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ATM modeling through Probabilistic and Reliability Approach Subject to Different Failures

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Abstract

An automated teller machine (ATM) is a financial distribution channel (FDC), which allows customers to complete the basic transactions without visiting the branch representative. Communication in Automatic Teller Machine (ATM) is completed through three main units namely ATM machine, host computer and bank computer. ATM machine, host computer and bank computer interacts with each other through networking. The objective of this paper is to improve the various performance measures of ATM process (ATMP) through mathematical modeling and reliability approach. The various performance measures of ATMP were obtained with the aid of mathematical modeling. In order to make the considered system more available/reliable, here authors have considered the bank computer and power supply in standby mode. Markov process, supplementary variable technique (SVT) and Laplace transform are used to calculate system's Availability, Reliability, and MTTF. Critical component of the system identified through sensitivity analysis. For best understanding, the results are explicated with the help of graphs.

Keywords: Markov Process**,** Performance measures, multi-state system, Host Computer, Bank Computer, Supplementary variable technique

1. Introduction

With the changing society and Machinery, information technology becomes progressively more important than ever and play crucial role in various process including automated teller machine, ticket reservation system, telephone system, the growing network of different industrial system/machines etc. In such channels the performability of each individual unit becomes much valuable (Saloner and Shepard [1]). An ATM machine offer significant advantage to both customer and bank (McAndrews [2]) through its working. The machine enable to the customers to deposit or collect the cash without visiting the bank.

Thornton [3] examined the response of the customers regarding the usage of financial distributed channels like ATM, Point of sale, Internet banking and tried to find that weather a relationship exit between customers and such financial channels. In order to be a good experience of a customer by using these networking processes, such process must be trouble free (Howcroft et al. [4], Narteh [5]) or one can say it must be reliable.

Calisir and Gumussoy [6] provided a study to compare various financial modes like internet banking, ATM, Phone banking, wireless application protocol (WAP), electronic fund transfer and found that internet banking, ATM, and phone banking are substitute of each other.

Automatic Teller Machine (ATM) is a kind of financial distributed channel which provides money to bank customers without going to the bank. In 1969 first automatic teller machine available for business. Initially it provide only cash withdrawal facility, latter in 1971 it can be used for multiple functions including providing customer's account balance etc. These machines have become commonly popular in 1980. Today ATMs are as vital to most people as cell phone. Now more than one million ATMs are used globally. Customer swipe card into ATM machine and the card reader reads the account information which is stored in magnetic strip of the card. Then ATM machine shows message to customer for inserting PIN code. The machine converts PIN into encryption and directed it to host processor/computer. The host processor compares the PIN with recorded information for verification. If PIN code is correct then host processor direct message to ATM machine and ATM machine shows a message to customer for inserting amount. This message of amount send to host processor and host processor send this message to the bank computer then bank computer check customer account for sufficient amount. If customers account have required amount then required amount provided to the customer by ATM machine. If customer account does not have sufficient amount then "not sufficient balance in your account" message shown to the customer by ATM machine.

In past many researcher have analyzed different type of ATM system with different technique. Gupta et al. [7] found the operational behavior of ATM with the help of reliability analysis. They use three subsystems namely ATM machine, the central computer and bank computer subjected to standby configuration. Aggarwal et al. [8] analyzed an ATM process by considering its four components in parallel configuration with the assumption of 2-out-of-4: F redundancy. Ram and Goyal [9] investigated the reliability measure and sensitivity analysis of a repairable ATM system with the help of stochastic modelling. In that work ATM machine communicate to the host computer and interface PC with the

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hub nodes for record the transaction of customer. Account is also connected with host by hub. Onyessolu and Ezeani [10] find out that fingerprint biometric authentication scheme for ATM is more redeemable rather than personal identification numbers (PINs) for identification and security clearances. Menna [11] provided a complete knowledge of ATM and its benefits. Chinedu et al. [12] discussed about the negative effects of ATM based banking services in Nigeria. Cheong et al. [13] discussed the daily ad-hoc ATM failures and then optimize the number of field service to develop in each geographical zone to minimize the number of daily unattended ad-hoc ATM failure by using forecasted result. Garg and Rom [14] presented a paper in which he discussed about Open-Net Switch Control Interface (ONSCI). Open local switch control protocol, for controlling an ATM switch.

Beside the above work the author also analyzed the research work which has been done in past in the field of reliability for some important industrial systems. Ram and Kumar [15] obtained the various performance measures of a paper mill plant by using Markov method and SVT. In this work they take four parts of the paper mill plant namely the head box, wire part, dryer and press part and found good results regarding the reliability for the same. The work on Schur functions and Bayesian implication for reliability research was analyzed by Barlow [16]. They also discussed about Coherent system regarding reliability. Dev et al. [17] gives an overview of Combined Cycle Power Plant (CCPP) using graph theoretic approach and evaluated graph theoretic model for CCPP. Cavalca [18] analyzed an availability problem of an engineering system connected in series configuration, using genetic algorithm. Kumar and Ram [19] analyzed the reliability measures of the coal handling unit of a thermal plant with the help of probabilistic approach. Gupta and Tiwari [20] presented a review about the development of a performance model of power generation system of a thermal power plant with the help of Markov technique.

Kumar et al. [21] discuss about casting process in foundry work using reliability approach for performance analysis and tried to improve the production of casting process. In this paper the authors considered four type of defect namely mold shrift, shrinkage, cold shut and blowholes. Ram [22], Ram and Singh [23], Ram and Singh [24] explored the concept of reliability and calculate the various reliability measures for different engineering models with the help of Gumbel-Hougaard family copula with different repair policies.

For a system like ATM which may fail in any one of the several possible way, reliability and safety analysis is much needed factors. Failure analysis is one of the major sections of reliability and safety (Srinath [25]). Rausand and Oien [26] studied the basic concepts of failure, failure mode, failure cause, and failure effect and give the suggestion on how to interpret it. After failure analysis maintenance management is required. Selvik and Aven [27] discussed about reliability centered maintenance for preventive maintenance planning and analyzed consequence of the failure in a system. The authors also suggested the extension of the method to reliability and risk maintenance.

1.1 Mathematical modeling

Keeping in mind the above research work about ATM process, reliability and system safety, authors get an idea to apply reliability approach in an ATM process through mathematical modeling. This work concentrated on the working of an ATM process through reliability measures by taking three key component of an ATM process namely ATM machine, Bank computer, and host computer. Throughout the task the considered system can fail/degraded due to failure/partial failure of ATM machine, Bank computer, Host computer, networking between these components, standby components failure, power supply failure. The diagrammatic representation of the ATMP is shown in the following Figure 1(a) and corresponding transition state diagram is shown in Figure 1(b).

2. Assumptions

The following assumptions are taken throughout the functioning of ATM.

Assumption 1: The working stints of each unit of the ATMP are supposed to be independent and identically exponentially distributed. Once a working unit breaks down, it will be repaired by the maintenance team.

Assumption 2: Various Markov/stochastic processes involved in the system are assumed to be independent of each other.

Assumption 3: The ATMP goes in down/ degraded state as soon as the units failure/failures occurs. We supposed that the shut-off rule is the suspended animation (SA) which means that there is no additional failure will occur when the system is down.

Assumption 4: Average failure rates of each component of the system are taken to be constant.

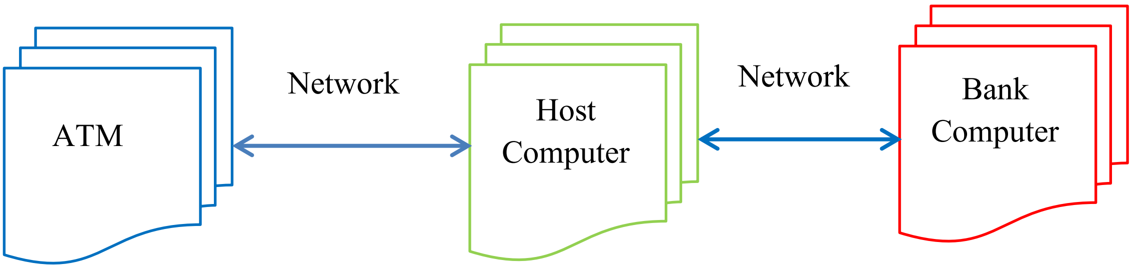

Fig. 1(a). Working of ATM system

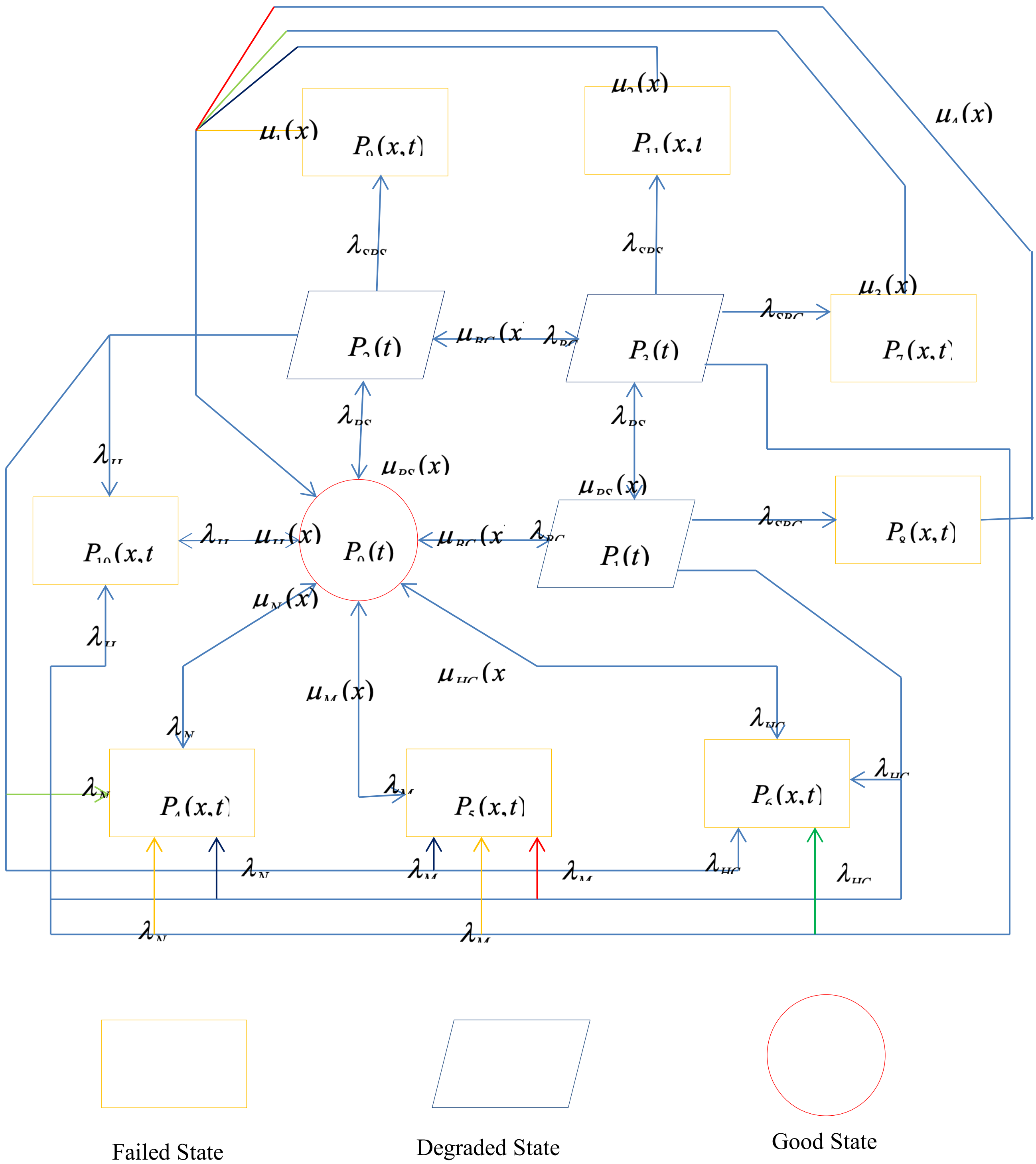

Fig. 1(b). State Transition Diagram

3. Symbolization

t/s	Time/Inverse Laplace variable.
$P_0(t)$	The state probability of ATMP at any time t in which it is working in perfect state.
$P_1(t)$	The state probability of ATMP at any time t in which it is working in degraded state due to failure of main Bank computer.
$P_2(t)$	The state probability of ATMP at any time t in which it is working in degraded state due to failure of main Power supply.
$P_3(t)$	The state probability of ATMP at any time t in which it is

	working in degraded state due to failure of main Bank computer and main Power supply.
$P_4(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of Network.
$P_5(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of ATM machine.
$P_6(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of Host computer.
$P_7(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of main Bank computer, main Power supply and standby Bank computer.
$P_8(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of main Bank computer and standby Bank computer.
$P_9(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of main Power supply and standby Power supply..
$P_{10}(x,t)$	The state probability of ATMP at any time t in which it is failed due to Human error.
$P_{11}(x,t)$	The state probability of ATMP at any time t in which it is failed due to failure of main Bank computer, main Power supply and standby Power supply.
$\lambda_{BC}/\lambda_{SBC}/\lambda_{PS}/\lambda_{SPS}/\lambda_{HC}/\lambda_N/\lambda_M/\lambda_H$	Failure rate of main Bank computer/ standby Bank computer/ main Power supply/ standby Power supply/ Host computer/ Network/ ATM machine/ Human error.
$\mu_{BC}(x)/\mu_{PS}(x)/\mu_{HC}(x)/\mu_N(x)/\mu_M(x)/\mu_H(x)$	Repair rate of main Bank computer/ main Power supply/ Host computer/ Network/ ATM machine/ Human error. .
$\mu_1(x)/\mu_2(x)/\mu_3(x)/\mu_4(x)$	Simultaneous repair rate of main Power supply and standby Power supply/ main Bank computer, main Power supply and standby Power supply/ main Bank computer, main Power supply and standby Bank computer/ main Bank computer and standby Bank computer.
K_1/K_2	Revenue/ Service cost of ATMP

4. Mathematical Formulation and Solution of the Proble

In order to find out the various performance measures of considered system, a mathematical model is developed as given in Figure 1(a) and 1(b) (On the basis of failure and repair rates). This shows the different state of the process throughout the task. On the basis of this state transition diagram the following set of intro-differential equations is generated.

$$\left(\frac{\partial}{\partial t}+\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC}\right)P_0(t)=\mu_{BC}(x)P_1(t)+\mu_{PS}(x)P_2(t)$$
$$+\sum_{i,j}\int_0^\infty \mu_i(x)P_j(x,t)dx;\ \text{Where } i=N,M,HC,3,4,1,H,2 \quad (1)$$
$$j=4,5,6,7,8,9,10,11 \text{ respectively}$$

$$\left(\frac{\partial}{\partial t}+\lambda_{SBC}+\lambda_{PS}+\mu_{BC}(x)+\lambda_{HC}+\lambda_M+\lambda_N+\lambda_H\right)P_1(t)= \quad (2)$$
$$=\mu_{PS}(x)P_3(t)+\lambda_{BC}P_0(t)$$

$$\left(\frac{\partial}{\partial t}+\lambda_{SPS}+\lambda_{BC}+\mu_{PS}(x)+\lambda_H+\lambda_M+\lambda_N+\lambda_{HC}\right)P_2(t)= \quad (3)$$
$$=\mu_{BC}(x)P_3(t)+\lambda_{PS}P_0(t)$$

$$\left(\frac{\partial}{\partial t}+\lambda_{SPS}+\mu_{PS}(x)+\mu_{BC}(x)+\lambda_{SBC}+\lambda_M+\lambda_N+\lambda_{HC}+\lambda_H\right)P_3(t)= \quad (4)$$
$$=\lambda_{PS}P_1(t)+\lambda_{BC}P_2(t)$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_i(x)\right]P_j(x,t)=0$$
$$\text{where } i=1,2,3,4,N,M,HC,.H$$
$$j=9,11,7,8,4,5,6,10 \text{ respectively} \quad (5)$$

Boundary Conditions

$$P_k(0,t)=\lambda_l\left[P_0(t)+P_1(t)+P_2(t)+P_3(t)\right]$$
$$\text{where } k=4,5,6,10 \quad (6)$$
$$l=N,M,HC,H \text{ respectively}$$

$$P_m(0,t)=\lambda_n P_3(t)$$
$$\text{where } m=7,8,9,11 \quad (7)$$
$$n=SBC,SBC,SPS,SPS \text{ respectively}$$

Initial Condition

$$P_i(t)=\begin{cases}1,\ i=0,t=0\\0,\ \text{Otherwise}\end{cases} \quad (8)$$

Taking Laplace transformation of the equations (1-20), one gets

$$\left(s+\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC}\right)\overline{P}_0(s)=$$
$$=\mu_{BC}(x)\overline{P}_1(s)+\mu_{PS}(x)\overline{P}_2(s)+\sum_{i,j}\int_0^\infty \mu_i(x)\overline{P}_j(x,s)dx; \quad (9)$$
$$\text{Where } i=N,M,HC,3,4,1,H,2$$
$$j=4,5,6,7,8,9,10,11 \text{ respectively}$$

$$\left(s+\lambda_{SBC}+\lambda_{PS}+\mu_{BC}(x)+\lambda_{HC}+\lambda_M+\lambda_N+\lambda_H\right)\overline{P}_1(s)= \\ =\mu_{PS}(x)\overline{P}_3(s)+\lambda_{BC}\overline{P}_0(s) \quad (10)$$

$$\left(s+\lambda_{SPS}+\lambda_{BC}+\mu_{PS}(x)+\lambda_H+\lambda_M+\lambda_N+\lambda_{HC}\right)\overline{P}_2(s)= \\ =\mu_{BC}(x)\overline{P}_3(s)+\lambda_{PS}\overline{P}_0(s) \quad (11)$$

$$\left(s+\lambda_{SPS}+\mu_{PS}(x)+\mu_{BC}(x)+\lambda_{SBC}+\lambda_M+\lambda_N+\lambda_{HC}+\lambda_H\right)\overline{P}_3(s)= \\ =\lambda_{PS}\overline{P}_1(s)+\lambda_{BC}\overline{P}_2(s)$$
(12)

$$\left[\frac{\partial}{\partial x}+s+\mu_i(x)\right]\overline{P}_j(x,s)=0$$

where $i=1,2,3,4,N,M,HC,.H$

$j=9,11,7,8,4,5,6,10$ respectively (13)

Boundary Conditions

$$\overline{P}_k(0,s)=\lambda_l\left[\overline{P}_0(s)+\overline{P}_1(s)+\overline{P}_2(s)+\overline{P}_3(s)\right]$$

where $k=4,5,6,10$ (14)

$l=N,M,HC,H$ respectively

$$\overline{P}_m(0,s)=\lambda_n\overline{P}_3(s)$$

where $m=7,8,9,11$ (15)

$n=SBC,SBC,SPS,SPS$ respectively

The solution of the above set of intro-differential equations provides the expression for transition state probabilities for the considered system as

$$\overline{P}_0(s)=\frac{1}{\left[\begin{array}{l} s+H_1-\lambda_H\overline{T}_H(s)-\lambda_N\overline{T}_N(s)-\lambda_M\overline{T}_M(s)-\lambda_{HC}\overline{T}_{HC}(s)-\left\{\dfrac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\dfrac{\lambda_{BC}}{(s+H_2)}\right\} \\ \left\{\mu_{BC}(x)+\lambda_H\overline{T}_H(s)+\lambda_N\overline{T}_N(s)+\lambda_M\overline{T}_M(s)+\lambda_{HC}\overline{T}_{HC}(s)+\lambda_{SBC}\overline{T}_4(s)\right\}- \\ \left\{\dfrac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\dfrac{\lambda_{PS}}{(s+H_3)}\right\}\left\{\begin{array}{l}\mu_{PS}(x)+\lambda_H\overline{T}_H(s)+\lambda_N\overline{T}_N(s)+\lambda_M\overline{T}_M(s)+\lambda_{HC}\overline{T}_{HC}(s) \\ +\lambda_{SPS}\overline{T}_1(s)\end{array}\right\} \\ -\left\{\dfrac{H_5}{H_6}\right\}\left\{\lambda_H\overline{T}_H(s)+\lambda_N\overline{T}_N(s)+\lambda_M\overline{T}_M(s)+\lambda_{HC}\overline{T}_{HC}(s)+\lambda_{SPS}\overline{T}_2(s)+\lambda_{SBC}\overline{T}_3(s)\right\} \end{array}\right]}$$

$$\overline{P}_1(s)=\left[\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}\right]\overline{P}_0(s)$$

$$\overline{P}_2(s)=\left[\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}\right]\overline{P}_0(s)$$

$$\overline{P}_3(s)=\frac{H_5}{H_6}\overline{P}_0(s)$$

$$\overline{P}_4(x,s)=\frac{\overline{P}_0(s)\lambda_N}{(s+\mu_N(x))}* \\ *\left[1+\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}+\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}+\frac{H_5}{H_6}\right]$$

$$\overline{P}_5(x,s)=\frac{\overline{P}_0(s)\lambda_M}{(s+\mu_M(x))}* \\ *\left[1+\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}+\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}+\frac{H_5}{H_6}\right]$$

$$\overline{P}_6(x,s)=\frac{\overline{P}_0(s)\lambda_{HC}}{(s+\mu_{HC}(x))}* \\ *\left[1+\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}+\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}+\frac{H_5}{H_6}\right]$$

$$\overline{P}_7(x,s)=\frac{\overline{P}_0(s)\lambda_{SBC}H_5}{(s+\mu_3(x))H_6}$$

$$\overline{P}_8(x,s)=\frac{\overline{P}_0(s)\lambda_{SBC}}{(s+\mu_4(x))}\left[\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}\right]$$

$$\overline{P}_9(x,s)=\frac{\overline{P}_0(s)\lambda_{SPS}}{(s+\mu_1(x))}\left[\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}\right]$$

$$\overline{P}_{10}(x,s)=\frac{\overline{P}_0(s)\lambda_H}{(s+\mu_H(x))}* \\ *\left[1+\frac{\mu_{PS}(x)H_5}{(s+H_2)H_6}+\frac{\lambda_{BC}}{(s+H_2)}+\frac{\mu_{BC}(x)H_5}{(s+H_3)H_6}+\frac{\lambda_{PS}}{(s+H_3)}+\frac{H_5}{H_6}\right]$$

$$\overline{P}_{11}(x,s)=\frac{\overline{P}_0(s)\lambda_{SPS}H_5}{(s+\mu_2(x))H_6}$$

Where $H_1=\left(\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC}\right)$

$$H_2=\left(\lambda_{SBC}+\lambda_{PS}+\mu_{BC}(x)+\lambda_N+\lambda_M+\lambda_{HC}+\lambda_H\right)$$

$$H_3=\left(\lambda_{SPS}+\lambda_{BC}+\mu_{PS}(x)+\lambda_N+\lambda_M+\lambda_{HC}+\lambda_H\right)$$

$$H_4 = \left(\lambda_{SPS} + \lambda_{SBC} + \mu_{PS}(x) + \mu_{BC}(x) + \lambda_N + \lambda_M + \lambda_{HC} + \lambda_H\right)$$

$$H_5 = \left[\frac{\lambda_{BC}\lambda_{PS}}{(s+H_3)} + \frac{\lambda_{BC}\lambda_{PS}}{(s+H_2)}\right]$$

$$H_6 = \left[s + H_4 - \frac{\lambda_{BC}\mu_{BC}(x)}{(s+H_3)} - \frac{\lambda_{PS}\mu_{PS}(x)}{(s+H_2)}\right]$$

From transition state diagram (Figure 1(b)) it can observed that the working state probability (i.e. good state/degraded) and failed state probability of the considered ATMP at any time t is given by

$$\overline{P}_{up}(s) = \overline{P}_0(s) + \overline{P}_1(s) + \overline{P}_2(s) + \overline{P}_3(s) \tag{16}$$

$$\begin{aligned}\overline{P}_{dwon}(x,s) &= \overline{P}_4(x,s) + \overline{P}_5(x,s) + \overline{P}_6(x,s) + \\ &+ \overline{P}_7(x,s) + \overline{P}_8(x,s) + \overline{P}_9(x,s) \\ &+ \overline{P}_{10}(x,s) + \overline{P}_{11}(x,s)\end{aligned} \tag{17}$$

5. Numerical Computation and Assessment of Various Reliability measures

5.1 Availability Analysis

Availability of a system can be defined as the ratio of the time that a system is available for functioning to the time which is accepted from it for functioning [15, 19, 21]. Here it is calculated by putting the value of different failure rates as

$$\lambda_{BC} = 0.05,\ \lambda_{SBC} = 0.07,$$
$$\lambda_{PS} = 0.02, \lambda_{SPS} = 0.04, \lambda_{HC} = 0.15,$$
$$\lambda_N = 0.10, \lambda_H = 0.009, \lambda_M = 0.20$$

and all repair rates as 1 in equation (16) and then solving it by Laplace Transformation, the availability expression for the considered ATMP is obtained as

$$P_{up}(t) = \begin{Bmatrix} -0.255449\, e^{(-1.362813\,t)} \cos(0.038540\ t) + 0.150365\, e^{(-1.362813\ t)} \\ \sin(0.038540\,t) - 0.000539 e^{(-2.418354\ t)} + 0.476242\, e^{(-1.3324621\,t)} \\ +0.779746\, e^{(0.000443\,t)} \end{Bmatrix} \tag{18}$$

Now varying time t in (18), we get the following Table 1 and corresponding Figure 2, which represent the behavior of availability of the ATMP.

Table 1. Behavior of Availability with Time unit (t)

Time unit (t)	**Availability $P_{up}(t)$**
0	1.000000
1	0.841841
2	0.797657
3	0.785566
4	0.782454
5	0.781843
6	0.781925
7	0.782199
8	0.782526
9	0.782868
10	0.783214

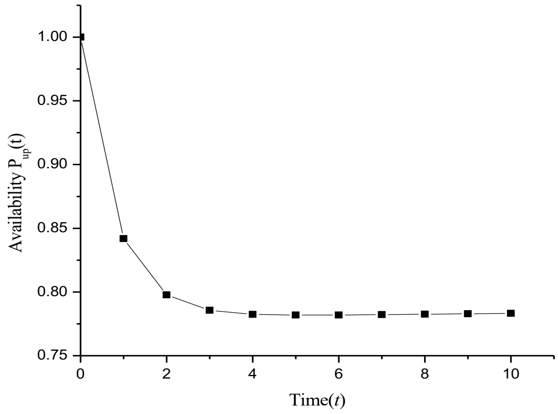

Fig. 2. Behavior of Availability with Time unit (t)

5.2 Reliability Analysis

Reliability is the probability of a system to perform its function adequately for a specific time and in a specific environmental condition [25]. Here it is calculated by taking all repair rates of system are zero and failure rates as $\lambda_{SPS} = 0.04, \lambda_{HC} = 0.15, \lambda_N = 0.10, \lambda_H = 0.009, \lambda_M = 0.20,$ $\lambda_{BC} = 0.05, \lambda_{SBC} = 0.07, \lambda_{PS} = 0.02$ in equation (16), the reliability of the ATMP is obtained as

$$\begin{aligned}R(t) &= 3.5\, e^{(-0.349\ t)} + 7\, e^{(-0.359\ t)} \sinh(0.01\,t) - \\ &-5\, e^{(-0.369\ t)} + 2.5 e^{(-0.389\,t)}\end{aligned} \tag{19}$$

Now varying time t in (19), we get the following Table 2 and corresponding Figure 3, which represent the behavior of reliability of the ATMP.

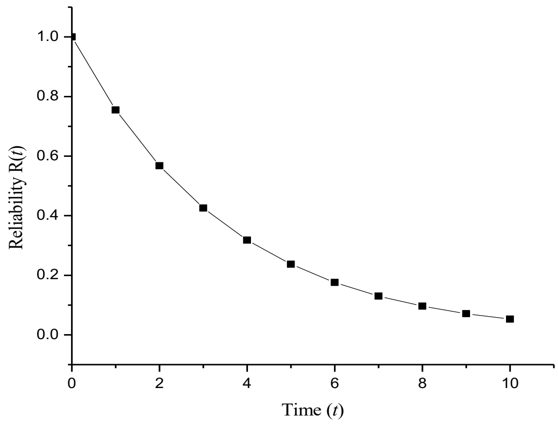

Fig. 3. Behavior of Reliability with Time unit (t)

Table 2. Behavior of Reliability with Time unit (t)

Time unit (t)	**Reliability $R(t)$**
0	1.000000
1	0.754971
2	0.567778
3	0.425505
4	0.317867
5	0.236767

6	0.175888
7	0.130342
8	0.096370
9	0.071102
10	0.052357

5.3 Mean Time to Failure (MTTF)

MTTF of a system is the average failure rate of a component/system [25]. This measure helps the management of a plant to identify the various failure rates which may occur during the process of the system/plant [19, 21]. It is also length of system performance at any time which is expected to last in operation. It is defined as

$$\mathrm{MTTF} = \lim_{s\to 0} \overline{R}(s) \tag{20}$$

So by using the reliability expression in (16), the following expression is obtained as MTTF of the ATMP.

$$MTTF = \frac{1}{\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC}} + \frac{\lambda_{BC}}{(\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC})(\lambda_{SBS}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC})} + \frac{\lambda_{PS}}{(\lambda_{BC}+\lambda_{PS}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC})(\lambda_{SPS}+\lambda_{BC}+\lambda_H+\lambda_N+\lambda_M+\lambda_{HC})} + \tag{21}$$

Now varying failure rates one by one in (16) and set the remaining failure rates same as used in section 5.1.The following Table 3 and corresponding Figure 4 is obtained for the MTTF of the ATMP.

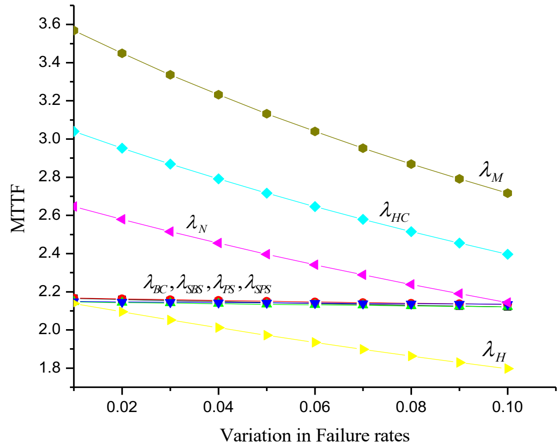

Fig. 4. Behavior of MTTF w.r.t. failure rates

Table 3. Behavior of MTTF w.r.t. Failure Rates

Failure rates	MTTF with respect to failure rates							
	λ_{BC}	λ_{SBC}	λ_{PS}	λ_{SPS}	λ_{HC}	λ_N	λ_H	λ_M
0.01	2.16531	2.16687	2.14684	2.14851	3.03996	2.64601	2.13896	3.56839
0.02	2.15952	2.16257	2.14349	2.14677	2.95222	2.57900	2.09473	3.44881
0.03	2.15396	2.15844	2.14027	2.14509	2.86932	2.51526	2.05228	3.33683
0.04	2.14862	2.15448	2.13718	2.14349	2.79088	2.45455	2.01149	3.23175
0.05	2.14349	2.15067	2.13420	2.14194	2.71654	2.39666	1.97228	3.13298
0.06	2.13855	2.14701	2.13134	2.14045	2.64601	2.34141	1.93455	3.03996
0.07	2.13380	2.14349	2.12858	2.13901	2.57900	2.28862	1.89823	2.95224
0.08	2.12923	2.14009	2.12592	2.13763	2.51526	2.23813	1.86323	2.86932
0.09	2.12482	2.13682	2.12335	2.13630	2.45455	2.18980	1.82950	2.79088
0.10	2.12056	2.13366	2.12088	2.13501	2.39666	2.14349	1.79695	2.71654

5.4 Sensitivity Analysis

This Analysis assists us to find out that which failure/factor in system affects the systems performance most also we understand relationship between input and output device with the help of sensitivity. Here the authors do this analysis for system reliability as well as system's MTTF as follows.

5.4.1 Sensitivity of Mean Time to Failure

Sensitivity analysis of the considered system with respect to MTTF is performed by differentiating the MTTF expression (21) with respect to various failure rates and then placed the values of various failure rates as $\lambda_{SPS}=0.04, \lambda_{HC}=0.15, \lambda_N=0.10, \lambda_H=0.009, \lambda_M=0.20,$ $\lambda_{BC}=0.05, \lambda_{SBC}=0.07, \lambda_{PS}=0.02$ in these partial derivatives. Now varying the failure rates one by one respectively in these partial derivatives, Table 4 and corresponding Figure 5 is obtained for sensitivity of MTTF of the ATMP.

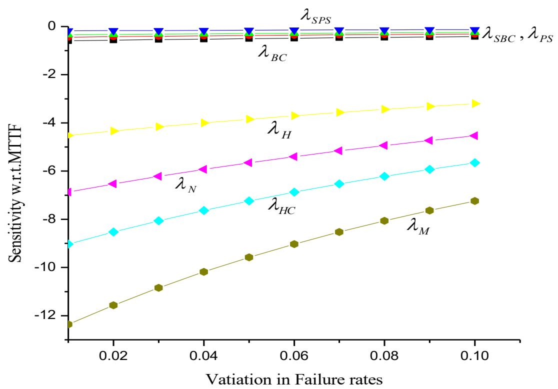

Fig. 5. Sensitivity of MTTF vs. Failure Rates

Table 4. Sensitivity of MTTF vs. Failure Rates

Failure rates	Sensitivity of MTTF							
	$\frac{\partial(MTTF)}{\partial\lambda_{BC}}$	$\frac{\partial(MTTF)}{\partial\lambda_{SBC}}$	$\frac{\partial(MTTF)}{\partial\lambda_{PS}}$	$\frac{\partial(MTTF)}{\partial\lambda_{SPS}}$	$\frac{\partial(MTTF)}{\partial\lambda_{HC}}$	$\frac{\partial(MTTF)}{\partial\lambda_{N}}$	$\frac{\partial(MTTF)}{\partial\lambda_{H}}$	$\frac{\partial(MTTF)}{\partial\lambda_{M}}$
0.01	-0.59160	-0.43901	-0.34178	-0.17776	-9.03050	-6.87262	-4.51540	-12.3635
0.02	-0.56740	-0.42106	-0.32816	-0.17068	-8.52547	-6.53379	-4.33252	-11.5658
0.03	-0.54466	-0.40418	-0.31534	-0.16401	-8.06112	-6.21914	-4.16044	-10.8417
0.04	-0.52326	-0.38830	-0.30324	-0.15773	-7.63325	-5.92645	-3.99833	-10.1826
0.05	-0.50309	-0.37334	-0.29183	-0.15179	-7.23816	-5.65374	-3.84544	-9.58104
0.06	-0.48406	-0.35922	-0.28105	-0.14618	-6.87262	-5.39925	-3.70109	-9.03050
0.07	-0.46609	-0.34588	-0.27085	-0.14088	-6.53379	-5.16140	-3.56465	-8.52547
0.08	-0.44911	-0.33328	-0.26120	-0.13586	-6.21914	-4.93878	-3.43557	-8.06112
0.09	-0.43303	-0.32135	-0.25204	-0.13110	-5.92645	-4.73013	-3.31333	-7.63325
0.10	-0.41780	-0.31005	-0.24336	-0.12659	-5.65374	-4.53431	-3.19745	-7.23816

5.4.2 Sensitivity of Reliability

In the same manner as the authors calculate sensitivity for MTTF, sensitivity of reliability is calculated by differentiating the reliability expression with respect to the failure rates and then put the values of different failure rates as

$\lambda_{BC} = 0.05, \lambda_{SBC} = 0.07,$

$\lambda_{SPS} = 0.04, \lambda_{HC} = 0.15, \lambda_{N} = 0.10, \lambda_{H} = 0.009, \lambda_{M} = 0.20,$

$\lambda_{PS} = 0.02$ in these partial derivatives.

Now varying the time unit *t*, Table 5 and corresponding Figure 6 is obtained for sensitivity of reliability of the ATMP as

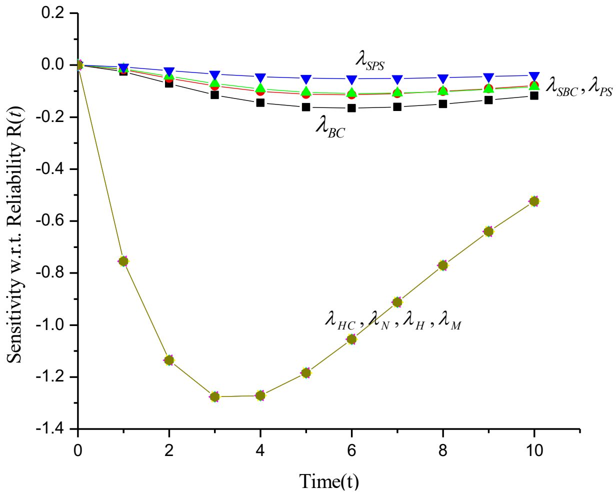

Fig. 6. Sensitivity of Reliability vs. Time (*t*)

Table 5. Sensitivity of Reliability vs. Time (*t*)

Time (*t*)	Sensitivity of Reliability R(*t*)							
	$\frac{\partial R(t)}{\partial\lambda_{BC}}$	$\frac{\partial R(t)}{\partial\lambda_{SBC}}$	$\frac{\partial R(t)}{\partial\lambda_{PS}}$	$\frac{\partial R(t)}{\partial\lambda_{SPS}}$	$\frac{\partial R(t)}{\partial\lambda_{HC}}$	$\frac{\partial R(t)}{\partial\lambda_{N}}$	$\frac{\partial R(t)}{\partial\lambda_{H}}$	$\frac{\partial R(t)}{\partial\lambda_{M}}$
0	0	0	0	0	0	0	0	0
1	-0.02501	-0.01774	-0.01470	-0.00730	-0.75497	-0.75497	-0.75497	-0.75497
2	-0.07143	-0.05035	-0.04313	-0.02128	-1.13555	-1.13555	-1.13555	-1.13555
3	-0.11469	-0.08030	-0.07094	-0.03477	-1.27651	-1.27651	-1.27651	-1.27651
4	-0.14540	-0.10112	-0.09198	-0.04478	-1.27147	-1.27147	-1.27147	-1.27147
5	-0.16191	-0.11186	-0.10458	-0.05057	-1.18383	-1.18383	-1.18383	-1.18383
6	-0.16606	-0.11396	-0.10935	-0.05253	-1.05533	-1.05533	-1.05533	-1.05533
7	-0.16090	-0.10969	-0.10788	-0.05148	-0.91239	-0.91239	-0.91239	-0.91239
8	-0.14953	-0.10126	-0.10195	-0.04833	-0.77096	-0.77096	-0.77096	-0.77096
9	-0.13458	-0.09053	-0.09321	-0.04389	-0.63992	-0.63992	-0.63992	-0.63992
10	-0.11810	-0.07891	-0.08302	-0.03883	-0.52357	-0.52357	-0.52357	-0.52357

5.5 Expected Profit

It is one of the important measures for a system. Basically it depends upon two things one is service cost of the system and other is revenue from the system. The expected profit function for the ATMP in the time interval [0 *t*) can be calculated as [15, 19, 22].

$$E_P(t) = K_1 \int_0^t P_{up}(t)\,dt - tK_2 \tag{22}$$

Using Equation (16) in (22), expected profit function for the same set of failures/repair rates is given by

$$E_P(t)=\left\{K_1\left[\begin{array}{l}0.18417\ e^{(-1.36281\,t)}\cos(0.03854\,t)-0.11554e^{(-1.36281\,t)}\sin(0.03854\,t)\\+0.00022\ e^{(-2.41835\,t)}-0.35741\ e^{(-1.33246\,t)}+1757.08667\\e^{(-0.00044t)}-1756.91365\end{array}\right]-K_2t\right\} \tag{23}$$

Fix revenue as 1 and varying time unit t and service cost of the system in (23), the following Table 6 and corresponding Figure 7 is obtained for the expected profit of the ATMP.

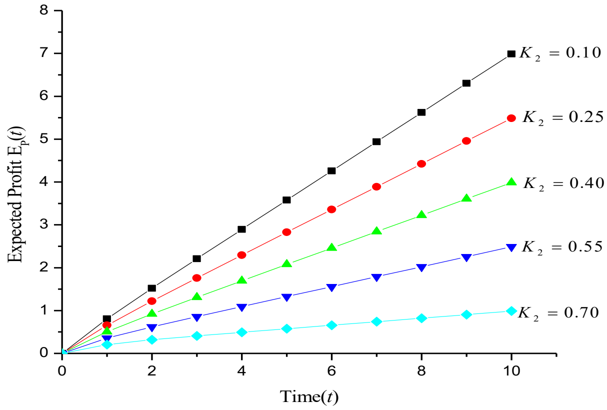

Fig. 7. Expected profit vs. service cost and Time (t)

Table 6. Expected profit vs. service cost and Time (t)

Time Unit (t)	Expected Profit $E_P(t)$				
	$K_2=0.10$	$K_2=0.25$	$K_2=0.40$	$K_2=0.55$	$K_2=0.70$
0	0	0	0	0	0
1	0.80462	0.65462	0.50462	0.35462	0.20462
2	1.51977	1.21977	0.91977	0.61977	0.31977
3	2.21009	1.76009	1.31009	0.86009	0.41009
4	2.89374	2.29374	1.69374	1.09374	0.49374
5	3.57579	2.82579	2.07579	1.32579	0.57579
6	4.25764	3.35764	2.45764	1.55764	0.65764
7	4.93970	3.88970	2.83970	1.78970	0.73970
8	5.62206	4.42206	3.22206	2.02206	0.82206
9	6.30476	4.95476	3.60476	2.25476	0.90476
10	6.98780	5.48780	3.98780	2.48780	0.98780

6. **Result Discussion and conclusion**

On the basis above calucation and graph the following result were obtained

- The behavior of availability of the ATMP is shown in Figure 2. It is observed that initially availability decrees rapidly and then after a specific time it becomes approximate constant. This shows that initially some parts/components of the ATMP not working properly but after repair it give satisfactory performance.
- The behavior of reliability with time of the ATMP is shown in Figure 3. The difference between the reliability and availability graph shows the importance of maintenance policy i.e. to make system more reliable a good maintenance policy is required.
- The behavior of system's MTTF with respect to failure rates is shown in Figure 4. By critically analyzing this Figure it is observed that MTTF of ATMP is highest with respect to the failure rate of ATM machine and lowest with respect to Human error. Also the behavior of MTTF is approximately equal with respect to the failure of bank computer, standby bank computer, power supply and standby power supply.
- The sensitivity with respect to systems MTTF is given in Figure 5. It reflects that the MTTF is highly sensitive with respect to the failure rate of ATM machine and Host computer. It shows that much more attention is required by the management of the ATMP to the failure rates of ATM machine and Host computer.
- The sensitivity with respect to systems reliability is given in Figure 6. It reflects that the systems reliability is highly sensitive with respect to the failure rate of Host computer, Human error, Network, and ATM machine. So in order to make system more reliable much more attention is required for these four components of the ATMP.
- Figure 7 represent the Expected profit of consider system with respect to time. It shows that the profit of the consider system is decreases with an increase in service cost as time passes. It means in order to get more profit one must control the service cost of the ATMP.

It asserts the results of this research are highly beneficial to the management of the concern system and with the help of these results they will enhance the service as well as reliability of the ATMP.

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