Analysis of a Call Center with Partial Closing Rules, Feedback and Impatient Calls

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***Abstract*—The Interactive Voice Response Units (IVRUs) have been used in call centers widely in recent years. In this paper, we study a call center made up of trunk lines, IVRUs and Customer Service Representatives（CSRs）. We discuss partial closing rules, calls' impatience and feedback phenomena in a call center. A call enter the call center whenever a trunk line is available, otherwise it is lost. Once a trunk line is seized, the call is served by the IVRUs first; then the call may leave the center or be routed to an available CSRs. If all CSRs are busy, the call is queued at the automatic call distributor until one line is free. While waiting for CSRs, calls may abandon the queue if their waiting time becomes unreasonably long. We assume that each call abandons the queue independently of each other when waiting for CSRs. From the perspective of the queuing theory, we present some significant performance measures for the system in steady-state. Finally, numerical results are presented with the focus on the effects of different parameters.**

***Index Terms*—Call center, partial closing rules, impatient, feedback, the Interactive Voice Response Units (IVRUs)**

I. Introduction

A call center is a place where large numbers of calls are processed and information services are provided by telephones. Call center business is developing rapidly and studied by many authors [1-9]. Call centers have become a preferred and prevalent approach for companies to communicate with their customers.

Several researchers [4-10] considered the call centers with calls' impatience, catastrophe and retrial phenomena. They obtained the stationary distribution of the system and other performance measures, but they did not consider the call centers with the Interactive Voice Response Units (IVRUs). It is reported that almost 60-80% of the operational costs for a call center involves personnel expenses [11]. Therefore, an efficient deployment of Customer Service Representatives（CSRs）keeping a high quality of service is indispensable for reducing operational expenses in a call center. In order to improve this trade-off, most companies install IVRUs [12], which is a method of customer self-service. Once arriving calls enter the call center, they first receive service by IVRUs, and then some of them can further receive service by agents. If all agents are busy, the calls who want further service are queued at the automatic call distributor (ACD). Once a call completes its transaction with an agent, it releases both the truck line and the agent simultaneously. Srinivasan [13] took into account the call centers with the IVRUs. By using flow controlled Jackson networks method; they obtain the explicit expressions for the stationary distribution of the system and other performance measures, and provide a way to calculate the number of trunk lines and the number of agents required simultaneously to meet some pre specified service levels. Sometimes, all the agents may be busy upon the caller's arrival after his IVRUs process. In practical situations, a caller will wait a limited time in the queue at ACD. If he can get the service before his patience expires, then he is routed to the available agent via ACD. Otherwise, he will leave the agent area and lost. Wang [14] took into account the call centers with the IVRUs and impatient customers. By using flow controlled Jackson networks method; they obtain the explicit expressions for the stationary distribution of the system, blocking probability, abandonment probability and other performance measures. Zhang[15] took into account the call centers with the IVRUs and calls' impatience, retrial and got some performance measures. Chen [16] considered a call center with a closing rule, impatient customers and IVRUs. They derived some performance measures and investigated the impact of various parameters on the performance measures. Inspired by new Internet technology, nowadays CSRs are not necessarily concentrated in the same place. They can work in any place where Internet connection is available allowing a more flexible work style for CSRs. Hashizume [17] focus on a two-stage tandem queue with retrials for Internet-based call centers with IVRUs. They formulated the queueing model using a level-dependent QBD process and derived performance measures.

In view of the customers who dissatisfied with the service can return back for service again. In this paper, we will investigate the combination of the calls (abandonment and feedback) and the role of the service channel (CSR and the IVRUs) in a call center and the research on this aspect has not found at present.

In this paper, the call center with partial closing rules, calls' impatience and feedback is discussed. This model is more close to widely used call centers. Based on queuing model, some significant performance measures for the system in steady-state have been presented, and some numerical examples are given.

The remainder of the paper is organized as follows. In Section 2, we present the model description. In Section 3, we develop some significant performance measures for the system in steady-state. In Section 4, some numerical examples are given and conclusions are presented at last in this paper.

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II. Model Description

In this paper, we consider a call center which is made up of telephone trunk lines, an automatic call distributor (ACD) together with the IVRUs and CSRs (or agents). Readers can see the operation process of a call center in Figure 1. The first one represents the IVRUs; the second queue represents the calls which will be served by agents. We assume that:

(1) The call center consists of N trunk lines, S CSRs (agents). ($S \le N$).This call center with IVRUs can handle at most N calls at a time, where N represents the total number of truck lines available. Arriving calls can enter the call center only when the total number of calls at the call center with IVRUs and the agents' pool is strictly less than the number of truck lines; otherwise, the call is lost. There is no queue at the IVRUs, whereas some calls may have to wait for an agent at ACD if all the CSRs are busy. The arrival process of incoming calls is a Poisson process with constant rate λ . A call enters the call center whenever a trunk line is available; otherwise it is lost. Once a trunk line is seized, the call is served by the IVRUs first; then the call may leave the call center with probability $1-p$ or be routed to an available agent with rate p . If all CSRs are busy, the call is queued at the ACD until one agent is free; while waiting for the services, calls may abandon the queue if their waiting time becomes unreasonably long. We assume that each call abandons the queue independently of each other while waiting for services. Customers' patience time is exponential distribution with rate θ . The processing times of the IVRUs are independent and identically distributed exponential random variables with rate μ_1 , and the agents' service times are independent and identically distributed exponential random variables with rate μ_2 .

(2) Once a call completes its services by an agent, it may releases both the truck line and the CSR simultaneously (leaving the call center) with probability $1-\gamma$ or may hold the truck line and releases the CSR (feedback to the IVRUs) with probability γ .

(3) The partial closing rule is as follow: Once the system is no calls, the system will shut down S-C servers simultaneously for a random time ($1 \le C < S \le N$), the shutdown time is exponential distributed with rate η . If any trunk line is seized before the end of the shutdown, S-C servers return to the system. Otherwise, these servers take another shutdown and continue until they find calls in the trunk lines.

(4) All above random variables in our model are mutually independent.

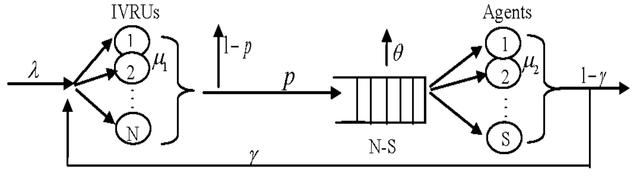

Fig. 1. The operation process in a call center

III. Results

We formulate the call center with IVRUs by a two-stage queueing system. The first-level queue represents the calls at the IVRUs, the IVRUs can handle at most N calls at a time; the second-level queue represents the calls needing agents' service (Including the waiting and being serviced calls). Let

$N(t)$: = The number of calls at the IVRUs at time t;

$K(t)$: =The number of calls needing agents' service at time t;

$I(t)$:=Servers statuses at time t, where $I(t)=0$ means C servers are open or $I(t)=1$ means all servers are open.

Note that $N(t)+\mathrm{K}(t) \le N$ for all $t \ge 0$.

It is easy to proof that the system has only a finite number of states and all random variables are independent and exponentially distributed, so $\{N(t), K(t), I(t): t \ge 0\}$ is an irreducible finite state Markov chain. The state space Ω is defined as

$$\Omega = \{(n,k,i) \mid 0 \le k, n \le N, 0 \le k+n \le N, i = 0,1\}.$$

Then we can find the stationary distribution of the system by quasi birth and death (QBD) method. For more details of this method, reader can refer to the literature [17].

Let $\pi_{(n,k,i)}$: = a steady state probability, when the system have n calls in the first-level queue and k calls in the second-level queue, the servers in state i , $(0 \le k, n \le N,$ $0 \le k+n \le N,\ i = 0,1)$. We further define:

$$\pi_0 = (\pi_{(0,0,0)}, \pi_{(0,1,0)}, \pi_{(0,1,1)}, \ldots \pi_{(0,N,0)}, \pi_{(0,N,1)}),$$
$$\pi_j = (\pi_{(j,0,0)}, \pi_{(j,0,1)}, \pi_{(j,1,0)}, \pi_{(j,1,1)}, \ldots \pi_{(j,N-j,0)}, \pi_{(j,N-j,1)});$$
$$(j = 1, 2, \ldots N).$$

Then we can define the stationary probability vector π as

$$\pi = (\pi_0, \pi_1, \pi_2, \ldots \pi_N),$$

which is uniquely determined by solving the equation $\pi\, Q = 0$ and the normalization condition $\pi\, \mathrm{I}^T = 1$, where I^T is a column vector of ones.

$$\text{That is } \begin{cases} (\pi_0, \pi_1, \pi_2, \ldots \pi_N) Q = 0, \\ \sum_{m=0}^{N} \sum_{n=0}^{N-m} \pi_{(m,n,0)} + \sum_{m=1}^{N} \sum_{n=0}^{N-m} \pi_{(m,n,1)} + \sum_{n=1}^{N} \pi_{(0,n,1)} = 1. \end{cases} \quad (1)$$

where Q in the above equation is the infinitesimal generator as follow.

$$Q = \begin{pmatrix} A_0 & C_0 & & & & & & \\ B_1 & A_1 & C_1 & & & & & \\ & \ddots & \ddots & \ddots & & & & \\ & & B_S & A_S & C_S & & & \\ & & & \ddots & \ddots & \ddots & & \\ & & & & B_{N-1} & A_{N-1} & C_{N-1} \\ & & & & & B_N & A_N \end{pmatrix}.$$

The Q matrix above is based on the first coordinate horizontal transfer of the steady state probability vector, which has the block tridiagonal form. The details of elements in Q are expressed below.

A_n $(n = 0,1,...,N)$ is the lower block tridiagonal form as follow.

$$A_n = \begin{pmatrix} A_{00}^n & & & & \\ A_{10}^n & A_{11}^n & & & \\ & A_{21}^n & A_{22}^n & & \\ & & \ddots & \ddots & \\ & & & A_{N-n\,N-n-1}^n & A_{N-n\,N-n}^n \end{pmatrix},$$

we define

$a_{1k}^n = -n\mu_1 - \eta - \min(\mathrm{k}, C)\mu_2 - \max\left[(k-C),0\right]\theta,$

$a_{2k}^n = -n\mu_1 - \min(k,S)\mu_2 - \max[(k-S),0]\theta,$

$(n = 0,1,...N; k = 0,1,2,...N-n)$,

then the sub-matrix of A_n is as follows.

$$A_{kk}^n = \begin{cases} (-\lambda) & , \quad if \quad n+k=0 \\ \begin{pmatrix} a_{1k}^n & \eta \\ 0 & a_{2k}^n \end{pmatrix} & , \quad if \quad n+k=N \\ \begin{pmatrix} a_{1k}^n - \lambda & \eta \\ 0 & a_{2k}^n - \lambda \end{pmatrix} & , \quad if \quad \begin{matrix} n+k \neq N \\ n+k \neq 0 \end{matrix} \end{cases}.$$

We further define

$a_{3k}^n = \min(k,C)\mu_2(1-\gamma) + \max\left[(k-C),0\right]\theta,$

$a_{4k}^n = \min(k,S)\mu_2(1-\gamma) + \max[(k-S),0]\theta,$

$(n = 0,1,...,N; k = 1,2,...,N-n)$, then

$$A_{kk-1}^n = \begin{cases} \begin{pmatrix} \mu_2(1-\gamma) \\ \mu_2(1-\gamma) \end{pmatrix} & , \quad if \quad n=1 \\ \begin{pmatrix} a_{3k}^n & 0 \\ 0 & a_{4k}^n \end{pmatrix} & , \quad if \quad n \neq 1 \end{cases}.$$

B_n $(n = 0,1,...,N)$ is the upper block tridiagonal form as follow.

$$B_n = \begin{pmatrix} B_{00}^n & B_{01}^n & & \\ & B_{11}^n & B_{12}^n & \\ & & \ddots & \ddots \\ & & B_{N-n\,N-n}^n & B_{N-n\,N-n+1}^n \end{pmatrix}.$$

The sub-matrix of B_n is

$$B_{kk}^n = \begin{cases} \begin{pmatrix} \mu_1 q \\ \mu_1 q \end{pmatrix} & , \quad n=1 \\ \begin{pmatrix} n\mu_1 q & 0 \\ 0 & n\mu_1 q \end{pmatrix} & , \quad n \neq 1 \end{cases},$$

$$B_{kk+1}^n = \begin{pmatrix} n\mu_1 p & 0 \\ 0 & n\mu_1 p \end{pmatrix},$$

$(n = 1,2,...,N, \quad k = 0,1,...,N-n)$.

C_n $(n = 0,1,...,N)$ is the lower block tridiagonal form as follow.

$$C_n = \begin{pmatrix} C_{00}^n & & & \\ C_{10}^n & C_{11}^n & & \\ & C_{21}^n & C_{22}^n & \\ & \ddots & \ddots & \\ & & C_{N-n-1\,N-n-2}^n & C_{N-n-1\,N-n-1}^n \\ & & & C_{N-n\,N-n-1}^n \end{pmatrix},$$

$(n = 0,1,...,N-1)$.

The sub-matrix of C_n is

$$C_{kk-1}^n = \begin{pmatrix} \min(k,C)\mu_2\gamma & 0 \\ 0 & \min(k,S)\mu_2\gamma \end{pmatrix},$$

$$C_{kk}^n = \begin{cases} \begin{pmatrix} \lambda & 0 \end{pmatrix}, & if \quad n+k=0 \\ \lambda \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, & if \quad n+k \neq 0 \end{cases},$$

$(n = 0,1,...,N-1; \; k = 0,1,...,N-n-1)$.

By using the Structured Gaussian Elimination method, which is introduced in the literature [18], we can solve the two equations in (1) perfectly, obtain the stationary distribution probability of the system and further get the performance measures below.

1) The idle probability of all lines: $P_0 = \pi_{(0,0,0)}$.
2) The probability of exactly m calls in the system
$$P_m = \sum_{k+n=m} \pi_{(n,k,0)} + \sum_{k+n=m} \pi_{(n,k,1)}.$$
3) the average number of calls in the system:
$$E(L) = \sum_{m=0}^{N} m p_m = \sum_{m=0}^{N} m\left(\sum_{k+n=m} \pi_{(n,k,0)}\right) + \sum_{m=0}^{N} m\left(\sum_{k+n=m} \pi_{(n,k,1)}\right).$$
4) The average number of the waiting customers in the second-level queue:
$$E(N_{Agents}) = \sum_{k=C+1}^{N} \sum_{n=0}^{N-k} (k-C)\pi_{(n,k,0)} + \sum_{k=S+1}^{N} \sum_{n=0}^{N-k} (k-S)\pi_{(n,k,1)}.$$
5) The busy probability of all lines:
$$P_B = \sum_{k+n=N} \sum_{i=0}^{1} \pi_{(n,k,i)}.$$
6) The leaving probability in the second-level queue for impatience:
$$P_{IL} = \sum_{k=C+1}^{N} \sum_{n=0}^{N-k} \frac{(k-C)\theta}{\eta + (k-C)\theta} \pi_{(n,k,0)} + \sum_{k=S+1}^{N} \sum_{n=0}^{N-k} \frac{(N-S)\theta}{S\mu_2 + (N-S)\theta} \pi_{(n,k,1)}.$$

Remark 1. If $\gamma = 0$ and $\eta \to 0$, then all the calls leave the system once they complete their services by agents and the call center becomes idle once there is no calls in the system. Our model can be simplified as a two-stage tandem queue [12]. If we further assume that $\gamma = 0, \eta \to 0$ and $\theta \to \infty$ in performance measures as shown above, then our results are in agreement with [13].

IV. NUMERICAL RESULTS

In order to demonstrate the impact of various parameters on the performance measures of our model, we will demonstrate some numerical examples. In this paper, we mainly show how the parameter p, the parameter θ, the arrival rate λ and the parameter γ affect the performance measures of the system by some numerical examples.

Case 1: Given $\mu_1^{-1}=1/3\min$, $\mu_2^{-1}=1\min$, $\lambda^{-1}=1/6\min$, $\eta^{-1}=1/2\min$, $\theta^{-1}=1\min$, $\gamma=0.2$, $N=3, S=2, C=1$. We study the changes of the parameter p to the idle probability P_0 and all lines busy probability P_B.

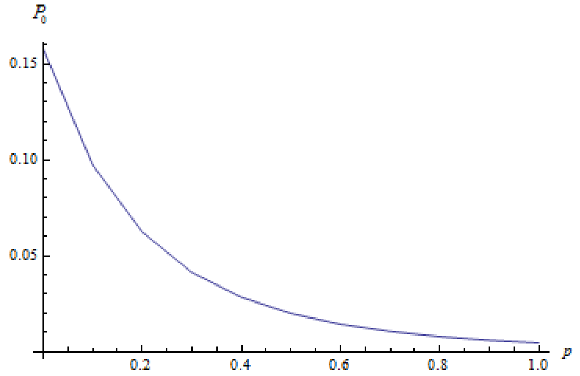

Fig. 2. The idle probability P_0 versus p

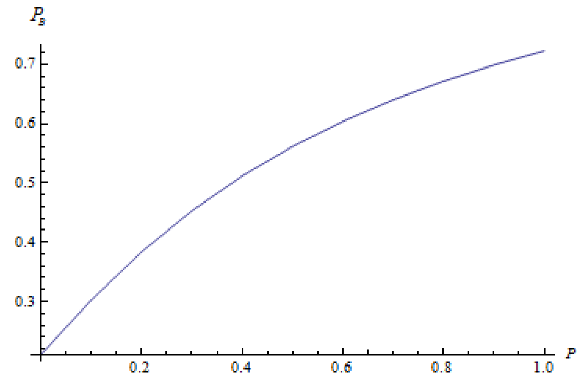

Fig. 3. All lines busy probability P_B versus p

It can be seen from figures 2-3 that when parameter p increases, the idle probability P_0 decreases, while all lines busy probability P_B can drastically increase. It is obvious that when more customers join the system, the idle probability of the system decreases, and all lines busy probability increase.

Case 2: Given $\mu_1^{-1}=1/2\min$, $\mu_2^{-1}=1/5\min$, $\lambda^{-1}=1\min$, $\eta^{-1}=1/2\min$, $\theta^{-1}=1/3\min$, $\gamma=0.2$, $N=3, S=2, C=1$. We study the changes of the parameter p to the following three performance measures.

It can be seen from figures 4-6: (1) when parameter p increases, the average number of the waiting customers in the second-level queue $E(N_{Agents})$ and all lines busy probability P_B and the leaving probability for impatience P_{IL} increase. (2) Compare figure 3 and figure 5, we found that there are different of the curve bending direction between the two figures, the main reason is that the system is also influenced by other parameters.

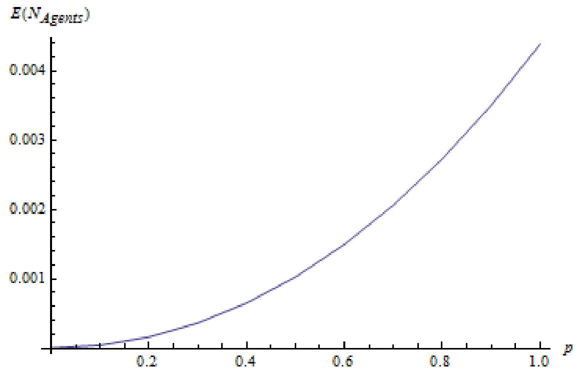

Fig. 4. The average number of the waiting customers in the second- level queue $E(N_{Agents})$ versus p

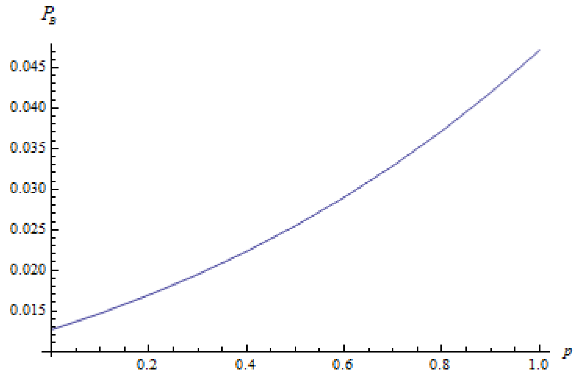

Fig. 5. All lines busy probability P_B versus p

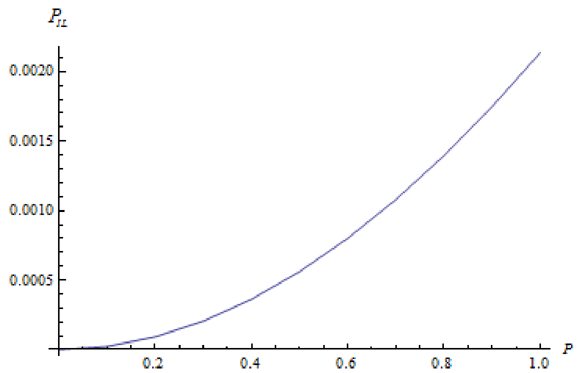

Fig. 6. The leaving probability for impatience P_{IL} versus p

Case 3: Given $\mu_1^{-1}=1/2\min$, $\eta^{-1}=1/2\min$, $\mu_2^{-1}=1/3\min$, $\gamma=0.2$, $N=3, S=2, C=1$. We study the changes of the parameter θ to the following four performance measures with $p=0.2,0.5$.

It can be seen from figures 7-10： (1) when the parameter θ increases, the idle probability P_0 increases, while all lines busy probability P_B and the average number of the waiting customers in the second-level queue $E(N_{Agents})$ decrease. When the parameter θ increases, the leaving probability in the second-level queue for impatience P_{IL} reaches a maximum value, and then it has a slow decline. (2)When the parameter θ is large enough, the system performance measures become stable. It is found that system performance measures are influenced by parameter θ, but the changes of the system performance measures is not big. (3)Because all calls should use the lines, the system performance measures must be influenced by parameter p.

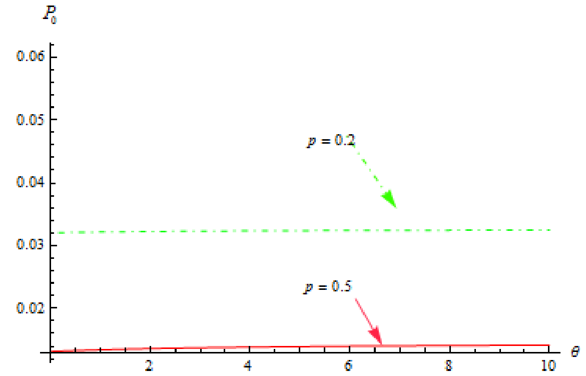

Fig. 7. The idle probability P_0 versus θ

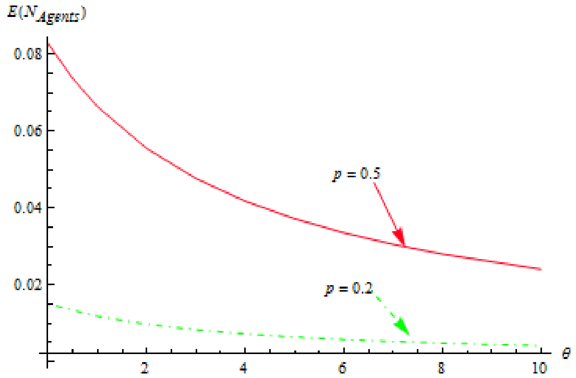

Fig. 8. The average number of the waiting customers in the second-level queue $E(N_{Agents})$ versus θ

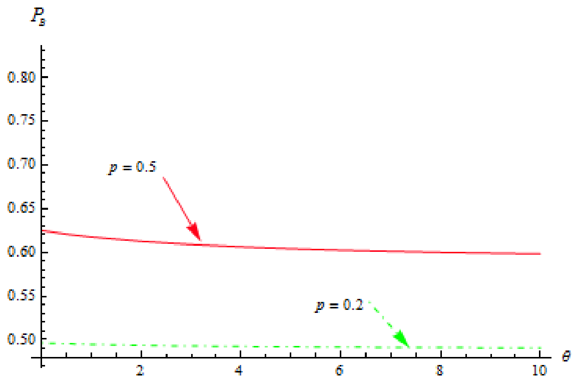

Fig. 9. All lines busy probability P_B versus θ

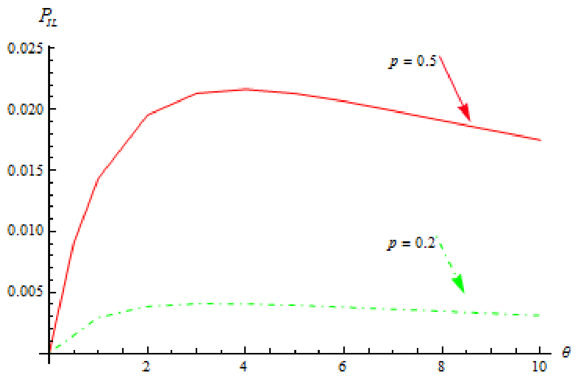

Fig. 10. The leaving probability in the second- level queue for impatience P_{IL} versus θ

Case 4: Given $\mu_1^{-1} = 1/2\,\text{min}$, $\mu_2^{-1} = 1/5\,\text{min}$, $\eta^{-1} = 1/2\,\text{min}$, $p = 0.5$, $\theta^{-1} = 1/3\,\text{min}$, $\gamma = 0.6, N = 3, S = 2, C = 1$. We study the changes of the arrival rate λ to the following four performance measures.

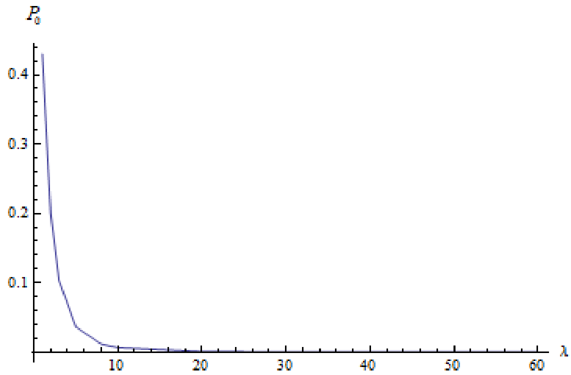

Fig. 11. The idle probability P_0 versus λ

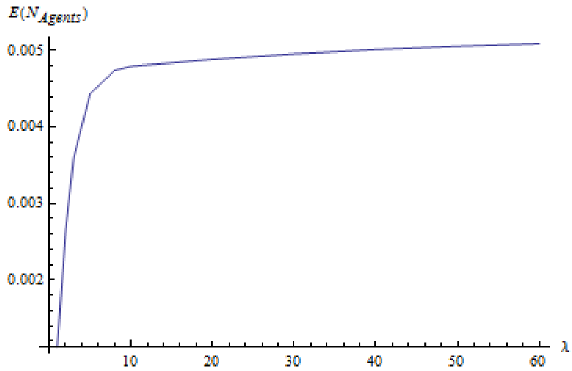

Fig. 12. The average number of the waiting customers in the second-level queue $E(N_{Agents})$ versus λ

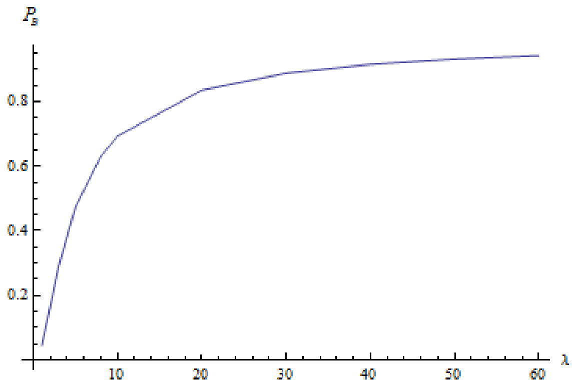

Fig. 13. All lines busy probability P_B versus λ

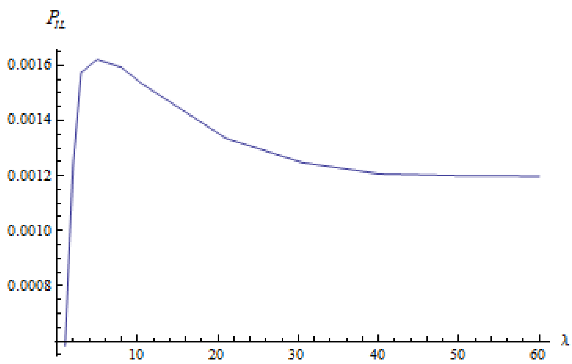

Fig. 14. The leaving probability in the second- level queue for impatience P_{IL} versus λ

It can be seen from figures 11-14: (1) When the arrival rate λ increases, the idle probability P_0 can drastically decreases, while all lines busy probability P_B and the average number of the waiting customers in the second-level queue $E(N_{Agents})$ increase. (2)The leaving probability in the second-level queue for impatience P_{IL} reaches a maximum point, and then starts to fall.

Case 5: Given $\mu_1^{-1}=1/3\min$, $\mu_2^{-1}=1\min$, $\lambda^{-1}=1/6\min$, $\eta^{-1}=1/2\min$, $\theta^{-1}=1\min$, $\gamma=0.6$ $N=3, S=2, C=1$. We study the changes of the parameter p to the following four performance measures.

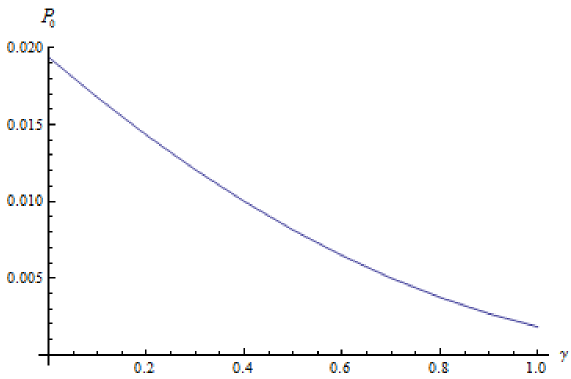

Fig. 15. The idle probability P_0 versus γ

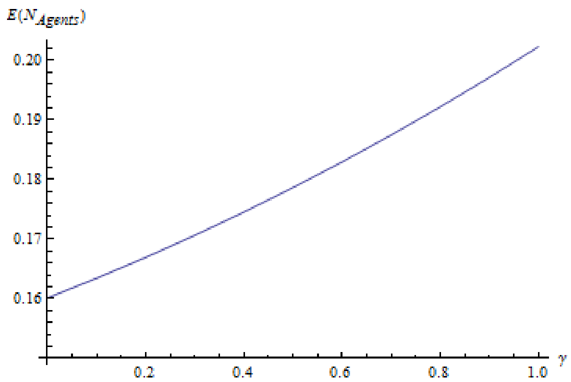

Fig. 16. The average number of the waiting customers in the second-level queue $E(N_{Agents})$ versus γ

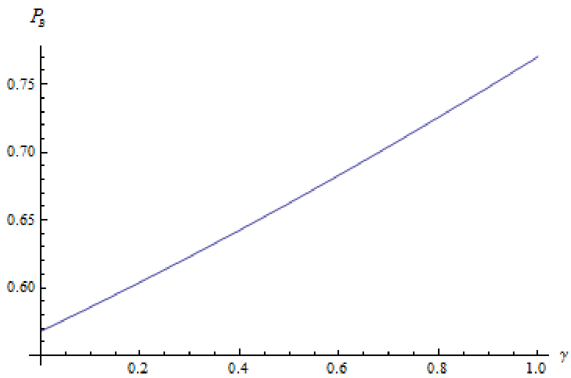

Fig. 17. All lines busy probability P_B versus γ

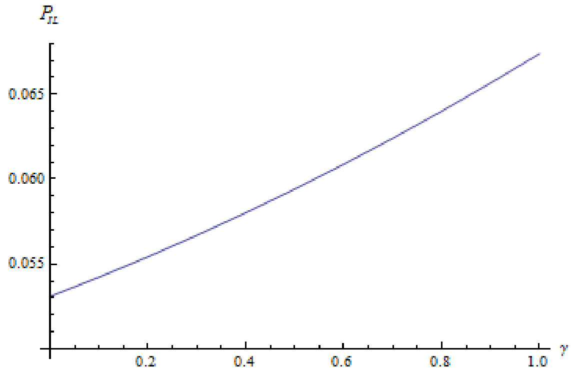

Fig. 18. The leaving probability in the second- level queue for impatience P_{IL} versus γ

It can be seen from figures 15-18 that when the parameter γ increases, the idle probability P_0 decreases, while all lines busy probability P_B, the average number of the waiting customers in the second-level queue $E(N_{Agents})$ and the leaving probability in the second-level queue for impatience P_{IL} increase.

V. CONCLUSIONS

In this paper, we study a call center made up of trunk lines, interactive voice recording units and agents. We discussed partial closing rules, calls' impatience and feedback in the call center by queueing theory. Some numerical examples are also investigated on how the design parameters affect some important performance measures of the system.

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