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Comparative Study of Waiting and Service Costs of Single and Multiple Server System: A Case Study on an Outpatient Department

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Abstract

Hospital management tradeoffs always exist between the costs in providing better service and waiting time of patients in any hospital. The objective of this study was to investigate whether increasing the cost for better service decreases the cost of patients waiting time or not, by using the technique of single and multiple servers which is based on the theory of Markovian queuing system. For this study, four weeks data has been taken from a public hospital. The results shows that as the service capacity level of doctors at the hospital increases from three to four servers then minimum total costs (include waiting and service costs) and the waiting time of patients as well as overutilization of doctors can be reduced. This study also suggests that increasing the service units up to four servers will achieve lower cost as against two or more service units.

Introduction

Outpatient department is one of the most important parts of hospital management and is visited by large section of community. This is the first point of contact between patient and hospital staff. The problems faced by the patients in that department are overcrowding, delay in consultation, lack of proper guidance etc. which lead to patients becoming dissatisfied. Every patient in each hospital is in search of hassle free and quick services in this fast growing world which is only possible with optimum utility of the resources through multitasking in a single server system in the OPD for better services.[1, 2]. As patients flow increases because of that demands for hospitals and, better and quick services increases. In any hospital, patients come to the Outpatient Department without prior appointment and patients have to wait to receive medical service that may be waiting before, during or after being served.

Generally queues are formed when the demand for a service exceeds its supply[3]. For many patients or customers, waiting in lines or queuing is annoying[4] or negative experience[5]. A few of the factors that are responsible for long waiting lines or delays in providing service are: lack of passion and commitment to work on the part of the hospital staff[6], overloading of available doctors, doctors attending to patients in more than one clinic etc.

A good patient flow means that the patient queuing is minimized while a poor patient flow means patients suffer considerable queuing delays[7]. Considering these points mentioned above, our present study proposes to evaluate the patients waiting problems in terms of the performance measure and also to determine the level of service that minimizes the total cost of the expected cost of service and the expected cost of waiting.

Materials and methods:

The study area is Guwahati, which is a fast developing city in the North-Eastern region of India. There is heavy inflow of sick patients in this region from neighboring rural areas or from smaller towns because of the availability of advanced health facilities. For our study we selected one of the leading public hospitals of the region, viz. Pandu P.H.C/F.R.U, Guwahati where it was observed that there was a heavy flow of patients thought the week. Data was collected over a period of four Weeks from 15.07.2013 to 13.08.2012. Data was collected from the Patients who visited Out- Patient Department during day shift (9.00 am – 2.00 pm) by using direct observation method.

In this observational study, the traffic intensity of the out patients at registration counters such as the arrival rate (λ), service rate (μ) and number of servers was measured at hourly interval. These are analyzed for simultaneous efficiency in patient satisfaction and cost minimization through the use of a single server M/M/1(∞: FCFS) and multi-server queuing models, which are then compared for a number of queue performances such as; the average time each patient spends in the queue and in the system, average number of patients in the queue and in the system and the probability of the system being idle.

In M/M/1(∞: FCFS) queuing model, the arrival of patients in a fixed time interval belongs to Poisson probability distribution at an average rate of λ patients per unit time. It is also assumed that the service time was exponentially distributed, with an average rate of μ patients per unit of time. The hypothetical structure of Single-server queuing model is shown in Figure 1.

For the multi-server queuing model, the M/M/c (∞: FCFS) model has been adopted. The basic hypothetical structure of multi-server queuing model is shown in Figure 2. In this queuing system, the arrival of patients is assumed to follow a Poisson process, and service times are assumed to have an exponential distribution. Let the number of servers be c, providing service independently of each other. It is also assumed that the arriving patients form a single queue and the one at the head of the waiting line enters into service as soon as a server is free. No server stays idle as long as there are patients to serve. If there are n patients in the queuing system, then two possibilities may arise:

Case.1: $k \leq c$. In this case no patient has to wait for service. However, (c-n) patients will be in queue and the rate of servicing will be kμ.

Case.2: $k > c$. In this case, all the doctors will be busy and the maximum number of patients will be (k-c) in the queue and the rate of service will be cμ.

The Variables are analyzed by using the

performance measures of the Queuing Models [M/M/1(∞: FCFS) and M/M/c (∞: FCFS)] as presented in Table 1. There are (5 x 4 weeks) working days in a month used in this study while the working hours per day are 24 hours for casualty service and 5 hours for outpatient service.

Queuing models can be used to determine the operating performance of a waiting-line system. In the economic analysis of waiting lines, we seek to use the information provided by the queuing model to develop a cost model for the waiting line under study. Then we can use the model to help the hospital management to make a trade-off between the increased costs of providing better service and the decreased waiting time costs of patients derived from providing that service.

To determine the level of service that minimizes the total cost of the expected cost of service and the expected cost of waiting, we utilize the cost analyzing model. In cost model, we will consider the cost of patient time, both waiting time and servicing time, and the cost of operating the system. Let Cw = the waiting cost per unit per patient and Cs = Cost of providing service per doctors per unit of time. Therefore, the total cost per minute is Total cost = Cw*Ls +Cs*C where L is the average number of patients in the system and C is the number of servers/ doctors.

Results

Table 2 summarizes the cost for the single and multiple-server. For better graphical representations of the above summarized table, **Figures 3-8** are shown. In **Figure 3** we depict the average server utilization in the system against the number of doctors. As observed, server utilization rate decreases with increasing number of doctors. It is also noted in **Figure 4** that the probability that there are zero patients rise upward as number of doctors increase and the expected length of the queue (*Lq*) and the system (*Ls*) in **Figure 5** decline and rise upward respectively. Also the expected waiting time in the queue (*Wq*) and the expected time in the system (*Ws*) decrease. **Figure 6-8** shows that the expected total cost and service cost fall downward and then rise upward. However, from the figures it is evident that the patients waiting time is optimum when the server is 4 as compared to server 2 and 3. It is also noted that patient's congestion and expected wait time is less than the optimum level.

Discussion:

Table 2 shows that a 4-server system is better than a single server, 2-server or 3-server system in terms of the performance criteria used. For instance, in terms of cost considerations, a 4-server system records the lowest cost of **449.4747** compared to a 2-server and 3-server system that records 520.3903 and 489.4848 respectively. These costs included the entire cost done by the hospital. The average time a patient spends in the system and in the queue are 7.2 minutes and 0.004 minutes respectively for a 4-server system. The probabilities of idleness are 30.0% and 20.0% respectively for 2 and 3 server systems respectively. The average time a patient spends in the queue and in the system for a single server system is 0.3 minutes and -1.5 minutes respectively while the system has 4.5 and –0.5 patients in the queue and in the system respectively. The system is likely to be idle for - 0.4 minutes.

In a survey[8] comparing the performance of a single channel with multi-channel queuing models in achieving cost reduction and patient satisfaction using a hospital Case Study, it was concluded that the 3-server system is better than a single server, 2-server or 4-server system. The average time a patient spends in the system and in the queue are 11 minutes and 1.79 minute. However, another study[9] revealed a positive correlation between arrival rates of customers and bank's service rates where it was concluded that the potential utilization of the banks service facility was 3.18% efficient and idle 68.2% of the time. A One week survey[10] revealed that 59.2% of the

390 persons making withdrawals from their accounts spent between 30 to 60 minutes while 7% spent between 90 and 120 minutes. Further it was observed in another survey[11] that although the mean time spent was 53 minutes by customers, they prefer to spend a maximum of 20 minutes only. Their study revealed worse service delays in urban centre's (average of 64.32 minutes) compared to (average of 22.2 minutes) in rural areas. Moreover those customers spend between 55.27 to 64.56 minutes making withdrawal from their accounts.[12] Efforts in this study are directed towards application of queuing models in capacity planning to reduce patient waiting time and total operating costs.

Conclusion:

The results of the analysis showed that that as the service capacity level of doctors at the hospital increases from three to four servers then minimum total costs (include waiting and service costs) and the waiting time of patients as well as overutilization of doctors can be reduced. The study also suggests that, to optimize the processing time for the patients it is necessary to rationalize the utilization of the servers for effective utilization of human resource. Otherwise, the service units may be increased to four to achieve better results at a lower cost as against two or three service units. A single server is not effective as much as compared to multiple servers. Whereas, five servers eliminates waiting cost but at a higher cost which is not optimal too.

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Table 1: Formula for computing performance measures of queuing system

Performance Measures	**Single server (M/M/1)**	**Multiple Server (M/M/c)**
Average server utilization in the system (ρ)	$\frac{\lambda}{\mu}$	$\frac{\lambda}{c\mu}$
Probability that there are no patient in the system i.e. the servers are idle (Po)	$\frac{1-\lambda}{\mu}$	$\left[\sum_{k=0}^{c-1}\frac{(\lambda/\mu)^k}{k!}+\frac{(\lambda/\mu)^c c\mu}{c!\,(c\mu-\lambda)}\right]^{-1}$
Average of number of patients in the system(Ls)	$\frac{\lambda}{\lambda-\mu}$	$L_q+\frac{\lambda}{\mu}$
Average time a patient spends in the system (Ws)	$\frac{1}{\lambda-\mu}$	$\frac{L_s}{\lambda}$
Average of number of patients in the queue(Lq)	$\frac{\lambda^2}{\mu-\lambda}$	$\frac{(\lambda/\mu)^c\lambda\mu}{(c-1)!\,(c\mu-\lambda)^2}$
Average time a patient spends in the queue (Wq)	$\frac{\lambda}{\mu(\mu-\lambda)}$	$\frac{L_q}{\lambda}$

Table 2: Performance measures of the single and multiple servers in outpatient department

Server	Average server utilization in the system (ρ)	Probability that there are no patient in the system i.e. the servers are idle (Po)	Average of number of patients in the system(Ls)	Average time a patient spends in the system (Ws)	Average of number of patients in the queue(Lq)	Average time a patient spends in the queue (Wq)	Expected Total Cost Per hour
1	60.0%	-0.4	-1.5	-0.5	4.5	0.3	-
2	30.0%	0.42042	0.64633	0.21544	0.04633	0.01544	860
3	20.0%	0.70175	0.60789	0.20263	0.00789	0.00263	520.3903
4	**15.0%**	**0.98124**	**0.60110**	**0.20037**	**0.00110**	**0.00037**	**449.4747**
5	12.0%	1.26002	0.60013	0.20004	0.00013	0.00004	489.4848
6	10.0%	1.53846	0.60001	0.20000	0.00001	0.00000	667.0913
7	8.6%	1.81671	0.60000	0.20000	0.00000	0.00000	1138.705

Figure 1: Single-server queuing model

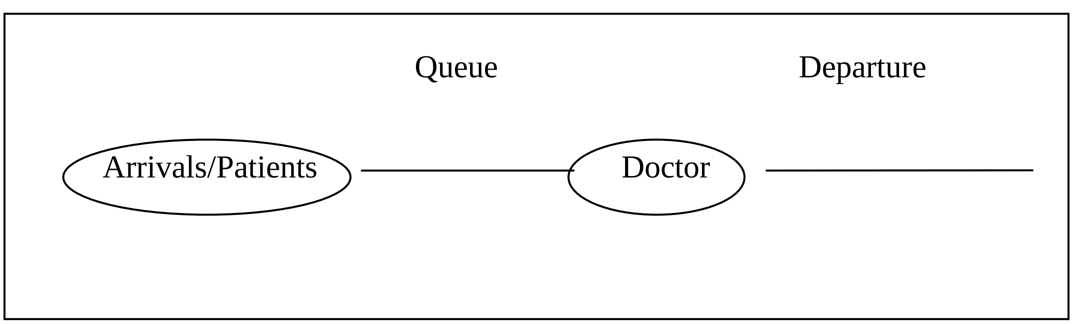

Figure 2: Multiple-server queuing model

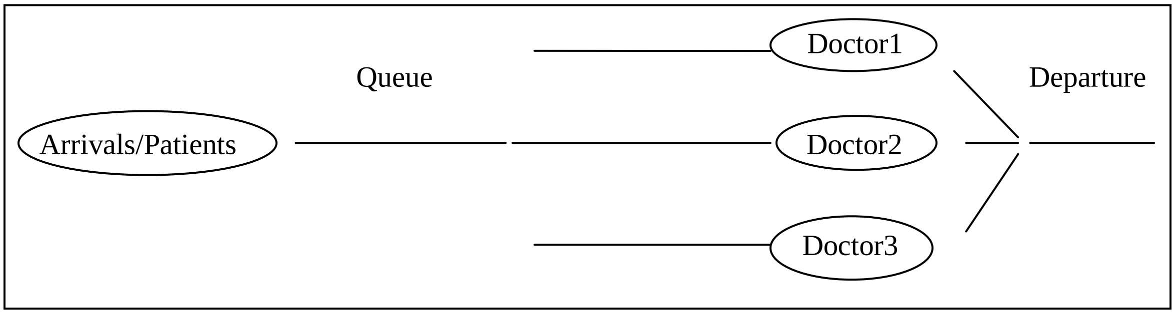

Figure 3: Utilization rate against number of server/doctors

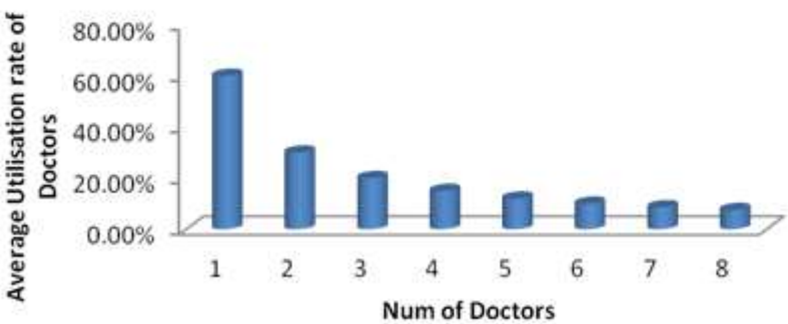

Figure 4: Probability of number of patient in the system against number of server/doctors

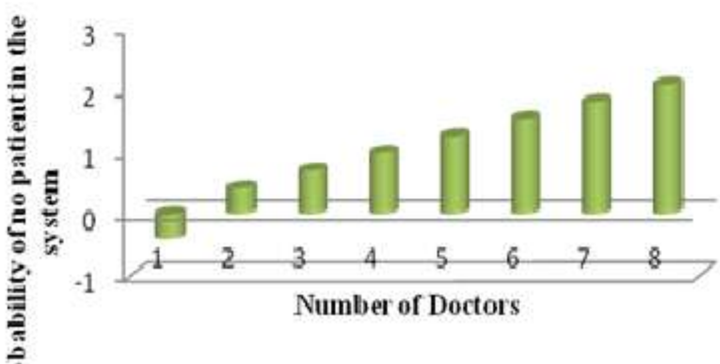

Figure 5: Average number of patients in the system and queue

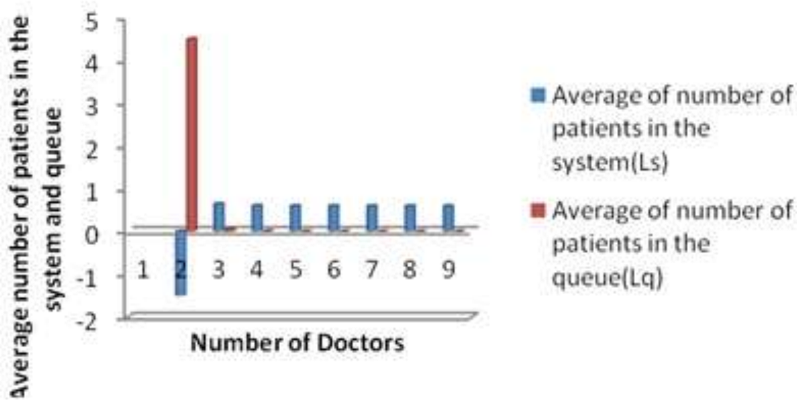

Figure 6: Average service cost against number of server/doctors

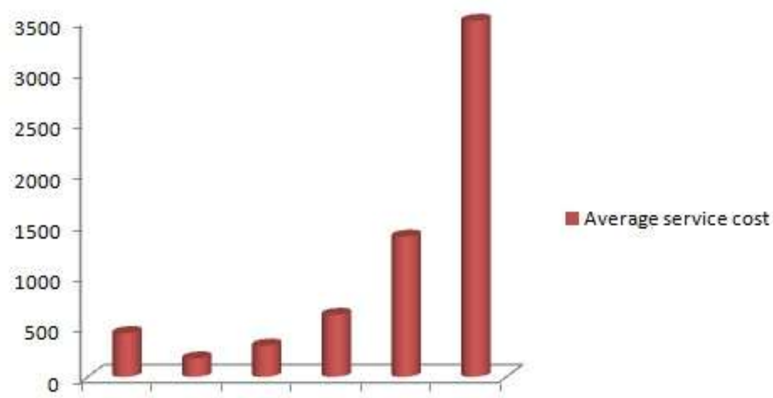

Figure 7: Average total cost and service cost against number of server/doctors

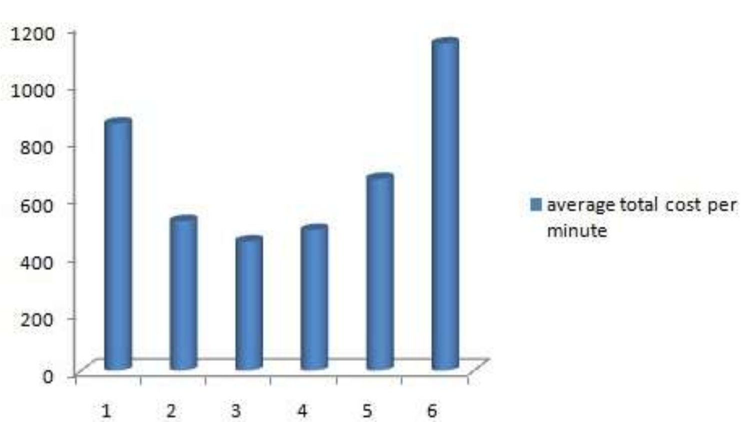

Figure 8.average total and service cost.