SCHOOL OF ENGINEERING, YABA COLLEGE OF TECHNOLOGY

2nd International Conference: Sustainable Engineering Solutions for Energy and Industrialization

Afunlehin O. Adesina , Ojo Babajide Adelaja

[1]Electrical & Electronic Department, Federal polytechnic Ilaro, Ogun State.

opeyemi.afunlehin@federalpolyilaro.edu.ng, babajide.ojo@federalpolyilaro.edu.ng

(+234-8124242045, +234-8030452814)

Pragmatic approaches of reliability on choice and economics of national development

Abstract

This paper investigates the general principles and system performance under static and dynamic conditions of reliability of measurable system towards national development by directing on choices and economic progress. Perceptively, reliability is the probability of success or survival of any product, within a specified period and condition assumed for maintainability. Conceptual analysis is not holistic enough rather principle of reliability engineering is pragmatic in nature and economic in design and technology. Of course the accuracy of a measurement system and measurement error played significant role under both steady-state and dynamic conditions. Therefore, reliability being another important characteristic of a measurement system, just as measurement is, provides a more coherent and integrated approach to all essential activities in every branch of science and technology. This is to update and expand extensively by taking into account recent developments in computing, solid-state electronics, optoelectronics and other areas of measurement technology.

Keywords: Reliability, failure rate, accuracy, measurement error, steady-state and dynamic conditions

1.1 Introduction

Reliability engineering is a developmental programme that is meant to enhance sustainable engineering solution for energy and industrialisation in present dispensation. Industrialised products must be cross-examined based on reliability testing in order to promote further geometric and provision for availability in the economic system. The strength of reliability concept seems to be infinitesimal because it’s the basic principle of criticism (that is statistical probability). Hence, if a large number of random, independence trials are made, the probability of a particular event occurring is given by the ratio:

$$P = \frac{\text{number of occurrences of the event}}{\text{total number of trials}} \qquad 1.1$$

A prediction of reliability is an important element in the process of selecting equipment for use by telecommunications service providers and other buyers of electronic equipment. **Reliability** is a measure of the frequency of equipment failures as a function of time. Reliability has a major impact on maintenance and repair costs and on the continuity of service. Every product has a failure rate, λ which is the number of units failing per unit time. This failure rate changes throughout the life of the product. It is the manufacturer's aim to ensure that product in the "infant mortality period" does not get to the customer. This leaves a product with a useful life period during which failures occur randomly i.e., λ is constant, and finally a wear-out period, usually beyond the products useful life, where λ is increasing. A practical definition of reliability is "the probability that a piece of equipment operating under specified conditions shall perform satisfactorily for a given period of time". The reliability is a number between 0 and 1 respectively.

The reliability of a product (or system) can be defined as the probability that a product will perform a required function under specified conditions for a certain period of time. If we have a large number of items that we can test over time, then the Reliability of the items at time t is given by :

$$R(t) = \frac{\text{Number of survivors at time } t}{\text{Number of items put on test at time } t = 0}$$

After this, the reliability, R(t), will decline as some components fail (to perform in a satisfactory manner).

1.2 Unreliability F(t)

This is 'the probability that the element or system will fail to operate to an agreed level of performance, for a specified period, subject to specified environmental conditions'. Since the equipment has either failed or not failed, the sum of the reliability R(t) and unreliability must be equal unity i.e.

$$R(t) + F(t) = 1$$

1.3 Concept of Failure and failure rate

Failure is defined as the termination of the ability of an item to perform a required function, or loss of ability to perform as required. Failure is an event which leads straight to either partial or complete loss of ability of an item to fulfil a required function.

1.4 Types of failure

Design failure: This occurs due to inadequate design. It is basically any failure directly related to item design. It means that due to item design a part of the whole degraded or got damaged and this resulted in a failure of the whole system.

Weakness failure: This is a failure which occurs due to weakness inherent or induced in the system such that the system cannot stand the stress it encounters in its normal environment.

Manufacturing failure: A failure caused by non-conformity during manufacturing and processing. It is basically any failure caused by faulty processing or inadequate manufacturing or error made while controlling the process during manufacturing tests and repairs.

Ageing failure: A failure caused by the effects of usage or age

Misuse failure: A failure caused by the misuse of the system (operating in the environments for which it was not designed)

Mishandling failure: A failure caused due to incorrect handling and lack of care and maintenance.

Software error failure: A failure caused by a PC programme error.

Catastrophic failure: A failure that can lead to death or can cause total system (item) loss.

Critical failure: A failure which results in many serious injuries or major damage. Sometimes, it's thought of as a failure or combination of failures that prevent an item from performing a required mission.

2.0 Related Work

2.1 Non-repairable items

If N individual items of a given non-repairable component are placed in service and the times at which failures occur are recorded during a test interval T. Also further assume that all the N items fails during

T and that the ith failure occurs at time T_i, i.e T_i is the survival time or **up time** for the ith failure. The total up time for N failures is therefore $\sum_{i=1}^{i=N} T_i$ and the **mean time to failure** is given by:

$$\text{Mean time to failure} = \frac{\textbf{Total up time}}{\textbf{Number of failures}}$$

i.e $$\text{MTTF} = \frac{1}{N}\sum_{i=1}^{i=N} T_i \qquad 1.2$$

The mean failure rate $\bar{\lambda}$ is correspondingly given by:

$$\text{Mean failure rate} = \frac{\textbf{Number of failures}}{\textbf{Total up time}}$$

i.e $$\bar{\lambda} = \frac{N}{\sum_{i=1}^{i=N} T_i} \qquad 1.3$$

i.e mean failure rate is the reciprocal of MTTF (Wright, R I (2007).

There are N survivors at time t = 0, N – i at time t = T_i , decreasing to zero at time t = T; figure 1.1(a) shows how the probability of survival, i.e reliability, R_i = (N – i) N decreases from R_i = 1 at t = 0, to R_i = 0 at t = T. The ith rectangle has height $\frac{1}{N}$ and length T_i and area $\frac{T_i}{N}$. Hence, from eqn 1.3,

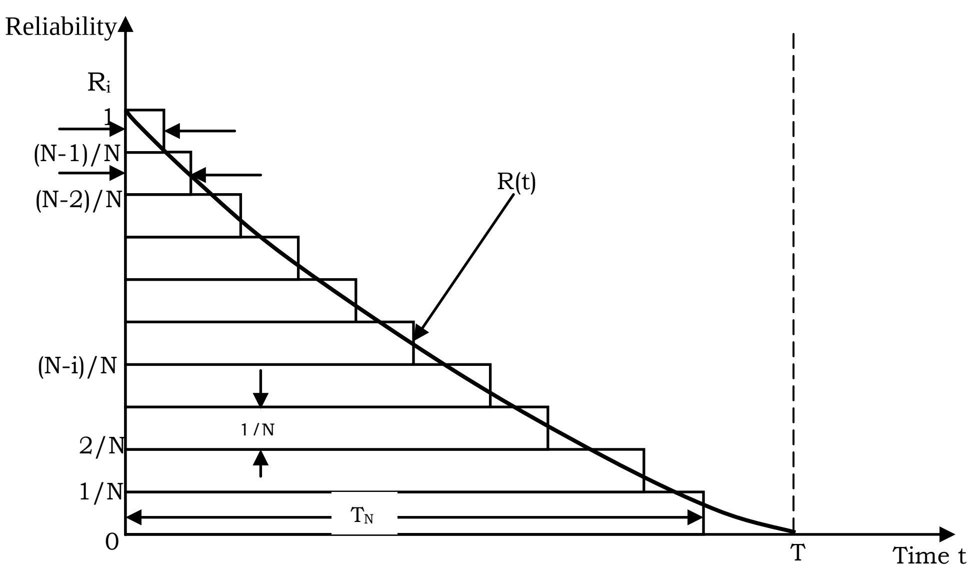

Figure 1.1a. Failure patterns: non-repairable items

MTTF = Total area under the graph

In the limit that N → ∞, the discrete reliability function R_i becomes the continuous function R(t). The area under R(t) is $\int_0^T \mathbf{R(t)}dt$ so that, in general:

$$\text{MTTF} = \int_0^{\infty} \mathbf{R(t)dt}$$

The upper limit of t = ∞ corresponds to N being infinite.

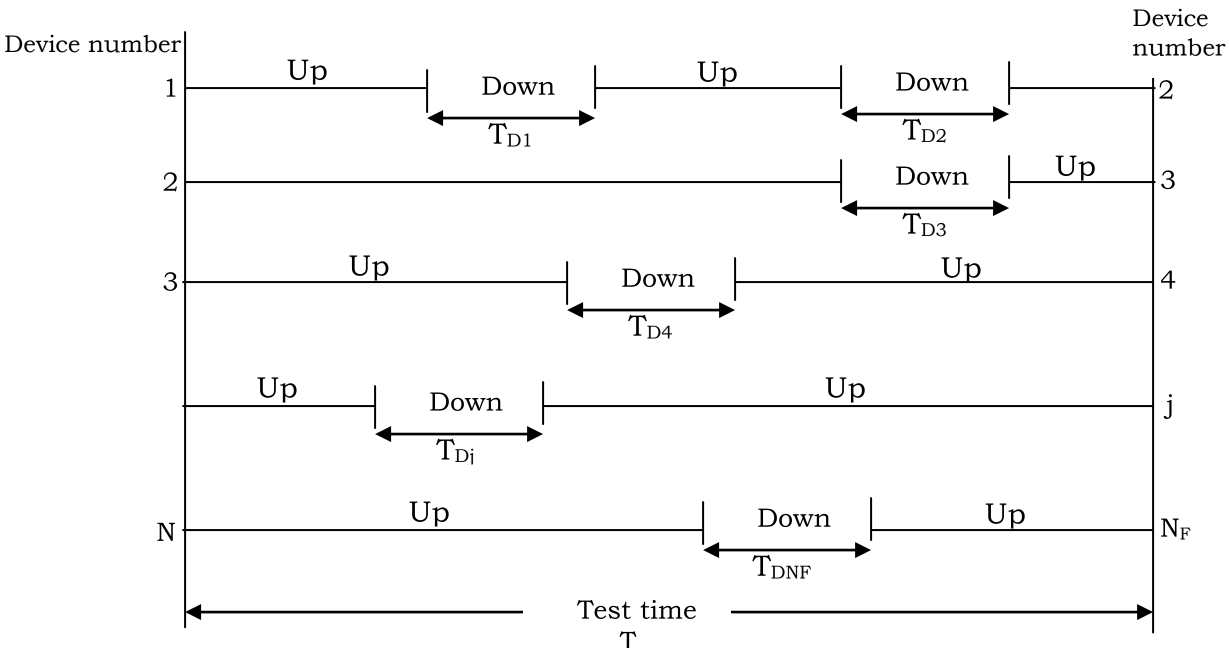

Figure 1.1b. Failure patterns: repairable

2.2 Repairable items

Figure 1.1b shows the failure pattern for N items of a repairable element observed over a test interval T. The down time T_{Dj} associated with the jth failure is the total time that elapses between the occurrence of the failure and the repaired item being put back into normal operation. The total down time for N_F failures is therefore $\sum_{j=1}^{j=N_F} \mathbf{T_{Dj}}$ and the mean down time is given by (Lees F P (2010))

$$\text{Mean down time} = \frac{\textbf{Total down time}}{\textbf{Number of failures}}$$

i.e

$$\text{MDT} = \frac{\mathbf{1}}{\mathbf{N_F}} \sum_{j=1}^{j=N_F} \mathbf{T_{Dj}}$$

The total up time can be found by subtracting the total down time from NT, i.e. :

$$\text{Total up time} = \text{NT} - \sum_{j=1}^{j=N_F} \mathbf{T_{Dj}} = \text{NT} - \mathbf{N_F}\ \text{MDT}$$

The mean up time or the mean time between failures (MTBF) is therefore given by:

$$\text{Mean time between failures} = \frac{\textbf{Total up time}}{\textbf{Number of failures}}$$

$$\text{MTBF} = \frac{\mathbf{NT - N_F MDT}}{\mathbf{N_F}}$$

The mean failure rate $\bar{\boldsymbol{\lambda}}$ is correspondingly given by: Mean failure rate $= \frac{\textbf{Number of failures}}{\textbf{Total up time}}$

i.e $$\bar{\lambda} = \frac{N_F}{NT - N_F MDT}$$

The availability of the element is the fraction of the total test interval that it is performing within specification, i.e

$$\text{Availability} = \frac{\textbf{Total up time}}{\textbf{Test interval}}$$

$$= \frac{\textbf{Total up time}}{\textbf{Total up time + Total down time}}$$

$$= \frac{N_F \times MTBF}{N_F \times MTBF + N_F \times MDT}$$

i.e. $$A = \frac{MTBF}{MTBF + MDT} \qquad 1.9$$

Unavailability, U is defined as the fraction of the total test interval that is not performing to specification, i.e. failed or down,

$$\text{Unavailability} = \frac{\textbf{Total down time}}{\textbf{Test interval}}$$

giving: $$U = \frac{MDT}{MTBF + MDT}$$

It follows from eqns 1.9 and 1.10 that:

$$A + U = 1 \qquad 1.11$$

If it's assumed that n items of an element survive up to time t $= \xi$ and that Δn items fail during the small time interval $\Delta\xi$ between ξ and $\xi + \Delta\xi$. The probability of failure during interval $\Delta\xi$ (given survival to time) is therefore equal to $\frac{\Delta n}{n}$. Assuming no repair during $\Delta\xi$ the corresponding instantaneous failure rate or hazard rate at time ξ is, from eqn. (1.8) given by:

$$\lambda(\xi) = \frac{\Delta n}{n\Delta\xi} = \frac{\textbf{Failure probability}}{\Delta\xi}$$

The unconditional probability ΔF that an item fails during the iternal $\Delta\xi$ is:

$\Delta F =$ Probability that item survives up to time ξ and probability that item fails between ξ and $\xi + \Delta\xi$ (given survival to ξ). The first probability is given by $R(\xi)$ and from eqn. (1.12) the second probability is $\lambda(\xi)\Delta\xi$. The combined probability ΔF is the product of these probabilities:

$$\Delta \mathbf{F} = \mathbf{R}(\boldsymbol{\xi})\,\boldsymbol{\lambda}(\xi)\Delta\xi$$

i.e. $$\frac{\Delta \mathbf{F}}{\Delta \xi} = \mathbf{R}(\boldsymbol{\xi})\,\boldsymbol{\lambda}(\xi)$$

Therefore, in the limit that $\Delta\xi \to 0$, $\frac{\mathbf{dF}}{\mathbf{d\xi}} = \mathbf{R}(\boldsymbol{\xi})\,\boldsymbol{\lambda}(\xi)$ 1.13

also since $\mathbf{F}(\boldsymbol{\xi}) = \mathbf{1} - \mathbf{R}(\boldsymbol{\xi})$, $\frac{\mathbf{dF}}{\mathbf{d\xi}} = -\frac{\mathbf{dR}}{\mathbf{d\xi}}$,

giving: $$-\frac{\mathbf{dR}}{\mathbf{d\xi}} = \mathbf{R}(\boldsymbol{\xi})\,\boldsymbol{\lambda}(\xi)$$

i.e. $$\int_{\mathbf{R(o)}}^{\mathbf{R(t)}} \frac{\mathbf{dR}}{\mathbf{R}} = -\int_{\mathbf{0}}^{\mathbf{t}} \boldsymbol{\lambda}(\boldsymbol{\xi})\mathbf{d\xi}$$ 1.14

2.3 Forms of failure rate function

The figure below shows the most general form of λ(t) throughout the lifetime of an element (product). This is the so-called bathtub curve and consists of three distinct phases: early failure, useful life and wear-out failure.

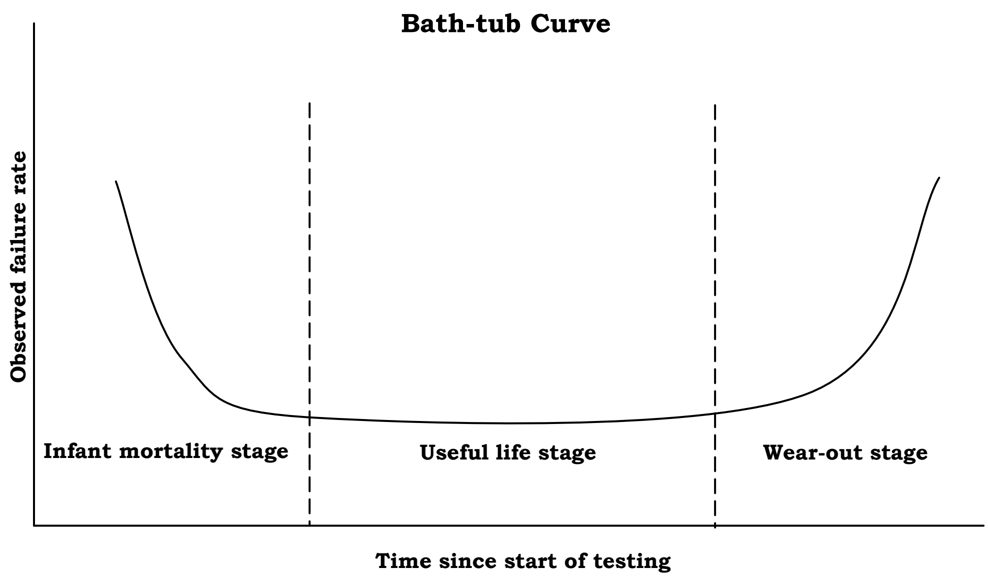

Figure 2. Typical variation in instantaneous failure rate (hazard rate) during the lifetime of element – ‘bathtub curve’

Infant mortality stage: This stage is also called early failure or debugging stage. The failure rate is high but decreases gradually with time. During this period, failures occur because engineering did not test products or systems or devices sufficiently, or manufacturing made some defective products. Again, the early failure region is characterised by λ(t) decreasing with time, when items are new, especially if the element is a new design, early failures can occur due to design faults, poor quality components, manufacturing faults, installation errors, operator and maintenance errors (due to unfamiliarity with the product). Therefore the failure rate at the beginning of infant mortality stage is high and then it decreases with time after early failures are removed by burn-in or other stress screening methods. The hazard rate falls as design faults are rectified, weak components are removed and the user becomes familiar with installing, operating and maintaining the element.

Useful life stage: This is the middle stage of the bath-tub curve. This stage is characterised by a low, constant failure rate. This period is usually given the most consideration during design stage and is the most significant period for reliability prediction and evaluation activities. Product or component reliability with a constant failure rate can be predicted by the exponential distribution. The weak components have been removed: design, manufacture, installation, operating and maintenance errors rectified so that failure is due to a variety of unpredictable lower level causes.

Wear-out stage: The region is characterised by λ(t) increasing with time as individual items approach the end of the design life for the product; long-life components which make up the element are now wearing out. The failure rate increases as the products begin to wear-out because of age or lack of maintenance. When the failure rate becomes high, repair, replacement of parts etc., should be done (Hellyer F G 2009).

However, failure rates are being affected by the following factors: component type, component design, component technology, operational stress (temperature, voltage, pressure etc.), component quality grade (involving production quality and control and post-production screening including burn-in), environmental stress (vibration, shock, humidity), activation and deactivation transients (voltage spikes, current surges, transient thermal stresses), component application.

Many measurement elements have a useful life region lasting many years, so that a constant failure rate model is often a good approximation. Therefore, there is:

$$\lambda(t) = \boldsymbol{\lambda}(\boldsymbol{\xi}) = \boldsymbol{\lambda} = \textbf{constant}$$

so that:

$$R(t) = \exp\left[-\ \boldsymbol{\lambda}\ \int_0^t \boldsymbol{\xi}\right] = \exp\left(-\boldsymbol{\lambda}\mathbf{t}\right)$$

and:

$$F(t) = 1 - \exp(-\lambda t) \quad 1.17$$

A constant failure or hazard rate gives rise to an exponential reliability time variation or distribution shown in figure 2.

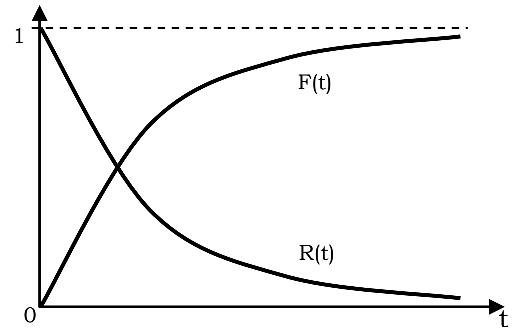

Figure 2. Reliability and unreliability with constant failure rate model

2.4 Design and maintenance for reliability

a. **Element selection**: Only elements with well-established failure rate data/models should be used. Furthermore some technologies are inherently more reliable than others. For instance, an inductive LVDT displacement sensor is inherently more reliable than a resistive potentiometer; the latter involves a contact sliding over a wire track which will eventually become worn. A vortex flow meter involves no moving parts and is therefore likely to be more reliable than a turbine flow meter which incorporates a rotor assembly (Bentley J P (2010)).

b. **Environment**: The environment in which the element is to be located should first be defined and the element should consist of the components and elements which are capable of withstanding that environment. e.g. the diaphragm of a differential pressure transmitter on a tetraoxosulphate (vi) acid duty should be made from a special alloy, which is resistant to corrosion.

c. **Minimum complexity**: For a series system, the system failure rate is the sum of the individual component/element failure rates. The number of components/elements in the system should be the minimum required for the system to perform its function.

d. **Redundancy**: The use of several identical elements/system connected in parallel increases the reliability of the overall system. Redundancy should be considered in situations where either the complete system or certain elements of the system have too high a failure rate.

e. **Diversity**: In practice faults can occur, which either causes more than one element in a given system or a given element in each of several identical systems, to fail simultaneously. These are referred to as common mode failures and can be caused by incorrect design, defective materials and components, faults in the manufacturing process, or incorrect installation. One common example is an electronic system where several of the constituent circuits share a common electrical power supply; failure of the power causes all of the circuits to fail.

2.5 Maintenance for reliability

Maintainability and reliability are the two major system characteristics that combine to form the commonly used effectiveness index called availability. While maintainability is important as a factor of availability, it also merits substantial consideration as an individual system characteristic. Maintainability is a characteristic of a design consideration and installation.

Maintenance is all actions necessary for retaining a hardware item in or restoring it to an optimal design condition through diagnosis, repair and inspection. The Mean Down Time MDT for a number of items of a repairable element has been defined as the mean time between the occurrence of the failure and the repaired element being put back into normal operation. It is important that MDT is as small as possible in order to minimize the financial loss caused by the element being out of action. There are two main types of maintenance strategy used with engineering system elements. **Corrective maintenance** is that maintenance performed on a non-scheduled basis to restore equipment to satisfactory condition by correcting a malfunction. This is breakdown maintenance simply because it involves repairing or replacing the element when it fails. In this case MDT or mean repair time, T_R is the sum of the times taken for a number of different activities. These include realization that a fault has occurred, access to the equipment, fault diagnosis, assembly of repair equipment, components and personnel, active repair/replacement and finally checkout. **Preventive maintenance** is the systematic inspection, detection and correction of incipient failures either before they occur or before they develop into major defects. Adjustment, lubrication and scheduled checks and servicing of equipment and replacement of components at regular fixed intervals are included in the definition; the corresponding maintenance frequency is *m* times per year. MDT or mean maintenance time, T_M is the sum of times for access, service/replacement and checkout activities and therefore should be significantly less than mean repair time with breakdown maintenance. Therefore the factors which affect the frequency with which maintenance is needed are reliability and the preventive maintenance schedule. Those which affect the ability to perform maintenance on a given system may be broken down into three categories: the physical design of the system, the technical personnel performing the maintenance and the support facilities required.

3.0 Methodology

3.1 Choice of engineering systems

The methods to be used and problems involved in choosing the most appropriate engineering system for a given application can be illustrated by a specific example. The first step to take is to draw up a specification for the required engineering system. This will be a list of all important parameters for the complete system such as measurement error, reliability, accuracy, cost (Hearley M (2009)); each with a desired value or range of values. The system measurement error in the steady state can be quantified in terms of the mean $\bar{E}$ and standard deviation σ_E of the error probability distribution p(E). These quantities depend on the imperfections e.g. non-linearity, repeatability of every element in the system. The system failure rate λ and repair time T_R must be clearly defined. Initial cost C_I is the cost of purchase, delivery, installation and commissioning of the complete system. C_R is the average cost of materials for each repair. The system must be technically feasible, also the environment of the user's plants and the maintenance strategy used. Therefore, based on a straightforward comparison of job and system specification, the best choice of application can be made possible. In order to choose the correct system for a given application, the financial value of each parameter in job specification must be taken into account; also in a costing application of engineering system, a digital system is more suitable than an analogue trend.

3.2 Total lifetime operating cost

The total lifetime operating costing (TLOC) of an engineering system is the total cost penalty, incurred by the user during the lifetime of the system. The TLOC is given by:

TLOC = initial cost of the system (purchase, delivery, installation and commissioning)

+ cost of failures and maintenance over lifetime of the system

+ cost of measurement error over lifetime of the system. 1.29

This therefore takes account of the financial value of each parameter in the job specification. The best system for a given specification is then the one with minimum TLOC. This method also enables the user to decide whether a measurement system is necessary at all. If no system is installed, TLOC may still be very large because no measurement implies a large measurement error. An engineering system should be purchased if it produces a significant reduction in TLOC.

If the system lifetime is T years and average failure rate $\boldsymbol{\lambda}$ fault $\mathbf{yr^{-1}}$, then the total 'downtime' due to repair is $\boldsymbol{\lambda}\mathbf{TT_R}$ hour**s.** The total lifetime cost of failures is the sum of the repair cost (materials and labour) and the process cost, i.e. the cost of lost production and efficiency while the engineering measuring system is withdrawn for repair. If we define

₦ $\mathbf{C_R}$ = average materials cost per repair
₦ $\mathbf{C_L}$ = repair labour cost per repair
₦ $\mathbf{C_P}$ = process cost per repair

then the total repair cost is ($\mathbf{C_R}\,\boldsymbol{\lambda}\mathbf{T} + \mathbf{C_L T_R}\,\boldsymbol{\lambda}\mathbf{T}$ **)** and the total process cost is $\mathbf{C_p T_R}\boldsymbol{\lambda}\mathbf{T}$**,** giving:

$$\text{Total lifetime cost of failures} = [\mathbf{C_R} + (\mathbf{C_L} + \mathbf{C_P})\mathbf{T_R}]\,\boldsymbol{\lambda}\mathbf{T} \qquad \mathbf{1.30}$$

The above costs only apply to breakdown maintenance; many users also practise preventive maintenance in order to reduce failure rates. Suppose preventive maintenance is carried out on a measurement system *m* times $\mathbf{yr^{-1}}$, the average maintenance time is $\mathbf{T_{\boldsymbol{m}}}$ hours and the materials cost per service is ₦ $\mathbf{C_M}$. The total number of service is *m*T and the total time taken for preventive maintenance is *m*T$\mathbf{T_{\boldsymbol{m}}}$ hours (Paradine C G and Pivett BHP (2011)). Usually preventive maintenance of measurement system is carried out at a time when the process of the plant itself is shut down for repair and maintenance. This means that no process costs are incurred during preventive maintenance (Sargent R A E (2010)), giving

$$\text{Total lifetime maintenance cost} = (\mathbf{C_M} + \mathrm{C_L T_M})\mathrm{mT}$$

4.1 Conclusion

The economy situation of the country needs to be criticised by the technological dimension rather political instability, the degree of control measure is unstable and challenging, inwardly, the reliability processes from pragmatic perspective will bring about choice of decision making in governmental policies and affair of the import goods and services to be rendered the technical personnel. The Standard Organisation of Nigeria (SON) is a form of reliability organisation that should immensely involve in technical challenges of products through update failure reporting and services to meet desired goals beyond reasonable doubt. The observability and controllability of importation of goods should meet international standard rather than using Nigeria as a dumping ground due to carelessness of the reliability engineers. It is detrimental to health and general safety. Nevertheless, the reasons for wanting high product or component or system reliability are obvious: higher customer satisfaction, increased sales, improved safety, decreased warranty costs and decreased maintenance costs, etc.

Meeting standard goes with the following categories of test: reliability demonstration test, acceptance test, calibration test, non-destructive test, identification and pre-production test, including packing and transportation test. If all these various testing could not be met, the degree of failure is very high. Government, societies, communities need to set a target in the field of science and technology to enhance national development.

References

Wright R I (SRD Warrington)(2007):‘ Instrument reliability,’ Instrument science and Technology, vol 1, Bristol, Institute of physics, pp.82-92.

Lees F P (2010): ‘The reliability of Instrumentation ,’ Chemistry and Industry ,March.pp.195-205.

Hellyer F G (Protech Instrumentation and systems)(2009): ‘The application of reliability engineering to high integrity plant control systems’ Measurement and control, 18 June, pp 172-6.

White J, Yeats A and Skipworth G (2005): Tables of statisticians ,Stanley Thorne, London,pp.18-19.

Bentley J P (2010): Error in industrial temperature measurement systems and their effect on the yield of a chemical degradation reaction ‘8th IMEKO Congress of the International Measurement Confederation, Moscow,May.

Hearley M (2009): Principle of Automatic Control, English Universities Press, London, pp. 308-9.

Paradine C G and Pivett BHP (2011): Statistical methods for Technologists, pp.165-7 English Universitties press, London

Sargent R A E (2010): ‘Predicting accuracy in gas mass flow computing systems,’ control,Jan.2010.