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Ezechukwu OA et al./ Elixir Elec. Engg. 93 (2016) 39404-39408

Available online at www.elixirpublishers.com (Elixir International Journal)



**Electrical Engineering** 



(4)

(5)

Elixir Elec. Engg. 93 (2016) 39404-39408

# Availability- An Ultimate Goal of Reliability Engineering

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## **ARTICLE INFO**

Article history: Received: 24 June 2015; Received in revised form: 5 April 2016; Accepted: 9 April 2016;

# ABSTRACT

This paper discusses the ways for maintaining high availability of a system in order to keep high reliability figure. In doing so, the basic principles of reliability are discussed. Since good maintenance practice enhances availability, some important topics on maintenance management are also discussed. At the end recommendations are made on how to keep a system in a high availability state.

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#### Keywords

Availability, Reliability, Maintenance, Failure, Equipment.

## **1.0 Introduction**

Reliability engineering is the aspect of engineering that emphasizes the ways and methods of keeping a system in good working condition so that it can be dependable. Maintainability on its own part can be defined as the probability that an equipment or system can be kept in good working condition under specified condition for a given period of time. That is, the equipment/system must be available at the required time. In looking for high maintainability and reliability, Availability is the must important thing sought for. Therefore, Availability of an equipment/system can be defined as the probability that it will be ready to perform the required function at a given time. To ensure high availability of a system, effective ways of keeping the system in good working condition must be put in place. Good maintenance management is all that is required to ensure that the item can be relied upon any time its function is needed. It is very important for the maintenance personnel to know everything about the equipment they operate to enable them address maintenance problems very effectively.

#### 2.0 Reliability

Tele:

The reliability of an item is its ability to perform the required function under stated condition for a specified period of time. High reliability material may be expensive but its services and high availability makes it cheaper at the long run [1]. Reliability, R, is given as

$$R = e^{-\lambda t} \tag{1}$$

Where;  $\lambda$  = failure rate (Number of failures per unit time) and t= period. for reliability assessment.

But  $\lambda$  is the reciprocal of the mean-time-between-failures (MTBF), m.

 $m = \frac{\text{Total survival hours}}{\text{Total population}} = \frac{\text{Total operating hours}}{\text{No of failures in time}} = \frac{1}{\lambda}$ Substituting value of  $\lambda$  in equation (1)

$$R = e^{-t/m} \tag{3}$$

Again reliability, R, =1-U

Where U= unreliability= 1-R

Substituting for R from eqn (1),  $U = 1 - e^{-\lambda t}$  (6)

The graph of reliability is exponential as shown in fig.1.



# Fig 1. Reliability functions (for constant failure rate period).

Reliability can be evaluated from the producer's point of view and from the customers view point. From the producers view point; before delivery, increasing reliability increases cost. After delivery, cost of warranty, claims and repairs etc, will decrease with increasing reliability [4]. See fig. 2. The cost of delivering the services is thus the sum of the costs before and after delivery.



Fig 2. Reliability and cost from producer's viewpoint.

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From the customers point of view; the after delivery cost falls with increase in reliability of the system. So the total cost is the sum of the purchase cost and after delivery cost and this is usually minimal. See fig. 3.



Fig 3. Reliability and cost from customer's view point.

In analyzing the reliability of a system, it is always necessary to find a model that best suits the system. The two basic models are the parallel and series models.

## 2.1 Parallel reliability.

In parallel reliability, if there are n components with equal reliability, the system can fail only when none of the components is high. In other words, the system must continue to work provided that at the least, one of the components is working.

Parallel reliability,	
$Rp=R1 + R2 + R3 + R4 + \dots Rn$	(8)
Appling eqn(6) for n components,	
$U=(1-R1)+(1-R2)+(1-R3)+\dots(1-Rn)$	(9)
$Up = U1 + U2 + U3 + \dots Un$	
$=\sum_{r=1}^{n}Ux$	(10)
	(1

Also from eqn (5), 
$$Rp=(1-U1)+(1-U2)+(1-U3)+....(1-Un)$$
  
= $R1+R2+R3+....Rn$  (11)  
eqn (1) implies that

$$Rp = e^{-\lambda tt} + e^{-\lambda 2t} + e^{-\lambda 3t} + \dots \cdot e^{-\lambda nt}$$

$$Rp = \sum_{x=1}^{n} e^{-\lambda xt}$$
(12)

$$also= Rp = 1 - \sum_{1}^{n} Ux$$
And  $Up = 1 - \sum_{x=1}^{n} e^{-\lambda xt}$ 
(13)
(14)

#### 2.2 Series reliability model

In this model, all the component reliabilities are in series. Unlike in parallel reliability, when any component reliability is zero, the system is unreliable.

Again if we consider a system of n reliability components, unreliability,

$$U_{s} = (1 - R1)(1 - R2)(1 - R3) \dots (1 - Rn)$$
(15)  
Then series reliability,  $R_{s} = (1 - R_{n})^{n}$ (16)

A system having 3 reliability components in series will

have  $U_s = (1 - R1)(1 - R2)(1 - R3)$ If  $R_{1} = R_{2} = R_{3} = R_{5}$ ,

$$Us = (1 - 3Rs + 3Rs^2 - Rs^3)$$
(17)  
And

$$Rs = 1 - U_s = 1 - (1 - 3Rs + 3Rs^2 - Rs^3)$$
(18)

#### 2.3 Series-parallel model

In this model the reliability components are arranged in series-parallel as shown in fig3b. It is advisable to resolve the series components first before the resultant parallel form.



Fig3b. series-parallel reliability model.

#### 3.0 Failure

Failure rate is a function of reliability. Failure is defined as the termination, for any reason and to any degree, of the ability of an item or system to perform its required function [3].

There many types of failure. These are shown in table1.

Table 1. Classification of failure.

FAILURE TYPE	REMARK
Sudden failure	Catastrophic failure
Complete failure	-
Gradual failure	Degradation failure
Partial failure	
Intermittent failure	
Inherent failure	
Misuse failure	
Critical failure	
Major failure	
Minor failure	

Failure is a statistical event. We can not say exactly the time it will occur but we can predict that in a given period of time there will be on average, a certain number of failures, and we can even set confidence limits on such statement [4]. The failure rate is also not constant. A plot of failure rate against time gives the familiar "Bath-tub" diagram. See fig 4. It is called the bath-tub diagram because of the shape which is similar to that of the bath-tub.



Fig 4.The bath-tub diagram.

Fig. 4 is made up of the early failure period, the constant failure rate or useful life period and the wear-out period.

The early failure period is where high failure rate and defects which escaped the quality control or supervision are exposed. Failures in any component or equipment should be eliminated before delivering to the customer. The early failure period can also be called the "burn-in-period". This includes to some extent, the guarantee period of the equipment or the free service period.

The constant failure rate or the useful life period: This is the period during which the reliability of the system is usually considered. It is the period when the rate of failure of components is almost constant.

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The third period is the wear-out period. This is the period in which part of the system or equipment fail due to wear and degradation. At this point replacement of the part is considered necessary.

#### 4.0 Endurance Test

The endurance test is the test carried out on equipment to ensure that it will withstand the normal stress during its useful life period. A good number of the specimens are subjected to normal stress and their failure rates are plotted against time base. During this period the exponential law of failure dominates other distributions, and the probability of no failures occurring in a given time[7], that is, the reliability, R, already given as  $R=e^{-x^t}$  in eqn (1).

The ability of an item to be serviceable is called maintainability. Some factors determine the maintainability of an item. They are:-

(a) Method of determining that fault exist : It may be easy to note that an automobile horn is faulty immediately you use it but it may not be easy to recognize that the boiling water in the pot is dry unless you open the pot.

(b) The method of quickly identifying the faulty component. The solution to this problem is training of service men, acquisition of test instruments and apparatus and knowledge of procedures. The designer who considers maintainability will always provide test points for wares. This will help to identify the faulty components.

(c) Rectification of the fault, which may include replacement of the parts that are defective. Again good designing ensures that the components with high failure rate are easily accessible. However it is advisable that one has to be very careful not to introduce another fault in the cause of clearing a fault.. Reset buttons must be placed where they can not accidentally be touched.

(d) Finally it will be very important to check if the system operates very well after the repair [4].

Thus maintainability is a statistical feature and can still be defined as the probability that the item will regain its operational status after repair, under normal condition [3]. 5.0.4 weight bility

## 5.0 Availability

Availability is the probability that an equipment can perform its required functions at the required time [6]. Availability, A, is expressed as:

$$A=m/(m+t)$$

where m= Meantime between failures (MTBF) and t= down time or maintenance time.

Alternatively A= (1 - U). U is unavailability (due to break down) and can be expressed as

U = MTTR/(m + MTTR)(6) Therefore Availability, A,= 1-[MTTR/(m+MTTR)] (7)

MTTR is the mean time to repair of the equipment or item .Note that MTTR is used for non-repairable items while MTBF, m, is used for repairable items.

The reliability of an equipment/system can be improved through better maintenance practices. But the cost of such maintenance related activities must be compared with enhanced availability [2]. Therefore, good maintenance practices are very necessary to maintain a high availability figure. The basic principles of maintenance management are discussed in the next section.

#### 6.0 Maintenance Management

Maintenance management is an essential part of engineering practice. A well planned maintenance schedule depicts the quality of the maintenance engineer and knowledge of maintenance techniques brings about huge savings and smooth operation of the system [1]. There are two major categories of maintenance; namely planned and unplanned or emergency maintenance (sometimes called also break-down maintenance) [1]

## 6.1 Planned Maintenance

Under planned maintenance, we have

A. Preventive maintenance

B. Design-out or improvement maintenance.

6.1.1 Preventive maintenance

The preventive maintenance can also be broken down into:

1. Condition-based (preventive) maintenance

2. Time-based (preventive) maintenance and

3. Condition-monitored maintenance.

#### 6.1.1.1Condition-basedmaintenance

This is the maintenance resulting from observed change/s in the monitored parameter. Such monitored parameters could be one or more of the following [4].

1. Temperature: abnormal temperature change e.g. motors, generators, electronic components etc.

2. Sound: Abnormal sound e.g. in machines. automobiles

3. Acoustic: Abnormal change in tunes and reproduction e.g. musical cassette/ disc players.

4. Corrosion: Corrosion attack e.g. structures.

5. Vibration: Unusual vibration e.g. rotating machineries.

6. Viscosity: Change in viscosity e.g. lubricant oil.

7. Color: Change in normal color e.g. silica gel, water etc.

8. Shock: The experiencing of shock e.g. in electrical appliances.

More parameters can be monitored or developed to suit a particular application provided the parameter being monitored has direct bearing on the general well being of the equipment. Condition based maintenance is capable of doing the following:

a. Giving early warning of fault development.

b. Giving good indication when the system is working smoothly and

c. Providing reliable basis for diagnosing developing faults. Condition based maintenance when properly applied will :-

i. Eliminate or reduce the down-time of a system and therefore increase system availability and so enhance productivity.

ii. Reduce the down-time/repair time since major damage is avoided and all necessary arrangement concluded before shut down.

iii. Reduce the inconveniencies caused by frantic search for spare parts during equipment break down (and savings in procuring spare parts at all cost on event of sudden break down), by scheduling maintenance with good knowledge of required spare parts.

iv. Elimination of component waste since only unserviceable components will be replaced.

v. Elimination of secondary damage (e.g. A faulty break pad not detected early enough could result in the damage of the wheel drum)

vi. Improvement in safety, quality of the product and customer satisfaction.

## 6.1.1.2 Time-based maintenance

This is the type of scheduled maintenance which is carried out at stipulated time intervals, sometimes recommended by the manufacturer. The time interval recommended for maintenance of a system could change as the equipment gets older and requires more frequent maintenance. Also maintenance intervals could be determined by other factors like; distance covered, environment, duty cycle etc.

#### 6.1.1.3 Condition monitored maintenance

In this method statistical approach is adopted and probability theory is used in determining when and how to replace an item. Trend detection through data analysis exposes failure cause and preventive actions that can be taken to avoid such failures in future. Statistical approach is most effective where there are large numbers of similar items. For example factory hall lights burnout within interval of time. This interval of time can be determined statistically giving a standard deviation around an average life time. It has been found that it is more economical to change all bulbs at such predetermined life time or soon after a certain percentage of the bulbs has burnt-out than replacing them as they get burnt [4].

Knowledge of failure pattern is a viable asset to condition monitored maintenance programme. Detecting a failure pattern helps to arrest failure modes before they spread to other similar items. If four items out of ten similar items develop identical faults in quick succession, it will be advisable to have a closer look at the other six and carry out preventive maintenance to avoid their break down.

#### 6.12 Design-Out Maintenance

The design-out maintenance, sometimes called improvement maintenance where applicable, is the most effective of all other methods described in terms of scientific approach and overall cost implications. While the previous methods strive to minimize the effect of failure, design-out maintenance strives to eliminate the cause of failure [1]. No matter the reliability of equipment, no matter how perfect the installation is, operation of the equipment in an environment not covered by the reliability specification will definitely affect its performance. In such a case the design-out maintenance is necessary to improve the reliability and maintainability of such equipment. For example an electric motor designed to be used at the dry and housed location must have to be drip-proofed if it is to be used in an area that contains moisture.

# 6.2 Emergency or Break-Down Maintenance

This is the type of maintenance nobody wants to have. It is the type of maintenance that results from unanticipated break down of the system. It waste material and resources since the system has to be put back to service at all cost in other to meet the required production target [1].

## 7.0 Training-an Important Tool in

#### Maintenance

Training is very essential in performing maintenance duties. All maintenance personnel should understand the working principles the functions of various parts of the equipment they are maintaining. Towards this end , it is necessary that are sent to training any time a new equipment is introduced into the system. Not only that, they supposed to be attending updating training programmes.

#### 7.1 .Continuous Professional

#### Development

For an engineer to be reliable, he must be updating himself in the ever-dynamic field of engineering. Continuous professional development, for an engineer, is the process of continuous upgrading of his professional experience in his field. This can be achieved through seminar/workshops, conferences, symposia, in-service training, discussions with senior or more experienced colleagues, surfing the internet and other electronic media, and so on.

## 8.0 Safty Measures in Maintenance

It is always necessary to maintain standard safety measures while performing any maintenance work. Environmental conditions may vary but in any condition one finds him self, he should try to apply appropriate safety measures.

When maintenance work is to be done on any item, all measures to prevent injury to the personnel or the equipment must be put in place. There is no compromise to this! For example, when maintenance work is to be done on any power equipment in situ, it is very necessary that the equipment must be isolated from power supply. Further more, measures must be taken to prevent accidental switching or re-energization while the maintenance work is going on.

## 8,1 Safety Wears

Safety wears are wears that protect the body from injury. Safety wears are necessary during maintenance work; and the type of safety wears depends on the maintenance environment. **9.0 Materials' Management** 

It has been said that it is always good to identify those materials or parts that break down more often in order to keep enough of their spares [9]. A good maintenance manager keeps stock of important items and the addresses of the suppliers, in case of emergency. An up-to-date stock inventory card is kept to reflect all the changes in the stocked materials. Some inventory cards will contain the address or location of the supplier Another card called the requisition form is used by the store men to issue materials to the maintenance workers. These cards help to monitor the availability of stock items. Typical requisition and stock inventory cards are shown as tables 3 and 4 respectively.

#### **10.0 INSPECTION**

Inspection can be defined as a move to judge the quality of an item. It can also be defined as the examination of the details of an item or a system. It must be emphasized here that inspection of any engineering facility must be headed by a professional engineer in the related field.

Inspection can be categorized into (a) scheduled and (b) unscheduled. See fig 6.

rubie et stoch requisition curu							
S/N	Material	Date of purchase	Quantity	Quant. issued	Work location	Collected by/sign	issued by
1							
2							
:							
n							
Reco	mmended by	1		Approved by			

Table 4 Stock inventory card

S/N	Material	Date of purchase	Unit cost	Quant. In stock	Quant. Issued	Date of last issue	Quant left	Checked by/date
1								
2								
n								



Fig 6. inspection components.

## **10.1 Routine/Periodic Inspection**

Routine inspection is the type of inspection that is mandatory at special conditions while periodic inspection is a routine inspection that is done periodically according to schedule.

Some of the benefits of routine inspection are:

(i) it is from the findings that the preventive maintenance is planned (for systems that are already in operation)

(ii) it helps to check the standard and quality of work

(iii) it helps to ascertain that standard materials and mixtures are used

(iv) it helps to ascertain that the work is being done by the right professional/s

(v) it helps to know the problems and needs of the workers. This helps to facilitate early execution of work.

In this type of inspection, items are scheduled for inspection at the required periods. Some may require hourly, some daily while some may require monthly or even annual inspections and so on.

An example of hourly inspection is in the power supply system where the system operators/dispatch personnel do visual inspection of all the power supply equipment on hourly basis, take hourly readings of meters and record them. At the end of their duties they submit their reports to the superintendent who compile and forwards them to appropriate quarters where action can be taken.

## **10.1.1 Daily Inspection**

Some items require daily inspection. Example of the daily inspection include checking your radiator water level, lubrication oil level, tire air pressure, etc., every morning before driving off. in power station At the assumption of duty every day, the system operator inspects the essential services supply and monitors the electrolyte level, the cells of the batteries, the battery terminals (for dryness) and the voltage levels of the bank and keep the record.

It is a good practice to check (inspect) the previous day's work for errors/mistakes before starting a new one. This helps to reduce the cost and time of amendments/repairs.

## 10.1.2 Inspection By Management Team

Some times the management team goes round to inspect the facilities. This helps to asses the competence of the maintenance supervisor whose duty it is to maintain regular inspection of the system. Another very important reason for this type of inspection is to ascertain that the work and its methods comply with appropriate regulatory provisions and that all the materials used conform to the required standards.

## **10.13 Executive Inspection**

More often, it is required that the executive do some inspection of the infrastructure (under construction, etc.) to ascertain:

(i) The extent of work/construction,

(ii)the quality of work and

compliance with appropriate regulations and construction agreement.

The advantages of executive's inspection are: (i) it helps to erect standard infrastructure (ii) it facilitates supply of required material/s and therefore helps to make the work move fast so that the project will be completed in a record time.

(iii) it also helps to maintain good relationship between the executive and the construction company or the work group.

## **10.2 Emergency Inspection**

This is an inspection done when there is unexpected major change in the facility. It is usually associated with very bad incidents like, vandalization, theft, collapse of infrastructure and so on.

## **10.3 Effects and Consequences of Poor Supervision**

Poor inspection gives room for unethical practices and production of substandard works which may result to collapse of infrastructure, fire outbreaks, accidents and other bad incidents.

In engineering, one cannot attempt to do any supervision in an area he/she is not specialized, no matter his experience

## **11.0** Conclusion

Availability of an item indicates its readiness to perform a required function. Whether one looks for high reliability or the best maintenance approach for an equipment/item, the ultimate goal is its availability at any required time

## **12.0 Recommendations**

It is believed that the performance of our utilities and other companies will improve if they adhere to the following:

1 Reactivate their training schools for the training and retraining of engineering and technical personnel.

2. Keep enough spare parts of essential items.

3.Always keep broad based maintenance schedule to cover all items in the system.

4.Individuals should be sensitive to condition changes in their environments and be maintenance conscious.

5.Effective supervision is required in all facets of engineering works in order to erect standard infrastructure. **References** 

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