EVALUATION OF TIME DEPENDENT RELIABILITY ANALYSES FOR HUMAN ERRORS IN DEVELOPMENT OF BRIDGE NETWORK SYSTEM

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ABSTRACT

A complex system can produce a non-series parallel structure. The most simple, non-series parallel structure is a bridge configuration. Time-dependent analysis is on reliability, as a function of time. Normally, the system conservatively estimates the prior reliability of each bridge, based on the human failure data. Where the condition of the bridge gives cause for concern, its reliability is evaluated in a more formal manner using time-dependent procedures.

In this paper, the impact of the reliability of the bridge system is illustrated, with the support of statistical models. Also, we discuss the time-dependent analyses for failure times through the exponential distribution model and Rayleigh distribution model to determine MTTF, probability density function and hazard rate function.

KEYWORDS: Reliability, MTTF, Hazard Rate Function & Probability Density Function.

Received: Mar 10, 2018; **Accepted:** Mar 31, 2018; **Published:** Apr 12 2018; **Paper Id.:** IJASRAPR201829

1. INTRODUCTION

Humans play a pivotal role in the design, development and operational phases of engineering systems. Reliability evaluation of systems without taking into consideration the human element does not provide a realistic picture. Hence, there is a definite need for incorporating the occurrence of human errors in system reliability evaluation.

A structure is called a complex when the reliability block diagram, either cannot be reduced to a serial or parallel structure with independent elements. Time dependency in the reliability function is to develop the models necessary to observe the reliability over the life of the system, instead of at just one point in time. In addition, performance measures such as failure rate, MTTF, and hazard rate are estimated for the entire system. The methods of obtaining the reliability function analytically remain identical to the ones with the exception that the reliabilities will be functions of time.

A human error is defined as a failure to perform a prescribed task (or the performance of a prohibited action) which could lead to disruption of scheduled operations or result in damage to property and equipment. Furthermore, depending upon the severity of human error consequences, human errors can be classified into two categories, namely, critical and noncritical. For our purpose, the occurrence of a critical human error causes the entire system to fail, whereas the occurrence of a non-critical human error results in a single unit failure only.

In this chapter, we discuss the reliability analyses of a bridge network with critical and non-critical human errors. A newly developed approach is used to perform system reliability analysis. This approach is a modified version of the block diagram approach and is demonstrated in the models I. model I represents a ten unit bridge network.

2. ASSUMPTIONS

The following assumptions are associated with analyses given below:

- A unit can fail either due to a hardware failure or due to a non-critical human error.
- The occurrence of a critical human error can result in total system failure, but the occurrence of a non-critical human error can cause the failure of a single unit only
- Each unit failure is independent of others.

3. NOTATIONS

The following symbols are associated with the Model I:

F_j	Hardware failure probability of j the unit, for $j = 1, 2, \dots, 10$
f_j	j the unit failure probability with respect to non-critical human errors, for $j = 1, 2, \dots, 10$
f_c	Critical human error occurrence probability associated with the system.
R_{Hj}	Hardware reliability of the j the unit
R_{NCj}	Reliability of the j the unit with respect to non-critical human errors
R_j	Reliability of the j the unit with respect to hardware failures and non-critical human errors
R_C	System reliability with respect to critical human errors

Figure 1: Block Diagram for Bridge Network

$R_{H, NC}$	System reliability with respect to hardware failures and non-critical human Errors
R_b	Bridge system reliability with respect to hardware failure, critical and non-critical human errors
s	Laplace transforms variable
t	time

4. ANALYSIS OF BRIDGE NETWORK

This model represents a ten-unit bridge network with critical and non-critical human errors as shown in Fig.1. In this figure, each real unit is represented by a rectangle. The failure probability of each unit is divided into two components, namely, hardware failure probability and non-critical human error probability. These failure probabilities are represented by blocks connected in series as shown in each rectangle in fig. 1. A hypothetical unit representing critical human errors is connected in series with the bridge network. The total system can fail due to the failure of this hypothetical unit.

The time-independent reliability analyses are developed in the following two cases:

Case 1: Non-Identical Units

The hardware reliability of j the unit is given by

$$R_{Hj} = 1 - F_j, \text{ for } j = 1, 2, \dots, 10 \quad (1)$$

The reliability of the unit with respect to non-critical human errors is

$$R_{NCj} = 1 - f_j, \text{ for } j = 1, 2, \dots, 10 \quad (2)$$

The reliability of the j th unit with respect to hardware failures and non-critical human errors is

$$R_j = R_{Hj} R_{NCj}, \text{ for } j = 1, 2, \dots, 10 \quad (3)$$

The bridge network's reliability with respect to hardware failures and non-critical human errors is:

$$\begin{aligned} R_{H,NC} = & 9 R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} - 4 R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} - 4 R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 - R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_9 R_{10} \\ & + R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} + R_1 R_3 R_4 R_5 R_6 R_7 R_9 R_{10} - \\ & 4 R_1 R_3 R_4 R_5 R_6 R_7 R_8 R_9 + R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_9 - R_2 R_3 R_4 R_6 R_7 R_9 R_{10} - R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 + R_1 R_2 R_4 R_5 R_6 R_7 R_9 R_{10} \\ & + R_2 R_3 R_4 R_6 R_7 R_8 R_9 R_{10} + (2 R_1 R_4 R_5 R_6 R_7 R_9 R_{10}) - R_1 R_2 R_3 R_4 R_5 R_8 R_9 + 2 R_1 R_3 R_4 R_5 R_6 R_7 R_9 - R_1 R_3 R_4 R_5 R_8 R_9 R_{10} + 2 R_1 R_3 R_4 R_6 R_7 R_8 R_9 \\ & + 4 R_1 R_5 R_6 R_7 R_8 R_9 + 2 R_1 R_4 R_5 R_8 R_9 R_{10} - R_2 R_3 R_6 R_7 R_9 R_{10} + 2 R_1 R_3 R_4 R_5 R_8 R_9 - R_3 R_4 R_6 R_7 R_8 - 4 R_2 R_5 R_8 R_9 - 2 R_1 R_6 R_7 R_9 \end{aligned} \quad (4)$$

The reliability of the bridge network with respect to critical human errors only is

$$R_C = 1 - f_c \quad (5)$$

Finally, we get the Reliability of the Bridge Network is

$$R_b = R_C \cdot R_{H,NC} \quad (6)$$

CASE 2: IDENTICAL UNITS

By setting $R_j = R$ (i.e., $F_j = F$ and $f_j = f$), for $j = 1, 2, \dots, 6, 7-10$ then the reliability of the Bridge Network is

$$R_b = R_C (9R^{10} - 7R^9 - 3R^8 - 4R^7 + 7R^6 - R^5 - 6R^4) \quad (7)$$

Where $R = R_H R_{NC}$, $R_H = 1 - F$ and $R_{NC} = 1 - f$

Time-dependent analyses of the following two cases are developed:

Case A: Exponentially distributed failure times

For exponentially distributed hardware failure, critical and non-critical human error times the time-dependent

equations for R_c , R , R_H , R_{NC} are as follows:

$$R_H(t) = e^{-\lambda_H t} : \text{Where } \lambda_H \text{ is the constant hardware failure rate of a unit} \quad (8)$$

$$R_{NC}(t) = e^{-\lambda_{NC} t}; \text{Where } \lambda_{NC} \text{ is the constant non-critical human error rate associated with a unit.} \quad (9)$$

$$R(t) = e^{-xt} ; \text{Where } x = \lambda_H + \lambda_{NC} \quad (10)$$

$$R_C(t) = e^{-\lambda_C t}; \text{where } \lambda_C \text{ is the constant critical human error rate associated with the system.} \quad (11)$$

Using equations (7) – (11), we get the reliability of identical unit bridge networks as follows:

$$R_b(t) = 9e^{-(bx+\lambda_C)t} - 7e^{-(9x+\lambda_C)t} - 3e^{-(8x+\lambda_C)t} - 4e^{-(7x+\lambda_C)t} + 7e^{-(6x+\lambda_C)t} - e^{-(5x+\lambda_C)t} - 6e^{-(4x+\lambda_C)t} \quad (12)$$

The M.T.T.F. of the bridge network by using the formula

$$M.T.T.F_b = \int_0^\infty R_b(t)dt = \frac{9}{10x+\lambda_C} - \frac{7}{9x+\lambda_C} - \frac{3}{8x+\lambda_C} - \frac{4}{7x+\lambda_C} + \frac{7}{6x+\lambda_C} - \frac{1}{5x+\lambda_C} - \frac{6}{4x+\lambda_C} \quad (13)$$

The plots of the above equation are shown in figure 4.

These plots clearly demonstrate the effect of varying critical and non-critical human error rates λ_C and λ_{NC} on the bridge system mean time to failure.

Table 1: Mean Time to Failure of the System

S. No	λ_C	Mean Time to Failure of the System				
		$\lambda_C=0.0$	$\lambda_{NC} = 0.01$	$\lambda_{NC} = 0.02$	$\lambda_{NC} = 0.03$	$\lambda_{NC} = 0.04$
1	0.0	6.8571	6.3246	5.8809	5.5054	5.1836
2	0.01	6.6155	6.1243	5.7121	5.3612	5.0590
3	0.02	6.3909	5.9369	5.5533	5.2250	4.9409
4	0.03	6.1819	5.7613	5.4038	5.0962	4.8287
5	0.04	5.9868	5.5966	5.2628	4.9741	4.7220
6	0.5	5.8045	5.441	5.129-	4.8584	4.6206

The variance of time to failure of the bridge system with human errors by using the formula

$$\sigma_b^2 = -2 \frac{Lt}{s} \frac{d}{ds} R_b(s) - (M.T.T.F_b)^2$$

$$= \left[\frac{18}{(10x+\lambda_C)^2} - \frac{14}{(9x+\lambda_C)^2} - \frac{6}{(8x+\lambda_C)^2} - \frac{8}{(7x+\lambda_C)^2} + \frac{14}{(6x+\lambda_C)^2} - \frac{2}{(5x+\lambda_C)^2} \right]$$

$$\left[\frac{9}{(10x+\lambda_C)} - \frac{7}{9x+\lambda_C} - \frac{3}{8x+\lambda_C} - \frac{4}{7x+\lambda_C} + \frac{7}{6x+\lambda_C} - \frac{1}{5x+\lambda_C} - \frac{6}{4x+\lambda_C} \right] \quad (14)$$

Where $R_b(s)$ is the derivative of the Laplace transform of $R_b(t)$ with respect to s .

The bridge system failure density functions by using the formula.

$$F_b(t) = -R_b(t)$$

$$= 9(10x+\lambda_C)e^{-(10x+\lambda_C)t} - 7(9x+\lambda_C)e^{-(9x+\lambda_C)t} - 3(8x+\lambda_C)e^{-(8x+\lambda_C)t} - 4(7x+\lambda_C)e^{-(7x+\lambda_C)t} + 7(6x+\lambda_C)e^{-(6x+\lambda_C)t} - (5x+\lambda_C)e^{-(5x+\lambda_C)t} - 6(4x+\lambda_C)e^{-(4x+\lambda_C)t} \quad (15)$$

$$\text{Where } R_b(t) = \frac{dR_b(t)}{dt}$$

Figure 2: Critical Human Errors Vs M.T.T.F

The hazard rate function of the bridge system by using the formula

$$H_b(t) = \frac{f_b(t)}{R_b(t)}$$

$$= \frac{9(10x+\lambda_c)e^{-(10x+\lambda_c)t} - 7(9x+\lambda_c)e^{-(9x+\lambda_c)t} - 3(8x+\lambda_c)e^{-(8x+\lambda_c)t} - 4(7x+\lambda_c)e^{-(7x+\lambda_c)t} + 7(6x+\lambda_c)e^{-(6x+\lambda_c)t} - (5x+\lambda_c)e^{-(5x+\lambda_c)t} - 6(4x+\lambda_c)e^{-(4x+\lambda_c)t}}{9e^{-10xt} - 7e^{-9xt} - 3e^{-8xt} - 4e^{-7xt} + 7e^{-6xt} - 5e^{-5xt} - 6e^{-4xt}} \quad (16)$$

Table 2: Hazard Rate Function of the Bridge System

S. No	Time(t)	Hazard rate function of the bridge system				
		$\lambda_c=0.0$	$\lambda_c = 0.01$	$\lambda_c = 0.03$	$\lambda_c = 0.05$	$\lambda_c = 0.07$
1	0	0	0.01	0.03	0.05	0.07
2	2	0.4056	0.4154	0.4354	0.4553	0.4755
3	4	0.5315	0.5411	0.5610	0.5814	0.6012
4	6	0.5745	0.5844	0.6035	0.6241	0.6436
5	8	0.5904	0.5990	0.6164	0.6371	0.6575
6	10	0.5980	0.6089	0.6280	0.6485	0.6689

Figure 3: Time Vs. Hazard Rate

Case B: Rayleigh Distributed Failure Times

For Rayleigh distributed failure times the time dependent equations for

R_H , R_{NC} , R and R_C are:

$$R_H(t) = e^{-\beta_{NC}t^2} \text{ Where } \beta_H = \frac{1}{\alpha_H}; \alpha_H \text{ is the scale parameter associated with}$$

The Rayleigh distribution representing hardware failure times of a unit

$R_{NC}(t) = e^{-\beta_{NC}t^2}$ Where $\beta_{NC} = \frac{1}{\alpha_{NC}}$; α_{NC} is the scale parameter associated with the Rayleigh distribution representing failure times of a unit due to non-critical human errors.

$$R(t) = e^{-yt^2} \text{ Where } y = \beta_H + \beta_{NC} \quad (17)$$

$R_C(t) = e^{-\beta_C t^2}$ Where $\beta_C = \frac{1}{\alpha_C}$, α_C is the scale parameter associated with the Rayleigh distribution representing bridge system failure times with respect to critical human errors.

(18)

$$2. R_B(t) = 9e^{-(\beta_C+10y)t^2} - 7e^{-(\beta_C+9y)t^2} - 3e^{-(\beta_C+8y)t^2} - 4e^{-(\beta_C+7y)t^2} + 7e^{-(\beta_C+6y)t^2} - 6e^{-(\beta_C+4y)t^2}$$

The system mean time to failure is given by $M.T.T.F = \int_0^\infty R_b(t)dt$

The numerical results pertaining to the equation (21) are tabulated in table 1

Table 3: Bridge System Reliability

S. No	Time(t)	Bridge System Reliability				
		$\beta_C=0.0$	$\beta_C = 0.02$	$\beta_C = 0.04$	$\beta_{NC} = 0.06$	$\beta_{NC} = 0.08$
1	0.0	1.000	1.000	1.000	1.000	1.000
2	0.3	0.999	0.997	0.993	0.992	0.991
3	0.6	0.967	0.959	0.952	0.943	0.940
4	0.9	0.882	0.866	0.853	0.839	0.836
5	1.2	0.737	0.713	0.680	0.654	0.643
6	1.5	0.502	0.480	0.460	0.430	0.410
7	1.8	0.397	0.387	0.360	0.334	0.320
8	2.1	0.140	0.130	0.124	0.112	0.102
9	2.4	0.054	0.053	0.050	0.0543	0.038
10	2.7	0.022	0.012	0.188	0.014	0.012
11	3.0	0.006	0.0056	0.0045	0.0043	0.0028

The system Mean Time to Failure is given by

$$M.T.T.F_b = \int_0^\infty R_b(t)dt$$

$$= \left(\frac{\pi}{\beta_C+10y}\right)^{1/2} - \frac{7}{9}\left(\frac{\pi}{\beta_C+9y}\right)^{1/2} - \frac{1}{3}\left(\frac{\pi}{\beta_C+6y}\right)^{1/2} - \left(\frac{\pi}{\beta_C+5y}\right)^{1/2} - \frac{2}{3}\left(\frac{\pi}{\beta_C+4y}\right)^{1/2} \quad (19)$$

The bridge system failure density function by curing the formula $f_b(t) = \frac{-dR_b(t)}{dt}$

$$= 18(\beta_C+10y)e^{-(\beta_C+10y)t^2} - 14(\beta_C+9y)e^{-(\beta_C+9y)t^2} - 6(\beta_C+8y)e^{-(\beta_C+8y)t^2} - 8(\beta_C+7y)e^{-(\beta_C+7y)t^2} + 14(\beta_C+6y)e^{-(\beta_C+6y)t^2} - 2(\beta_C+5y)e^{-(\beta_C+5y)t^2} - 12(\beta_C+4y)e^{-(\beta_C+4y)t^2} \quad (20)$$

Figure 4: Time vs. Bridge System Reliability

The system hazard rate function is expressed as $h_b(t) = \frac{f_b(t)}{R_b(t)} = \frac{A(t)}{B(t)}$

$$A(t) = 2t \left[9(f_c + 10y)e^{-10yt^2} - 7(\beta_c + 9y)e^{-9yt^2} - 3(\beta_c + 8y)e^{-8yt^2} - 4(\beta_c + 7y)e^{-7yt^2} + 7(\beta_c + 6y)e^{-6yt^2} - 6\beta_c + 5ye^{-5yt^2} - 5yt^2 - 6\beta_c + 4ye^{-4yt^2} \right] \quad (21)$$

$$B(t) = 9e^{-10yt^2} - 7e^{-9yt^2} - 3e^{-8yt^2} - 4e^{-7yt^2} + 7e^{-6yt^2} - e^{-5yt^2} - 6e^{-4yt^2}$$

Table 4: Hazard Rate Function

Time (t)	Hazard Rate Function				
	Bc = 0.0	Bc = 0.02	Bc = 0.04	Bc = 0.06	Bc = 0.08
0.0	1	1	1	1	1
0.3	0.999	0.997	0.993	0.992	0.991
0.6	0.967	0.959	0.952	0.943	0.94
0.9	0.882	0.866	0.853	0.839	0.846
1.2	0.737	0.713	0.68	0.654	0.643
1.5	0.53	0.503	0.48	0.451	0.427
1.8	0.36	0.342	0.325	0.294	0.277
2.1	0.14	0.13	0.124	0.112	0.102
2.4	0.054	0.053	0.05	0.043	0.038
2.7	0.022	0.012	0.0188	0.014	0.012
3.0	0.0066	0.0056	0.0045	0.0043	0.0028

Figure 5: Time vs. Hazard Rate

5. DISCUSSIONS

The development of the time development, analysis using exponential and Rayleigh model and the exponential model for critical human errors in bridge network systems is described in this paper. This analysis utilized critical and non-

critical human errors as historical failure data to the model in terms of quantitative reliability parameters viz., probability density function, meant time to failures and hazard rate parameters.

The time-dependent reliability analysis of the bridge network system through established statistical models, evaluates hazard rate increases with time variant. The MTTF value evaluated in the system by using both models discussed in this paper. As further critical non-bridge factors are identified and incorporated into the model, the accuracy of correlations with a bigger number of human error index, as well as bridge network system will be analyzed based on time-dependent analysis with other multiple statistical models to analyze the human errors in the development of systems.

6. CONCLUSIONS

In conclusion, the main goal of this research is to develop an appropriate reliability methodology for an effective bridge network system condition by analyzing the historical data of the relevant human error elements. In exponential distribution, critical human error rate versus M.T.T.F curves is plotted. In fig 1 the bridge system M.T.T.F decreases as critical human error rate increases. In fig 2 Bridge system hazard rate increases as the time period increases. In Rayleigh distribution model, bridge system reliability versus time curves are plotted. In fig 3 the bridge system reliability decreases slowly as the time period increases. In fig 4 bridge system hazard rate increases as the time period increases. The time-dependent analysis is believed to be a useful methodology for ineffective implementation of exponential and Rayleigh models into bridge network systems. However, further insight into the appropriate bridge factors to analyze the human error impact on the system with non-parameter models and other statistical models.

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