M/M/1 Queue with N-Policy Two-Phase, Server Start-Up, Time-Out and Breakdowns

A.AnkammaRao, V.N.RamaDevi, K.Chandan

Abstract: This paper analyzes M/M/1 vacation two-phase queueing model with server Start-up, Time-out and Breakdowns. Customers arrivals are assumed as Poisson process and be given batch mode in the first phase followed by individual models second phase. Arrivals during batch service are allowed to enter the batch without Gating. After providing the second phase of service to all customers individually, server returns to first phase to serve the existing customers followed by individual service. If no one presents, then server waits for a fixed time ‘C’ is called server Time-out. If units arrived during this fixed time, then the server starts the cycle again by providing them batch service followed by individual service, otherwise after expiration of fixed time he takes a vacation. The server comes back from vacation, after N-customers are accumulated. The server passes a random period as pre-service procedure after coming back from vacation. During individual service the server is susceptible to random failures. Various performance measures are evaluated in steady state. Cost function is established to define the threshold and sensitivity analysis is also presented through numerical examples.

Keywords: Vacation, Two-phase, Pre-service, Time-Out and Server Breakdown.

I. INTRODUCTION

We deal with the optimal analysis of M/M/1 two-phase vacation queueing system with server startup, timeout and breakdowns. The two-phase M/M/1 queueing model was first presented by Krishna and Lee(1990).Doshi (1990) studied the two-phase M/G/1 queueing system. Vacation queueing models by using the probability generating function technique was first introduced by Levy and Yechiali. Kim and Chae (1998) analyzed the two-phase queueing system with N-policy. Oliver C.Ibe. et.al studied M/M/1 multiple vacation queueing system with differentiated vacation. Olive C.Ibe introduced the timeout concept and he derived mean waiting time of the vacation queue with timeout.K.Satish Kumar, K.Chandan and A.AnkammaRao studied optimal strategyanalyzed N-policy M/M/1 vacationqueueing system with server startup and timeout. V.N.RamaDevi,K.Satish Kumar and K.Chandan analyzed M/M/1 vacationqueueing system with startup and timeout in Transient mode. There are many papers in Two-Phase; this paper is an extension to improve server’s utility with the concept of Timeout.

II. THE SYSTEM AND ASSUMPTIONS

Arrivals are assumed to follow Poisson process with mean arrival rate λ and join the first phase of batch service. The server delivers service to all the customers with mean service rate 1/β. On completion of batch service, everyone of this batch receive individual service with mean rate of 1/μ. In the individual service phase, the server may fail with a failure rate α. It can be instantly repaired with a repair rate β, and resumes service immediately. After this server returns to first phase to serve all the customers if any and provide second phase then. If no one is waiting in batch queue then the server waits for a fixed time ‘C’ is called server Timeout. If units arrived during this fixed time he does the service to that unit as batch service followed by individual service. If no units arrived during this fixed time, then it takes a vacation and after N customers accumulates in the batch queue and start pre-service work with mean 1/θ. Once the period of startup is ended, the server starts service cycle. This cycle is shown as follows:

III. ANALYSIS OF THE MODEL

Various steady state probabilities of the system are shown below:

\[
\begin{align*}
\lambda p_{0,0} & \text{ } (i=0,1,2,3,\ldots) \text{ the server is on vacation.} \\
\lambda p_{1,i} & \text{ } (i=N+1,N+2,\ldots) \text{ the server is on Start-up.} \\
\lambda p_{2,i} & \text{ } (i=0,1,2,3,\ldots) \text{ the server is on Time-out.} \\
\lambda p_{3,i} & \text{ } (i=1,2,3,\ldots) \text{ the server is in Batch service.} \\
\lambda p_{4,i} & \text{ } (i=0,1,2,3,\ldots \text{ and } j=1,2,3,\ldots) \text{ the server is in individual service.} \\
\lambda p_{5,i} & \text{ } (i=0,1,2,3,\ldots \text{ and } j=1,2,3,\ldots) \text{ the server breakdown.} \\
\end{align*}
\]

The following are the satisfied system size steady state equations:

\[
\begin{align*}
\lambda p_{0,0} & = C p_{2,0} \\
\lambda p_{0,i} & = \lambda p_{0,1-i} : \quad 1 \leq i \leq N-1
\end{align*}
\]

Revised Manuscript Received on November 19, 2019.

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K.Chandan, Professor, Department of Statistics, Acharya Nagarjuna University, Guntur, AP, India, kotagirichandan@gmail.com
From using equations (1) to (12) 

\[ (\lambda + \theta) p_{1,N,0} = \lambda p_{0,N-1,0} \]

\[ (\lambda + \theta) p_{1,i,0} = \lambda p_{i+1,1,0}; \quad i > N \]

\[ (\lambda + C) p_{2,0,0} = \mu p_{4,0,1} \]

\[ (\lambda + \beta) p_{3,1,0} = \lambda p_{2,0,0} + \mu p_{4,1,1} \]

\[ (\lambda + \beta) p_{3,i,0} = \lambda p_{3,i-1,0} + \mu p_{4,i+1,1}; \quad 2 \leq i \leq N - 1 \]

\[ (\lambda + \beta) p_{3,i,0} = \lambda p_{3,i-1,0} + \mu p_{4,i+1,1} + \theta p_{1,i,0}; \quad i \geq N \]

\[ (\lambda + \alpha + \mu) p_{4,0,i} = \mu p_{4,0,i+1} + \beta p_{4,0,i} + + \gamma p_{5,0,i}; \quad j \geq 1 \]

\[ (\lambda + \alpha + \mu) p_{4,i,0} = \mu p_{4,i,0+1} + \lambda p_{4,i-1,0} + + \gamma p_{5,i,0}; \quad i, j \geq 1 \]

\[ (\lambda + \gamma) p_{5,0,i} = \alpha p_{4,0,i}, \quad j \geq 1 \]

\[ (\lambda + \gamma) p_{5,i,0} = \alpha p_{4,i,0} + + \gamma p_{5,i-1,0}; \quad i, j \geq 1 \]

These equations can be solved with the following PGFs:

\[ G_0(z) = \sum_{i=0}^{\infty} p_{0,i,0} z^i; G_1(z) = \sum_{i=0}^{\infty} p_{1,i,0} z^i; G_2(z) = \] 

\[ G_3(z) = \sum_{i=1}^{\infty} p_{3,i,0} z^i, \]

\[ G_4(z,y) = \sum_{i=0}^{\infty} \sum_{j=1}^{\infty} p_{4,i,j} z^i y^j, \]

\[ G_5(z,y) = \sum_{i=0}^{\infty} \sum_{j=0}^{\infty} p_{5,i,j} z^i y^j, \]

\[ R_j(z) = \sum_{i=0}^{\infty} p_{4,i,j} z^i \text{and } S_j(z) = \sum_{i=0}^{\infty} p_{5,i,j} z^i, \quad |z|, |y| \leq 1 \]

From using equations (1) to (12) 

\[ G_2(Z) = \frac{\lambda}{C} P_{0,0,0} \]

\[ G_0(Z) = \frac{(1-z^N)}{(1-z)} P_{0,0,0} \]

\[ G_1(Z) = \frac{\lambda N P_{0,0,0}}{[\lambda(1-z)+\theta]} \]

\[ P_{4,0,1} = \frac{\lambda (\lambda + C P_{0,0,0})}{\mu C} \]

\[ [\lambda(1-z) + \beta] G_3(z) = \mu R_1(z) + \theta G_1(z) + \frac{\lambda}{C} [\lambda(z-1) - C] P_{0,0,0} \]

\[ [\lambda(1-z) + \mu + \gamma R_j(z) = \mu R_{j+1}(z) + \gamma S_j(z) + \beta p_{3,i,0} \]

\[ [\lambda y(1-z) + \mu(y-1) + \alpha y] G_4(z,y) = \gamma y G_5(z,y) + \beta y G_3(y) - \mu y R_1(z) \]

\[ (\lambda + \gamma) S_j(z) = \alpha R_1(z) + \lambda z S_j(z) \]

\[ [\lambda(1-z) + \gamma] G_5(z, y) = \alpha G_4(z, y) \]

The normalizing condition is 

\[ G(1,1) = \frac{G_0(z) + G_1(z) + G_2(z) + G_3(z) + G_4(1,1) + G_5(1,1)}{1} \]

On solving 13 - 19 expressions 

\[ G_0(1) = N P_{0,0,0} \]

\[ G_1(1) = \frac{\lambda}{\beta} P_{0,0,0} \]

\[ G_2(1) = \frac{\lambda}{C} P_{0,0,0} \]

\[ G_3(1) = \frac{\lambda}{\beta} R_1(1) \]

\[ G_4(1,1) = \frac{\lambda \gamma R_1(1) + \beta y G_1(1)}{\beta y [\gamma R_1(1) + \beta y G_1(1)]} \]

\[ G_5(1,1) = \frac{\alpha}{y} G_4(1,1) \]

Where 

\[ P_{0,0,0} = \frac{1 - \left[ \frac{C}{\beta} (1 + \frac{C}{\beta}) \right]^2}{\frac{C}{\beta} (1 + \frac{C}{\beta})} \]

Normalizing condition (20) leads to 

\[ R_1(1) = \frac{\lambda}{\mu} \]
And is substituting in equations (24), (25) and (26) leads to

\[ G_3(1) = \frac{\lambda}{\beta} \]

\[ G_4(1,1) = \frac{\lambda}{\mu} \]

And

\[ G_5(1,1) = \frac{\lambda \alpha}{\mu \gamma} \]

The steady state probabilities that the server is in different modes are

\[ P_0, P_1, P_2, P_3, P_4 \] and \[ P_5 \] are equals to equations (21), (22), (23), (24), (25) and (26) respectively.

IV. EXPECTED SYSTEM LENGTH

When the server is in different modes the mean number of customers in the system are assumed \( L_0, L_1, L_2, L_3, L_4 \) and \( L_5 \) are given as

\[ L_0 = G_0(1) = \frac{N(N-1)}{2} P_{0,0,0} \]  \hspace{1cm} (28)

\[ L_1 = G_1(1) = \frac{\lambda [N + N(N-1)]}{\theta^2} P_{0,0,0} \]  \hspace{1cm} (29)

\[ L_2 = G_2(1) = 0 \]  \hspace{1cm} (30)

\[ R_1(1) = \frac{\lambda^2 (\alpha + \gamma)}{\mu^2 \gamma} \]

\[ L_3 = G_3(1) = \frac{\lambda}{\beta} \]

\[ L_4 = G_4(1,1) = \frac{\lambda [\lambda^2 \beta \alpha + \mu^2 (\lambda + \beta)]}{\gamma \beta [\mu \gamma - \lambda (\alpha + \gamma)] + \lambda \gamma [2 \lambda (\lambda + N \theta) + \theta^2 N(N-1)]} P_{0,0,0} \]  \hspace{1cm} (31)

\[ L_5 = G_5(1,1) = \frac{\lambda \mu}{\gamma} G_4(1,1) + \frac{\alpha}{\gamma} G_0(1,1) \]  \hspace{1cm} (32)

The expected system length is

\[ L(N) = L_0 + L_1 + L_2 + L_3 + L_4 + L_5 \]

V. SOME OTHER SYSTEM PERFORMANCE MEASURES

Let \( E_0 \) (idle), \( E_1 \) (startup), \( E_2 \) (timeout), \( E_3 \) (batch service), \( E_4 \) (individual service) and \( E_5 \) (breakdown) denotes the expected length of periods of different states and long run fractions are given below. Also the cycle expected length is given by

\[ E_c = E_0 + E_1 + E_2 + E_3 + E_4 + E_5 \]  \hspace{1cm} (35)

The fractions of time that the server in these different modes is obtained as follows:

\[ \frac{E_0}{E_c} = P_0 = G_0(1) = \frac{\lambda}{\theta} P_{0,0,0} \]  \hspace{1cm} (36)

\[ \frac{E_1}{E_c} = P_1 = G_1(1) = \frac{\lambda}{\theta} P_{0,0,0} \]  \hspace{1cm} (37)

\[ \frac{E_2}{E_c} = P_2 = G_2(1) = \frac{\lambda}{\mu} P_{0,0,0} \]  \hspace{1cm} (38)

\[ \frac{E_3}{E_c} = P_3 = G_3(1) = \frac{\lambda}{\mu} \]  \hspace{1cm} (39)

\[ \frac{E_4}{E_c} = P_4 = G_4(1) = \frac{\lambda}{\mu} \]  \hspace{1cm} (40)

\[ \frac{E_5}{E_c} = P_5 = G_5(1) = \frac{\lambda \alpha}{\mu \gamma} \]  \hspace{1cm} (41)

Idle period expected length is

\[ E_0 = \frac{N}{\lambda} \]

Using it in (36)

\[ \frac{1}{E_c} = \frac{\lambda [1 - \frac{1}{\mu} + \frac{\lambda}{\mu}]}{[N + \frac{\lambda}{\mu}]} \]  \hspace{1cm} (42)

VI. EVALUATION OF OPTIMAL N-POLICY \( (N^*) \)

We construct a cost function for the present queueing model with the objective to find \( N \) that can minimize this function. For this, we define various costs that incur per unit of time as shown below:

\[ C_0 = \text{holding cost for each customer} \]
C_o = operational cost of server
C_m = pre service cost per cycle
C_t = timeout cost per cycle
C_s = setup cost per cycle
C_b = breakdown cost
C_r = reward for the server being on vacation

The function of total expected cost per unit time is given by

\[ T(N) = c_h L(N) + c_o \left[ \frac{E_x + E_s}{E_c} \right] + c_m \left[ \frac{E_s}{E_c} \right] + c_a \left[ \frac{E_x}{E_c} \right] + c_b \left[ \frac{E_s}{E_c} \right] + \frac{1}{E_r} \left( \frac{E_x}{E_c} \right) - \frac{c_r}{E_r} \left( \frac{E_x}{E_c} \right) \]

After simplification, this function attains minima where

\[ N^* = -\frac{b + \sqrt{b^2 - 4ac}}{2a} \]

Where \( a = \frac{c_h \lambda \vartheta \Theta + C}{2[\mu \gamma - \lambda (a + \gamma)]} \), \( b = \frac{c_h \lambda \vartheta \Theta C}{[\mu \gamma - \lambda (a + \gamma)]} \) and

\[ c = \frac{c_h \lambda [2\vartheta \gamma - \mu \gamma]}{2[\mu \gamma - \lambda (a + \gamma)]} - \lambda [C(C_m + C_r) + \Theta(C_t + C_r) + C_r \Theta C] \]

VII. SENSITIVITY ANALYSIS

We perform numerical experiments to evaluate the impact of various parameters (both non-monetary and monetary) on system performance measures as well as threshold \( N^* \) as follows:

The sensitivity analysis is carried over by fixing

Non-monetary parameters as \( \lambda = 0.5, \mu = 2.5, \beta = 2, \Theta = 2, \vartheta = 2, \alpha = 0.1, C = 1 \)

and monetary parameters as \( C_b = 5, C_v = 100, C_o = 100, C_m = 100, C_r = 40, C = 500, C = 30 \).

Case I: Non-monetary parameters effect

- Table 1 and Figure 1 show that by increasing the value of \( \lambda, N^* \) and \( T(N^*) \) are increases, where as \( L(N^*) \) is a convex function of \( \lambda \).
- Table 2 and Figure 2 show that by increasing the value of \( \mu, N^* \) and \( T(N^*) \) are increases and \( L(N^*) \) is decrease.
- Table 3 and Figure 3 show that by increasing the value of \( \beta, N^* \) is constant, \( T(N^*) \) is increase and \( L(N^*) \) is decrease.
- Table 4 and Figure 4 show that by increasing the value of \( \Theta, N^* \), \( T(N^*) \) and \( L(N^*) \) are decreases.
- Table 5 and Figure 5 show that by increasing the value of \( \vartheta, N^* \) and \( T(N^*) \) are increases, and \( L(N^*) \) is decrease.
Figure 3:

Table 4:

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Figure 4:

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Figure 5:

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Figure 6:

Table 7:

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Figure 7:

Case II: Monetary parameters effect

- Table 8 and Figure 8 show that by increasing the value of $C_h$, $N^*$ and $L(N^*)$ are decreases, and $T(N^*)$ is increase.
- Table 9, Table 10 and Figure 9, Figure 10 show that by increasing the values of $C_0$ and $C_b$, $N^*$ and $L(N^*)$ are constants, and $T(N^*)$ is increase.
- Table 11, Table 13, Table 14 and Figure 11, Figure 13, Table 14 show that by increasing the values of $C_m$, $C_s$, and $C_t$, $N^*$, $L(N^*)$ and $T(N^*)$ are increases.
- Table 12 and Figure 12 show that by increasing the value of $C_r$, $N^*$ and $L(N^*)$ are increases, and $T(N^*)$ is decrease.
- The following tables: 8, 9, 10, 11, 12, 13 and 14 shows the effect of $C_h$, $C_0$, $C_b$, $C_m$, $C_s$, and $C_t$ on $N^*$, $L(N^*)$ and $T(N^*)$ respectively.
- The following figures: 8, 9, 10, 11, 12, 13 and 14 shows the effect of $C_h$, $C_0$, $C_b$, $C_m$, $C_s$, and $C_t$ on $N^*$, $L(N^*)$ and $T(N^*)$ respectively.

Table 8:

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M/M/1 Queue with N-Policy Two-Phase, Server Start-Up, Time-Out and Breakdowns

Figure 8:

Table 9:

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Figure 9:

Table 10:

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Figure 10:

Table 11:

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Figure 11:

Table 12:

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Figure 12:

Table 13:

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<td>79.03794</td>
<td>86.85336</td>
<td>93.80023</td>
</tr>
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</table>

Figure 13:

Table 14:

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<th>Cn</th>
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<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
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<tbody>
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<td>3.413987</td>
<td>3.440161</td>
<td>3.466143</td>
<td>3.491937</td>
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<tr>
<td>T(N*)</td>
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<td>58.72377</td>
<td>58.98782</td>
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<td>59.51006</td>
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VIII. CONCLUSIONS

In this model we have obtained explicit expressions for the system length of a queuing model in different modes. Sensitivity analysis made for and numerical values are presented for the different values of monetary and non-monetary parameters to illustrate the validity of the proposed model.

REFERENCES

1. V. Vasanta Kumar And K. Chandan, Optimal Strategy analysis Of An N-Policy Two-Phase M/M/1 Queueing System With Server Breakdowns.

AUTHORS PROFILE

A. Ankammarao completed his Masters degree from Acharya Nagarjuna University and joined as a Research Scholar in the same university under the guidance of Prof. K. Chandan. He has attended 2 National/International conferences and also has published 4 papers in various international journals.

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