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Reliability and Sensitivity Analysis of Harvesting Systems

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RELIABILITYANDSENSITIVITYANALYSISOFHARVESTINGSYSTEMS

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Reliability and Sensitivity Analysis of Harvesting Systems

Ashish Kumar [α] & Monika Saini [σ]

Abstract- The objective of the present paper is to obtain the reliability of a harvesting system having three unit tractor (T), combine (C) and wagon (W) using supplementary variable technique. For successful operation of the system units T and C must be remain operative while when unit W fails system works partially. Two repairmen are involved in repairing of the system. One of the repairmen (the first) is the foreman (boss) and the other an assistant (apprentice). Whenever unit T and C fails repair is undertaken by boss while repair of the wagon is undertaken by the trainee. If the boss is busy in repairing and at the same time other unit fails then the repair is undertaken by apprentice. With the help of Supplementary variable technique, Laplace transformations and copula methodology, the transition state probabilities, asymptotic behavior, reliability, M.T.T.F. and sensitivity analysis of the system have been evaluated.

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I. Introduction

Machinery dominate all other cost categories in farming and much is to be gained by adapting and balancing resources according to the actual needs arising from farm size, crop plan, etc. In this situation, wheat harvesting is a good example of compromise machinery management, highlighting the inherent complex evaluations. Ismail et al. (2009**)** indicted that the harvesting costs make up 35% of the total machinery costs. This emphasizes the need for developing reliable harvesting equipment. The analysis and prediction of agricultural machinery performance are important aspects of all machinery management efforts **(**Witney, 1995**)**. Abdel-Mageed et al. (1987) mentioned that almost every agricultural operation required for successful crop production must be timely. Untimely completion of any of these operations will cause a substantial loss of yield and quality, which ultimately will affect the farm's income. In view of the above, harvesting systems reliability occupies progressively more significant issue. Maintaining a required level of reliability is often an essential requirement of the systems. On the reliability of harvesting systems not much attention is given by the researcher. Furthermore, repairman is one of the essential parts of harvesting systems, and can affect the economy of the systems, directly or indirectly. Therefore, his action and work forms are vital on improving the reliability of harvesting systems. Singh et al. (2011) developed a reliability model of a three component system with two repairmen. Barak et al.(2012) developed a reliability model for a cold standby system with single server subject to maximum operation and repair time.

In the present study we consider a harvesting system having three unit tractor (T), combine (C) and wagon (W). For successful operation of the system preferred units T and C must be remain operative while when unit W fails system works partially. Two repairmen are involved in repairing of the system. One of the repairmen (the first) is the foreman (boss) and the

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other an assistant (apprentice). Whenever unit T and C fails repair is undertaken by boss while repair of the wagon is undertaken by the trainee. If the boss is busy in repairing and at the same time other unit fails then the repair is undertaken by apprentice. In the present model an important aspect of repairs have been taken, i.e. how to obtain the reliability measures of a system when there are tworepairmen involved in repairing jointly with different repair rates? It is not uncommon to see diverse ranges of performance between repairmen due to high degree of variability that exists in organization providing job as well as the diverse range of training and experience among employees. Keeping this fact in view, i.e. two repairmen, a boss and an apprentice, with the incorporation of human error, the author has tried to study the reliability measures of the harvesting system with the assumptions mentioned in the next section. Whenever both the repairmen are involved in repairing of the harvesting system, the joint probability distribution of the repair is obtained with the help of Gumbel-Hougaard family of copula. Failure rates are assumed to be constant in general whereas the repairs follow general distribution in all the cases.

By using Supplementary variable technique, Laplace transformation and copula following reliability characteristics of the system have been analyzed:

(1) Transition state probabilities of the system.
(2) Steady state behavior of the system using Abel's lemma.
(3) Various measures such as reliability, M.T.T.F and sensitivity analysis of the system.

Some numerical examples have been used to illustrate the model mathematically. Transition diagram of the system is shown in Figure 1.

II. Assumptions

1. Initially all the components are working properly.
2. The system consisting of three components tractor (T), combine (C) and wagon (w), all the units of the system are operative.
3. Each unit is either operative or failed.
4. All the units fails two type of failures either constant failure or human failure.
5. The whole system can fail directly from normal state due to human failure.
6. Repairs are perfect.
7. Joint probability distribution of repair rate, when repair is done by two repairmen followsGumbel-Hougaard family of copula.
8. When one of the preferred units of the system fails, the boss starts its repair while wagon is repaired by the trainee. When the second unit in this state fails, the trainee starts to work on its repair.
9. Failure rate of all the units are constant.

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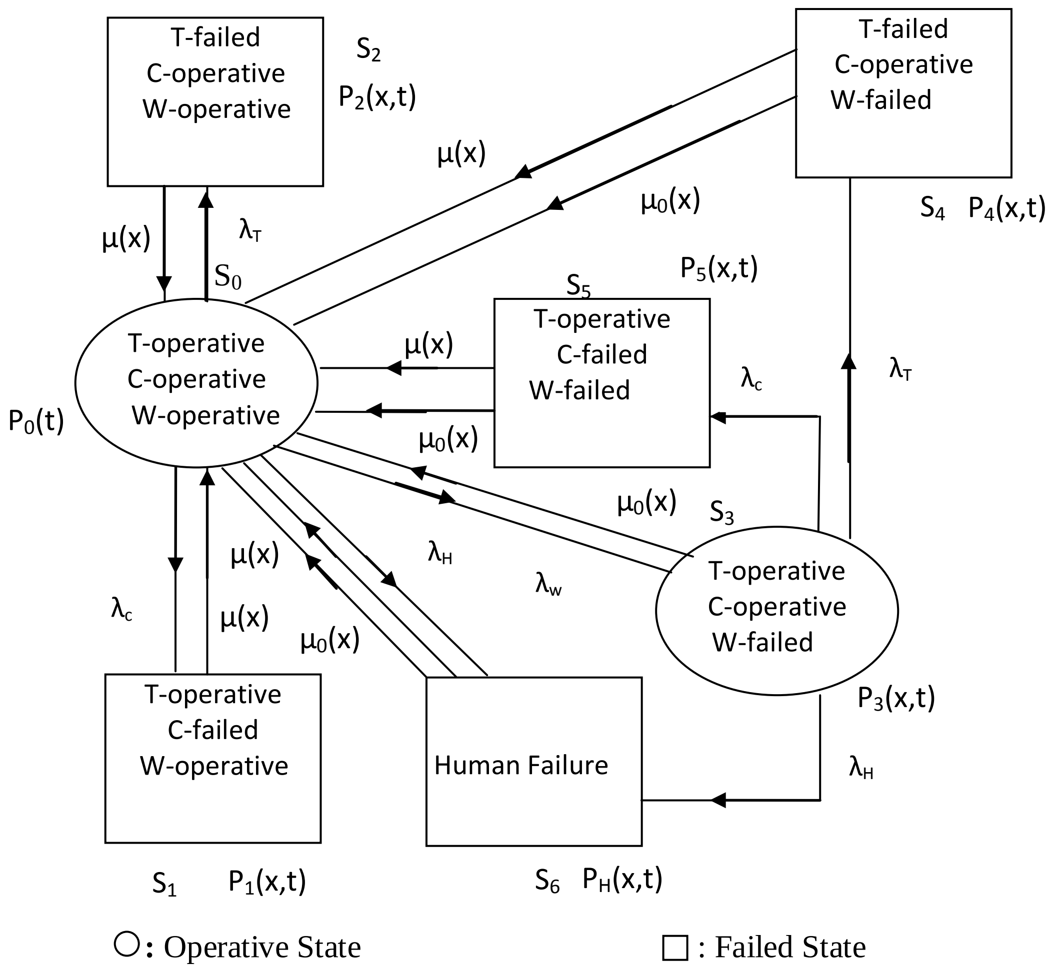

Fig. 1: State Transition Diagram

III. Notations

The following notations are used in this model:

$P_0(t)$: The probability that at time t, thesystem is in the state S_0.

$P_i(x,t)$: The pdf, system is in state S_i and isunder repair; elapsed repair time is x, t,where i=1, 2, 3, 4,5.

$P_H(x,t)$: The pdf, system is in state S_6 and isunder repair; elapsed repair time is x, t.

λ_T :Failure rate of subsystem tractor

λ_C : Failure rate of the combine

λ_W : Failure rate of the wagon

λ_H : Human Failure rate

$\mu_0(x)$: Repair rate when repair is done by trainee

$\mu(x)$: Repair rate when repair is done by boss

$\phi(x)$: Coupled repair rate i.e. repair rate when repair is done by boss and trainee both and it is given by Gumbel Hougaard copula as

$$\phi(x) = \exp\{x^\theta + (\log \mu_0(x))^\theta\}^{1/\theta}$$

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IV. Formulation and Solution of Mathematical Model

By probability considerations and continuity arguments, the following difference-differential equations governing the behavior of the system may seem to be good.

$$(\frac{\partial}{\partial t}+\lambda_C+\lambda_T+\lambda_W+\lambda_H)P_0(t)=\int_0^\infty P_1(x,t)\mu(x)dx+\int_0^\infty P_2(x,t)\mu(x)dx+\int_0^\infty P_3(x,t)\mu(x)dx+$$
$$\int_0^\infty P_4(x,t)\mu(x)dx+\int_0^\infty P_5(x,t)\mu(x)dx+\int_0^\infty P_H(x,t)\mu(x)dx \quad (1)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\mu(x))P_1(x,t)=0 \quad (2)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\mu(x))P_2(x,t)=0 \quad (3)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\mu_0(x)+\lambda_H+\lambda_T+\lambda_C \quad P_3 \quad x \quad t \quad = \quad (4)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi(x))P_4(x,t)=0 \quad (5)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi(x))P_5(x,t)=0 \quad (6)$$

$$(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}\phi(x))P_H(x,t)=0 \quad (7)$$

Boundary Conditions:

$$P_1(0,t)=\lambda_C P_0(t) \quad (8)$$
$$P_2(0,t)=\lambda_T P_0(t) \quad (9)$$
$$P_3(0,t)=\lambda_W P_0(t) \quad (10)$$
$$P_4(0,t)=\lambda_T P_3(0,t)=\lambda_T\lambda_w P_0(t) \quad (11)$$
$$P_5(0,t)=\lambda_C\lambda_w P_0(t) \quad (12)$$
$$P_H \quad t \quad =\lambda_H P_3 \quad t \quad +\lambda_H P_0 \quad t \quad =\lambda_H\lambda_w P_0 \quad t \quad +\lambda_H P_0 \quad t \quad =\lambda_H \quad +\lambda_W \quad P_0 \quad t \quad (13)$$

Initial Conditions:

$P_0(0)=1$ and other probabilities are at t=0 (14)

Solving equations (1-7) through (8-14), we have

$$\overline{P_0(s)}=\frac{1}{T(s)} \quad (15)$$

Transition state probabilities of the system in other states are given by

$$\overline{P_1(s)}=\lambda_c\overline{P_0(s)}\frac{(1-S_u(s))}{s} \quad (16)$$

$$\overline{P_2(s)}=\lambda_T\overline{P_0(s)}\frac{(1-S_u(s))}{s} \quad (17)$$

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$$\overline{P_3(s)} = \lambda_W \overline{P_0(s)} \frac{(1 - S_u(\lambda_c + \lambda_T + \lambda_H + s))}{\lambda_c + \lambda_T + \lambda_H + s} \tag{18}$$

$$\overline{P_4(s)} = \lambda_T \lambda_W \overline{P_0(s)} \frac{(1 - S_\phi(s))}{s} \tag{19}$$

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$$\overline{P_5(s)} = \lambda_c \lambda_W \overline{P_0(s)} \frac{(1 - S_\phi(s))}{s} \tag{20}$$

$$\overline{P_H(s)} = \lambda_H (1 + \lambda_W) \overline{P_0(s)} \frac{(1 - S_\phi(s))}{s} \tag{21}$$

Probability that the system is in upstate is obtained as;

$$\overline{P_{up}(s)} = \overline{P_0(s)} + \overline{P_3(s)} \tag{22}$$

$$\overline{P_{up}(s)} = \frac{1}{T(s)}[1 + \frac{\lambda_w(1 - S_u(\lambda_c + \lambda_T + \lambda_H + s))}{\lambda_c + \lambda_T + \lambda_H + s}] \tag{23}$$

Probability that the system is in downstate is obtained as;

$$\overline{P_{down}(s)} = \overline{P_1(s)} + \overline{P_2(s)} + \overline{P_4(s)} + \overline{P_5(s)} + \overline{P_6(s)} \tag{24}$$

$$\overline{P_{down}(s)} = \frac{1}{sT(s)}[\lambda_c \frac{(1 - S_u(s))}{s} + \lambda_T \frac{(1 - S_u(s))}{s} + \lambda_T \lambda_w \frac{(1 - S_\phi(s))}{s} + \lambda_c \lambda_w \frac{(1 - S_\phi(s))}{s} + \lambda_H (1 + \lambda_w) \frac{(1 - S_\phi(s))}{s}] \tag{25}$$

where

$$T(s) = (s + \lambda_c + \lambda_T + \lambda_w + \lambda_H) - [\lambda_c S_u(s) + \lambda_T S_u(s) + \lambda_w S_{u_0}(s) + \lambda_T \lambda_w S_\phi(s) + \lambda_c \lambda_w S_\phi(s) + \lambda_H (1 + \lambda_w) S_\phi(s)] \tag{26}$$

It is worth noticing that

$$p_0(s) + p_1(s) + p_2(s) + p_3(s) + p_4(s) + p_5(s) + p_H(s) = \frac{1}{s} \tag{27}$$

V. Steady State Behavior of the System

Using Abel's lemma, viz.,$\lim_{s \to 0} s[F(s)] = \lim_{t \to \infty} F(t) = F(say)$, Provided the limit R.H.S. exists, in Equations (15) to (21), the time independent probabilities are obtained as follows:

$$\overline{P_0(s)} = \frac{1}{T(0)} \tag{28}$$

and

$$\overline{P_1(s)} = \frac{\lambda_c}{T(0)} \tag{29}$$

$$\overline{P_2(s)} = \frac{\lambda_T}{T(0)} \tag{30}$$

$$\overline{P_3(s)} = \frac{\lambda_w}{T(0)} \tag{31}$$

$$\overline{P_4(s)} = \frac{\lambda_T \lambda_w}{T(0)} \tag{32}$$

$$\overline{P_5(s)} = \frac{\lambda_c \lambda_w}{T(0)} \tag{33}$$

$$\overline{P_6(s)} = \frac{\lambda_H (1+\lambda_w)}{T(0)} \tag{34}$$

Where

$$T(0) = \lambda_w[1 - \frac{\mu_0}{\mu_0 + \lambda_T + \lambda_H + \lambda_c} + (\lambda_T + \lambda_H + \lambda_c)] \tag{35}$$

VI. Particular Cases

Reliability of The System: Assuming all repairs rate zero in (23) reliability of the system becomes

$$\overline{R(s)} = \frac{1}{s + \lambda_c + \lambda_T + \lambda_w + \lambda_H} \tag{36}$$

Taking inverse Laplace transform of (36) the reliability of the system at any time 't' is given by

$$R(t) = e^{-(\lambda_c + \lambda_T + \lambda_w + \lambda_H)t} \tag{37}$$

M.T.T.F. of The System: Taking all repairs zero in (23), Mean-Time-to-Failure (M.T.T.F.) of the system is obtained as

$$\text{M.T.T.F.} = \lim_{s \to 0} \overline{P_{up}(s)} = \frac{1}{\lambda_c + \lambda_T + \lambda_w + \lambda_H} \tag{38}$$

VII. Numerical Computation

Various measures of system effectiveness such as reliability, M.T.T.F. and sensitivity have been analyzed.

Reliability Analysis Let us fix failure rates as λ_c = 0.08, λ_T = 0.02, λ_H = 0.05 and λ_w = 0.07, repair rates $u = u_0 = \varphi = 0$, $\theta = 1$ and $x = 1$. Also, let the repair follows exponential distribution. Now, by putting all these values in Equation (37) and setting t =0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, one can obtain Table 1and Figure 2 which represent how reliability varies as the time increases.

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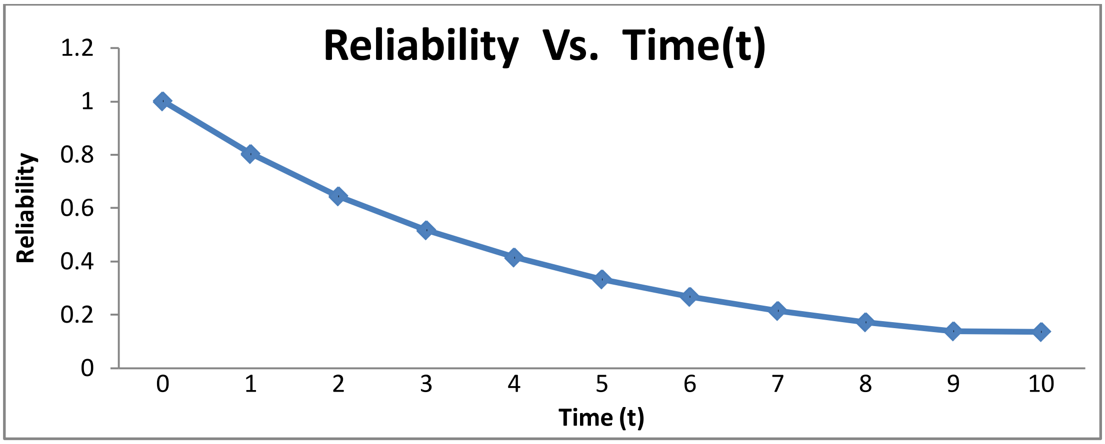

Fig. 2: Reliability Vs. Time

Time	Reliability
0	1
1	0.802519
2	0.644036
3	0.516851
4	0.414783
5	0.332871
6	0.267135
7	0.214381
8	0.172045
9	0.138069
10	0.135335

Table 1: Reliability Vs. Time

M.T.T.F. Analysis: Let us suppose that repair follows exponential distribution then using equation () and fromM.T.T.F. = $\lim_{s\to 0} \overline{P_{up}(s)}$ we have the following four cases:

1. Fixing $\lambda_c = 0.08$, $\lambda_T = 0.02$, $\lambda_H = 0.05$ andvarying the value of λ_w =1,.01,.02,.03,.04,.05,.06,.07,.08,.09,.1, repair rates $u = u_0 = \varphi=0$, $\theta = 1$ and$x = 1$. one can obtain the variation in MTTF with respect to λ_w .
2. Fixing $\lambda_c = 0.08$, $\lambda_T = 0.02$, $\lambda_w = 0.07$ andvarying the value of λ_H =1,.01,.02,.03,.04,.05,.06,.07,.08,.09,.1, repair rates $u = u_0 = \varphi=0$, $\theta = 1$ and$x = 1$. one can obtain the variation in MTTFwith respect to λ_H.
3. Fixing $\lambda_c = 0.08$, $\lambda_w = 0.07$, $\lambda_H = 0.05$ andvarying the value of λ_T =1,.01,.02,.03,.04,.05,.06,.07,.08,.09,.1, repair rates $u = u_0 = \varphi=0$, $\theta = 1$ and$x = 1$. one can obtain the variation in MTTF with respect to λ_T.
4. Fixing $\lambda_W = 0.07$, $\lambda_T = 0.02$, $\lambda_H = 0.05$ andvarying the value of λ_c =1,.01,.02,.03,.04,.05,.06,.07,.08,.09,.1, repair rates $u = u_0 = \varphi=0$, $\theta = 1$ and$x = 1$. one can obtain the variation in MTTFwith respect to λ_c.

With above relations one can obtain Table 2 and Figure 3 which represent how MTTF varies as the failure rate varies..

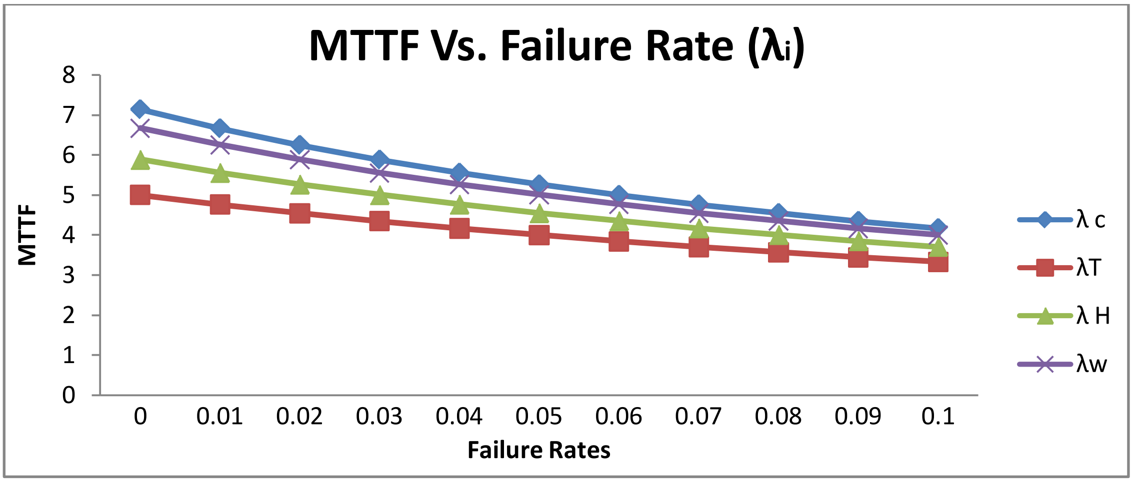

Fig.3: MTTF Vs. Failure Rates (λi)

Variation w.r.t λ c, λT, λw ,λH	λ c	λT	λ H	Λw
0	7.142857	5.000000	5.882353	6.666667
0.01	6.666667	4.761905	5.555556	6.250000
0.02	6.250000	4.545455	5.263158	5.882353
0.03	5.882353	4.347826	5.000000	5.555556
0.04	5.555556	4.166667	4.761905	5.263158
0.05	5.263158	4.000000	4.545455	5.000000
0.06	5.000000	3.846154	4.347826	4.761905
0.07	4.761905	3.703704	4.166667	4.545455
0.08	4.545455	3.571429	4.000000	4.347826
0.09	4.347826	3.448276	3.846154	4.166667
0.1	4.166667	3.333333	3.703704	4.000000

Table.2: MTTF Vs. Failure Rates (λi)

Sensitivity Analysis Assuming that all repair rates follows exponential distribution, we first perform a sensitivity analysis for changes in R(t) resulting from changes in system parameters λ_c, λ_T, λ_H and λ_w . Putting $\lambda_c = 0.08$, $\lambda_T = 0.02$, $\lambda_H = 0.05$ and $\lambda_w = 0.07$, repair rates $u = u_0 = \varphi = 0$, $\theta = 1$ and $x = 1$ in equation (36), and then differentiating w.r.t. λ_c, λ_T, λ_w and λ_H respectively ,we get:

$$\frac{\partial R(s)}{\partial \lambda_c} = \frac{\partial R(s)}{\partial \lambda_T} = \frac{\partial R(s)}{\partial \lambda_w} = \frac{\partial R(s)}{\partial \lambda_H} = -\frac{1}{(s+\lambda_c+\lambda_T+\lambda_w+\lambda_H)^2}$$

After taking inverse Laplace transformation, we get

$$\frac{\partial R(t)}{\partial \lambda_c} = \frac{\partial R(t)}{\partial \lambda_T} = \frac{\partial R(t)}{\partial \lambda_w} = \frac{\partial R(t)}{\partial \lambda_H} = -te^{-(\lambda_c+\lambda_T+\lambda_w+\lambda_H)t}$$

Now, we perform a sensitivity analysis of changes in M.T.T.F. with respect to λ_c, λ_T, λ_w and λ_H . Setting $\lambda_c = 0.08$, $\lambda_T = 0.02$, $\lambda_H = 0.05$ and $\lambda_w = 0.07$, repair rates $u = u_0 = \varphi = 0$, $\theta = 1$ and $x = 1$ in equation (38) and taking $\lim_{s\to 0}$ then differentiating w.r.t. λ_c, λ_T, λ_w and λ_H respectively ,we get:

$$\frac{\partial MTTF}{\partial \lambda_c} = \frac{\partial MTTF}{\partial \lambda_T} = \frac{\partial MTTF}{\partial \lambda_w} = \frac{\partial MTTF}{\partial \lambda_H} = \frac{-1}{(\lambda_c+\lambda_T+\lambda_w+\lambda_H)^2}$$

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Numerical results of the sensitivity analysis for the system reliability and the M.T.T.F. are presented in Figures 4 - 5 and Tables 3-4.

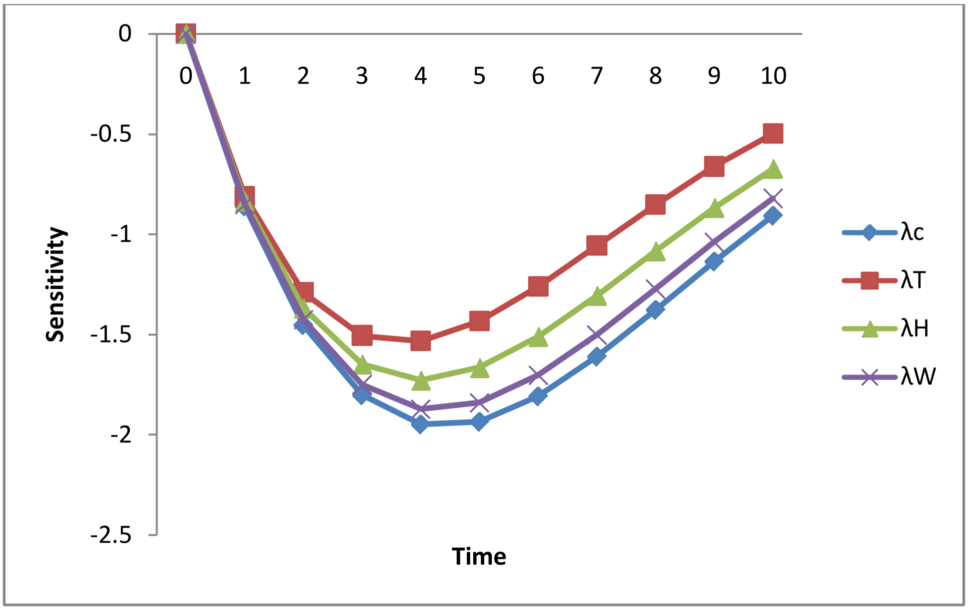

Fig. 4: Sensitivity Analysis w.r.t. failure rates λ_c, λ_T, λ_H and λ_w

Time	λc	λT	λH	λW
0	0	0	0	0
1	-0.86071	-0.81058	-0.83527	-0.85214
2	-1.4523	-1.28807	-1.36772	-1.42354
3	-1.80149	-1.50473	-1.64643	-1.74824
4	-1.94701	-1.53157	-1.72684	-1.87067
5	-1.93371	-1.43252	-1.66436	-1.8394
6	-1.80717	-1.26082	-1.50947	-1.70192
7	-1.60948	-1.0575	-1.30462	-1.50067
8	-1.37636	-0.85167	-1.08268	-1.27054
9	-1.13567	-0.66181	-0.86695	-1.03793
10	-0.90718	-0.49787	-0.67206	-0.82085

Table 3: Sensitivity Analysis of Reliability w.r.t. failure rates λ_c, λ_T, λ_H and λ_w

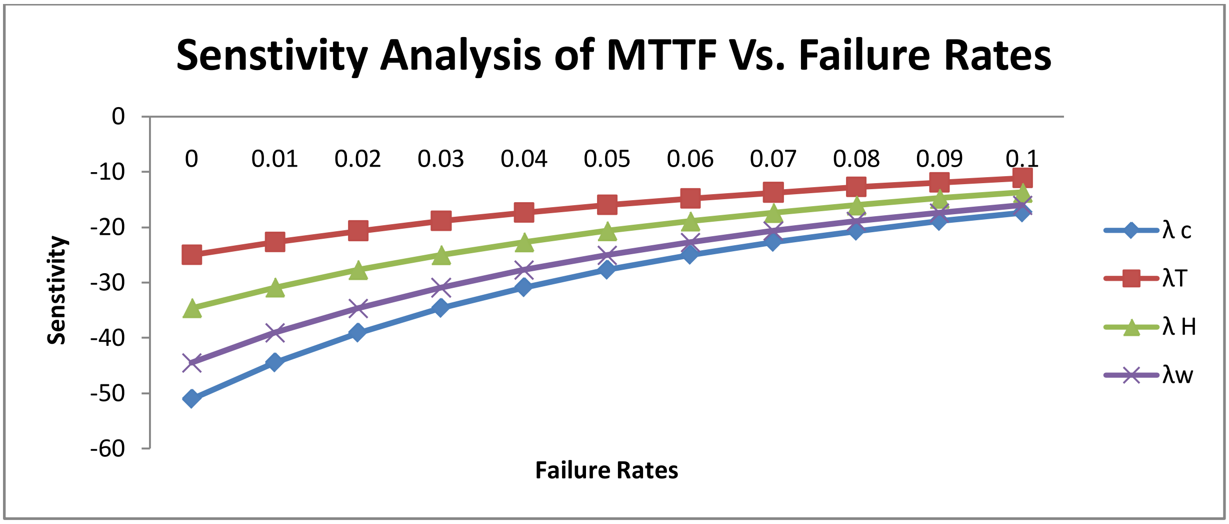

Fig. 5: Sensitivity Analysis of MTTF w.r.t. failure rates λ_c, λ_T, λ_H and λ_w

Variation w.r.t λ c, λT,λw,λH	Sensitivity Analysis of MTTF w.r.t λ c	Sensitivity Analysis of MTTF w.r.t λT	Sensitivity Analysis of MTTF w.r.t λ H	Sensitivity Analysis of MTTF w.r.t λw
0	-51.0204	-25.0000	-34.6021	-44.4444
0.01	-44.4444	-22.6757	-30.8642	-39.0625
0.02	-39.0625	-20.6612	-27.7008	-34.6021
0.03	-34.6021	-18.9036	-25.0000	-30.8642
0.04	-30.8642	-17.3611	-22.6757	-27.7008
0.05	-27.7008	-16.0000	-20.6612	-25.0000
0.06	-25.0000	-14.7929	-18.9036	-22.6757
0.07	-22.6757	-13.7174	-17.3611	-20.6612
0.08	-20.6612	-12.7551	-16.0000	-18.9036
0.09	-18.9036	-11.8906	-14.7929	-17.3611
0.1	-17.3611	-11.1111	-13.7174	-16.0000

Table 4: Sensitivity Analysis of MTTF w.r.t. failure rates λ_c, λ_T, λ_H and λ_w

VIII. Conclusion

In this paper, we analyzed the reliability, MTTF and sensitivity of the harvesting system incorporating different failures. To numerically examine the behavior of reliability and M.T.T.F of the system, the various parameters are fixed as $\lambda_c = 0.08$, $\lambda_T = 0.02$, $\lambda_H = 0.05$ and $\lambda_w = 0.07$, repair rates $u = u0 = \varphi=0$, $\theta = 1$ and $x = 1$. One can easily conclude from Figure 2 and Table 1 that the reliability of thesystem decreases with the increment in time and it attains a value of 0.135 after a long period of time.By critically examining the Figure 3 and table 2 onecan conclude that M.T.T.F. of the system decreasesfrom 7.142857 to 4.166667, from 5.000000 to 3.333333,from 5.882353 to3.703704 andfrom6.666667 to 4.000000 with respect to λ_c , λ_T , λ_H and λ_w respectively in a same manner for the consideredvalues. M.T.T.F. of thesystem has been obtained in the order: M.T.T.F. w. r. t. λ_c> M.T.T.F. w. r. t. λ_w> M.T.T.F. w. r. t.λ_H> M.T.T.F. w. r. t. λ_T. So M.T.T.F. of thesystem is highest with respect to λ_c and lowest withrespect to λ_T.
The sensitivities of the system reliability withrespect to λ_c, λ_T , λ_H and λ_w are shown in Figures 4 and table 3.

It reveals that the sensitivity initiallydecreases and then tends to increase as time passesand attain a value-0.90718, -0.49787, -0.67206 and -0.82085 at t= 10 with respect to λ_c ,

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λ_T , λ_H and $\lambda_w$respectively. It isclear from the graph that system reliability is moresensitive w. r. t. λ_T . It is interesting tonote that the system becomes more sensitive withthe increase in failure rate of tractor (T). So, we can concludethat the system can be made less sensitive bycontrolling its failure rates. Moreover, Figure 5 and table 4 show the sensitivity of M.T.T.F. withrespect to λ_c , λ_T , λ_H and $\lambda_w$which show that itincreases. Criticalobservation of these graphs points out thatM.T.T.F. of the system is more sensitive withrespect toλ_T.

Notes

References Références Referencias

1. Abdel-Mageed, H.N., M.H. Ramadan and M.M. Ibrahim (1987): A mathematical model for predicting optimum power and machinery sizes in a three year crop rotation in Egypt. ***Misr J. Ag. Eng.***, Vol.27 (1), pp.134 – 148.
2. Witney, B. (1995). Choosing and Using Farm Machines. UK: Longman Scientific and Technical. WMO. 1974. Manual on Codes. Vol I.World Meteorological Organization, No. 306. Geneva, Switzerland:WMO.
3. Ismail, Z.E.and A.E. Abdel-Mageed (2010): **“**Workability and machinery performance for wheat harvesting”, ***Misr J. Ag. Eng.***, Vol.27 (1), pp.90 – 103.
4. Singh, S. B., Ram, M. and Chaube, S.(2011): “ Analysis of the reliability of a three component system with two repairmen”, ***International Journal of Engineering***, Vol. 24, No. 4, pp. 395-401.
5. Malik, S. C. and Kumar, A. (2012): Stochastic Modeling of a Computer System with Priority to PM over S/W Replacement Subject to Maximum Operation and Repair Times. *International Journal of Computer Applications*, Vol.43 (3), pp. 27-34.

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