A Nonparametric Analysis of Asymptomatic Hazard Rates in a Brewing Plant Using the Probability Failure Functions

J.I. Achebo; O. Oghoore

Abstract- A human error is an act of commission or omission which leads to a failure to perform a specified task. This failure could result in damage to property and equipment inevitably creating a hazardous scenario. There are two types of human errors; critical human error which could cause imminent system break down (unplanned breakdown). Secondly, there are latent (asymptomatic) human errors, which would not usually lead to an immediate system breakdown. The inability of employees to operate machines and equipment, and perform routine and thorough maintenance exercises within specified safety regulations in an engineering system could lead to a significant rise in asymptomatic hazard rates, hence this project. The probability density and hazard rate functions were used to determine the hazard rates of the plant studied. The acceptable failure time is the longest time a system is expected to remain functional at 95% confidence level before it fails. From the computations in this study it was discovered that the acceptable and anticipated range of mean time to failure (MTTF) should fall between 18.96 hours and 53.7 hours, being the normal range for failure distribution for the plant. The design life of the plant studied is originally 21 hours but it attained a MTTF of 40 hours. Therefore, the System's MTTF of 40 hours falls within the computed range of MTTF anticipated. The desired goal has been met, because the system is working within the acceptable range. For this reason the incidence of hazard can be controlled. If the MTTF falls below the anticipated range and is operational at a mere 5% confidence level, the lifespan of the system is cut short and breaks down long before time. Therefore, those plant component parts that fall within this 5% confidence interval failure time range must be given more maintenance attention to avoid latent damage which could lead to catastrophic failure consequently leading to total plant breakdown, a hazardous setting, and therefore, possible employee injury.

Index Terms- **Asymptomatic hazard rate, Human error, Mean time to failure, Plant breakdown, Reliability function**

I. INTRODUCTION

A large percentage of job related accidents are caused by human error. The employment of unskilled workers may lead to a component failure as well as unanticipated machine breakdown through poor maintenance culture. Asymptomatic hazards are associated with unexpected or latent human errors [1]. A hazard is the potential for harm. In an engineering system or job environment, a hazard is something that causes danger or risk. Hazards are often associated with any condition, habit or activity that, if left uncontrolled, could result in injury or illness for the employees and the environment on the one hand, and complete/acute or latent/gradual failure of the engineering system on the other. While critical human errors lead to immediate or catastrophic accidents and complete shut down and obvious, sometimes irreparable, damage associated with significant down time, asymptomatic human errors are gradual and could cause considerable problems by perhaps slowing down production or compromising quality control to such an extent as to render the products useless. Dangerous effluents may be gradually released into the environment endangering employees and destroying the surrounding ecosystem. Asymptomatic errors are often a precursor to critical breakdown thereby increasing production costs in the long run, as damaged parts need to be replaced.

A hazard rate deals with the probability of exposing an employee to risk posed by the work environment and the level of effect such risks could have on him. It is generally accepted that every workplace has its expected and peculiar hazards, therefore workers are trained to adhere strictly to safety rules to prevent accidents [2].

Job accidents compromise employee efficiency and certain accidents actually cause fatal injuries. In a standard industrialized setting, risk assessments are done adopting different reliability models, with the aim of reducing human – machine contact and consequently reducing the occurrence of hazards [3]. However in job environments that ignore rudimentary safety standards, less attention is given to employees who have higher exposure to work hazards, there is often insufficient to no insurance cover [4]. Therefore plenty of research must be dedicated to hazard or risk assessment aimed at improving productivity and increasing employee safety. Some researchers have worked on the effect of hazard on productivity and workers' safety [5]; other researchers have classified levels of hazard occurrence [6].

The production unit of a brewing plant in Nigeria has been affected by continuous machine breakdown and there have been plant shutdowns due to failure of various component parts. In this study the hazard rate was assessed by observing and detailing human – machine interaction effects. Particular attention was given to mean time to failure (MTTF) being the time between asymptomatic errors and unanticipated catastrophic failure. Some of these

J.I. Achebo is with the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria (josephachebo@yahoo.co.uk)

O. Oghoore is a Student with the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria (oviemuno2002@yahoo.co.uk)

ISBN: 978-988-18210-8-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

human errors observed were unexpected, and were able to cause significant damage.

II. RESEARCH METHODOLOGY

This research is carried out by using the probability and hazard rate functions in determining the hazard rate of the plant as proposed by Ebeling,[7] .

Probability Density Function and Hazard Rate Function

These functions are expressed using the failure density function as written in (1).

$$f(t) = \frac{R(t_{i+1}) - R(t_i)}{t_{i+1} - t_i} = \frac{1}{(t_{i+1} - t_i)(n+1)} \; for \; t_i \angle t \angle t_{i+1} \qquad (1)$$

The reliability function can be determined by (2).

$$R(t_i) = 1 - \frac{i}{n+1} = \frac{n+1-i}{n+1} \qquad (2)$$

The hazard rate, λ(t) can be obtained by using (3)

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{1}{(t_{i+1} - t_i)(n+1-i)} \; for \; t_i \angle t \angle t_{i+1} \qquad (3)$$

In estimating the mean time to failure (MTTF) from the sample mean

$$MTTF = \sum_{i=1}^{n} \frac{t_i}{n} \qquad (4)$$

This variance of the failure distribution, S^2 can be obtained from the sample variance as expressed in (5).

$$S^2 = \sum_{i=1}^{n} \frac{(t_i - MTTF)^2}{n-1} \qquad (5)$$

Alternatively, the variance can be expressed as

$$S^2 = \frac{\sum_{i=1}^{n} t_i^2 - nMTTF^2}{n-1} \qquad (6)$$

For large sample size of n failure times, an approximate 100 (1 - α) percent confident interval for the MTTF is obtained using

$$MTTF \pm t_{\alpha/2, n-1} \frac{S}{\sqrt{n}} \qquad (7)$$

where n is the number of units or parts at risk at the start of the test.

III. PRESENTATION AND DISCUSSION OF RESULTS

A. *Presentation of Results*

The failure times in hours of the brewing plant is presented in Table 1

Table 1: Failure Distribution Time, Reliability Density and Hazard Rate of the Brewing Production Plant.

i	Time	Reliability R(t)	Density f(t)	Hazard Rate λ(t)
0	0.0	1.0	0.0072	0.0072
1	12.6	0.9090	0.0568	0.0625
2	14.2	0.8182	0.0111	0.0136
3	22.4	0.7273	0.0337	0.0463
4	25.1	0.6363	0.0253	0.0397
5	28.7	0.5455	0.0202	0.0370
6	33.2	0.4545	0.039	0.0087
7	56.3	0.3636	0.0041	0.0113
8	78.4	0.2727	0.0064	0.0235
9	92.6	0.1818		

i = 1, 2, …k, where i in this study indicates that there are 10 failure times.

Equations (1) – (4) were used to obtain the values in Table 1 and (4) – (7) were applied to determine the desired confidence interval as expressed hereunder.

A 95% confidence interval may be found from:

$$MTTF = \frac{0 + 12.6 + 14.2 + 22.4 + 25.1 + 28.7 + 33.2 + 56.3 + 78.4 + 92.6}{10}$$

$$= \frac{363.5}{10} = 36.35$$

And

$$S^2 = \frac{12.6^2 + 14.2^2 + 22.4^2 + 25.1^2 + 28.7^2 + 33.2^2 + 56.3^2 + 78.4^2 + 92.6^2 - 10(36.35^2)}{9}$$

$$= \frac{21309.11 - 10(36.35^2)}{9}$$

$$= \frac{8095.885}{9} = 899.5428$$

$$S = \sqrt{899.5428} = 29.992$$

$$\approx 30$$

From the t-table, $t_{0.05, 9} = 1.833$

Therefore, from (7)

$$36.35 \pm 1.833 \times \frac{(30)}{\sqrt{10}} = 36.35 \pm 17.39$$

is the desired confidence interval.

The 95% confidence interval is from 18.96 hours to 53.74 hours.

The component parts of the production machine operate as a serial system . The design life of the machine, td considering a continuous failure rate model, is

$$t_d = \left[\frac{-In \, R(t)}{\lambda(t)} \right] hrs \qquad (8)$$

Where

Reliability, $$R = R(t) = \frac{\sum_{i=1}^{n} R_i}{n} \tag{9}$$

And hazard rate, $$\lambda = \lambda(t) = \frac{\sum_{i=1}^{n} \lambda_i}{n} \tag{10}$$

Using values in Table 1, R = 0.5909 and λ = 0.0250.

Therefore t_d , becomes 21 hrs. The system's MTTF is calculated from (11)

$$MTTF_{sys} = \frac{1}{\lambda} \tag{11}$$

In this study MTTF_{sys} is 40 hrs

The various relationships between the empirically derived or non parametric reliability, R(t), failure density, f(t), hazard rate, λ(t) functions and their corresponding failure times were investigated as shown in Figs (1) – (3).

Fig. 1 shows the empirical reliability curve.

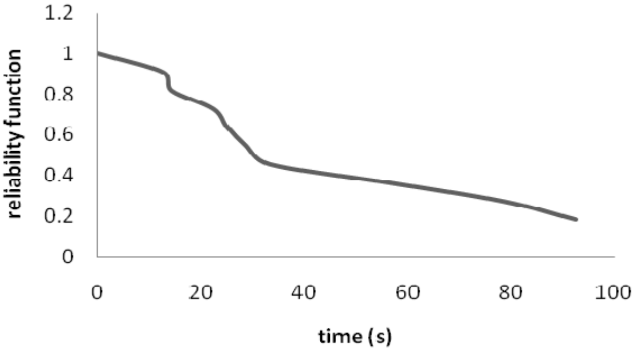

Fig 1. The Empirical Reliability Curve

Fig. 2 shows the empirical failure density chart

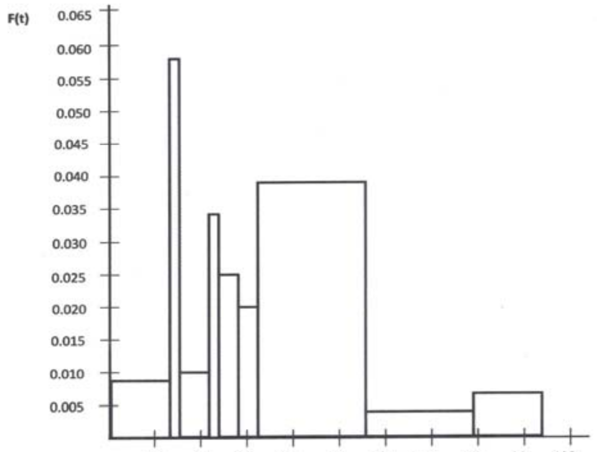

Fig 2. The Empirical Failure Density Chart

Fig. 3 shows the empirical hazard chart

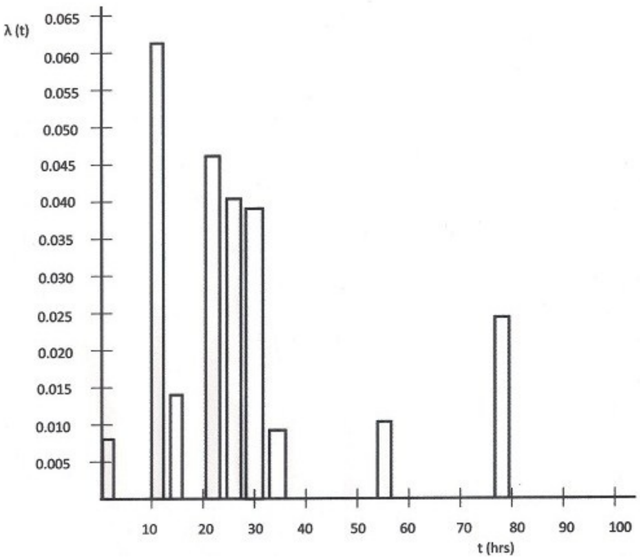

Fig 3 Empirical Hazard Chart

B. *Discussion of Results*

This analysis is carried out to determine the mean time to failure (MTTF) that would cause the most harm to operators and loss to the organization. The aim is to plan a maintenance policy that would prevent asymptomatic hazards leading to a catastrophic failure in the plant, and to ensure the safety of plant operators. At the 95% confidence level, the expected range of MTTF was obtained, being 18.96 hrs and 53.74hrs. The design life of the machine was estimated to be 21hrs, this value is less than the system's upper range of anticipated MTTF of 53.74hrs, supporting the statement by Lewis [8], that a design life is usually less than its expected MTTF.

The actual MTTF of the entire system was found to be 40 hrs. This value falls within the anticipated range of MTTF at the stated 95% confidence interval. Falling within this expected range indicates that the failure distribution of the machine is normal and that the desired goal was successfully achieved. O'Conner [9] also observed that the confidence level contains the true value and that the larger the range of values computed, the greater would be the intuitive confidence, that the estimate of the population parameter will be close to the true value.

Component parts that display MTTF above the ones within the 95% confidence interval, being 53.74hrs, would not cause any significant hazard effect. Whereas, any MTTF falling below this range, being 18.96hrs, could be very hazardous. These component part failures could lead to catastrophic damage. The component parts breakdown involved within this range of time are very vital to the performance of the machine. In Table 1 the corresponding values of reliability, densities, and hazard rates are stated.

However, from Fig (1), it can be seen that as the reliability of the plant increases, the mean time to failure correspondingly reduces. This means that the less there are plant breakdowns, the more productive the system, and the less the possibility of the plant becoming hazardous.

Fig.2 shows that the failure distribution or probability density function over the mean time to failure is highest at 12.4hrs with a probability failure density of 0.055.

For the period covering 22.4 hrs however, there is a sharp fall in the series to a probability failure density of 0.008. The conditions at 12.4hrs do not fall within the expected range as computed applying (7), being unusually high. Therefore failure density functions are not proportional to the expected level of hazard rate at given or particular points in time, instead they represent the mean of a random range.

Hence, the possibility of predicting the failure rate is therefore not apparent from merely looking at Fig (2) because of this lack of proportionality. However, the distribution of the failure rate of the system is presented in Fig (2) in order to itemize and reduce all the accumulated data to a simplified form. This gives a broad view and aids any observer to reduce the frequency of failure occurrences of some component parts in the system in respect of their significance to catastrophic failure and employee safety. The failure density function is used to describe the conditional probability of a failure in the time interval from t to t + Δ t given that the system has survived to time t [7].

Fig. 3 presents the hazard rate function over the corresponding mean time to failure (MTTF). The hazard rate function $\lambda(t)$ provides an alternative way of describing a failure distribution. It provides an instantaneous (at time, t) rate of failure [7]. However, in Fig (3), a cluster of bars of high hazard rates falls within the determined most hazardous intervals. Surprisingly, the bar indicated on 78.4hrs failure time shows a high hazardous level which does not fall within the most acceptable and expected computed hazardous interval. Therefore the operators, upon observing the spike caused by the component part relevant to that period, even though it has high hazard indications, may think that such parts would not cause significant catastrophe to plant operations. Believing the system to be running smoothly, such spikes as indicated on 78.4hrs failure time, would not ring the necessary alarm bells. Regardless, the component parts with such high hazard indications must not be ignored as they could cause plant shutdown if the problems persist. They constitute potential and/or latent hazards and specific attention must be given to them, as allowing their high hazard status to remain unabated could gradually compromise the entire system and eventually lead to a critical breakdown.

IV. CONCLUSION

The hazard rates caused by the failure of the component parts in the brewing plant have been successfully investigated. The range of hazardous mean time intervals capable of causing insignificant, normal and catastrophic failures either to the machine or plant or the operators has been determined.

Illustrations in Figs (1) – (3) clearly show that plant reliability, probability density functions are strong factors in determining the hazardous status of a machine or plant. The more reliable a plant is, the less the failure times and the more productive and functional it becomes. However, these factors are inversely proportional to the corresponding hazard functions. The probability density functions show the cluster of highly hazardous failure times attainable by the plant under investigation. On the other hand, the hazard rate over a range of failure times show the effect and consequential outlay of these failure times on the productivity of the machine or plant and the corresponding effect on the safety of their operators. A non parametric analysis has been successfully achieved.

This entire investigation is used to outline, or draw up a maintenance policy that would be used to prevent major hazardous situations in the plant. This study has been proposed to management.

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