitutes failure
5. A description of the test procedure with accept / reject criteria that will be used to demonstrate the specified reliability.

Reliability requirement is a prediction or forecast of the performance of a product / item in the future. It is typically part of a technical specification document. There are four basic ways in which a reliability requirement may

Essential element of reliability requirements are:
1) Measurable
2) Customer usage and operating conditions
3) Time
4) Failure definition
5) Confidence

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be defined. Note that the reliability requirement must be specified quantitatively.

1. Mean Time Between Failure (MTBF): This definition is useful for long life systems in which the form of the reliability distribution is not too critical or where the planned mission lengths are always short relative to the specified mean life.

2. As a probability of survival for a specified period of time, t. This definition is useful for defining reliability when a high reliability is required during the mission period but mean time to failure beyond the mission period is of little tactical consequence except as it influences availability.

3. As a probability of success, independent of time: This definition is useful for specifying the reliability of one-shot devices such as the flight reliability of missiles. It is also specified for items which are cyclic in nature such as the launch reliability.

4. As a failure rate over a specified period of time. This definition is useful for specifying the reliability of parts, units and assemblies whose mean lifes are too long to be meaningful or whose reliability for the time period of interest approaches unity.

There are two possible ways in which the reliability requirement may be specified:

1. As a nominal or design value with which the customer would be satisfied, on the average, or

2. As a minimum acceptable value below which the customer would find the system totally unacceptable and could not be tolerated in the operational environment a value based upon the operational requirements.

Whichever value is chosen as the specified requirement, there are two rules that should be applied:

1. When a nominal value is specified as a requirement,

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always specify a minimum acceptable value which the system must exceed.

2. When a minimum value alone is used to specify the requirement, always ensure that it is clearly defined as minimum.

RELIABILITY METRICS

Reliability metrics are statistical in nature. They are not a single and comprehensive tool used for determining the cause of a failure and as such they can't be used to predict reliability with certainty and accuracy. Some popular reliability metrics are presented below:

1. Failure Rate (λ): This is the total number of failures within an item population, divided by the total time expended by that population during a particular measurement interval under stated conditions.

2. Hazard Rate: This is also referred to as instantaneous failure rate. This occurs at any point in the life of an item, so that it is the incremental change in the number of failures per associated incremental change in time.

3. Mean Time Between Failure (MTBF): This is a basic measure of reliability for repairable items. It is the average time during which all parts of the item perform within their specified limits during a particular measurement period under stated conditions.

4. Mean Time Between Maintenance (MTBM): This is a basic measure of reliability for reparable field systems. It is the average time between all system maintenance actions. Such maintenance action may be for repair or preventive purposes. It can also be defined as the time (i.e operating hours, flight hours) between the

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need for maintenance actions to restore a system to full operational condition, including confirmation that no fault exists (a NO DEFECT maintenance action). This parameter provides the frequency of the need for maintenance and complements the labor hours parameter to project maintenance workload. This parameter is also used to identify unscheduled maintenance (MTBUMA) and scheduled maintenance (MTBSMA).

5 Mean Time Between Repair (MTBR). This is a basic measure of reliability for repairable fielded systems. It is defined as the average time between all system maintenance actions requiring removal and replacement or insitu repairs of a box or subsystem.

6 Mean Time Between Critical failure (MTBCF). This is a measure of system reliability which includes the effects of any fault tolerance that may exist. The average time between failures that cause a loss of a system function defined as 'critical' by the customer.

7. Mean Time Between Operational Mission failure (MTBOMF) This is a measure of operational mission reliability for the system. It is the average time between operational mission failures which causes a loss of the system's mission as defined by the customer. This parameter may include both hardware and software failures.

8. Mean Time to failure (MTTF). This is a measure of reliability for non-repairable systems. It is the average failure free operating time during a particular measurement period under stated conditions.

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Basic Concept of Maintenance

Maintenance is defined as the work undertaken to keep or restore a system to it operational state. Technically, maintenance involves functional checks, servicing, repairing or replacing of necessary components or parts in a system. There are two broad types of maintenance which are preventive maintenance and corrective maintenance.

Preventive Maintenance: this is a scheduled, regular and routine maintenance of an equipment in order to keep it running and prevent any costly unplanned downtime from unexpected equipment failure. It involves the replacement of any components or parts of the equipment that has worn out. This replacement takes place before the component or parts actually fails. Failures of components entering the wear out period or subject to continuous wear are not random and as such can be predicted. The reliability of the equipment or system can be improved by replacing these components or parts before they fail. There are different types of preventive maintenance:

- Time Based Maintenance (TBM)
- Failure finding Maintenance (FFM)
- Risk Based Maintenance (RBM)
- Condition Based Maintenance (CBM)
- Predictive Maintenance (PdM)

Time Based Maintenance: This refers to the replacing or renewing of a component or parts for the purpose of restoring its relia-

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against the failure of known wearing parts which have predictable MTBF. TBM assumes that failure is a function of age and as such a clear service life can be determined. TBM cannot effectively manage non-age related failure modes, and therefore should only form a small part of the overall maintenance program as >70% of the failure modes in an equipment or system are not age related.

B Failure finding Maintenance: This is aimed at detecting hidden failures typically associated with protective functions. It is usually conducted at fixed time intervals derived from legislation or risk based approaches. FFM can be typically applied to pressure safety valves and trip transmitters. This type of equipments won't be required to function until something else has failed. That implies that under normal operating conditions it is difficult to know whether the equipment is still functional because the failure modes are hidden. As such it is necessary to identify and find out these failures before it can be relied upon to perform its operations efficiently. FFM do not prevent failure but only help to detect it.

C Risk Based Maintenance: This involves using a risk assessment methodology to assign the scare maintenance resources to those assets that carries the most risk in case of failure. Note that risk = likelihood x consequence). Hence an equipment that has a higher risk along with a very high consequence of failure will be subjected to a more frequent maintenance and inspection, while equipments with low risk and consequence will be maintained at a much lower frequency. An effective

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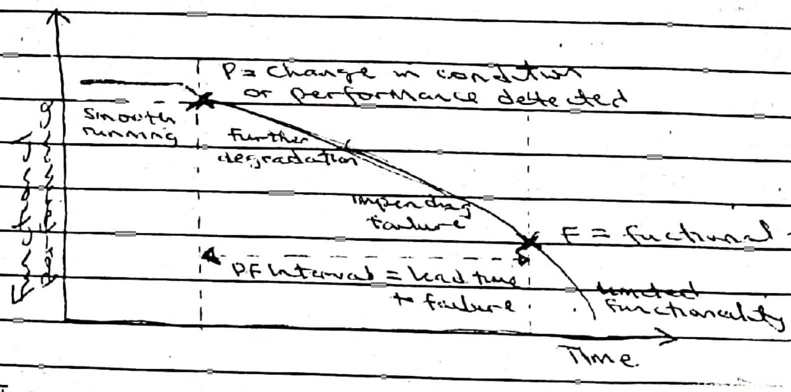
implementation of RBM will reduce the total risk of failure across the equipment which will be most economical. RBM is a preventive maintenance where the frequency and scope of maintenance activities are continuously been optimised based on the findings from testing or inspection and a thorough risk assessment. Examples of RBM would be Risk Based inspection applied to static equipment like vessels and piping or even pressure relief valves.

Δ Condition Based Maintenance: Before failure occurs, most failure modes do give some sort of warning showing that they are in the process of occuring or are about to occur. If such evidence can be found that an equipment is in the early stages of failure, it is possible to take necessary actions to prevent it from failing completely and/or to avoid the consequence of failure. CBM searches for physical evidence that a failure is occuring or is about to occur. The P-F curve helps to explain an important concept within CBM



The curve shows that as a failure starts manifesting, the equipment performance deteriorates to the point at which it can possibly be detected

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at point P. If the failure is not detected and mitigated, it continues until a functional failure occurs at point F. The time range between P and F is called the P-F interval and it is the window of opportunity during which an inspection can possibly detect an imminent failure and it give time for it to be addressed. CBM as a maintenance strategy does not reduce the likelihood of failure occuring through life-renewal, but instead it is aimed at intervening before the failure occurs on the premise that this is more economical and would have less impact on availability. A common rule of thumb for CBM is that the interval between CBM tasks should be one-half or one-third of the P-F interval. The effectiveness of CBM above breakdown maintenance depends on how long the P-F interval is. With plenty of warning the rectification can be planned, materials and resources can be mobilsed and breakdown prevented. But when the P-F interval is only a few days the resulting organisational and workplace actions are much likely a breakdown and the value of CBM is largely costly. For CBM to be very effective, early intervention is most essential. This requires an essential and effective process for data gathering, data analysis, decision making and finally intervention. For equipment whose P-F interval for its failure modes has a large variability, CBM is ~~not~~ an effective strategy.

E Predictive Maintenance: Not until recently, people considered PDM as an synonym for CBM. But with the advent of AI there seem to be a clearly distinction between PDM and CBM. PDM is an extension of CBM with a more advanced approach where potentially many process parameters gained

Disadvantages of PM
- Difficult to accurately predict the point at which components enters wear-out period
- Sometimes, it can be uneconomical
- Disturbance which may itself cause failures

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from online sensors are used to determine if an equipment is moving away from stable operating conditions and is heading toward failure.

2 Corrective maintenance: this is an unscheduled action performed on a failed equipment so that it can be restored to its operational condition. This form of maintenance is usually performed after a failure has occured. It is based on the assumption that failure is acceptable (no significant impact on safety or the environment) and preventing failure is either not economical or not possible. CM apart from the fact that it is the outcome of a deliberate Run to failure strategy, it is also as a result of unplanned failures which were not avoided through preventive maintenance. When opting for corrective maintenance as a strategy, it is important to ensure that the failure modes under consideration do not have the potential of becoming Emergency Maintenance. There are two types of corrective maintenance:
- Deferred Corrective Maintanance (DCM)
- Emergency Maintenance (EM)

A. Deferred Corrective maintenance: This refer to any situation in which the equipment is allowed to degrade further or remain non-functional before maintenance is carried out. It is the practice of postponement of maintenance activities such as repairs of an equipment in order to save cost.

B. Emergency Maintenance: This is the form of maintenance required when an equipment experiences an unexpected breakdown or change in it operation. It involves the coordination and repair following breakdown or malfunctioning of an equipment regardless of the cause. EM has been observed to be 3 to 5 times as expensive as normal preventive maintenance. It typically leads to longer equipment outages/downtime and more production impact. It is also less safe. It is therefore safe to say that EM is the one and only maintenance strategy that must be avoided at all cost.

MAINTENANCE POLICY

Policies are statements of principles which define the style in which an organization aims at conducting its business. Maintenance policy is therefore a statement of principle by which the management of an organization communicates its intentions and expectations on maintenance concept with the establishment. It serves as a tool with which the maintenance personnal plan their appropriate maintenance strategies. The particular maintenance policy adopted by an organization depends on the following factors:

1. The type of organization
2. The location
3. The effect of the environment on which the equipment is been used.
4. The required levels of reliability and availability of the equipment including availability of spare parts.
5. The standard of skilled maintenance staff
6. The problem of spare parts.

MAINTENANCE STRATEGIES

This refers to the method adopted to achieve maintenance policy in an organization. An effective maintenance strategy is concerned about maximizing equipment uptime and facility performance while balancing the associated resources expended and ultimately the cost. It is important to ensure that there is sufficient return on investment. There are a number of maintenance strategies which can be specified either seperately or a combination of one or more strategies.

- Run-to-Failure
- Preventive Maintenance
- Predictive Maintenance
- Reliability Centered Maintenance

A. Run-to-failure: This is the simplest maintenance strategy where the equipment is actually allowed to operate until it breaks down. This implies that the equipment receives no maintenance until the failure occurs after which it is fixed without causing any production issues.

B. Preventive maintenance: This is a proactive form of maintenance and include adjustments, cleaning, lubrication, repairs and parts replacements. It ensures that the equipment is in good working condition and reduces unscheduled downtime and major repairs.

C. Predictive maintenance: This employs condition monitoring tools in tracking the performance of the equipment during its normal operation for the purpose of detecting possible defects and fixing them before the equipment Fails.

D. Reliability Centered Maintenance: This is implemented to optimize the maintenance program of an organization. It means having a specific maintenance strategy for each equipment that is optimized so that productivity is maintained using cost-effective maintenance techniques.

There are Pros and cons in implementing these maintenance strategies and they are presented based on the type below:

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A Run-to-failure: Pros:

- its simple and easy to understand
- it requires minimal planning
- it requires fewer human resources since less work is done day-to-day

Cons:

- its highly unpredictable
- it can be expensive in some cases
- it makes scheduling/planning for staff difficult
- There is a safety risk involved

B Preventive maintenance: Pros:

- minimizes equipment breakdowns
- Reduces downtime
- Safer work environment
- increases equipment's productive life
- Improves production quality

Cons:

- more labor intensive
- Unnecessary maintenance of equipment (loss of man hours and revenue)
- Doesnt eliminate catastrophic failures
- Can cause early deterioration of equipment.

C Predictive maintenance: Pros

- Decreased maintenance costs
- Reduced unexpected failures and repair time
- Increased production efficiency
- Increased service life of parts
- Improved worker and environmental safety

Cons:

- High start-up costs
- limitations of some equipment

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- misinterpreted data leading to false maintenance requests
- Difficult to install, configure and run.

D Reliability-Centered Maintenance Pros
- increase equipment availability & reliability
- reduces maintenance cost
- lowers staff costs
- Helps to prevent loss of life, property damage, and environmental harm.
- incorporates root cause analysis

Cons:
- Really high up-front costs for training and equipment
- saving potential not evident to management
- To be effective, RCM requires a certain level of maintenance maturity to ensure accurate and complete asset data