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AUTOMATED TELLER MACHINE RELIABILITY, PROBLEMS AND RISKS

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ABSTRACT

As machines and devices are manufactured, engineers and designers try as hard as possible to be perfect and produce devices that perform to optimal levels. However, no matter how good the design is, it is prone to failure at some stage in its life time. This is because devices are mostly made of moving parts, which may wear out due to friction, or electronic components which may be affected by the environment they function in. This brings about the problem of device reliability. This paper aims at coming up with reliability models for Automated Teller Machines (ATMs) that can be extended to other computer hardware. Reliability models were formulated. Comparisons were made between simulated data and actual data collected over time at a local Building society Bank in Zimbabwe. The results indicate that the value of the hazard rate function is 0.02. This means that the probability of failure in a very small interval of time is very low and we are unlikely to get a failure in such an interval. The mean time before failure (MTBF) is 28.704 which translate to 28 days before a failure at the stated values of k (the average failure rate of the system) and, the initial number of failures at time. This is a fairly large period that provides some confidence that the system is reliable.

***Key Words**: Reliability, Failure.*

1. INTRODUCTION

An automated teller machine or automatic teller machine or automated banking machine is a computerized telecommunications device that provides the clients of a financial institution with access to financial transactions in a public space without the need for a cashier, human clerk or bank teller (Wikipedia, 2012). During the past two decades the financial sector has developed rapidly in terms of size, industry structure and the variety of consumer banking business (Edey, 1996). This prompted most banking sectors to reduce pressure within the banking hall and hence the intensive use of ATMs. However some authors view them as a result of Technological developments and financial liberalisation (Edey & Gray, 1996; Thompson, 1996; Gardener et al. 1999). These technological changes motivated banks to be aware of future trends in order to survive and compete. Automated service provides a good opportunity for organisations to provide new models for service design strategies and new service development (Henderson et al., 2003). This means that there is reduced manual and paper work within the banking system. The invention of these ATMs has prompted most researchers to find out on the reliability of the machines. Gupta (1992) defines device reliability as the probability of a device performing adequately for the period of time intended, under the operating conditions encountered. The problem of reliability means that it is impossible to have a device in working state 100% of the time.

Computer hardware are devices prone to such failure, in particular, Automated Teller Machines (ATMs). Thus we are faced with the problem of ATM reliability, that is, the probability that an ATM will perform adequately for the period of time intended under the operating conditions encountered. An ATM is expected to be in service for 24 hours per day throughout the year. Adequate performance for an ATM means that the machine should be able to: -

1. Dispense cash to clients.
2. Give out account statements and balance receipts.
3. Provide journal printouts for ATM minders and audit purposes.
4. Provide any other e-commerce services it is expected of.

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An inability to perform any of the above services means an ATM failure has occurred.

Reliability engineering started in military and space technology around the early 1950s. With high advances in the design and development of highly complex equipment in the fields of missile and space technology, under the use of such equipment under high stress conditions and relatively unknown exotic environments, the problems of performance failure began to demand increasing attention in America. The US Department of Defence and the electronics industry set up a task force - The Advisory Group on Reliability of Electronic Equipment (AGREE)- in 1950 hence it was the beginning of the current reliability thinking. The general accepted definition of reliability is "the characteristic of an item expressed by the probability that it will perform a required function under the stated period of time (Leitch, 1988).

Examples of reliability indices and goals are: -

1. For a telephone system, the down time for each switching centre should be a maximum of 24 hours per 40 years.
2. For an engine manufacturer, 70% of the engines produced should pass through the warranty period without generating a claim. The number of failures per failed engine should not exceed 1.
3. For a consumer product manufacturer, the percentage failure shall be a maximum of 5.7% 'dead on arrival' , 6.4% during the first month, an average of 2% per month during the first year, and an average of 1.2% during the 5 year service life. (Beasley, 1991)

The reliability of an item that can only fail once, such as a transistor or a light bulb, is usually defined as the probability of no failure over a specified time period, which might be expected life time of the item. During this period the instantaneous probability of failure is called the hazard rate (Corder, 1977). Other reliability characteristics such as MTTF (Mean Time to Fail) or the expected life, by which a specified proportion, say 10%, might have failed, are also used. For repairable items and systems, the reliability can be characterised by the MTBF (Mean Time Before Failure), but only when the failure rate is constant with time.

Hazard rates can be constant, or can vary with time. Knowledge of the hazard rate trend can be very revealing in helping to identify and understand the underlying causes of failure. A constant hazard rate is usually characteristic of failures caused by random application of loads that exceed the design strength, occurring at a constant average rate. Decreasing hazard rates are seen in items that become less likely to fail with increasing time. This pattern is characteristic of failure due to production quality problems, such as the production of weak components which fail early, leaving a population of good components with longer life to failure (Gupta, *1992*). The ' burn in' of electronic components is a good example of how the knowledge of a decreasing hazard rate is used to improve the reliability of a product, by deliberately causing weak items to fail without damaging good ones. Increasing hazard rates are found in devices that suffer strength deterioration with age due, for example, to wear, fatigue, corrosion, etc.

Even though many people think that most ATMs are unreliable there are some scientific and technical mechanisms which are done to avert the problem of reliability. Martin(1995) outlines that there are three basic techniques to achieve reliability: ARQ (Automatic Repeat Request), FEC (Forward Error Correction) and hybrid mechanisms of ARQ in combination with FEC. ARQ is a mechanism based on retransmissions of data that were not correctly received due to some technical problems (Stephan, 1998). ARQ offers two variants and both require the transmitter and receipt to exchange state information. In a variant the receiver sends positive acknowledgement (ACK) messages back to the sender even when it has successfully received the packets. This is a mechanism to improve reliability in unicast transmissions. In the second variant of ARQ the receivers send negative acknowledgement messages (NACK) back to the sender only when there are lost data. According to Ernst (1993) FEC is an important alternative to ARQ whose operation principle is to encode the packets in emitter with redundant information so that it is possible to reconstruct the original packet reducing, or even eliminating, the retransmissions and the negative effect of implosion. While ARQ adds latency (due to cost of NACK) and implosion, FEC adds overhead and hence the redundant code added by this method is useless when the network is experiencing congestion. Hence, ARQ may not be suitable for applications with requirements of low latency, and FEC has worse behaviour in networks with low bandwidth or that experiences frequent congestion.

2. METHODOLOGY

The research aims at coming up with reliability models for ATMs which however can be extended to other computer hardware. This is a fairly new area of mathematics with not much detailed previous studies. Basic mathematical modelling forms an important part of this. This means that data and other observations collected from the environment under investigation (in this case, Building Society in Zimbabwe) coupled with the experience gained by the author while on work related learning in the organisation’s Information Technology department.

Logical assumptions will be made so as to make modelling feasible. Basic assumptions enable the investigator to

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have some control over the environment under study since it is difficult to analyse an open environment. Existing reliability growth models for example the Duane reliability growth model, Weibull distributed models and Exponential models, will be used as foundation for model formulation. Comparisons will be carried out using system of ATMs at local Building Society in Zimbabwe.

2.1 Benefits of the Research

This research is of importance to almost all banks and building societies since ATMs do most of the bulk transactions on a day to day basis. The research is also important to the scientific and engineering world as it tries to establish the mathematics behind ATM reliability.

The main benefits of this research are: -

1. It shall provide a basic understanding of reliability.
2. Allow hardware users to have an idea of how reliable their devices are and be able to budget for their repairs and replacements.
3. The research will enable repair technicians to schedule their Preventive Maintenance appropriately.
4. Enable scientists to describe hardware reliability in mathematical terms and improve their approach to hardware design.

2.2 Model formulation

Below we explain the notation which is going to be used and in the model formulation.

n : the number of preventive maintenances done on the system ($0 \le n \le 12$).

N_0 : the initial number of failures at time t_0

k :the average failure rate of the system ($0 < k < 1$).

t : time (months).

t_0 : the initial time.

ε : is the inverse of the number of preventive services done annually.

2.3 Assumptions

1. The workload for each machine in the system is the same.
2. Each machine contributes equally to the reliability or unreliability of the ATM.
3. System faults are independent of each other within the system of ATMs.
4. A fault is removed instantaneously without delay.
5. Removal of a fault does not generate a secondary fault.
6. Some preventive maintenance is done on the system n times a year.
7. Each ATM is restored to as good as new status after fault removal.
8. Reliability depends on some factor of the preventive maintenance.
9. The reliability depends on some time t_0 and the number of faults at that time, N_0
10. The rate of fault occurrence in the system is indirectly proportional to the reliability.
11. The reliability is an exponential function of time.
12. All the ATMs in the system started operating at the same time and are of the same age.

Notes

1. If we assume that the number of possible preventive maintenance, n, is such that $1< n <12$ (at most one preventive maintenance a month), we can safely state, from assumption 8, that a factor of 1/n affects the reliability directly.
2. If we assume a failure rate of k, then from assumption 3, then a factor of 1/k affects reliability.

From Reliability principles, hardware reliability decreases with time. From assumption 11 we can state an exponential relationship of the form:

$$R(t) = Ae^{-CT}$$

where R(t) is reliability at time t.
A is some constant
C is another constant and
T is a function of time

From notes 1 and 2, we can assume the value of A to be the quotient of $\left(\frac{1}{n}\right)^2$ and k to give us

$$A = \frac{(1/n)^2}{k}.$$

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Assuming that number of faults at time t_0 is N_0, we can take C to be the quotient of the failure k and the initial number of faults N_0 to yield

$$C = k/N_0$$

Let T be the function of time that describes the difference between the current time and the initial time.

Then

$$T = t - t_0$$

Therefore the reliability at time t is given by

$$R(t) = \frac{\varepsilon^2}{k} e^{-\frac{k}{N_0}(t-t_0)}$$

where ε= 1/n

[R (t) is the probability that a system does not fail in time t].

Assuming that the random variable T describes the time to the next failure, and that U(t) is the unreliability of the system.

Then
R (t) = 1- U (t) and R(t) = prob (T>t)

Supposing that some function, f(t), denotes a probability function, representing the reliability value, T`.

$$R(\theta) = \int_t^{\infty} f(\theta) d\theta$$

$$f(\theta) = \frac{d}{d\theta} \frac{\varepsilon^2}{k} e^{-\frac{k}{N_0}(\theta - t_0)}$$

$$= -\frac{\varepsilon^2}{N_0} e^{-\frac{k}{N_0}(\theta - t_0)} \qquad t \le \theta \le \infty$$

This gives a negative probability density function. Since f(θ) defines the gradient of R(θ) at some point in the interval t ≤ θ ≤ ∞, we can note the overall change in the gradient by taking the difference of the gradient functions at the extreme points of the interval that is

$f(t) = f(t_\infty) - f(t)$ is given by

$$f(t) = -\frac{\varepsilon^2}{N_0} e^{-\frac{k}{N_0}(\infty - t_0)} - \left[-\frac{\varepsilon^2}{N_0} e^{-\frac{k}{N_0}(t-t_0)} \right]$$

$$= \frac{\varepsilon^2}{N_0} e^{-\frac{k}{N_0}(t-t_0)} \quad \text{for } t > 0$$

This function is only important in finding the other reliability characteristics like the cumulative distribution of failure; F(t), mean time to fail (MTTF) and mean time between failures (MTBF). In this research we are interested in F(t) and MTBF. MTTF tends to describe devices/components which fail once in their life time e.g. transistors, resistors and light bulbs and is of no concern in this research because we are studying devices which fail more than once.
The cumulative distribution, F (t), is given by

$$F(t) = \int_0^t \frac{\varepsilon^2}{N_0} e^{-\frac{k}{n_0}(\theta - t_0)} d\theta$$

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$$= -\frac{\varepsilon^2}{N_0}\frac{N_0}{k}e^{-\frac{k}{N_0}(\theta - t_0)}\Bigg|_0^t$$

$$= \frac{\varepsilon^2}{k}e^{-\frac{k}{N_0}(\theta - t_0)}\Bigg|_0^t$$

$$= \frac{\varepsilon^2}{k}\left[-e^{-\frac{k}{N_0}(t-t_0)} - \left(-e^{\frac{kt_0}{N_0}}\right)\right]$$

$$= \frac{\varepsilon^2}{k}\left(e^{-\frac{k}{N_0}(t-t_0)} + e^{-\frac{kt_0}{N_0}}\right)$$

$$= \frac{\varepsilon^2}{k}e^{\frac{kt_0}{N_0}}\left(1 - e^{-\frac{kt}{N_0}}\right)$$

The MTBF is the expected time, E(t), to the next failure and is given by

$$MTBF = E(t) = \int_0^\infty R(t)dt$$

$$= \int_0^\infty \frac{\varepsilon^2}{N_0}e^{-\frac{k}{N_0}(t-t_0)}dt$$

$$= \frac{\varepsilon^2}{N_0}\left[-\frac{N_0}{k}e^{-\frac{k}{N_0}(t-t_0)}\Bigg|_0^\infty\right] t_0 << \infty$$

$$= \frac{\varepsilon^2}{N_0}\left(\frac{N_0}{k}e^{-\frac{k}{N_0}(-t_0)}\right)$$

$$= \frac{\varepsilon^2}{k}e^{\frac{kt_0}{N_0}}$$

The hazard rate function, z(t), is given by

$$z(t) = \frac{-d\ln R(t)}{dt}$$

$$= -\frac{d}{dt}\left[\ln\left(\frac{\varepsilon^2}{k}e^{-\frac{k}{N_0}(t-t_0)}\right)\right]$$

$$= -\frac{d}{dt}\left[\ln\frac{\varepsilon^2}{k} + \ln e^{-\frac{k}{N_0}(t-t_0)}\right]$$

$$= -\frac{d}{dt}\left[\ln\frac{\varepsilon^2}{k} - \frac{k}{N_0}(t-t_0)\right]$$

$$= -\left(-\frac{k}{N_0}\right)$$

$$= \frac{k}{N_0}$$

2.4 Testing Of The Model

2.4.1 Goodness Of Fit Test

This is done to check the validity of the model. The hypothesis to be tested is:

H_0 : Model describes ATM reliability over time.
H_1 : Model does not describe ATM reliability over time.

$$\chi_0 = \Sigma_{i=1}^{n}\frac{(O_i - E_i)^2}{E_i} \sim \chi^2(n-1)$$

where
O_i is the observed frequency,
E_i is the expected frequency and
n is the total number of observations.

χ_0 statistic is compared with the tabled χ^2(n-1) at α level of significance. H_0 is rejected when the test statistic is greater than the table value. The model will be tested on 3 categories of faults, Normal, High and Critical.

Definitions of categories

1. Normal faults are those light faults which allow the ATM to continue operating even when they are present for example a receipt printer fault, the machine can still continue providing services without receipts.
2. High faults are those faults which, when left unattended, will generate more faults or cause the ATM not to function at all, e.g. a blown sensor in the cash dispenser will put more workload on the working ones exposing them to failure.
3. Critical faults are those faults that hinder the operation of the ATM upon their occurrence. Examples include, a failure in the journal printer upon which no appropriate recording of transactions can take place, or a mistiming dispenser which will lead to the dispensing of either too much money or too little from that requested.

Data used for comparison was collected from the local Building Society Help Desk system (Zimbabwe). The data spans over 35 months, from May 2001 to March 2004 for all the 3 categories of faults. The system is made up of 35 ATMs.

3. RESULTS AND DISCUSSION

We shall consider the value of $\varepsilon = \frac{1}{n} = \frac{1}{6}$ in this research.

3.1 Models

From the derivations made above in section 2.3 the following models were derived.

(a) Reliability Growth model. $R(t) = \frac{\varepsilon^2}{k} e^{-\frac{k}{N_0}(t-t_0)}$

(b)The mean time between failures (MTBF)

$$MTBF = \frac{\varepsilon^2}{k} e^{\frac{kt_0}{N_0}}$$

(c)The Hazard rate

$$z(t) = \frac{k}{N_0}$$

3.2 Model Verification

In this section we seek to find out whether R(t) lies between 0 and 1 (that is 0<R(t)<1). Also there was need to check if these probabilities would give feasible expected number of faults, (N>1). The model brought about probabilities between 0.9241 to 0.7799 for the simulated period of 50 months at the ideal values of k=0.03 and with six occurrences of preventive maintenance per annum. The simulated expected number of faults in the system produced a range of number of faults from 3.04 to 8.80 for the simulated period of 50 months. R(t) displayed an exponential decrease over time for the simulated 50 months as shown in figure 1.1 below.

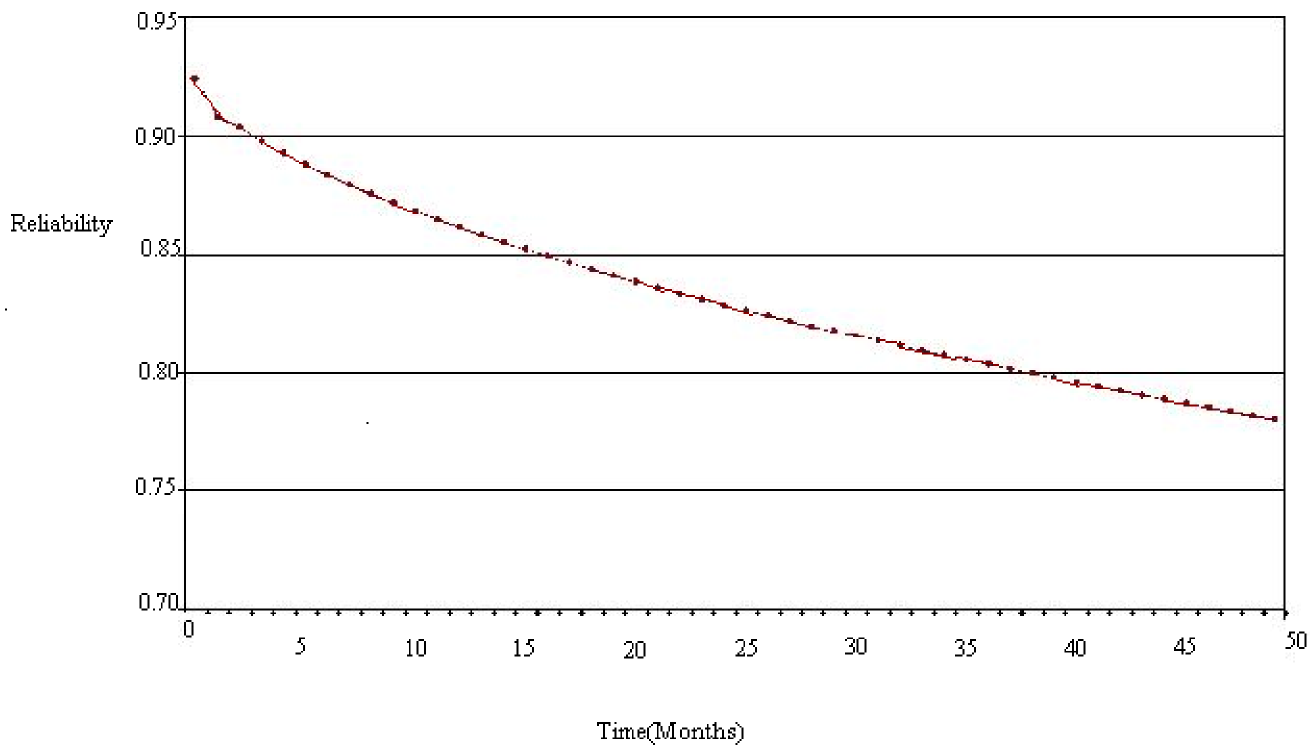

Fig. 1.1: Graph of Reliability against Time.

3.3 Model Validation

The generated probabilities were checked to see if they described ATM reliability using the following hypothesis.

H_0: the model describes ATM Reliability over time.

H_1: the model does not describe ATM Reliability over time.

The three χ^2test statistics for the Normal, High and Critical type of faults were found to be 38.22, 37.85 and 42.34 respectively, compared with the table value of 59.3 from the chi-square distribution at α=0.05 (two tail test).

A graph showing the average number of faults for the 3 types of faults and the projected number of faults from the reliability growth model for 35 months is shown below.

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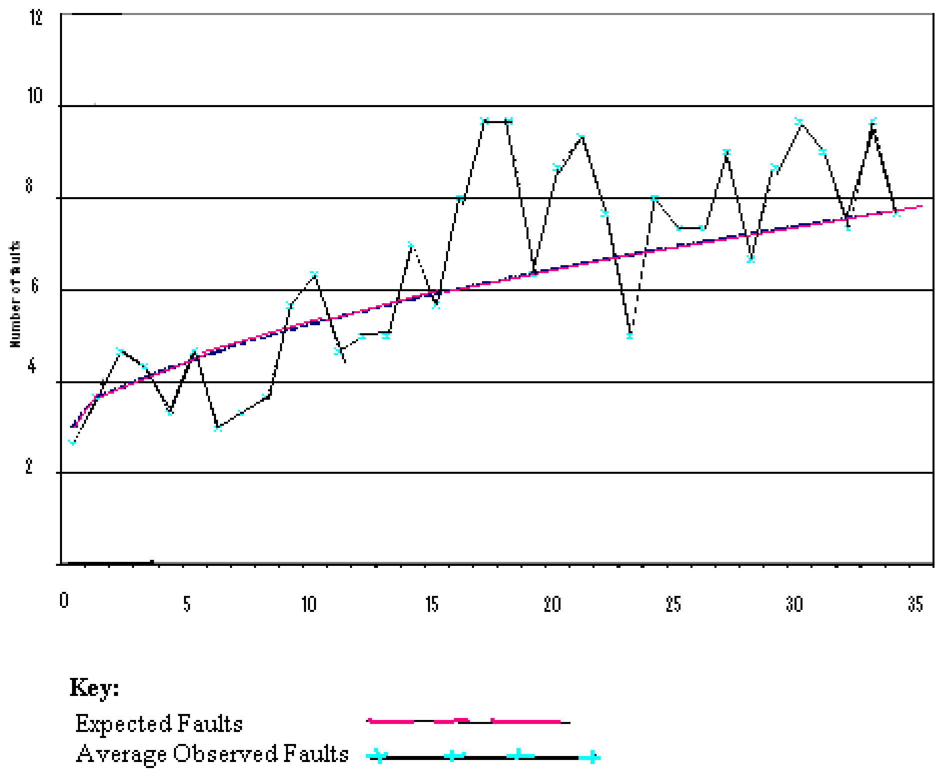

Fig. 1.2: Graph of expected faults and average of observed faults over time.

It can be observed from Fig 1.2 that the observed number of faults and the projected number of faults both generally show an upward trend meaning that number of faults per month are increasing over time. This is a result of decreasing reliability over time since Reliability is inversely proportional to the number of failures that occur.

3.4 The Reliability Function, R (t)

This was found to depend on the constants k and N_0 (the average failure rate and the initial number of failures). We shall analyse the behaviour of R (t) at different values of k and N_0. For k we seek to verify the assertion by previous researchers that the value of k is in the neighbourhood of 0.03 for a normal system.

3.4. 1 R (t) Calculated Over Different Values Of N_0

The reliability values were calculated using different initial number of failures over a period of 50 months. The author arbitrarily picked values of N_0 used. The values were: 10, 15, and 20. The behaviour of R (t) over these initial values is shown in the graphs below.

From fig 1.3, fig 1.4 and fig 1.5 it can be observed that the function behaves in a very similar way for all the three values of N_0 chosen. The starting points for the function are different for each N_0 and so are the corresponding values at the points in between. The corresponding values of R (t) to the respective initial N_0 are given in the Table 1.1 below.

Table 1.1: Corresponding values of R (t) to different values of N_0

N_0	$R(t_0)$	$R(t_{50})$
10	0.923152311	0.779878208
15	0.924075925	0.779878208
20	0.924538078	0.779878208

The value of R (t) at the initial time is greatest for the largest N_0 and smallest for the least N_0. However, the value of R (t) at t = 50 is the same for all the 3 initial values that is 0.779878208. This means there is a greater change of gradient in the R(t) function for greater values of N_0. The graphs for the different initial number of faults in the system over time are given below. They serve to show the similarities in the behaviour of the reliability growth function, R (t).

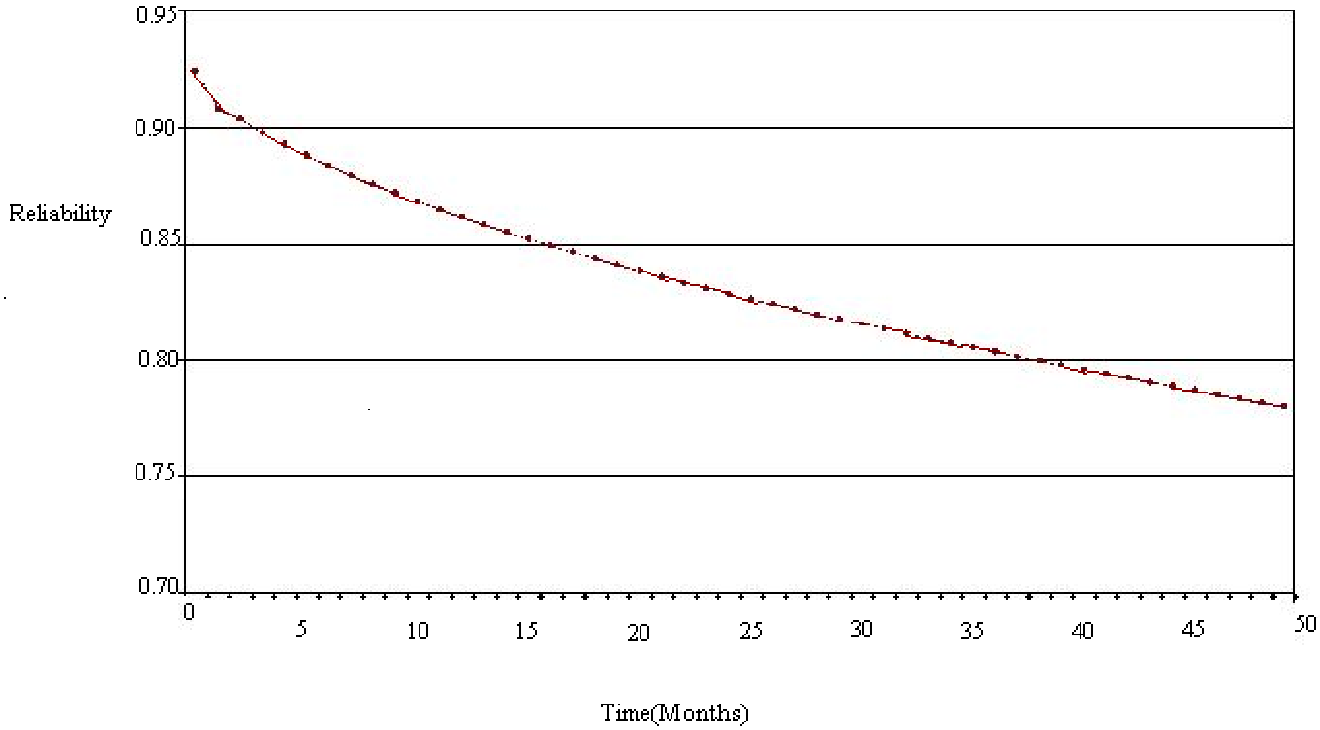

Fig. 1.3: Graph of reliability over time beginning at N_0=10

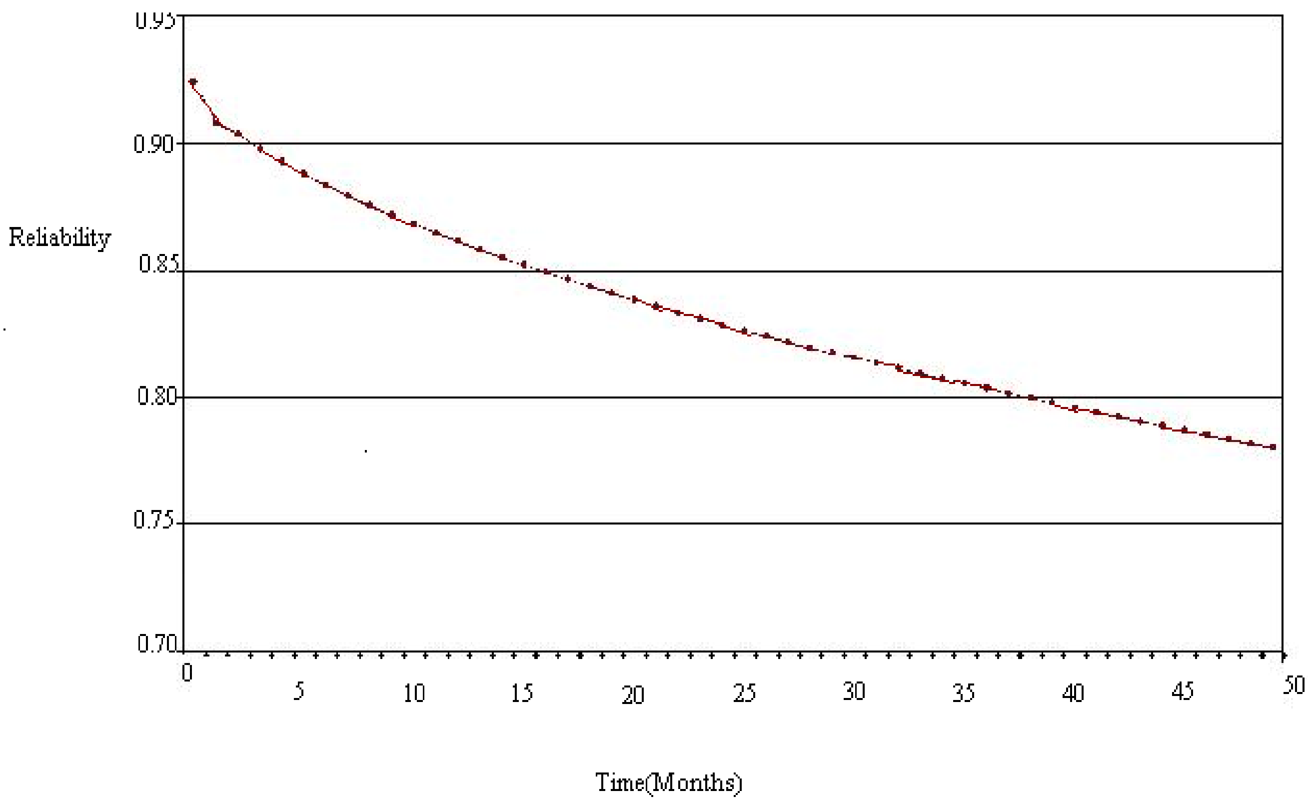

Fig 1.4: graph of reliability over time beginning at N_0=20

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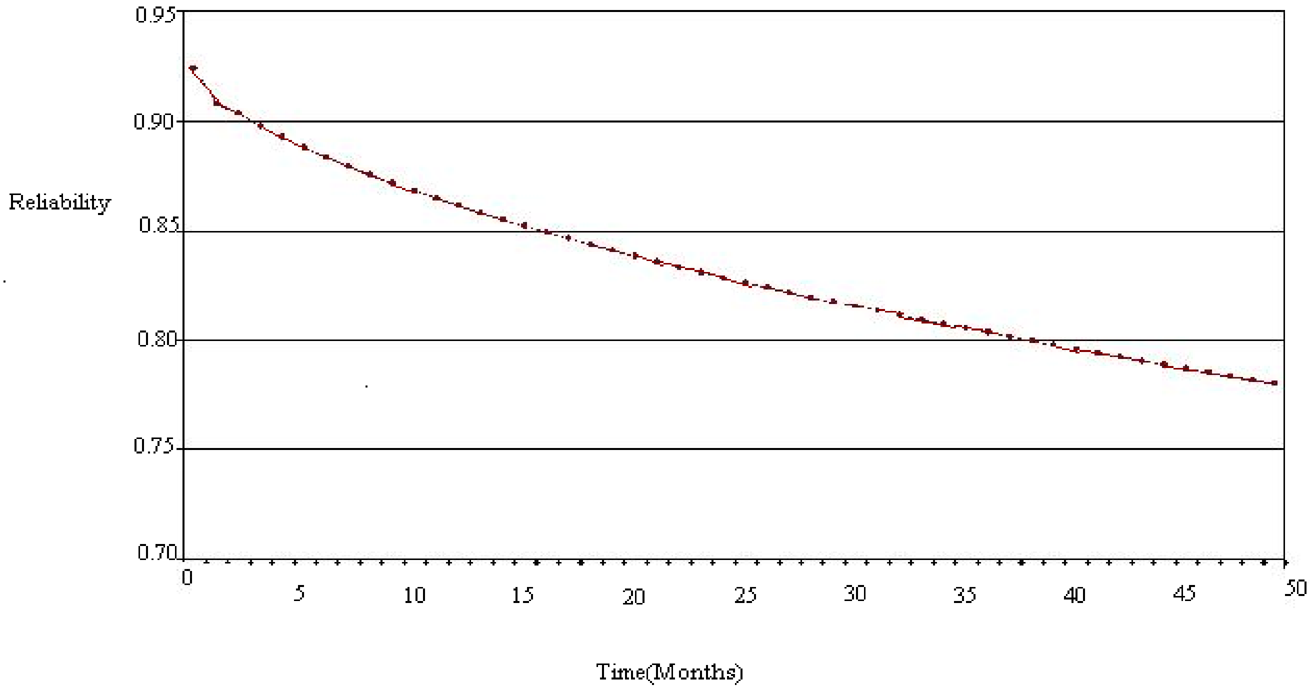

Fig.1.5: Graph of Reliability over time beginning at N_0=15

3.4.2 R (t) Calculated Over Different Values Of k

The values of k arbitrarily in the neighborhood of 0.03 were chosen. These values used are: 0.020, 0.0298, 0.0300, 0.032 and 0.035. N_0 was held at 15.

At k = 0.02

The values of R(t) ranged from 1.387038 to 1.299315 for the simulated period of 50 months. The expected number of faults ranged from –15.48 to –11.97 for the same period of time. These are negative values hence the expected number of faults under such a scenario do no exist.

At k = 0.0298

R (t) values ranged between 0.93029 and 0.843998. The test statistic for the Normal, High and Critical categories of faults are 24.89, 43.94 and 37.99 respectively, against a table value of 59.3. Therefore we accept our null hypothesis, hence the model is valid.

At k = 0.032

R(t) values start at a lower value than that of k=0.03 at R(t)=0.866206 and ends at 0.7802 for t=50. The test statistics (42.39, 45.76, 37.57) are still in the region of acceptance (<59.3) of the null hypothesis and we therefore accept H_0

At k=0.035

R(t) values are range between 0.7918 and 0.7063 for the simulated period of 50 months. The test statistics are 110.21, 105.48 and 96.83 respectively. Therefore we reject the null hypothesis.

3.4.3 The Hazard Rate and MTBF.

Gupta (1992) states that a model of an exponential form should have a constant Hazard rate and a constant MTBF. This is true for our model as our hazard rate and MTBF are given by:

$$z(t) = \frac{k}{N_0} \quad \text{and} \quad MTBF = \frac{\varepsilon^2}{k} e^{\frac{kt_0}{N_0}} \text{ respectively.}$$

The values of k and N_0 are the ones that determine the magnitudes of these 2 characteristics. For example, if $t_0 = 0$, k = 0.03 and N_0 = 15, the values of z(t) and MTBF will be given by :-

$$z(t) = \frac{0.03}{15} = 0.002$$

and

$$MTBF = \frac{\varepsilon^2}{0.03} e^{\frac{0.03*0}{N_0}} = \frac{\varepsilon^2}{0.03} = 0.925925925$$ of a month which translates to 28.704 days.

3.4.4 ATM Life Span Policies

These can be determined by the values of R(t). Two options deduced in this research project are:-

1. Have a cut off reliability value of say R(t)=0.600 that is a system reliability of 60%. When R(t) have reached this value, it means some of the ATMs in the system are no longer reliable and we would have to look at individual histories for each ATM in the system and determine which machines are contributing more on the unreliability of the system. Then we either remove them from the system or replace them.

It is important to note the differences in successive values of R(t) i.e. $R(t_{i+1}) - R(t_i)$. If this difference is some stated value (depending on the organization's reliability policies), large say greater than 0.1, then the system is rendered unreliable. We then proceed to examine the individual histories of each machine in the system and eliminate or replace those which seem to contribute more to the unreliability of the system. The justification for this life span option is that this difference reflects the rate at which reliability falls between 2 successive time intervals.

4. CONCLUSIONS AND RECOMMENDATIONS

An analysis of the behavior of R (t) at N_0=10, 15 and 20 provided from Figures 1.3, 1.4 and 1.5, it was realized that the behavior of R(t) is similar in all graphs. Table 1.1 shows the values of R(t) at the beginning and at the end of the simulated period of 50 months. From the behavior of R(t) we can conclude that the reliability values falls faster for greater values of N_0 than for smaller values. Thus device reliability will be compromised as number of faults increase.

For a value of k=0.02, the values of R (t) ranged from 1.387038 to 1.299315 which are out of the range of $0 \le R(t) \le 1$. Therefore we can conclude that k=0.02 is not a feasible value as it produces values of R(t) out of the range $0 \le R(t) \le 1$. These values of R(t) suggest a perfect system which has no failures. This is impossible in real life.

It was realized that for k=0.0298, k=0.03 and k=0.032, the model is valid. Hence we can conclude that these values are feasible values of k. We can also conclude the assertion that k in the neighborhood of 0.03 is justified. We can take these values of k as those that are characteristic of a normal system.

For k=0.035, the model was rejected and therefore, 0.035 is not a feasible value of k as it assumes a system with an unacceptable failure rate.

The value of the hazard rate found is 0.02 at k=0.03 and N_0=15. This means that the probability of failure in a very small interval of time is very low and we are unlikely to get a failure in such an interval. The MTBF at k=0.03 and N_0=15 is 28.704 which translate to 28 days before a failure occurs (depends on the values of k and N_0). This is a fairly large period that provides some confidence that the system is reliable. We can recommend that engineers have to service their ATMs at a rate dependent on the MTBF. For example, using the value of MTBF above, it would be recommended that the ATMs be serviced once in every 25 days to avoid failures at approximately the 28th day. They also have to try to maintain a constant failure rate of around 0.03 by continuously monitoring the system and replacing obsolete components from the machines.

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