Research Article

Benefit-function of two- identical cold standby system subject to failure due to high temperature or failure due to change in rain fall pattern caused by global warming

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Abstract

Warming May Cause Crop Failures, Food Shortages by 2030: Impoverished farmers in South Asia and southern Africa could face growing food shortages due to climate change within just 20 years, a new study says. Increasing levels of greenhouse gases, including carbon dioxide, are heating up the planet, with droughts and shifting rainfall patterns predicted for many parts of the world. "The majority of the world's one billion poor depend on agriculture for their livelihoods," said the lead author of the new study, David Lobell of Stanford University. "Unfortunately, agriculture is also the human enterprise most vulnerable to changes in climate." Climate change will affect some places more than others, so Lobell and colleagues focused on 12 regions where most of the world's impoverished live and the crops that the poor tend to grow and eat in those places. They identified two hot spots—South Asia and southern Africa—where higher temperatures and drops in rainfall could cut yields of the main crops people grow there. "We were surprised by how much, and how soon, these regions could suffer if we don't adapt," said study co-author Marshall Burke, also at Stanford. **Corn, Wheat at Risk:** The researchers used computer models to predict changes in temperature and rainfall as the planet warms. Most of the 12 regions were predicted to warm up about 1.8 degrees Fahrenheit (1 degree Celsius) by 2030—about the same amount of warming that Earth as a whole experienced over the 20th century. "To identify which crops in which regions are most under threat by 2030, we combined projections of climate change with data on what poor people eat, as well as past relationships between crop harvests and climate The predictions from the various climate models often didn't agree on rainfall changes, he noted. But the overall analysis did suggest that southern Africa and South Asia were two spots where hotter temperatures and lack of water are most likely to stress crops. "By looking systematically across regions and at a wide range of crops of importance to the poor, we hope to provide a way to prioritize investments in adaptation," Lobell said. In southern Africa, corn (also known as maize) is a major crop, but it will suffer especially, the study suggests. Lobell and colleagues predict about a 30 percent drop in corn yields there, along with a 15 percent drop in wheat yields, and smaller drops for soybeans and sugarcane. They predict a small increase in rice yields for the southern Africa, and little change for sorghum or cassava. In South Asia, on the other hand, almost every major crop would suffer a decline of about 5 to 10 percent, with only soybeans experiencing a slight gain in yields, the study predicts. Changing which crops are cultivated in these areas could help populations cope with climate change, the authors argue. **A Global Impact:** Taking a global view of crop yields could be important because the markets are globalized, and worldwide decreases in yields could drive up food costs, argues a commentary also published in *Science.* Molly Brown of the NASA Goddard Space Flight Center in Greenbelt, Maryland, and Christopher Funk of the University of California, Santa Barbara wrote the commentary. By making fundamental changes, these regions could cope much better with today's problems and those to come with climate change, they say. "Transform these agricultural systems through improved seed, fertilizer, land use, and governance, and food security may be attained by all," Brown and Funk write. Tom Sinclair, an agronomist at the University of Florida in Gainesville who was not involved in the study, said, "The big unknown is water." Climate models, including those used in the new study, don't agree on how rainfall will change in the coming decades, Sinclair says. In addition, he says, the new study's approach of looking at average rainfall and temperatures misses what's most important for plants. "What gets them is extremes [of] hot or cold," Sinclair said. "Or if you have episodes where the rainfall is spread apart, where the crops are more vulnerable to drought, then that's a real problem." Like Brown and Funk, Sinclair also calls for more spending on improved crops, especially breeding drought-resistant produce. "If I had a stack of money, that's where I'd put it," Sinclair says. In this paper we have taken **Failure due to high temperature or failure due to change in rain fall pattern caused by global warming.** When the main unit fails due to **high temperature caused by global warming** then cold standby system becomes operative. **Failure due to change in rain fall pattern caused by global warming** cannot occur simultaneously in both the units and after failure the unit undergoes very costly repair facility immediately. Applying the regenerative point technique with renewal

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process theory the various reliability parameters MTSF, Availability, Busy period, Benefit-Function analysis have been evaluated.

Keywords: Cold Standby, Failure due to high temperature or failure due to change in rain fall pattern caused by global warming**,** first come first serve, MTSF, Availability, Busy period, Benefit -Function.

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INTRODUCTION

Massive crop failures more likely with global warming SUMMIT COUNTY: Global warming is likely to result in more frequent crop failures like the recent Russian wheat crisis, according to research conducted by the University of Leeds, the Met Office Hadley Centre and University of Exeter. The worst effects of these events on agriculture could be mitigated by improved farming and the development of new crops, said Dr. Evan Fraser, one of the authors of the study. “What is becoming clear is that we need to adopt a holistic approach; new crops for a changing climate and better farming practices that can only come about under more favorable socio-economic conditions,” Fraser said. “It appears that more developed countries with a higher gross domestic product tend to evolve more advanced coping mechanisms for extreme events. In China this is happening organically as the economy is growing quickly, but poorer regions such as Africa are likely to require more in the way of aid for such development.” The researchers zeroed in on China for their study, looking at spring wheat crops in North East China. They used a climate model to make weather projections up to the year 2099 and then looked at the effect on crop yields. In parallel, they looked at socio-economic factors to determine how well farmers were able to adapt to drought. While the study only looked at crops in China, the authors said the methodology can be applied to many of the other major crop-growing regions around the globe. The unpredictability of the weather is one of the biggest challenges faced by farmers struggling to adapt to a changing climate. Some areas of the world are becoming hotter and drier, and more intense monsoon rains carry a risk of flooding and crop damage. A summer of drought and wildfires has dramatically hit harvests across Russia this year, leading the government to place a ban on wheat exports. This led to a dramatic rise prices on the international commodity markets which is likely to cause higher prices of consumer goods. “Due to the importance of international trade, crop failure is an issue that affects everyone on the planet, not just those in crop-growing regions,” said Dr, Andy Challinor, from the University of Leeds School of Earth and Environment. “More extreme weather events are expected to occur in the coming years due to climate change and we have shown that these events are likely to lead to more crop failures. What we need to do now is think about the solutions. “It is highly unlikely that we will find a single intervention that is a silver bullet for protecting crops from failure. What we need is an approach that combines building up crop tolerance to heath and water stress with socio-economic interventions.” The team will now expand their research to look at other crops in different regions and they will look more closely at the reasons why increased GDP appears to protect against drought. Stochastic behavior of systems operating under changing environments has widely been studied.. Dhillon, B.S. and Natesan, J. (1983) studied an outdoor power systems in fluctuating environment. Kan Cheng (1985) has studied reliability analysis of a system in a randomly changing environment. Jinhua Cao (1989) has studied a man machine system operating under changing environment subject to a Markov process with two states. The change in operating conditions viz. fluctuations of voltage, corrosive atmosphere, very low gravity etc. may make a system completely inoperative. Severe environmental conditions can make the actual mission duration longer than the ideal mission duration. In this paper we have taken. **Failure due to high temperature or failure due to change in rain fall pattern caused by global warming** When the main operative unit fails then cold standby system becomes operative. The failure due to high temperature or failure due to change in rain fall pattern caused by global warming is non-instantaneous and after failure the unit undergoes repair facility of very high cost in case of Failure due to high temperature immediately. The repair is done on the basis of first fail first repaired.

ASSUMPTIONS

1. $\lambda_{1,}$ $\lambda_{2,}$ are constant failure rates for Failure due to high temperature caused by global warming, failure due to change in rain fall pattern caused by global warming respectively. The CDF of repair time distribution of Type I and Type II are G_1 (t) and G_2 (t).
2. The failure due to high temperature or failure due to change in rain fall pattern caused by global warming is non-instantaneous. The repair starts immediately after the failure due to high temperature or failure due to change in rain fall pattern caused by global warming works on the principle of first fail first repaired basis.
3. The repair facility does no damage to the units and after repair units are as good as new.
4. The switches are perfect and instantaneous.
5. All random variables are mutually independent.
6. When both the units fail, we give priority to operative unit for repair.
7. Repairs are perfect and failure of a unit is detected immediately and perfectly.
8. The system is down when both the units are non-operative.

Notations

$\lambda_{1,}$ λ_2 are the **Failure due to high temperature caused by global warming, failure due to change in rain fall pattern caused by global warming** respectively. G_1(t), G_2(t) – repair time distribution Type -I, Type-II due to Failure due to high temperature caused by global warming, failure due to change in rain fall pattern caused by global warming respectively. p, q - probability of **failure due to high temperature caused by global warming, failure due to change in rain fall pattern caused by global warming** respectively such that p+ q=1

M_i(t) System having started from state i is up at time t without visiting any other regenerative state

A_i (t) state is up state as instant t

R_i (t) System having started from state i is busy for repair at time t without visiting any other regenerative state.

B_i (t) the server is busy for repair at time t.

H_i(t) Expected number of visits by the server for repairing given that the system initially starts from regenerative state i

Symbols for states of the System

Superscripts: O, CS, HTGWF, RFGWF

Operative, Cold Standby, **Failure due to high temperature caused by global warming, failure due to change in rain fall pattern caused by global warming** respectively

Subscripts: nhtgwf, htgwf, rfgwf, ur, wr, uR

No Failure due to high temperature caused by global warming, Failure due to high temperature caused by global warming,failure due to change in rain fall pattern caused by global warming, under repair, waiting for repair, under repair continued from previous state respectively

Up states: 0, 1, 2, 7, and 8;

Down states: 3, 4, 5, 6

Regeneration point: 0, 1, 2, 7, 8

STATES OF THE SYSTEM

0(O_{nhtgwf}, CS_{nhtgwf})

One unit is operative and the other unit is cold standby and there is no failure due to high temperature caused by global warming in both the units.

1($HTGWF_{htgwf, ur}$, O_{nhtgwf})

The operating unit fails due to Failure due to high temperature caused by global warming and is under repair immediately of very costly Type- I and standby unit starts operating with no Failure due to high temperature caused by global warming

2($RFGWF_{rfgwf, ur}$, O_{nhtgwf})

The operative unit fails due to RFGWF resulting from failure due to change in rain fall pattern caused by global warming and undergoes repair of Type II and the standby unit becomes operative with no Failure due to high temperature caused by global warming**.**

3($HTGWF_{htgwf,uR}$, $RFGWF_{rfgwf,wr}$)

The first unit failure due to high temperature caused by global warming and under very costly Type-I repair is continued from state 1 and the other unit fails due to RFGWF resulting from failure due to change in rain fall pattern caused by global warming and is waiting for repair of Type -II.

4($HTGWF_{htgwf,uR}$, $HTGWF_{htgwf,wr}$)

The repair of the unit is failed due to HTGWF resulting from failure due to high temperature caused by global warming is continued from state 1and the other unit failed due to HTGWF resulting from failure due to high temperature caused by global warming is waiting for repair of very costly Type-I.

5($RFGWF_{rfgwf,\ uR}$, $RFGWF_{rfgwf,\ wr}$)

The operating unit failS due to change in rain fall pattern caused by global warming (RFGWF mode) and under repair of Type - II continue from the state 2 and the other unit fails also due to failure due to change in rain fall pattern caused by global warming is waiting for repair of Type- II.

6($RFGWF_{rfgwf,uR}$, $HTGWF_{htgwf,wr}$)

The operative unit fails due to RFGWF resulting from failure due to change in rain fall pattern caused by global warming and under repair continues from state 2 of Type –II and the other unit is failed due to HTGWF resulting from failure due to high temperature caused by global warming and under very costly Type-I

7(O_{nhtgwf}, $HTGWF_{htgwf,ur}$)

The repair of the unit failed due to HTGWF resulting from failure due to high temperature caused by global warming failure is completed and there is no failure due to high temperature caused by global warming and the other unit is failed due to HTGWF resulting from failure due to high temperature caused by global warming is under repair of very costly Type-I

8(O_{nhtgwf}, $RFGWF_{rfgwf,ur}$)

The repair of the unit failed due to HTGWF resulting from failure due to high temperature caused by global warming is completed and there is no failure due to high temperature and the other unit is failed due to RFGWF resulting from failure due to change in rain fall pattern caused by global warming is under repair of Type-II.

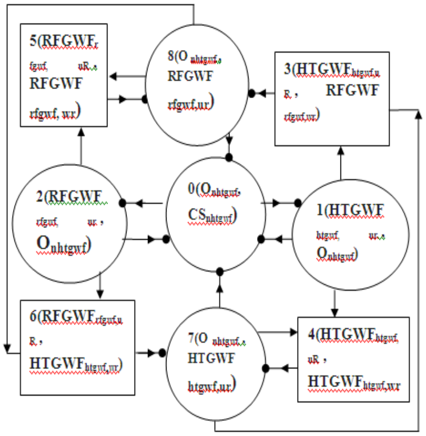

Figure 1: The State Space Diagram

○ Up state ☐ down state ● Regeration point

TRANSITION PROBABILITIES

Simple probabilistic considerations yield the following expressions:

$p_{01} = p_{,}\ p_{02} = q,$

$p_{10} = pG_1^*(\lambda_1)+q\ G_1^*(\lambda_2)= p_{70,}$

$p_{20} = pG_2^*(\lambda_1)+q\ G_2^*(\lambda_2)= p_{80,}$

$p_{11}^{(3)}= p(1- G_1^*(\lambda_1))= p_{14} = p_{71}^{(4)}\ p_{28}^{(5)}= q(1- G_2^*(\lambda_2))= p_{25} = p_{82}^{(5)}$ (1)

We can easily verify that

$p_{01} + p_{02} = 1,\ p_{10} + p_{17}^{(4)} (= p_{14}) + p_{18}^{(3)} (=p_{13}) = 1,$

$p_{80} + p_{82}^{(5)} + p_{87}^{(6)} = 1$ (2)

And mean sojourn time is

$\mu_0 = E(T) = \int_0^\infty P[T > t]dt$

Mean Time To System Failure

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

$Ø_1(t) = Q_{10}(t)[s]\, Ø_0(t) + Q_{13}(t) + Q_{14}(t)$

$Ø_2(t) = Q_{20}(t)[s]\, Ø_0(t) + Q_{25}(t) + Q_{26}(t)$ (3-5)

We can regard the failed state as absorbing

Taking Laplace-Stiljes transform of eq. (3-5) and solving for

$ø_0^*(s) = N_1(s) / D_1(s)$ (6)

where

$N_1(s) = Q_{01}^*[\, Q_{13}^*(s) + Q_{14}^*(s)\,] + Q_{02}^*[\, Q_{25}^*(s) + Q_{26}^*(s)\,]$

$D_1(s) = 1 - Q_{01}^* Q_{10}^* - Q_{02}^* Q_{20}^*$

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

$$MTSF = E[T] = \frac{d}{ds}\, ø_0^*(s) \Big|_{s=0} = (D_1'(0) - N_1'(0)) / D_1(0)$$

$= (\mu_0 + p_{01}\mu_1 + p_{02}\mu_2) / (1 - p_{01}p_{10} - p_{02}p_{20})$

where

$\mu_0 = \mu_{01} + \mu_{02}$,

$\mu_1 = \mu_{01} + \mu_{17}^{(4)} + \mu_{18}^{(3)}$,

$\mu_2 = \mu_{02} + \mu_{27}^{(6)} + \mu_{28}^{(5)}$

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

$M_0(t) = e^{-\lambda_1 t} e^{-\lambda_2 t},$

$M_1(t) = p\, G_1\overline{(t)}\, e^{-(\lambda_1 + \lambda_2)} = M_7(t)$

$M_2(t) = q\, G_2\overline{(t)}\, e^{-(\lambda_1 + \lambda_2)} = M_8(t)$

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

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

$A_1(t) = M_1(t) + q_{10}(t)[c]A_0(t) + q_{18}^{(3)}(t)[c]A_8(t) + q_{17}^{(4)}(t)[c]A_7(t)$

$A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + [q_{28}^{(5)}(t)[c]\, A_8(t) + q_{27}^{(6)}(t)]\, [c]A_7(t)$

$A_7(t) = M_7(t) + q_{70}(t)[c]A_0(t) + [q_{71}^{(4)}(t)[c]\, A_1(t) + q_{78}^{(3)}(t)]\, [c]A_8(t)$

$A_8(t) = M_8(t) + q_{80}(t)[c]A_0(t) + [q_{82}^{(5)}(t)[c]\, A_2(t) + q_{87}^{(6)}(t)]\, [c]A_7(t)$ (7-11)

Taking Laplace Transform of eq. (7-11) and solving for $\hat{A}_0(s)$

$\hat{A}_0(s) = N_2(s) / D_2(s)$ (12)

where

$N_2(s) = \widehat{M}_0 (1 - \hat{q}_{78}^{(3)} - \hat{q}_{87}^{(6)}) - \hat{q}_{82}^{(5)}(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)} - \hat{q}_{71}^{(4)}$

$(\hat{q}_{17}^{(4)} + \hat{q}_{87}^{(6)} \hat{q}_{18}^{(3)}) + \hat{q}_{71}^{(4)} \hat{q}_{82}^{(5)} (\hat{q}_{17}^{(4)} - \hat{q}_{27}^{(6)} \hat{q}_{18}^{(3)})] + \hat{q}_{01}[\widehat{M}_1(1 -$

$\hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{71}^{(4)}(\widehat{M}_7 + \hat{q}_{78}^{(3)} \widehat{M}_8) + \hat{q}_{18}^{(3)}(\widehat{M}_7 \hat{q}_{87}^{(6)} - \widehat{M}_8) -$

$\hat{q}_{82}^{(5)}(\widehat{M}_1(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) + \hat{q}_{17}^{(4)} (- \widehat{M}_2(\hat{q}_{78}^{(3)} + \widehat{M}_7 \hat{q}_{28}^{(5)}) -$

$\hat{q}_{18}^{(3)}(\widehat{M}_2 + \widehat{M}_7 \hat{q}_{27}^{(6)})\}]\ \hat{q}_{02}[\widehat{M}_2(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{27}^{(6)}($

$\widehat{M}_7 + \hat{q}_{78}^{(3)} \widehat{M}_8) + \hat{q}_{28}^{(5)}(\widehat{M}_7 \hat{q}_{87}^{(6)} + \widehat{M}_8) - \hat{q}_{71}^{(4)}(\widehat{M}_1(- \hat{q}_{27}^{(6)} - \hat{q}_{28}^{(5)} +$

$\hat{q}_{87}^{(6)}) + \hat{q}_{17}^{(4)} (\widehat{M}_2 + \hat{q}_{28}^{(5)} \widehat{M}_8) - \hat{q}_{18}^{(3)} (- \widehat{M}_2 \hat{q}_{87}^{(6)} + \widehat{M}_8 \hat{q}_{27}^{(6)})\}]$

$\hat{q}_{18}^{(3)}(\widehat{M}_2 + \widehat{M}_7 \hat{q}_{27}^{(6)})\}]$

$D_2(s) = (1 - \hat{q}_{78}^{(3)} - \hat{q}_{87}^{(6)}) - \hat{q}_{82}^{(5)}(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)}) - \hat{q}_{71}^{(4)}$

$(\hat{q}_{17}^{(4)}+ \hat{q}_{87}^{(6)} \hat{q}_{18}^{(3)})+ \hat{q}_{71}^{(4)} \hat{q}_{82}^{(5)} (\hat{q}_{17}^{(4)} \hat{q}_{28}^{(5)}- \hat{q}_{18}^{(3)})]+ \hat{q}_{01}[- \hat{q}_{10} (1 -$
$\hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) - \hat{q}_{71}^{(4)}(\hat{q}_{70}+ \hat{q}_{78}^{(3)} \hat{q}_{80})- \hat{q}_{18}^{(3)}(\hat{q}_{70} \hat{q}_{87}^{(6)}- \hat{q}_{80})-$
$\hat{q}_{82}^{(5)}(- \hat{q}_{10}(\hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)})+ \hat{q}_{17}^{(4)} (\hat{q}_{20} (\hat{q}_{78}^{(3)}- \hat{q}_{70} \hat{q}_{28}^{(5)})+$
$\hat{q}_{18}^{(3)}(\hat{q}_{20}+ \hat{q}_{70} \hat{q}_{27}^{(6)})\}] \hat{q}_{02}[- \hat{q}_{20}(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) - \hat{q}_{27}^{(6)}(\hat{q}_{70} + \hat{q}_{78}^{(3)} \hat{q}_{80}) -$
$\hat{q}_{28}^{(5)}(\hat{q}_{70} \hat{q}_{87}^{(6)}+ \hat{q}_{80}) - \hat{q}_{71}^{(4)}(\hat{q}_{10} (\hat{q}_{27}^{(6)}+ \hat{q}_{28}^{(5)} \hat{q}_{87}^{(6)})- \hat{q}_{17}^{(4)} (\hat{q}_{20}-$
$\hat{q}_{28}^{(5)} \hat{q}_{80})- \hat{q}_{18}^{(3)} (\hat{q}_{20} \hat{q}_{87}^{(6)}+ \hat{q}_{80} \hat{q}_{27}^{(6)})\}]$
(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

$$A_0 = \lim_{s\to 0}\frac{N_2(s)+s\,N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)} \qquad (13)$$

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

$$\lambda_u(t) = \int_0^{\infty} A_0(z)\,dz \text{ So that } \overline{\lambda_u}(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)} \qquad (14)$$

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

$$\lambda_d(t) = t- \lambda_u(t) \text{ So that } \overline{\lambda_d}(s) = \frac{1}{s^2} - \overline{\lambda_u}(s) \qquad (15)$$

The expected busy period of the server when there is RFGWF - Failure due to change in rain fall pattern or HTGWF- failure due to high temperature caused by global warming in (0,t]

$R_0(t) = q_{01}(t)[c]R_1(t) + q_{02}(t)[c]R_2(t)$
$R_1(t) = S_1(t) + q_{10}(t)[c]R_0(t) + q_{18}^{(3)}(t)[c] R_8(t) + q_{17}^{(4)}(t)[c]R_7(t)$
$R_2(t) = S_2(t) + q_{20}(t)[c]R_0(t) + q_{28}^{(5)}(t) R_8(t) +q_{27}^{(6)}(t)][c]R_7(t)$
$R_7(t) = S_7(t) + q_{70}(t)[c]R_0(t) + Q_{71}^{(4)}(t) R_1(t) +q_{78}^{(3)}(t)][c]R_8(t)$
$R_8(t) = S_8(t) + q_{80}(t)[c]R_0(t) + Q_{82}^{(5)}(t) R_2(t) +q_{87}^{(6)}(t)][c]R_7(t)$ (16-20)

Taking Laplace Transform of eq. (16-20) and solving for $\overline{R_0}(s)$

$$\overline{R_0}(s) = N_3(s) / D_2(s) \qquad (21)$$

where

$N_3(s) = \hat{q}_{01}[\hat{S}_1(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{71}^{(4)}(\hat{S}_7 + \hat{q}_{78}^{(3)} \hat{S}_8)+ \hat{q}_{18}^{(3)}(\hat{S}_7$
$\hat{q}_{87}^{(6)}- \hat{S}_8)]- \hat{q}_{01} \hat{q}_{82}^{(5)}(\hat{S}_1 \hat{q}_{27}^{(6)} \hat{q}_{78}^{(3)} + \hat{q}_{28}^{(5)})+ \hat{q}_{17}^{(4)} (\hat{S}_2 \hat{q}_{78}^{(3)}+ \hat{S}_7 \hat{q}_{28}^{(5)}) -$
$\hat{q}_{18}^{(3)}(\hat{S}_2+ \hat{S}_7 \hat{q}_{27}^{(6)})]+ \hat{q}_{02}[\hat{S}_2(1 - \hat{q}_{78}^{(3)} \hat{q}_{87}^{(6)}) + \hat{q}_{27}^{(6)}(\hat{S}_7 + \hat{q}_{78}^{(3)} \hat{S}_8)+ \hat{q}_{28}^{(5)}(\hat{S}_7$
$\hat{q}_{87}^{(6)}+ \hat{S}_8) - \hat{q}_{02} \hat{q}_{71}^{(4)}(\hat{S}_1(- \hat{q}_{27}^{(6)}- \hat{q}_{28}^{(5)} \hat{q}_{87}^{(6)} \hat{q}_{17}^{(4)} (\hat{S}_2+ \hat{q}_{28}^{(5)} \hat{S}_8)- \hat{q}_{18}^{(3)} (-\hat{S}_2$
$\hat{q}_{87}^{(6)}+ \hat{S}_8 \hat{q}_{27}^{(6)})]$
and
$D_2(s)$ is already defined.
(Omitting the arguments s for brevity)

$$\text{In the long run, } R_0 = \frac{N_3(0)}{D_2'(0)} \qquad (22)$$

The expected period of the system under RFGWF - failure due to change in rain fall pattern or HTGWF- failure due to high temperature caused by global warming in (0,t] is

$$\lambda_{rv}(t) = \int_0^{\infty} R_0(z)\,dz \text{ So that } \overline{\lambda_{rv}}(s) = \frac{\hat{R}_0(s)}{s}$$

The expected number of visits by the repairman for repairing the identical units in (0,t]

$H_0(t) = Q_{01}(t)[s][1+ H_1(t)] + Q_{02}(t)[s][1+ H_2(t)]$
$H_1(t) = Q_{10}(t)[s]H_0(t)] + Q_{18}^{(3)}(t)[s] H_8(t) + Q_{17}^{(4)}(t)] [s]H_7(t),$
$H_2(t) = Q_{20}(t)[s]H_0(t) + Q_{28}^{(5)}(t) [s] H_8(t) +Q_{27}^{(6)}(t)] [c]H_7(t)$

$H_7(t) = Q_{70}(t)[s]H_0(t) + Q_{71}^{(4)}(t)\ [s]\ H_1(t) + Q_{78}^{(3)}(t)]\ [c]H_8(t)$
$H_8(t) = Q_{80}(t)[s]H_0(t) + Q_{82}^{(5)}(t)\ [s]\ H_2(t) + Q_{87}^{(6)}(t)]\ [c]H_7(t)$ (23-27)

Taking Laplace Transform of eq. (23-27) and solving for $H_0^*(s)$

$H_0^*(s) = N_4(s) / D_3(s)$ (28)

In the long run, $H_0 = N_4(0) / D_3'(0)$ (29)

Benefit- Function Analysis

The Benefit-Function analysis of the system considering mean up-time, expected busy period of the system under failure due to high temperature or failure due to change in rain fall pattern caused by global warming, expected number of visits by the repairman for unit failure. The expected total Benefit-Function incurred in (0, t] is C (t) = Expected total revenue in (0, t]

- expected busy period of the system under failure due to high temperature or failure due to change in rain fall pattern caused by global warming for repairing the units in (0,t]
- expected number of visits by the repairman for repairing of identical the units in (0,t]

The expected total cost per unit time in steady state is

$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2C(s))$

$= K_1A_0 - K_2R_0 - K_3H_0$

where

K_1: revenue per unit up-time,
K_2: cost per unit time for which the system is under repair of type- I or type- II
K_3: cost per visit by the repairman for units repair.

CONCLUSION

After studying the system, we have analyzed graphically that when the failure rate due to under failure due to high temperature or failure due to change in rain fall pattern caused by global warming increases, the MTSF and steady state availability decreases and the Benefit-function decreased as the failure increases.

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