AVAILABILITY MEASURES FOR THREE COMPONENT SYSTEM WITH HUMAN ERRORS AND CCS FAILURES

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Abstract—**This paper presents and emphasizes to demonstrate the impact of human errors and common cause shock failures (CCSF) in reliability analysis of a three unit identical system. Various measures of system effectiveness such as time-dependent availability, steady-state availability and frequency of failures of the system are obtained. The failed units are repaired singly and repair times are exponentially distributed. The numerical illustration is provided in order to highlight the effect of human errors and common cause shock failures on the system.**

Keywords–***system availability***, ***frequency of failures***, ***three unit identical system***, ***human errors, common cause shock failures (CCSF)***

1. INTRODUCTION

Sometimes the components may not fail individually. There are another factors to fail the system such as common cause shock failures, human errors etc., these external causes would diminish the reliability indices. B.S. Dhillon et al [3] discussed the role Common cause shock failures and human errors on standby systems. Verma et al [4] considered the CCSF in order to derive the system availability and frequency of failures for two-unit identical system.

This paper deals with three-unit identical system repairable which is affected by CCSFs and human error. The system/component can fail due to a CCSFs or human error or individually. The aim of this paper is to develop the system availability and frequency of failure expressions with CCS failures in addition to human error and to show the impact of CCSF and human error in the reliability analysis of repairable system with numerical illustration.

2. NOTATIONS

λ_i, λ_c and λ_h	:	the failure rates of individual, CCS and human errors respectively
c_1, c_2 and c_3	:	the chance of individual, CCS and human errors respectively
μ_0, μ_1	:	repair rates
R_{sh} (t)	:	reliability of the series configuration with human error and Common cause shock failures
R_{ph} (t)	:	reliability of the parallel configuration with human error as well as Common cause shock failures
A_{sh} (t)	:	availability of series configuration in the presence of human error and CCS failures
A_{ph} (t)	:	availability of the parallel configuration in the presence of human error and CCS failures
f_{sh} (down)	:	frequency of down state in the presence of CCS failures as well as human error for series configuration
f_{ph} (down)	:	frequency of down state in the presence of CCS failures as well as human error for parallel configuration

3. ASSUMPTIONS

1. The system consists of three s-independent and identical components.
2. The components in the system may fail by individually or common cause shocks or human errors or occurrence of all these failures simultaneously at the rates λi, λc and λh respectively. The chance of these failures are c1, c2 and c3, s.t c1+ c2+ c3 =1
3. The system is affected by individual and CCS failures as well as human errors.
4. Common cause failure, human error and individual failure rates are constant.
5. The components are repaired singly and repair times follow an exponential distribution.

4. THE MODEL

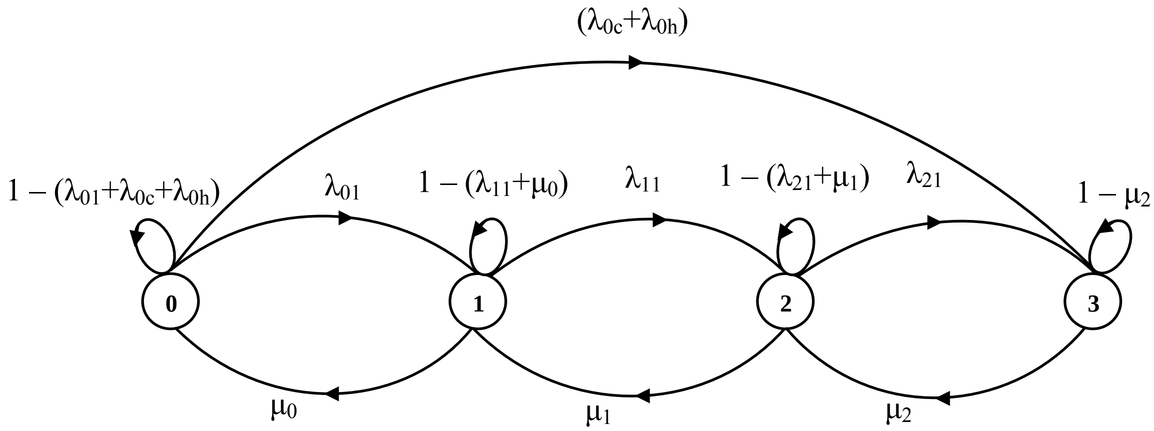

Fig. 1: Availability Markov graph – three-component identical *system with individual and CCS failures as well as human errors.*

Under the above assumptions we have been formulated a Markov graph which represents a three unit identical system given in Fig. 1 to derive the availability function [A(t)] and the frequency of encountering different states in the presence of individual failures, CCS failures as well as human errors. The numerals in figure 1 denote the state numbers.

The quantities λ_{01}, λ_{11}, λ_{21}, λ_{0c}, λ_{0h}, μ_0 , μ_1 and μ_2 appeared in fig. 1 are defined as follows:

$$\lambda_{01} = 3\lambda_i\, c_1,\ \lambda_{11} = 2\lambda_i\, c_1,\ \lambda_{21} = \lambda_i\, c_1,\ \lambda_{0c} = \lambda_c\, c_2,\ \lambda_{0h} = \lambda_h\, c_3,\ \mu_0 = \mu,\ \mu_1 = 2\mu \text{ and } \mu_2 = 3\mu \qquad \text{---------- (1)}$$

The differential equations associated with the system states are

$$\left.\begin{aligned}
p_0(t+dt) &= p_0(t)\,[\,1-(\lambda_{01}+\lambda_{0c}+\lambda_{0h}).dt\,] + p_1(t)\,\mu_0.\,dt\\
p_1(t+dt) &= \lambda_{01}.\,p_0(t).\,dt + p_1(t)\,[\,1-(\lambda_{11}+\mu_0).dt\,] + p_2(t)\,\mu_1.\,dt\\
p_2(t+dt) &= \lambda_{11}.\,p_1(t).\,dt + p_2(t)\,[\,1-(\lambda_{21}+\mu_1).dt] + \mu_2\,.\,p_3(t).\,dt\\
p_3(t+dt) &= (\lambda_{0c}+\lambda_{0h}).\,P_0(t).\,dt + \lambda_{21}.\,p_2(t)\,.\,dt + p_3(t)\,[\,1-\mu_2.dt\,]
\end{aligned}\right\} \qquad \text{------- (2)}$$

On simplification, the set of differential equations are

$$\left.\begin{aligned}
p'_0(t) &= -(\lambda_{01}+\lambda_{0c}+\lambda_{oh})\,.\,p_0(t) + \mu_0\,.\,p_1(t)\\
p'_1(t) &= \lambda_{01}\,.\,p_0(t) - (\lambda_{11}+\mu_0)\,p_1(t) + \mu_1\,.\,p_2(t)\\
p'_2(t) &= \lambda_{11}\,.\,p_1(t) - (\lambda_{21}+\mu_1)\,p_2(t) + \mu_2\,.\,p_3(t)\\
p'_3(t) &= (\lambda_{0c}+\lambda_{0h})\,p_0(t) - \lambda_{21}\,.\,p_2(t) - \mu_2\,.\,p_3(t)
\end{aligned}\right\} \qquad \text{---------- (3)}$$

Using the Laplace transformation, the set of equations stated in (3) can be solved with the help of the initial conditions, given at t = 0, $p_0(t) = 1$, $p_1(t) = p_2(t) = p_3(t) = 0$ and the solution is

$$\begin{aligned}
p_0(t) = {}& [\,(\gamma_1^3+\gamma_1^2 G_1 + H_1\gamma_1 + I_1)/\gamma_1(\gamma_1-\gamma_2)(\gamma_1-\gamma_3)\,]\exp(\gamma_1.t)\\
&-[\,(\gamma_2^3+\gamma_2^2 G_1 + H_1\gamma_2 + I_1)/\gamma_2(\gamma_1-\gamma_2)(\gamma_2-\gamma_3)]\exp(\gamma_2.t)\\
&+[\,(\gamma_3^3+\gamma_3^2 G_1 + H_1\gamma_3 + I_1)/\gamma_3(\gamma_1-\gamma_3)(\gamma_2-\gamma_3)]\exp(\gamma_3.t) - I_1/(\gamma_1\gamma_2\gamma_3)
\end{aligned} \qquad \text{------ (4)}$$

$$p_1(t) = [\,(\gamma_1^2 G_2 + \gamma_1 H_2 + I_2) / \gamma_1 (\gamma_1 - \gamma_2)(\gamma_1 - \gamma_3)\,] \exp(\gamma_1.t) - [\,(\gamma_2^2 G_2 + \gamma_2 H_2 + I_2) / \gamma_2 (\gamma_1 - \gamma_2)(\gamma_2 - \gamma_3)] \exp(\gamma_2.t) + [\,(\gamma_3^2 G_2 + \gamma_3 H_2 + I_2) / \gamma_3 (\gamma_1 - \gamma_3)(\gamma_2 - \gamma_3)] \exp(\gamma_3.t) - I_2 / (\gamma_1 \gamma_2 \gamma_3) \quad \text{------- (5)}$$

$$p_2(t) = [\,(\gamma_1 H_3 + I_3) / \gamma_1 (\gamma_1 - \gamma_2)(\gamma_1 - \gamma_3)\,] \exp(\gamma_1.t) - [\,(\gamma_2 H_3 + I_3) / \gamma_2 (\gamma_1 - \gamma_2)(\gamma_2 - \gamma_3)] \exp(\gamma_2.t) + [\,(\gamma_3 H_3 + I_3) / \gamma_3 (\gamma_1 - \gamma_3)(\gamma_2 - \gamma_3)] \exp(\gamma_3.t) - I_3 / (\gamma_1 \gamma_2 \gamma_3) \quad \text{------- (6)}$$

$$p_3(t) = 1 - [\,p_0(t) + p_1(t) + p_2(t)\,]$$

γ_1, γ_2 and γ_3 in equations (4) – (6) are defined as

$$\left.\begin{aligned} \gamma_1 &= -\gamma \operatorname{Sin} \alpha - A_1 / 3 \\ \gamma_2 &= \gamma \operatorname{Sin} (\pi/3+\alpha) - A_1 / 3 \\ \gamma_3 &= \gamma \operatorname{Sin} (-\pi/3+\alpha) - A_1 / 3 \end{aligned}\right\} \quad \text{----------- (7)}$$

and $\alpha = \theta$ is the solution of the equation.

$$\operatorname{Sin} 3\theta = -4q / \gamma^3$$

Where q and γ are given by

$$q = A_3 - A_1 A_2 / 3 + 2 A_1^3 / 27$$
$$\gamma = (2/3)(A_1^2 - 3 A_2)^{1/2}$$

Where A_1, A_2 and A_3 are defined as follows

$$A_1 = (\mu_0 + \mu_1 + \mu_2 + \lambda_{01} + \lambda_{11} + \lambda_{21} + \lambda_{0c} + \lambda_{0h})$$
$$A_2 = (\mu_0 \lambda_{21} + \lambda_{11} \lambda_{21} + \lambda_{11} \mu_2 + \lambda_{01} \mu_1 + \mu_1 \lambda_{0c} + \lambda_{11} \lambda_{0c} + \lambda_{0c} \mu_2 + \mu_0 \mu_2 + \lambda_{0h} \mu_2 + \lambda_{0c} \lambda_{21} + \lambda_{11} \lambda_{0h} + \mu_0 \lambda_{0c} + \mu_0 \mu_1 + \mu_1 \lambda_{0h} + \lambda_{01} \mu_2 + \mu_1 \mu_2 + \lambda_{01} \lambda_{21} + \lambda_{01} \lambda_{11} + \mu_0 \lambda_{0h} + \lambda_{0h} \lambda_{21})$$
$$A_3 = (\lambda_{0h} \mu_0 \mu_1 + \lambda_{01} \lambda_{11} \lambda_{21} + \lambda_{0c} \mu_0 \lambda_{21} + \mu_2 \lambda_{11} \lambda_{0h} + \lambda_{0h} \mu_0 \lambda_{21} + \mu_0 \mu_1 \mu_2 + \lambda_{0c} \mu_0 \mu_1 + \mu_0 \mu_2 \lambda_{0c} + \lambda_{01} \lambda_{11} \mu_2 + \lambda_{0c} \lambda_{11} \lambda_{21} + \mu_1 \mu_2 \lambda_{0h} + \mu_2 \lambda_{11} \lambda_{0c} + \lambda_{01} \mu_1 \mu_2 + \mu_1 \mu_2 \lambda_{0c} + \lambda_{0h} \lambda_{11} \lambda_{21} + \mu_2 \mu_0 \lambda_{0h})$$

respectively, and in (4) – (6)

$$\left.\begin{aligned} G_1 &= (\mu_0 + \mu_1 + \mu_2 + \lambda_{11} + \lambda_{21}) \\ G_2 &= \lambda_{01} \end{aligned}\right\} \quad \text{--------- (8)}$$

$$\left.\begin{aligned} H_1 &= (\mu_0 \mu_1 + \lambda_{11} \mu_2 + \lambda_{11} \lambda_{21} + \mu_1 \mu_2 + \mu_0 \lambda_{21} + \mu_0 \mu_1) \\ H_2 &= (\lambda_{01} \mu_1 + \lambda_{01} \mu_2 + \lambda_{01} \lambda_{21}) \\ H_3 &= (\lambda_{01} \lambda_{11} + \lambda_{0h} \mu_2 + \lambda_{0c} \mu_2) \end{aligned}\right\} \quad \text{---------- (9)}$$

$$\left.\begin{aligned} I_1 &= (\mu_0 \mu_1 \mu_2) \\ I_2 &= (\lambda_{01} \mu_1 \mu_2 + \mu_1 \mu_2 \lambda_{0c} + \mu_1 \mu_2 \lambda_{0h}) \\ I_3 &= (\mu_2 \mu_0 \lambda_{0c} + \mu_2 \lambda_{11} \lambda_{0c} + \lambda_{01} \lambda_{11} \mu_2 + \mu_2 \mu_0 \lambda_{0h} + \mu_2 \lambda_{11} \lambda_{0h}) \end{aligned}\right\} \quad \text{--------- (10)}$$

And the quantities λ_{01}, λ_{11}, λ_{21}, λ_{0c}, λ_{0h}, μ_0, μ_1 and μ_2 as seen in (1) are to be substituted using (7) – (10).

5. AVAILABILITY FUNCTION

Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability properties of a system. The three component system which has either a series or a parallel configuration.

5. 1 Time – dependent availability

We derive the time-dependent availability for both series and parallel in the case of individual failures and CCS failures as well as human errors.

5. 1. 1 Series configuration

For series case the time-dependent availability is given by

$$A_{sh}(t) = p_0(t)$$

$$= [(\gamma_1^3 + \gamma_1^2 G_1 + H_1 \gamma_1 + I_1) / \gamma_1 (\gamma_1 - \gamma_2) (\gamma_1 - \gamma_3)] \exp (\gamma_1.t) - [(\gamma_2^3 + \gamma_2^2 G_1 + H_1 \gamma_2 + I_1) / \gamma_2 (\gamma_1 - \gamma_2) (\gamma_2 - \gamma_3)] \exp (\gamma_2.t) + [(\gamma_3^3 + \gamma_3^2 G_1 + H_1 \gamma_3 + I_1) / \gamma_3 (\gamma_1 - \gamma_3) (\gamma_2 - \gamma_3)] \exp (\gamma_3.t) - I_1 / (\gamma_1 \gamma_2 \gamma_3) \quad \text{------- (11)}$$

Where G_1, H_1 , I_1 and γ_1, γ_2 , γ_3 are seen in (8) - (10) and (7)

For series case there is no transition is allowed from state '1' to state '2' and state '2' to state '3'. Hence $\lambda_{11} = \lambda_{21} = 0$ and also substitute the quantities λ_{01}, λ_{11}, λ_{21}, λ_{0c}, λ_{0h}, μ_0 , μ_1 and μ_2 as seen in (1) then the expression (11) becomes

$$A_{sh} (t) = D_1 \exp (\gamma_1.t) - D_2 \exp (\gamma_2.t) + D_3 \exp (\gamma_3.t) - 6 \mu^3 / (\gamma_1 \gamma_2 \gamma_3) \quad \text{---------- (12)}$$

$$D_1 = [(\gamma_1^3 + 6 \mu \gamma_1^2 + 11 \mu^2 \gamma_1 + 6 \mu^3) / \gamma_1 (\gamma_1 - \gamma_2) (\gamma_1 - \gamma_3)]$$
$$D_2 = [(\gamma_2^3 + 6 \mu \gamma_2^2 + 11 \mu^2 \gamma_2 + 6 \mu^3) / \gamma_2 (\gamma_1 - \gamma_2) (\gamma_2 - \gamma_3)]$$
$$D_3 = [(\gamma_3^3 + 6 \mu \gamma_3^2 + 11 \mu^2 \gamma_3 + 6 \mu^3) / \gamma_3 (\gamma_1 - \gamma_3) (\gamma_2 - \gamma_3)]$$

And

$$\left.\begin{aligned} \gamma_1 &= - \gamma \sin \alpha - A_1 / 3 \\ \gamma_2 &= \gamma \sin (\pi/3+\alpha) - A_1 / 3 \\ \gamma_3 &= \gamma \sin (-\pi/3+\alpha) - A_1 / 3 \end{aligned}\right\} \quad \text{----------- (13)}$$

and $\alpha = \theta$ is the solution of the equation.

$$\sin 3\theta = - 4q / \gamma^3$$

Where q and γ are given by

$$q = A_3 - A_1 A_2 / 3 + 2 A_1^3 / 27$$
$$\gamma = (2 / 3)(A_1^2 - 3 A_2)^{1/2}$$

Where A_1, A_2 and A_3 are defined as follows

$$A_1 = (6 \mu + 3 \lambda_i c_1 + \lambda_c c_2 + \lambda_h c_3)$$
$$A_2 = (15 \lambda_i c_1 \mu + 6 \lambda_c c_2 \mu + 6 \lambda_h c_3 \mu + 11\mu^2)$$
$$A_3 = (11 \lambda_h c_3 \mu^2 + 6\mu^3 + 11 \lambda_c c_2 \mu^2 + 18 \lambda_i c_1 \mu^2)$$

In this series system, the availability expression given in (12) agrees with the availability expression already arrived [4] in the case of individual and CCS failures affect the system when there is no transition from states '1' to '2' and '2' to '3' and also human errors are not affecting the system (i.e $\lambda_{21} = 0$, $c_3 = 0$ or $\lambda_h = 0$). If we assume CCS failures and human errors are not affecting the system ($c_2 = 0$ or $\lambda_c = 0$ & $c_3 = 0$ or $\lambda_h = 0$) , the present expression given in (12) agrees with the availability formula already derived [1, p128] when there is no transition from states '1' to '2' and '2' to '3'.

5. 1. 2 Parallel Configuration

The time dependent availability for a parallel system in the case of individual failures and CCS failures as well as human errors cab be obtained by

$$A_{ph} (t) = p_0 (t) + p_1 (t) + p_2 (t)$$
$$= (X_1 + Y_1 + Z_1) \exp (\gamma_1.t) - (X_2 + Y_2 + Z_2) \exp (\gamma_2.t) + (X_3 + Y_3 + Z_3) \exp (\gamma_3.t) + (X_4 + Y_4 + Z_4) \quad \text{------------- (14)}$$

Where

$$X_1 = [(\gamma_1^3 + \gamma_1^2 G_1 + H_1 \gamma_1 + I_1) / \gamma_1 (\gamma_1 - \gamma_2) (\gamma_1 - \gamma_3)]$$
$$X_2 = [(\gamma_2^3 + \gamma_2^2 G_1 + H_1 \gamma_2 + I_1) / \gamma_2 (\gamma_1 - \gamma_2) (\gamma_2 - \gamma_3)]$$
$$X_3 = [(\gamma_3^3 + \gamma_3^2 G_1 + H_1 \gamma_3 + I_1) / \gamma_3 (\gamma_1 - \gamma_3) (\gamma_2 - \gamma_3)]$$

$$Y_1 = [(\gamma_1^2 G_2 + \gamma_1 H_2 + I_2) / \gamma_1 (\gamma_1 - \gamma_2) (\gamma_1 - \gamma_3)]$$
$$Y_2 = [(\gamma_2^2 G_2 + \gamma_2 H_2 + I_2) / \gamma_2 (\gamma_1 - \gamma_2) (\gamma_2 - \gamma_3)]$$
$$Y_3 = [(\gamma_3^2 G_2 + \gamma_3 H_2 + I_2) / \gamma_3 (\gamma_1 - \gamma_3) (\gamma_2 - \gamma_3)]$$

$$Z_1 = [(\gamma_1 H_3 + I_3) / \gamma_1 (\gamma_1 - \gamma_2) (\gamma_1 - \gamma_3)]$$
$$Z_2 = [(\gamma_2 H_3 + I_3) / \gamma_2 (\gamma_1 - \gamma_2) (\gamma_2 - \gamma_3)]$$

$Z_3 = [(\gamma_3 H_3 + I_3) / \gamma_3 (\gamma_1 - \gamma_3) (\gamma_2 - \gamma_3)]$
$X_4 = -I_1 / (\gamma_1 \gamma_2 \gamma_3)$
$Y_4 = -I_2 / (\gamma_1 \gamma_2 \gamma_3)$
$Z_4 = -I_3 / (\gamma_1 \gamma_2 \gamma_3)$

5. 2 Steady – State availability

We can develop the steady state availability for both series and parallel configurations in the presence of individual and CCS failures as well as human errors.

5. 2. 1 Series Configuration

For steady state, $t \rightarrow \infty$ the expression can be obtained by using the final value theorem of Laplace transform,

$$A_{sh}(\infty) = \lim_{t\rightarrow\infty} A_{sh}(t) = \lim_{t\rightarrow\infty} [p_0(t)]$$

$$= \lim_{s\rightarrow 0} [s\, p_0^*(s)]$$

$$A_{sh}(\infty) = -I_1 / (\gamma_1\gamma_2\gamma_3) \qquad \text{----------------} (15)$$

Where $G_1, G_2, H_1, H_2, H_3, I_1, I_2, I_3$ and $\gamma_1, \gamma_2, \gamma_3$ are seen in (8)-(10) and (7).

Even in the parallel system, the expression given in (14) agrees with the formula already developed [4] when the system affected by only CCS failures this means there is no human error (i.e $c_3 = 0$ or $\lambda_h = 0$) and no transition allowed from '1' to '2' and '2' to '3' states.
Where I_1 and $\gamma_1, \gamma_2, \gamma_3$ can be seen in (10) and (13)

5. 2. 2 Parallel configuration

The steady-state availability of the parallel system is arrived at as a limiting case of the availability which is given by

$$A_{ph}(\infty) = \lim_{t\rightarrow\infty} A_{ph}(t) = \lim_{t\rightarrow\infty} [p_0(t) + p_1(t) + p_2(t)]$$

$$= \lim_{s\rightarrow 0} [s\, p^*_0(s) + s\, p^*_1(s) + s\, p^*_2(s)]$$

Using the final value theorem of the Laplace transformation, the availability would be

$$A_{ph}(\infty) = -(I_1 + I_2 + I_3) / (\gamma_1\gamma_2\gamma_3) \qquad \text{--------------} (16)$$

Where I_1, I_2, I_3 and $\gamma_1, \gamma_2, \gamma_3$ are seen in (10) and (7).

6. FREQUENCY OF ENCOUNTERING DIFFERENT STATES – CCS FAILURES AND HUMAN ERRORS

The frequency of encountering different states of the system in the presence of Common cause shock failures as well as human errors is evaluated in terms of the steady state probabilities of the different states. Which are given by

$p_0 = -I_1 / (\gamma_1\gamma_2\gamma_3)$

$p_1 = -I_2 / (\gamma_1\gamma_2\gamma_3)$

$p_2 = -I_3 / (\gamma_1\gamma_2\gamma_3)$

$p_3 = -I_4 / (\gamma_1\gamma_2\gamma_3)$

Where $I_4 = [\lambda_{01} \lambda_{11} \lambda_{21} + (\lambda_{0c} + \lambda_{0h}) (\lambda_{11} \lambda_{21} + \mu_0 \lambda_{21} + \mu_0 \mu_1)]$

and I_1, I_2, I_3 and $\gamma_1, \gamma_2, \gamma_3$ are seen in (10) and (7) respectively. The quantities $\lambda_{01}, \lambda_{11}, \lambda_{21}, \lambda_{0c}, \lambda_{0h}, \mu_0, \mu_1$ and μ_2 can be seen in (1)

6. 1 Series configuration

The frequency of down-state in the case of series configuration is obtained by

$$f_{sh}\,(\text{down}) = -\, I_1 \,(\, 3\lambda_i c_1 + \lambda_c c_2 + \lambda_h c_3 \,) \,/\, (\gamma_1\gamma_2\gamma_3)\,; \qquad \text{Where } I_1 \text{ and } \gamma_1, \gamma_2, \gamma_3 \text{ are seen in (10) and (7)}$$

6. 2 Parallel configuration

The frequency of down – state in the case of parallel configuration is obtained by

$$f_{ph}\,(\text{down}) = -\,3\mu\,[\,(\,\lambda_c c_2 + \lambda_h c_3\,)\,(\,2\mu^2 + \lambda_i c_1 \mu + 2\,(\lambda_i c_1)^2\,) + 6\,(\lambda_i c_1)^3\,]\,/\,(\gamma_1\gamma_2\gamma_3)$$

Where $\gamma_1, \gamma_2, \gamma_3$ can be seen in (7)

7. NUMERICAL ILLUSTRATION

Table 1. Availability in the case of CCS failures and human error – Series system $c_1 = 0.5$, $c_2 = 0.25$, $c_3 = 0.25$

Time t	$\lambda_i = 0.1, \lambda_c = 0.2, \lambda_h = 0.3$			$\lambda_i = 0.2, \lambda_c = 0.4, \lambda_h = 0.6$		
	$R_{sh}(t)$	$A_{sh}(t)$		$R_{sh}(t)$	$A_{sh}(t)$	
		$\mu = 5$	$\mu = 10$		$\mu = 5$	$\mu = 10$
0	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
1	0.759572	0.930096	0.963633	0.576950	0.868962	0.929678
2	0.576950	0.929678	0.963632	0.332871	0.868478	0.929677
3	0.438235	0.929677	0.963632	0.192050	0.868477	0.929677
4	0.332871	0.929677	0.963632	0.110803	0.868477	0.929677
5	0.252840	0.929677	0.963632	0.063928	0.868477	0.929677
6	0.192050	0.929677	0.963632	0.036883	0.868477	0.929677
7	0.145876	0.929677	0.963632	0.021280	0.868477	0.929677
8	0.110803	0.929677	0.963632	0.012277	0.868477	0.929677
9	0.084163	0.929677	0.963632	0.007083	0.868477	0.929677
10	0.063928	0.929677	0.963632	0.004087	0.868477	0.929677

Table 2. Availability in the case of CCS failures and human error – Parallel system $c_1 = 0.5$, $c_2 = 0.25$, $c_3 = 0.25$

Time T	$\lambda_i = 0.05, \lambda_c = 0.1, \lambda_h = 0.2$			$\lambda_i = 0.1, \lambda_c = 0.2, \lambda_h = 0.3$		
	$R_{sh}(t)$ $\mu = 10$	$A_{ph}(t)$		$R_{sh}(t)$ $\mu = 10$	$A_{ph}(t)$	
		$\mu = 10$	$\mu = 15$		$\mu = 10$	$\mu = 15$
0	*1.000000*	*1.000000*	*1.000000*	1.000000	1.000000	1.000000
1	*0.930385*	*0.997716*	*0.998521*	0.886076	0.996147	0.997454
2	*0.865770*	*0.997716*	*0.998521*	0.785373	0.996147	0.997454
3	*0.805642*	*0.997716*	*0.998521*	0.696114	0.996147	0.997454
4	*0.749690*	*0.997716*	*0.998521*	0.617000	0.996147	0.997454
5	*0.697624*	*0.997716*	*0.998521*	0.546878	0.996147	0.997454
6	*0.649174*	*0.997716*	*0.998521*	0.484725	0.996147	0.997454
7	*0.604088*	*0.997716*	*0.998521*	0.429635	0.996147	0.997454
8	*0.562134*	*0.997716*	*0.998521*	0.380807	0.996147	0.997454
9	*0.523094*	*0.997716*	*0.998521*	0.337528	0.996147	0.997454
10	*0.486765*	*0.997716*	*0.998521*	0.299167	0.996147	0.997454

Table: 3 Frequency of down-state – three component system – series and parallel configurations

$\mu = 5$ c_1=0.5, c_2=0.25, c_3=0.25			Series configuration Frequency of down-state	Parallel configuration Frequency of down-state
λ_i	λ_c	λ_h		
0.01	0.02	0.03	0.027297	0.012414
0.02	0.04	0.06	0.054186	0.024655
0.03	0.06	0.09	0.080674	0.036725
0.04	0.08	0.12	0.106770	0.048630
0.05	0.10	0.15	0.132481	0.060371
0.06	0.12	0.18	0.157814	0.071952
0.07	0.14	0.21	0.182778	0.083376
0.08	0.16	0.24	0.207379	0.094647
0.09	0.18	0.27	0.231624	0.105767
0.10	0.20	0.30	0.255521	0.116740

8. CONCLUSIONS

The availability measures for three component system such as availability function for both time-dependent, steady state and frequency of down state in the case of series and parallel configurations have been developed when the system affected by CCS and human errors. The reliability function and availability function are compared in the case of CCS failures as well as human errors and it is observed that $A(t) \geq R(t)$ remains valid in the present model.

The frequency of down-state is computed for various values of failure rates and presented. It is observed from table (3) that the frequency of the down-state for both series and parallel configurations increases with increase in rate of individual, CCS and human error failures. However, it is also observed that the frequency of down-state in the series system is more than the parallel system. By and large, the availability measures and frequency of down-state of three-component series and parallel system in the context of CCS failures as well as human errors are reduced and hence these failures need to be consider in the present work.

9. REFERENCES

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