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Profit-Function of Two Similar Warm Standby Navy Ship System Subject to Failure Due to Struck with Iceberg and Collision with Oil Tanker

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Abstract- *Notable Disasters*- The sinking of RMS Titanic in 1912, with 1,517 fatalities, is probably the most famous shipwreck, but not the biggest in terms of life lost. The wartime sinking of the Wilhelm Gustloff in January 1945 in World War II by a Soviet Navy submarine, with an estimated loss of about 9,400 people, remains the greatest maritime disaster ever. In peacetime, the 1987 loss of the ferry Doña Paz, with an estimated 4,386 dead, is the largest non-military loss recorded. In this paper we have taken failure due to struck with iceberg and collision with oil tanker. When the main unit fails then warm standby system becomes operative. Failure due to collision with oil tanker cannot occur simultaneously in both the units and after failure the unit undergoes Type-I or Type-II or Type-III repair facility immediately. Applying the regenerative point technique with renewal process theory the various reliability parameters MTSF, Availability, Busy period, Benefit-Function analysis have been evaluated.

Keywords: *warm standby, failure due to struck with iceberg, failure due to collision with oil tanker, first come first serve, MTSF, availability, busy period, benefit -function.*

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Strictly as per the compliance and regulations of :

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I. Introduction

Many maritime disasters happen outside the realms of war. All ships, including those of the military, are vulnerable to problems from weather conditions, faulty design or collision with oil tanker. Some of the disasters occurred in periods of conflict, although their losses were unrelated to any military action.

Year	Country	Description	Lives lost
1912	United Kingdom	RMS *Titanic* – A passenger ocean liner and, at the time, the world's largest ship. On 14 April 1912, on her maiden voyage, she struck an iceberg, buckling part of her hull and causing her to sink in the early hours of 15 April. 706 of her 2,223 passengers and crew survived. Her loss was the catalyst for major reforms in shipping safety and is arguably the most famous maritime disaster, being the subject of countless media portrayals.'	1,517
1987	Philippines	*Doña Paz* – On 20 December 1987, the ferry bound for Manila with more than its capacity of unlisted passengers collided with the oil tanker *MT Vector* in the Tablas Strait, near Marinduque. The resulting fire and sinking left an estimated 4,386 dead which included all but 24 of *Doña Paz*'s passengers, and all but two of *Vector*'s 13-man crew.	4,386

In this paper we have taken failure due to struck with iceberg and collision with oil tanker. When the main operative unit fails then warm standby system becomes operative. Failure due to collision with oil tanker cannot occur simultaneously in both the units. After failure the unit undergoes repair facility of Type-I or Type- II by ordinary repairman and Type-III or Type IV by multispecialty repairman immediately when failure due to struck with iceberg and failure due collision with oil tanker. The repair is done on the basis of first fail first repaired.

II. Assumptions

- λ_1, λ_2 λ_3 are constant failure rates when failure due to struck with iceberg failure due to collision with oil tanker respectively. The CDF of repair time distribution of Type I, Type II and multispecialty repairmen Type-III, IV are $G_1(t)$, $G_2(t)$ and $G_3(t)$ $G_4(t)$.

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- The failure due to collision with oil tanker is non-instantaneous and it cannot come simultaneously in both the units.
- The repair starts immediately after failure due to struck with iceberg and failure due to collision with oil tanker and works on the principle of first fail first repaired basis. The repair facility does no damage to the units and after repair units are as good as new.
- The switches are perfect and instantaneous.
- All random variables are mutually independent.
- When both the units fail, we give priority to operative unit for repair.
- Repairs are perfect and failure of a unit is detected immediately and perfectly.
- The system is down when both the units are non-operative.

III. Symbols for States of the System

a) *Superscripts O, CS, SIF, COTF,*

Operative, Warm Standby, failure due to struck with iceberg failure due to collision with oil tanker respectively.

Subscripts nsif, sif, cotf, ur, wr, uR

No failure due to struck with iceberg, failure due to struck with iceberg, failure due to collision with oil tanker, under repair, waiting for repair, under repair continued from previous state respectively

Up states – 0, 1, 2, 3, 10 ; Down states – 4, 5, 6, 7,8,9,11, regeneration point – 0,1,2, 3, 8, 9,10

b) *States of the System*

0(O_{nsif}, CS_{nsif}) One unit is operative and the other unit is warm standby and there is no failure due to struck with iceberg of both the units.

1($SIF_{sif,\ urI}$, O_{nsif}) The operating unit failure due to struck with iceberg is under repair immediately of Type- I and standby unit starts operating with no failure due to struck with iceberg

2($COTF_{cotf,\ urII}$, O_{nsif}) The operative unit failure due to collision with oil tanker and undergoes repair of Type II and the standby unit becomes operative with no failure due to struck with iceberg

3($COTF_{cotf,\ urIII}$, O_{nsif}) The first unit failure due to collision with oil tanker and under Type-III multispecialty repairman and the other unit is operative with no failure due to struck with iceberg

4($SIF_{sif,uR1}$, $SIF_{sif,wrI}$) The unit failed due to SIF resulting from failure due to struck with iceberg under repair of Type- I continued from state 1and the other unit failed due to SIF resulting from failure due to struck with iceberg is waiting for repair of Type-I.

5($SIF_{sif,uR1}$, $COTF_{cotf,\ wrII}$) The unit failed due to SIF resulting from failure due to struck with iceberg is under repair of Type- I continued from state 1and the other unit fails due to collision with oil tanker is waiting for repair of Type- II.

6($COTF_{cotf,\ uRII}$, $SIF_{sif\ ,wrI}$) The operative unit failed due to collision with oil tanker is under repair continues from state 2 of Type –II and the other unit failed due to SIF resulting from failure due to struck with iceberg is waiting under repair of Type-I.

7($COTF_{cotf\ ,uRII}$, $SIF_{sif,wrII}$) The one unit failed due to collision with oil tanker is continued to be under repair of Type II and the other unit failed due to SIF resulting from failure due to struck with iceberg is waiting for repair of Type-II.

8($SIF_{sif,urIII}$, $COTF_{cotf,\ wrII}$) The one unit failure due to struck with iceberg is under multispecialty repair of Type-III and the other unit failed due to collision with oil tanker is waiting for repair of Type-II.

9($SIF_{sif,urIII}$, $COTF_{cotf,\ wrI}$) The one unit failure due to struck with iceberg is under multispecialty repair of Type-III and the other unit failed due to collision with oil tanker is waiting for repair of Type-I

10(O_{nsif} $COTF_{cotf,\ urIV}$) The one unit is operative with no failure due to struck with iceberg and warm standby unit fails due to collision with oil tanker and undergoes repair of type IV.

11(O_{nsif} $COTF_{cotf,\ uRIV}$) The one unit is operative with no failure due to struck with iceberg and warm standby unit fails due to collision with oil tanker and repair of type IV continues from state 10.

IV. Transition Probabilities

Simple probabilistic considerations yield the following expressions:

$p_{01} = \lambda_1 / \lambda_1 + \lambda_2 + \lambda_3$, $p_{02} = \lambda_2 / \lambda_1 + \lambda_2 + \lambda_3$, $p_{0,10} = \lambda_3 / \lambda_1 + \lambda_2 + \lambda_3$

$p_{10} = pG_1^*(\lambda_1) + q\,G_2^*(\lambda_2)$, $p_{14} = p - pG_1^*(\lambda_1) = p_{11}^{(4)}$,

$p_{15} = q - q\,G_1^*(\lambda_2) = p_{12}^{(5)}$, $p_{23} = pG_2^*(\lambda_1) + q\,G_2^*(\lambda_2)$,

$p_{26} = p - pG_2^*(\lambda_1) = p_{29}^{(6)}$,$p_{27} = q - qG_2^*(\lambda_2) = p_{28}^{(7)}$,

$p_{30} = p_{82} = p_{91} = 1$, $p_{0,10} = pG_4^*(\lambda_1) + q\,G_4^*(\lambda_2)$,

$p_{10,1} = p- pG_4^*(\lambda_1) = p_{10,1}^{(11)}$ $,p_{10,2} = q- q\, G_4^*(\lambda_2) = p_{10,2}^{(11)}$ (1)

We can easily verify that

$p_{01} + p_{02} + p_{03} = 1,\ p_{10} + p_{14}\,(=p_{11}^{(4)}) + p_{15}\,(=p_{12}^{(5)}) = 1,$

$p_{23} + p_{26}\,(=p_{29}^{(6)}) + p_{27}\,(=p_{28}^{(7)}) = 1\ p_{30} = p_{82} = p_{91} = 1$

$p_{10,0} + p_{10,1}^{(11)}\,(=p_{10,1}) + p_{10,2}^{(12)}\,(=p_{10,2}) = 1$ (2)

And mean sojourn time is $\mu_0 = E(T) = \int_0^\infty P[T > t]dt$

V. Mean Time to System Failure

$Ø_0(t) = Q_{01}(t)[s]\, Ø_1(t) + Q_{02}(t)[s]\, Ø_2(t) + Q_{0,10}(t)[s]\, Ø_{10}(t)$

$Ø_1(t) = Q_{10}(t)[s]\, Ø_0(t) + Q_{14}(t) + Q_{15}(t)$

$Ø_2(t) = Q_{23}(t)[s]\, Ø_3(t) + Q_{26}(t) + Q_{27}(t)$, $Ø_3(t) = Q_{30}(t)[s]\, Ø_0(t)$,

$Ø_{10}(t) = Q_{10,0}(t)[s]\, Ø_{10}(t) + Q_{10,1}(t)[s] Ø_1(t) + Q_{10,2}(t)[s]\, Ø_2(t)$ (3-6)

We can regard the failed state as absorbing
Taking Laplace-Stiljes transiform of eq. (3-6) and solving for

$$ø_0^*(s) = N_1(s) / D_1(s) \quad (7)$$

where

$N_1(s) = \{Q_{01}^* + Q_{0,10}^*\, Q_{10,1}^*\}\, [\, Q_{14}^*(s) + Q_{15}^*(s)\,] + \{Q_{02}^* + Q_{0,10}^*\, Q_{10,2}^*\}\, [\, Q_{26}^*(s) + Q_{27}^*(s)\,]$

$D_1(s) = 1 - \{Q_{01}^* + Q_{0,10}^*\, Q_{10,1}^*\}\ Q_{10}^* - \{Q_{02}^* + Q_{0,10}^*\, Q_{10,2}^*\}\ Q_{23}^*\, Q_{30}^* - Q_{0,10}^*\, Q_{10,0}^*$

Making use of relations (1) & (2) it can be shown that $ø_0^*(0) = 1$, which implies that $ø_0(t)$ is a proper distribution.

$$MTSF = E[T] = \frac{d}{ds}\, ø_0^*(s)\ \Big|_{s=0}$$

$= (D_1'(0) - N_1'(0)) / D_1(0)$

$= (\mu_0 + \mu_1 (p_{01} + p_{0,10}\, p_{10,1}) + (p_{02} + p_{0,10}\, p_{10,2})(\mu_2 + \mu_3) + \mu_{10}\, p_{0,10} / (1 - (p_{01} + p_{0,10}\, p_{10,1})\, p_{10} - (p_{02} + p_{0,10}\, p_{10,2})\, p_{23}) - p_{0,10}\, p_{10,0}$

where

$$\mu_0 = \mu_{01} + \mu_{02} + \mu_{0,10}\ ,\ \mu_1 = \mu_{10} + \mu_{11}^{(4)} + \mu_{12}^{(5)},$$

$$\mu_2 = \mu_{23} + \mu_{28}^{(7)} + \mu_{29}^{(6)},\ \ \mu_{10} = \mu_{10,0} + \mu_{10,1} + \mu_{10,2}$$

VI. Availability Analysis

Let $M_i(t)$ be the probability of the system having started from state i is up at time t without making any other regenerative state. By probabilistic arguments, we have

$M_0(t) = e^{-\lambda_1 t} e^{-\lambda_2 t}\ e^{-\lambda_3 t}$, , $M_1(\overline{t}) = p\, G_1(t)\ e^{-\lambda_1 t}$

$M_2(t) = q\, \overline{G_2}(t)\, e^{-\lambda_2 t}$, $M_3(t) = \overline{G_3}(t)$, $M_{10}(t) = \overline{G_4}(t)\, e^{-\lambda_3 t}$

The point wise availability $A_i(t)$ have the following recursive relations

$A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{02}(t)[c]A_2(t) + q_{0,10}(t)[c]A_{10}(t)$

$A_1(t) = M_1(t) + q_{10}(t)[c]A_0(t) + q_{12}^{(5)}(t)[c]A_2(t) + q_{11}^{(4)}(t)[c]A_1(t)$,

$A_2(t) = M_2(t) + q_{23}(t)[c]A_3(t) + q_{28}^{(7)}(t)[c]A_8(t) + q_{29}^{(6)}(t)][c]A_9(t)$

$A_3(t) = M_3(t) + q_{30}(t)[c]A_0(t)$,$A_8(t) = q_{82}(t)[c]A_2(t)$

$A_9(t) = q_{91}(t)[c]A_1(t)$,

$$A_{10}(t) = M_{10}(t) + q_{10,0}(t)[c]A_0(t) + q_{10,1}^{(11)}(t)[c]A_1(t)+q_{10,2}^{(11)}(t)[c]A_2(t) \tag{8-15}$$

Taking Laplace Transiform of eq. (8-15) and solving for $\hat{A}_0(s)$

$$\hat{A}_0(s) = N_2(s) / D_2(s) \tag{16}$$

where

$N_2(s) = \{ \hat{q}_{0,10} \hat{M}_{10} + \hat{M}_0 \} [\{1 - \hat{q}_{11}^{(4)}\}\{1- \hat{q}_{28}^{(7)} \hat{q}_{82}\} - \hat{q}_{12}^{(5)} \hat{q}_{29}^{(6)} \hat{q}_{91}] + \{ \hat{q}_{01} + \hat{q}_{0,10} \hat{q}_{10,1}^{(11)}\}[\hat{M}_1\{1 - \hat{q}_{28}^{(7)} \hat{q}_{82}\} + \hat{q}_{12}^{(5)} \hat{q}_{23} \hat{M}_3 + \hat{M}_2] + \{ \hat{q}_{02} + \hat{q}_{0,10} \hat{q}_{10,2}^{(11)}\} [\{\hat{q}_{23} \hat{M}_3\}\{1 - \hat{q}_{11}^{(4)}\} + \hat{q}_{29}^{(6)} \hat{q}_{91} \hat{M}_1]$

$D_2(s) = \{1 - \hat{q}_{11}^{(4)}\}\{1- \hat{q}_{28}^{(7)} \hat{q}_{82}\} - \hat{q}_{12}^{(5)} \hat{q}_{29}^{(6)} \hat{q}_{91} - \{ \hat{q}_{01} + \hat{q}_{0,10} \hat{q}_{10,1}^{(11)} \}[\hat{q}_{10} \{1 - \hat{q}_{28}^{(7)} \hat{q}_{82}\} + \hat{q}_{12}^{(5)} \hat{q}_{23} \hat{q}_{30}] - \{ \hat{q}_{02} + \hat{q}_{0,10} \hat{q}_{10,2}^{(11)}\}\{[\hat{q}_{23} \hat{q}_{30} \{1 - \hat{q}_{11}^{(4)}\} + \hat{q}_{29}^{(6)} \hat{q}_{91} \hat{q}_{10}]$

(Omitting the arguments s for brevity)
The steady state availability

$$A_0 = \lim_{t\to\infty}[A_0(t)] = \lim_{s\to 0}[s\,\hat{A}_0(s)] = \lim_{s\to 0} \frac{s\,N_2(s)}{D_2(s)}$$

Using L' Hospitals rule, we get

$$A_0 = \lim_{s\to 0} \frac{N_2(s) + s\,N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)} \tag{17}$$

The expected up time of the system in (0,t] is

$$\lambda_u(t) = \int_0^\infty A_0(z)\,dz \qquad \text{So that } \bar{\lambda}_u(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)} \tag{18}$$

The expected down time of the system in (0,t] is

$$\lambda_d(t) = t - \lambda_u(t) \qquad \text{So that } \bar{\lambda}_d(s) = \frac{1}{s^2} - \bar{\lambda}_u(s) \tag{19}$$

Similarly, we can find out

- The expected busy period of the server when there is failure due to struck with iceberg and collision with oil tanker in (0,t]-R_0.
- The expected number of visits by the repairman Type-I or Type-II for repairing the identical units in (0,t]-H_0.
- The expected number of visits by the multispecialty repairman Type-III or Type-IV for repairing the identical units in (0,t]-W_0, Y_0.

VII. Benefit-Function

The Benefit-Function analysis of the system considering mean up-time, expected busy period of the system under failure due to struck with iceberg and collision with oil tanker, expected number of visits by the repairman for unit failure. The expected total Benefit-Function incurred in (0,t] is

$$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2 C(s)) = K_1A_0 - K_2R_0 - K_3H_0 - K_4W_0$$

where

K_1- revenue per unit up-time, K_2 - cost per unit time for which the system is busy under repairing, K_3 - cost per visit by the repairman type- I or type- II for units repair,
K_4 - cost per visit by the multispecialty repairman Type- III for units repair

VIII. Conclusion

After studying the system, we have analyzed graphically that when the failure rate due to struck with iceberg and due to collision with oil tanker increases, the MTSF, steady state availability decreases and the Profit-function decreased as the failure increases.

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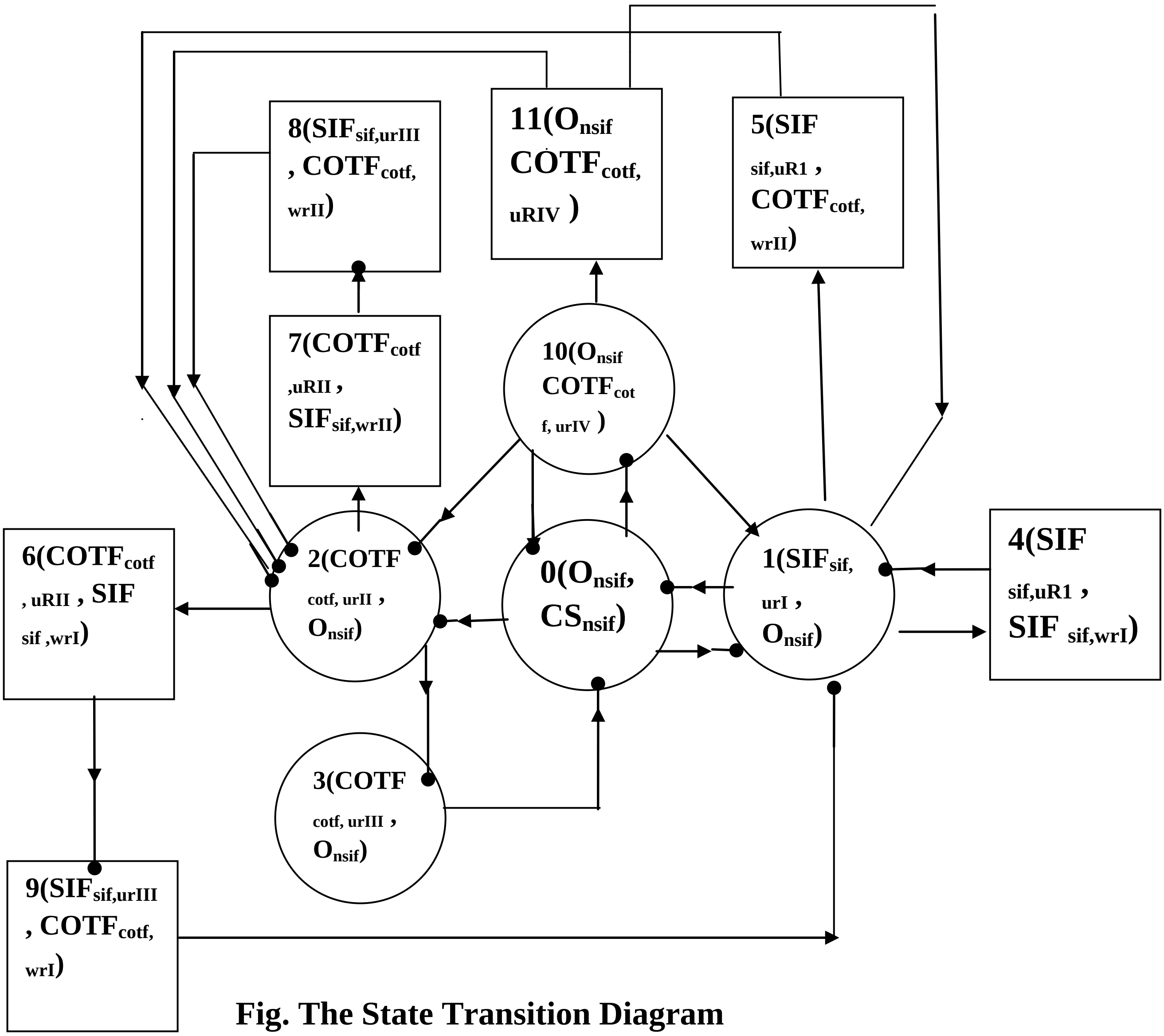

Fig. The State Transition Diagram

Up-State ◯ **Down-State** □

● **regeneration point**

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