Maintenance Error Oriented Reliability Determination Model.

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ABSTRACT

This work represents a computer based model for predicting reliability based on maintenance errors. It considers the fact that maintenance is supposed to improve system reliability but due to human errors in maintenance, systems deteriorate with the attendant reduction in reliability. The model consists of a deterministic mathematical model which was integrated into a stochastic model, and simulated with computer based Monte Carlo method using the C++ programming language. A questionnaire based survey provided the model test and validation data. The results provide an excellent quantitative and qualitative basis for maintenance error elimination decisions. Hence, whenever this method is properly applied productivity improves, downtime reduces, operating profits increases and plant safety improves.

(Keywords: human error, maintenance, failure, risk, Monte Carlo simulation, system reliability)

INTRODUCTION

Error, according to Wikipedia (2008), refers to a difference between actual behavior or measurement and the norms or expectations for the behavior or measurement. The *Oxford Advanced Learners' Dictionary* defines error as: "A thing done wrongly or the state of being wrong in belief or behavior".

Maintenance activities, according to Wikipedia (2008), refers to the fixing of any sort of device should it become out of order or broken (repair) as well as performing the routine actions which keep the device in working order or prevent trouble from arising. The European Federation of National Maintenance Societies defines maintenance as: All actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial and supervision actions. According to Dhillon and Liu (2006), maintenance error occurs due to incorrect repair or preventive actions.

Reliability is defined as the probability of a device performing its purpose adequately for the period of times intended under the operating conditions encountered (Verma, 2005). From the foregoing, it is apparent that if errors are none existent, maintenance would be perfect. If maintenance is perfect the probability of failure would be zero, hence reliability would be one.

In view of these facts, this work was done to develop a model for predicting system failure risk and reliability based entirely on maintenance errors.

DATA ACQUISITION

In a previous research, twenty main sources of human error in maintenance were comprehensively identified. These error sources were: Poor work place design, poor housekeeping, fatigue, poor motivation, physical disability, mental unfitness and behavioral factors, poor on the job training, unqualified personnel, inadequate maintenance tools, inexperience, lack of predictive tools, aged equipment, poorly designed equipment, low quality spares, poor communication, poor interpretation of manuals, unavailability of manuals, maintenance procedure violations, behavioral violations, and poor supervision, and work assignment. Ten process industries were surveyed and the frequencies of occurrence of errors due to these sources in these industries were determined. The questionnaire for the survey was designed such that error sources were given scores, 0, 1, 2, 3 according to their frequency of occurrence designated as never, rarely, occasionally and often respectively. The result obtained for process industry is shown in Table 1. This result was used for the error based reliability prediction model validation.

MODEL DEVELOPMENT

In Table 1, let γ_i denote total score for an error source i. Let the sum of the total scores of the errors be denoted by Φ_1. Hence,

$$\Phi_1 = \sum_{i=1}^{n} \gamma_i \qquad (1)$$

$$f_i = \gamma_i / \Phi_1 \qquad (2)$$

Table 1: Frequency Values for Different Error Sources for Process Industries.

Error Source	Sample										Totals	Frequency
	1	2	3	4	5	6	7	8	9	10		
	Scores											
1. Poor work place design	1	2	0	2	1	0	2	1	0	2	11	0.030986
2. Poor housekeeping	3	1	1	1	1	3	0	1	1	1	13	0.03662
3. Fatigue	2	1	0	3	1	3	0	2	3	3	18	0.050704
4. Poor motivation	3	1	1	2	3	2	2	3	3	1	21	0.059155
5. Physical disability	1	0	0	2	0	1	0	0	1	3	8	0.022535
6. Mental unfitness and behavioral factor	1	0	1	3	0	0	0	1	1	3	10	0.028169
7. Poor on the job training	2	2	0	3	1	3	3	2	3	3	22	0.061972
8. Unqualified personnel	1	3	2	2	2	3	3	2	2	3	23	0.064789
9. Inadequate maintenance tools	0	3	3	2	2	3	3	2	3	3	24	0.067606
10. Inexperience	1	3	2	2	1	3	3	3	3	3	24	0.067606
11. Lack of predictive tools	1	3	3	3	3	3	3	1	3	3	26	0.073239
12. Aged equipment	2	2	3	2	3	3	3	2	2	1	23	0.064789
13. Poorly designed equipment	1	2	3	3	2	2	3	3	2	3	24	0.067606
14. Low quality spares	0	2	2	2	3	3	3	2	3	2	22	0.061972
15. Poor Communication	1	2	3	2	1	2	2	2	2	2	19	0.053521
16. Poor interpretation of manuals	1	1	0	2	1	2	3	1	2	3	16	0.04507
17. Unavailability of manuals	1	0	0	3	0	2	1	0	0	1	8	0.022535
18. Maintenance procedure Violations	1	1	1	2	2	2	2	2	2	3	18	0.050704
19. Behavioral violations	1	0	0	3	1	1	0	0	2	2	10	0.028169
20. Poor supervision and work assignment	1	1	1	2	2	2	2	1	1	2	15	0.042254
	25	30	26	46	30	43	38	31	39	47	355	1

If an error source is eliminated, then the new sum of the total scores of the errors is denoted by Φ_2 hence,

$$\Phi_2 = \Phi_1 - \gamma \qquad \textbf{(3)}$$

Let Ω denote the error reduction ratio which is given by

$$\Omega = \frac{\Phi_2}{\Phi_1} \qquad \textbf{(4)}$$

If an error source is eliminated, system reliability changes, hence Given that system reliability, R, is determined by the equation:

$$R = e^{-(\lambda)t} \qquad \textbf{(5)}$$

Where λ = Failure rate
t = time

System failures are due to maintenance errors. In a perfect system, there are no errors and no failures. If errors are non existent, failures will not exist, hence failure or error rate, $\lambda=0$, Hence reliability,

R is: $R = e^{-(0)t} = 1$

Hence, in a perfect system, the system reliability, R, equals one.

It follows that if a maintenance error is eliminated, failure rates reduce, and hence the new failure rate when a maintenance error is eliminated is denoted by: λ_2, while the failure rate before the error elimination is denoted by λ_1.

Let the reliability before maintenance error elimination be denoted by R_1 and the reliability after maintenance error elimination by R_2 .Hence,

$$R_1 = e^{-(\lambda_1)t} \qquad \textbf{(6)}$$

$$R_2 = e^{-(\lambda_2)t} \qquad \textbf{(7)}$$

From the deduction above, the following relationship could be established: suppose that the failure rate reduction ratio denoted by α is given by:

$$\alpha = \frac{\lambda_2}{\lambda_1} \qquad \textbf{(8)}$$

$$\Phi \propto \lambda \qquad \textbf{(9)}$$

$$\Phi_1 = k\lambda 1 \qquad \textbf{(10)}$$

$$\Phi_2 = k\lambda 2 \qquad \textbf{(11)}$$

Where k is a constant.

$$\frac{\Phi_2}{\Phi_1} = \frac{k\lambda_2}{k\lambda_1} \qquad \textbf{(12)}$$

Reference

$$\frac{\Phi_2}{\Phi_1} = \frac{\lambda_2}{\lambda_1} \qquad \textbf{(13)}$$

$$\Omega = \alpha \qquad \textbf{(14)}$$

Substituting (14) into (8) Equation 15 is obtained.

$$\Omega = \frac{\lambda_2}{\lambda_1} \qquad \textbf{(15)}$$

$$\lambda_2 = \Omega\lambda_1 \qquad \textbf{(16)}$$

Substituting (16) into (7) Equation 17 is obtained.

$$R_2 = e^{-(\Omega\lambda_1)t} \qquad \textbf{(17)}$$

A major consequence of system failure is downtime and its associated cost. Downtime cost and the deterministic model developed above was integrated into the stochastic model shown in Figure 2, an error based reliability prediction model. In the model, Module 1 is optional and at the same time the failure cost calculation aspect could be removed depending on the application. The model was solved using the data shown in Table 1 with the computer based Monte Carlo simulation method. A test problem formulated to solve the model follows.

Assuming system reliability is R, as used above. Hence, frequency of downtime, δ is given by

$$\delta = 1-R \qquad \textbf{(18)}$$

The frequency of system's operation denoted by the reliability R, and the frequency of downtime denoted by, δ, were used to construct Table 2, the frequency table. The table was used for the computer simulation.

The Monte Carlo simulation program used for the model solution is shown in the appendix. The simulation program was run 10 times and the results are tabulated in Tables 3-6.

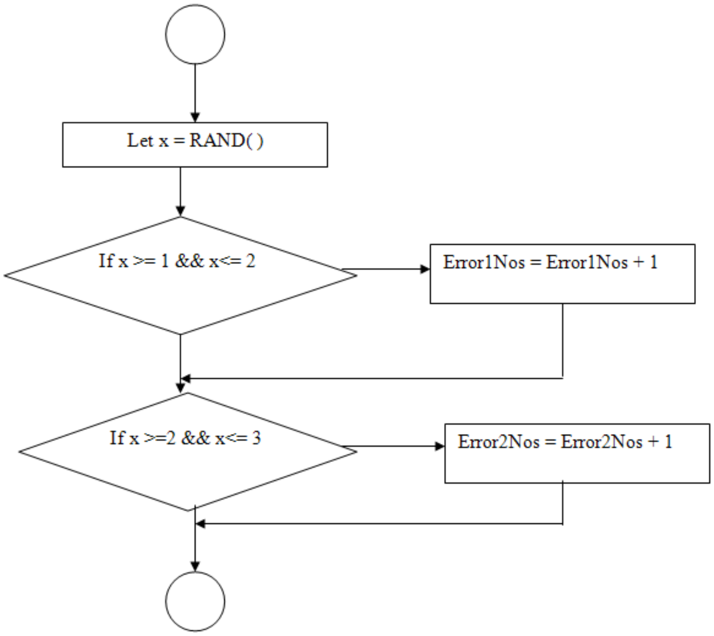

Figure 1: Model 1 Flowchart Model.

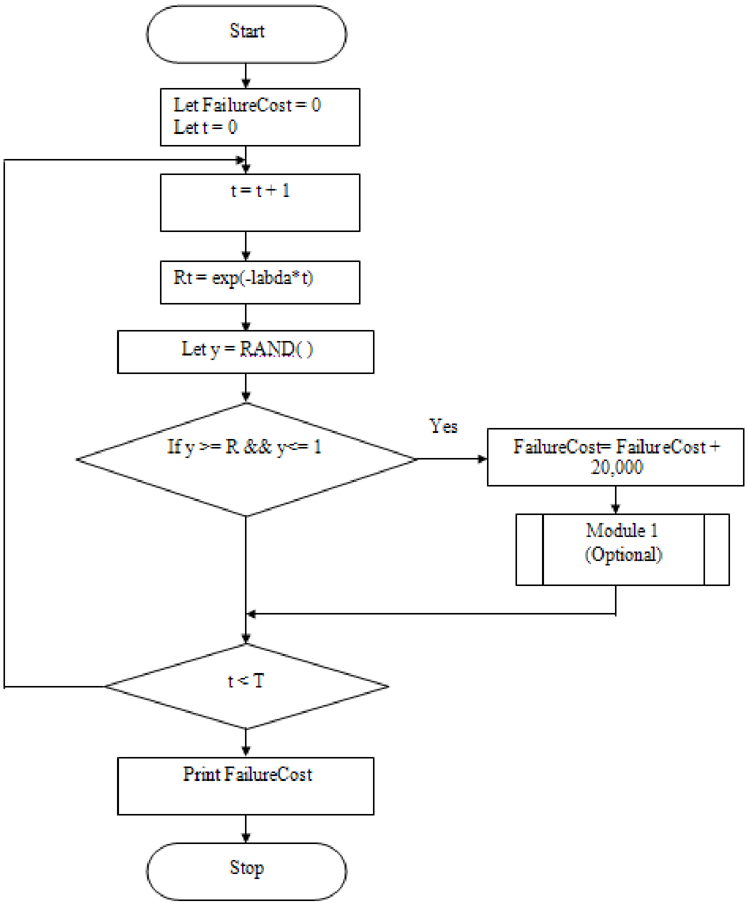

Figure 2: Error Based Reliability Prediction Model.

Table 2: Frequency/Probability Table For Downtime.

Error Status	Probability	Cumulative Probability	Random Number
Operating period	R	R	0-R
Downtime	δ	1	R-1

TEST PROBLEM FORMULATION

A test problem is formulated here which will be used to test and validate the models developed above.

Test Problem: The reliability of a plant operating at a constant hazard rate is 0.9. A study carried out on the plant reveals that the frequencies of maintenance errors are distributed as shown in Table 1. Assuming the reliability was for a one week operation of the plant. It was found that the average weekly downtime/failure cost is 20,000.00 naira. It was equally found that the average cost of eliminating errors due to low quality spares is 400.00 naira in ten (10) weeks. If the error is eliminated, determine the new value of plant reliability.

Using Monte Carlo Simulation:

(1) Determine the total cost of downtime if the error was not eliminated and the plant operates for fifty weeks?

(2) Determine the total cost of downtime if the error was eliminated and the net cost of eliminating the error if the plant operates for fifty weeks?

TEST PROBLEM RESULTS

The model developed in Figure 2 was used to write the simulation program with C++ (Appendix) which was used to solve the test problem. The simulation program/model was tested for reliability before use and was found to be very reliable. Solving the test problem from the equations in chapter two we have:

Solution 1: From (6), $R_1 = e^{-(\lambda_1)t}$. Therefore: $0.9 = e^{-(\lambda_1)}$; $e^{-(\lambda_1)} = 10/9$; $\lambda_1 = 0.10536$

Solution 2: From Table 1: $\Phi_1 = 355$; $\Phi_2 = 333$; Hence, from (4) $\Omega = 333/355 = 0.938$; From (17), $R_2 = e^{-(\Omega\lambda_1)t}$ $R_2 = e^{-(0.938x0.10536)} = 0.9059$
The data calculated from the equations above were used as inputs to the simulation program used to solve the test problem.

The test result of test problem 1 is presented in Tables 3 and 4 below.

Table 3: Results of Test Problem 1.

	SIMULATIONS						
Downtime cost	1	2	3	4	5	6	7
	760000	780000	900000	800000	840000	840000	860000

Table 4: Results of Test Problem 1.

	SIMULATIONS						
Downtime cost	8	9	10	MEAN	SD	99% upper confidence limit	99% lower confidence limit
	840000	800000	860000	828000	42373.99622	854263.176	801736.8

The test result of test Problem 2 is presented in Tables 5 and 6 below.

Table 5: Results of Test Problem 2.

	SIMULATIONS						
Downtime cost after error elimination	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	800000	840000	820000	820000	860000	880000	840000

Table 6: Results of Test Problem 2:

	SIMULATIONS						
Downtime cost after error elimination	**8**	**9**	**10**	**MEAN**	**SD**	**99% upper confidence limit**	**99% lower confidence limit**
	860000	800000	720000	824000	45018.51 471	851902.235	796097.8

From the test problem results, it could be observed that eliminating the errors lead to the mean downtime cost being reduced to N824, 000 down from N828, 000. The downtime cost reduction is N4, 000. But the average cost of eliminating the error is N2, 000. Hence, eliminating the error is economical.

DISCUSSION

From the test problem the initial reliability value prior to the elimination of an error source was 0.9000. When the error source was eliminated, the initial reliability value increased to 0.9059. This shows that reliability increases when maintenance errors are eliminated. Secondly, if the cost of eliminating errors due to low quality spares were say N1000.00 in 10 weeks. The total cost in 50 weeks would be N5000.00. When compared to savings in downtime of only N4000.00, it is clearly uneconomical to eliminate the error. Hence, it is necessary, depending on the application, to always determine the economics of maintenance error elimination or reduction before decisions on error elimination or reduction are made. In continuation, it is apparent from the simulation results that failure costs reduce when maintenance errors are eliminated. In the models developed here a single component system was assumed.

The successful test and validation of the models developed in this work as evident from the results shows that we can actually simulated and predict failure risks in complex systems (systems with several components) based on maintenance errors.With the simulative approach used in the analysis one would always expect an excellent result which would always be a very close approximation to the real world events.

SUMMARY OF FINDINGS

After my survey and research, the authors made the following major findings and results:

1. Elimination of maintenance errors increases system reliability but increases operating cost.

2. A model for simulating plant reliability based completely on human errors in maintenance was successfully, developed, tested and validated and with the model developed in this work, failure risks in complex systems (systems with several components) can easily be simulated and predicted.

RECOMMENDATIONS

In the light of these findings, we wish to make these recommendations:

- The model developed here should be used as an aid to managerial decision making towards eliminating human errors in maintenance and study of plant reliability.

- When faced with a decision to eliminate a maintenance error, managers must evaluate the economics of the maintenance error elimination.

CONCLUSION

Productivity is the key to a prosperous economy. The best way to do a job is the safe way. Human error is responsible for the staggering figures in lost revenue and other costs due to downtime, injuries and deaths. Suffice it to say that elimination or reduction of human error in maintenance operations should be paramount in the mind of any good manager. I have been able to show through the model developed in this work that human error is solely responsible for system failure. But eliminating maintenance errors comes at a cost. The model developed in this work in this study should be made available to managers and engineers. Armed with the knowledge gained from this research, they should be able to bring about safe, reliable, economical and efficient operations in their various organizations.

APPENDIX : SIMULATION PROGRAM WITH C++ FOR SIMULATING RELIABILITY BASED ON MAINTENANCE ERRORS

```
// A C++ Program for Simulating Reliability Based on Maintenance Errors
# include <iostream.h>
# include <stdlib.h>
# include <time.h>
# include <math.h>
int t,downtimecost;
double x,y,R,k,lambda;
void determineErrors();
main()
{
        unsigned seed = time (NULL);
        srand(seed);
        t=1;
        errorcost=0; downtimecost=0;
        lambda=0.09883;// lambda is error rate or failure rate
do
        {
                ++t;
                k = lambda*t;
                R = exp(-k); //Reliability calculation
                y=double(rand())/RAND_MAX;
                 if (y>=R && y<=1){
                        downtimecost=downtimecost+20000;
                }
        }while(t<=50);
        cout<<"Downtime Cost= "<<downtimecost<<endl;
        return 0;
}
```

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