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Research Article
Analysis of Service Delivery System Using Markov Chain Approach and M/G/1 Queuing Systems

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Abstract
Service delivery systems, such as restaurant, emergency department and airport checking terminals are faced with the tough task of processing an increasing demand of customers. At the same time, customers have to decide finally either to accept or reject. However, the customer can order to reprocess the service before making the final decision. Single-server, such as M/G/1 system is simple and can be utilized as preliminary models. Modeling of the systems state using Markov chain approach and queuing models provides a more rigid approach to better understand the dynamics of the service delivery system. Therefore, this study proposes a conceptual model using of Markov chain approach combined with M/G/1 queuing model to optimize general service delivery systems. To illustrate the model, a numerical example is introduced and solved and the optimum system's parameters are determined. The obtained results showed a high sensitivity of net profit to the mean variation, service and arrival rates while the effect of other parameters is not high.

Key words: Markov chains modeling, service delivery systems, single-server systems, queuing models

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INTRODUCTION

The queuing theory is an essential mathematical study in which waiting time and cost can be optimized using applied probability theory. It is used frequently to maximize the net profit of the business. Furthermore, it deals with service delivery systems providing information about service waiting time, number of service in the queue and server utilization. Service delivery systems are major interest for industrial engineers. Furthermore, this area has been investigated over the years by a large number of researchers focusing on modeling, optimization and operations research (Hamasha *et al*., 2013). Although the services can vary (e.g., food, heathcare, etc.), the researchers aim directly or indirectly to the same thing which is optimizing their business and their net profit. Generally, the net profit can be improved by optimizing various service parameters, such as service quality, customer satisfaction, customer waiting time and queuing length. Many researchers stated at least one parameter in their study. For example, Yan and Pei (2009) developed a model for retail services, strategic role in a dual-channel competitive market; Gunay and Yolum (2010) used the service discovery approach based on service matchmaking and they represent a mechanism of mapping appropriate services to customer requests; Yee *et al*. (2011) studied the relationships among worker/employee attributes operational performance and Meepadung *et al*. (2009) investigated the impact of IT-based retail banking services on the efficiency and they found that IT-based transactions at the branch level have significant impact on profit efficiency.

However, service delivery systems encounter with many challenges. It is very difficult to determining the appropriate level of different parameters to optimize the business. Furthermore, the service parameters should be determined based on its impacts on several associated cost, such as processing, rejection and reprocessing of the service. The second challenge is that the parameters are not necessarily to be constant values, mainly because the demand is always not constant. The third challenge is that the service processing time is usually difficult to predict and the customer satisfaction is difficult to predict as well. The satisfaction with the service solely depends on the customer and his thought. If the service does not meet the customer satisfaction, they may reject or request a reprocessing of the service which could increase the cost. Indeed, service reprocessing could lead to increase in the wait time and require additional resources and then reduce the overall net profit.

Service delivery is the fastest growing industry in the word with a high employment rate of 83% while the employment rate for manufacturing industry is only 10% (Karacapilidis *et al*., 2006). Examples of services delivery systems with a high growing rate include insurance companies (Moshirian, 1999), banks (Meepadung *et al*., 2009), healthcare (Farmer *et al*., 2010; Skordis-Worrall *et al*., 2010; Ngo and Hill, 2011; Neuman *et al*., 2010), transportation (Karacapilidis *et al*., 2006; Neutens *et al*., 2011) and food service (Voordouw *et al*., 2012; Shokri *et al*., 2010; Ha and Jang, 2010; Zarei *et al*., 2011).

Many researchers discussed the service delivery systems from different aspect. For example, Marianov and Serra (2002) studied the quality of service and observed the importance of the quality on customer's perceptions. Pullman and Moore (1999) stated that the capacity utilization is an important factor in the service delivery systems. Appropriate demand to capacity ratio is critical since increasing of this ratio may have negative impacts, such as increasing in waiting time, waiting queue and customer leave. Therefore, determining the optimal service rates (parameters) is critical to maximize the profit. The combination of Markov chain and queuing models have been used in various research such as (Bhaskar and Lallement, 2009; Pillai and Chandrasekharan, 2008; Bhaskar and Lallement, 2011). Furthermore, stochastic queuing have been used in optimizing the pricing and the capacity and it used to study the effects of the relationship between waiting times and associated costs (Pullman and Moore, 1999).

Many researchers conducted research on single server and multiple servers systems, such as Barrer (1957). Particularly, he studied the ratio of lost customers to the arrival rate as he was trying to minimize the customer loss. Takacs (1968) studied the average waiting times for customers in two queues serviced by a single server. An extension of Tackacs work was later carried out by Eisenberg (1972) who studied the waiting time and inter-visit distribution of multiple queues serviced periodically by a single server in sequence. Hokstad (1979) studied a single server single queuing system in which customers rejected service when waiting and service times were beyond a threshold. Hitchcock (1997) investigated a single server system with two distinct priorities (two queues) where the customers from that high priority queue are served when one queue is longer than the other. Other methods were used to solve the critical issues of service delivery systems, such as the simulation and genetic algorithm. For example, simulation was used by Michael and Mariappan (2011) to manage an electricity service, while a genetic algorithm model was introduced by Zolfaghari *et al*. (2010) to schedule retail services and another genetic algorithm model was developed by Manimaran *et al*. (2011) to analysis a service network of supply chain. Weber (1978) studied the customer assigning strategy that optimize the capacity of customers who are being served by multiple servers. Taylor and Templeton (1980) presented a multiple server queuing system with low and high priority customers with a threshold service discipline. Their object was to determine the required ambulance fleet capable of serving emergency patients. Whitt (1986) studied multi-queue multi-server service delivery systems with unlimited capacity where the customer have to select the desired queue. He provided counter examples of situations where it is not faster to choose the shortest queue. Pekoz (2002) studied waiting time minimization for the priority customers based on a multi-server queuing system with high and low priority customers.

Bowling *et al.* (2004) used Markovchain approach to study the optimal process mean for multi-stage production systems. Ray and Jewkes (2004) introduced a model to study the effects of demand and price in service delivery systems. The authors observed that a longer delivery time leads to a lower price. The reason of this reduction is possibly the leave of customer or the rejection of the service after a long waiting time. Cachon and Zhang (2006) considered a model with two servers where the demand allocation was distributed according to their performance. They claimed that this model can enhance the ability to utilize capacities of servers and then increase throughput.

Pillai and Chandrasekharan (2008) proved that Markov chain have been applied extensively in manufacturing. The Markov chain has been extensively presented as a best approach to model the non-deterministic cases (Pillai and Chandrasekharan, 2008). Pillai and Chandrasekharan (2008) discussed material flow of production systems at absorbing state of Markov chain characterized by the uncertainty of scrapping and reworking tasks. According to the fact that the arrival and service rates are usually exponentially distributed, a service delivery system can be handled using a combination of a Markovian approach and queuing theory.

The motivation for this study was brought about based on the research by Hamasha *et al.* (2013), wherein the determination of the optimum service delivery system parameters is discussed. This research borrows the basic Markov chain framework along with the integration with an M/G/1 queue instead of M/M/1 and M/M/s. The delivered service in this model can be accepted, accepted after reprocessing or rejected. In this study, the effects of the customers waiting time in queue is considered as a parameter increases the associated costs. The customer waiting time is a significant variable that impacts the actual system throughout and the total net profit.

PROPOSED MODEL

This section discusses the proposed service delivery model structure which includes Markov chain combined with M/G/1 queuing theory.

Notations: The following notations were used in the development of the proposed model:

P_{ij}	:	Transition probability from state (i) to state (j)
Nps	:	Net profit per hour
SP	:	Service price
PC	:	Processing cost per service
RJC	:	Rejection cost per service
RC	:	Reprocessing cost per service
μ	:	Service rate per server per hour
λ	:	Arrival rate
L_Q	:	Average number of customers waiting in the queue
W_Q	:	Average waiting time in the queue
QC	:	Queuing cost per customer per hour
A	:	Identity matrix for an absorbing Markov chain
O	:	Zeros matrix for an absorbing Markov chain
R	:	A matrix that includes all probabilities of transferring from any recurrent state to an absorbing state
Q	:	A square matrix that includes all probabilities of a state staying within the recurrent state (s)
M	:	Fundamental matrix which refers to the average number of transitions within the recurrent state(s) before absorption in any of the absorbing states
I	:	Identity matrix with the same order as Q
m_{11}	:	Expected number of transitions within the recurrent state (s) before absorption
F	:	Absorption probability matrix: long run probabilities of transition from any recurrent state to any absorbing state
f_{ij}	:	Steady state probability of transition from non-absorbing state to absorbing state
σ^2	:	Variance of service time

Service delivery modeling: Assume a situation where a customer can accept, reject, or request reprocessing of the service in the system of service delivery (e.g., restaurant). Once the service is accepted, customer make payment. Figure 1 demonstrates the three potential choices that can be taken by customers. The processing of the service depends on the customers' acceptance the service provided. In contrast, the act of reprocessing the service is due to happens when

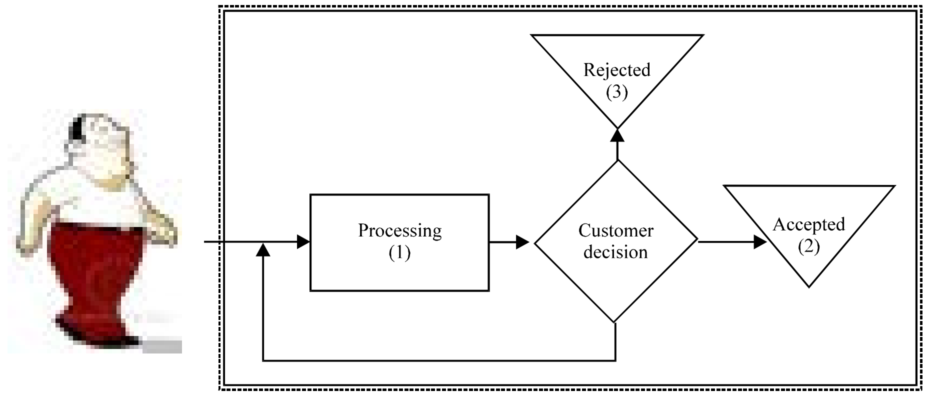

Fig. 1: A representation of a service delivery system and its possible states (Hamasha *et al*., 2013)

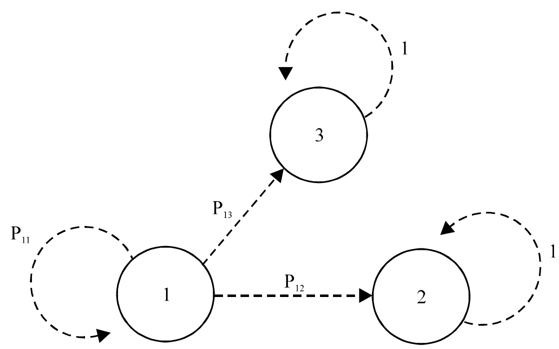

Fig. 2: Transition diagram

customers are displeased by the service delivered. A relevant portrayal of services offered can be spotlighted by examining an electronics products or devices store (e.g., Radio Shack) customers' consideration to change or add value to the service delivered.

Such as, Radio Shack customers who walk in to buy an electronic device like a cellular phone. After many investigations about the cellular phone's specifications and price, the customer may choose to accept or decline the device. In the case a customer buy a cellular phone and based on their utility level with its performance in use, he or she may decide to reprocess the service by demanding to add an extra memory or a software installation. Likewise, customers at a fast food restaurant like Burger King may order an item from the menu with the option to design his or he own meal. At the time of delivering the meal, customers can choose to accept or reject the item based on their own satisfaction. Alternatively, customers may demand a reprocess of the requested meal as appropriate (Hamasha *et al*., 2013):

$$
\begin{array}{cc}
 & \begin{array}{ccc} 1 & 2 & 3 \end{array} \\
P \begin{array}{c} 1 \\ 2 \\ 3 \end{array} & \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
\end{array}
$$

A representation of the system using transition probability matrix is illustrated as following. Figure 2 represents the three states of the service being processed, accepted or rejected, respectively. The transition probability matrix shown above demonstrates an absorbing Markov chain with State 1 being a temporary state; while State 2 and State 3 are in an absorbing state. Explicating this Markov chain absorbing states needs the rearrangement of the probability matrix as following:

$$
P = \left[\begin{array}{c|c} A & 0 \\ \hline R & Q \end{array}\right] = \left[\begin{array}{cc|c} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \hline P_{12} & P_{13} & P_{11} \end{array}\right]
$$

where, the probability of accepting a service is P_{12} or rejecting a service is P_{13} and the probability of reprocessing the service is P_{11}. From the matrix above, a fundamental matrix (M) can be derived as follows:

$$M = (I - Q)^{-1} = M_{11} = \frac{1}{1 - p_{11}}$$

'I' represents the identity matrix and 'Q' represents the transient probabilities matrix is Q. The value of m_{11} is equal to the expected number of times that transient State 1 is engaged before the absorption in either State 2 or 3. In this way, it reveal the number of times the service is being processed prior to any decision made by customers on accepting or rejecting the service. In the long-run absorption probability matrix, F, can be defined as following:

$$F = M \times R = \left[\frac{p_{12}}{1 - p_{11}} \quad \frac{p_{13}}{1 - p_{11}} \right]$$

In this case, the F matrix includes:

$$f_{12} \left(\text{i.e.,} \frac{p_{12}}{1 - p_{11}} \right)$$

and:

$$f_{13} \left(\text{i.e.,} \frac{p_{13}}{1 - p_{11}} \right)$$

in the long run, f_{12} is the probability of service accepted while f_{13} is the probability of the rejection of service. The service with the probability of either being accepted or rejected in one cycle can be represented by the equation (1-P_{11}). Hence, the number of cycles of processing a service before it being accepted or rejected is:

$$\left(\frac{1}{1 - P_{11}} \right)$$

Then the representation of the net profit can be defined as follows:

Net profit = E (selling price-processing cost-rejection cost-reprocessing cost-queuing cost)

where, E represents an expected value:

$$\text{Selling price per service} = SP \times \left(\frac{P_{12}}{1 - p_{11}} \right)$$

which is the selling price per service multiplied by the probability of service acceptance:

$$\text{Processing cost per service} = PC$$

$$\text{Rejection cost per service} = RJC \times \left(\frac{P_{13}}{1 - P_{11}} \right)$$

which is the rejection cost per service multiplied by the probability of service rejection:

$$\text{Repocessing cost per service} = RC \times \left(\frac{1}{1 - P_{11}} - 1 \right)$$

which is the reprocessing cost per service multiplied by the probability of service reprocessing and queuing cost is the cost that will be added to cover any additional services for customers waiting in queue.

When the server is busy and it doesn't charge money for waiting, the net profit is then multiplied by the service rate (μ) and is expressed by the following equation:

$$NP = \left[SP \left(1 - \frac{P_{13}}{1 - P_{11}}\right) - PC - RJC \left(\frac{P_{13}}{1 - P_{11}}\right) - RC \left(\frac{1}{1 - P_{11}} - 1\right) \right] \mu \quad (1)$$

This study main focus is to maximize the net profit by evaluating the different system parameters which are the selling price, reprocessing cost, arrival rate and service rate for the single queue single server service delivery systems as mentioned previously.

The model is composed of one customer being serviced while others wait in the queue, as illustrated in Fig. 3.

Examining the service delivery system, supplementary assumptions are needed as follows:

- Arrival and service distributions are both Markovian
- Service times have a general distribution
- There are no restrictions on the system capacity or the number of customers (i.e., demand) and
- The service rate (μ) is greater than the arrival rate (λ)

Referring to the abovementioned assumptions, the queuing system follows an M/G/1 model. Taking into account

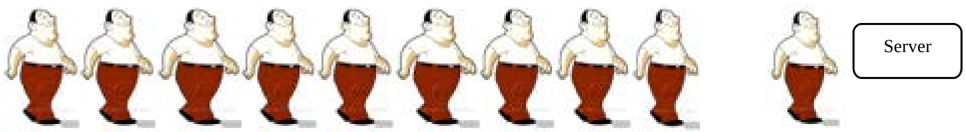

Fig. 3: Illustration of the SQSS delivery system

only the portion of time that the system is busy, Eq. 1 is multiplied by λ/μ. Accounting for the queuing cost, the net profit is represented after subtracting $L_Q W_Q QC$ as follows:

$$NP_S = \left[SP\,(1 - \frac{P_{13}}{1-P_{11}}) - PC - RJC\,(\frac{P_{13}}{1-P_{11}}) - RC\,(\frac{1}{1-P_{11}} - 1) \right] \mu \times \frac{\lambda}{\mu} - L_Q W_Q QC \quad (2)$$

Where:

$$L_Q = \frac{\lambda^2 \sigma^2 + \frac{\lambda^2}{\mu^2}}{2(1 - \frac{\lambda}{\mu})}$$

is the average number of customers in queue and

$$W_Q = \frac{L_Q}{\lambda}$$

is the average customer waiting time in queue.

Therefore, substituting the values of L_Q and W_Q results in the following equation for the net profit for the service delivery system:

$$NP_S = \left[SP\,(1 - \frac{P_{13}}{1-P_{11}}) - PC - RJC\,(\frac{P_{13}}{1-P_{11}}) - RC\,(\frac{1}{1-P_{11}} - 1) \right] \lambda - \frac{(\lambda^2 \sigma^2 + \frac{\lambda^2}{\mu^2})^2\, QC}{4\lambda (1 - \frac{\lambda}{\mu})^2} \quad (3)$$

RESULTS

Numerical example: For a clear illustration of a proposed models, this section demonstrates the obtained results of the numerical examples for the model in which the values of the net profit maximization system parameters are obtained. The inclusion of queuing cost should be well noted for providing a method to apply penalties on the service delivery system due to an excess of number of customers waiting in the system. Moreover, a service delivery facility is considered with the parameters as follows: ($P_{12} = 0.97$, $P_{13} = 0.02$, $P_{11} = 0.01$) signifying the probabilities for service acceptance, rejection and reprocessing; (SP = \$1000, PC = \$200, RJC = \$80, RC = \$50, QC = \$120, σ = 0.1) symbolizing the Service Price (SP), Processing Cost (PC), Rejecting Cost (RJC), Reprocessing Cost (RP), Queuing Cost per customer per hour (QC) and Variance of service time. The following parameters are used: service rate (μ) is 5 customers per hour while the arrival rate (λ) is 4 customers per hour. The resulting Net Profit (NPs) was determined to be \$2,170. The following sections represent a further investigation on the optimization of the system parameters to understand how they impact the performance of the service delivery systems.

Parameters optimization: Increasing the profit is the main goal of all businesses as well as assuring high quality of service and customer satisfaction; eventually it is a very challenging task to simultaneously control associated costs. As a result, operation managers use a model provided to service systems or facilities as a making tool that permits optimization of different parameters to increase overall net profit of the business. The various parameters were optimized by varying one parameters at a time. The provided illustrations were conducted to recognize its impact on the net profit. In Fig. 4, the relationship between NPs and the probability of service being reprocessed is defined as (P_{11}) or rejected as (P_{13}). As illustrated, an increase in P_{13} yields in a linear decline in NPs until a P_{13} value around 0.65 which afterwards NPs turn to negative. Initially for P_{11}, a slow decline in NPs is observed and a faster decline happens for P_{13} values above 0.6.

Furthermore, Fig. 5 demonstrates the impact of the service price and the cost parameters on the net profit. As P_{11} increases the customer's waiting time for service increases, therefore, increasing Queuing Cost (QC). More to this, once the arrival rate approaches the service rate, a reduced speed (by increasing the probability of reprocessing) in the service process will result to an increase in the customer's waiting time in the queue. Eventually, an increase in NPs is achieved by an increase in SP and a decline in NPs is observed by an increase in PC, QC and RJC.

Additionally, any changes in λ and μ showed a huge impact on the net profit, as demonstrated in Fig. 6 and 7, respectively. The increase in λ results in a rapid increase in the net profit as long as $\lambda << \mu$, mainly because the availability of the system's resources are high, therefore permitting a new

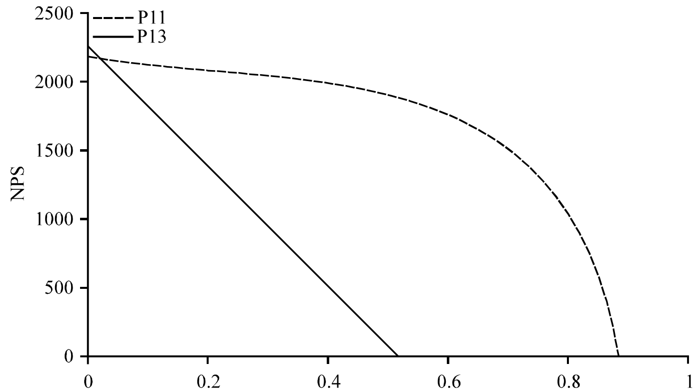

Fig. 4: Effect of rejection and reprocessing probabilities on the net profit

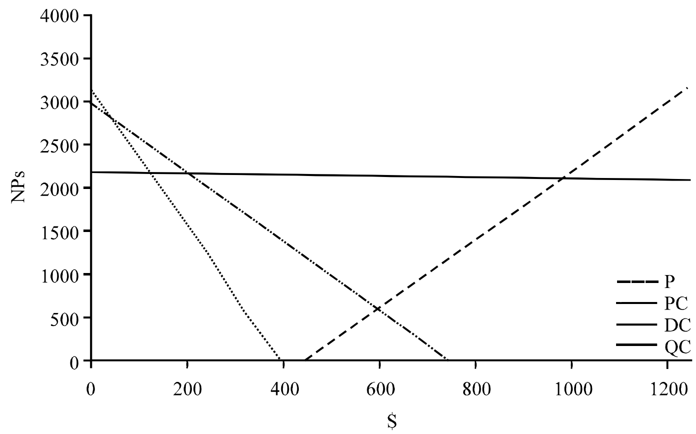

Fig. 5: Effect of service price, processing, rejection and queuing costs on the net profit

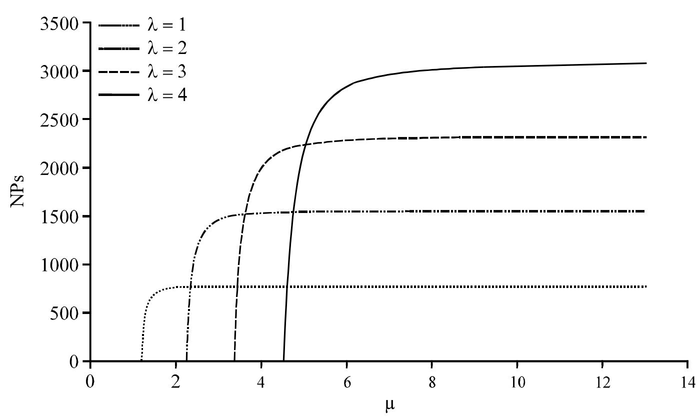

Fig. 6: Effect of service rate on the net profit

customer to rapidly enter a system and receive service whereas reducing queuing cost to a minimum. On the other hand, when λ approaches μ, any increase in λ leads to adding more customers to the queue resulting in a major increase in the QC which explains the quick decline instantly after an optimum λ value (λ*), shown in Fig. 7. Likewise, an increase in μ reduces W_Q and L_Q by serving additional customers, thus increasing the net profit, particularly when λ is close to μ. Yet,

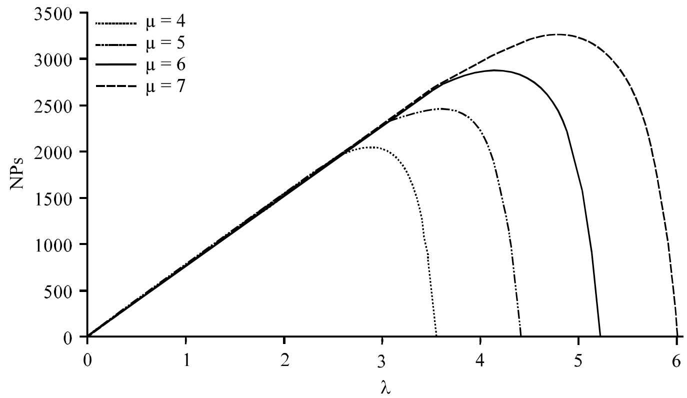

Fig. 7: Effect of arrival rate on the net profit

increasing μ when λ<<μ will have no effect on the net profit or the total queuing cost, especially because the system is nearly empty due to the low arrival rate. At last, increasing λ and μ at the same time will increase the net profit because additional customers can be served.

DISCUSSION

In this section based on the results obtained, some general conclusions can be drawn based on the numerical example considered. The uncertainty of the various cost parameters seems to have major effects on the net profit generally. For instance, as predicted, the net profit declined with an incline in processing, rejection and queuing costs. However, the net profit increased due to an increase in the selling price. Equally, the increase in the probability of rejection leads to linear decline in the net profit while an increase in the probability of reprocessing results in a concave decline in the net profit. Moreover, the results examined found that better emphasis needs to be placed on the service and arrival rates due to the sensitivity of the variations in net profit due to these parameters. With the increase in service rate, the net profit sharply increases until the optimal level is obtained; afterwards, it gradually decline and stabilizes at a certain level. In contrast, the net profit gradually increases with the increase in the arrival rate parameter until the optimal net profit is obtained in which it sharply declines afterwards. The closer research to this paper is (Hamasha *et al*., 2013). Although their system is different, the results are close to this research. They found that the net profit increases with the price and decreases with the different type of cost, including queuing, rejection and reprocessing costs. However, our system look more sensitive to the arrival and departure rates. Further, most researcher reported that the profit is a function of different type of cost. The benefit of this research that it shows the shape of relationship between the arrival and departure rates with the net profit.

To reduce waiting time and remove any bottlenecks, it is important to consider performance efficiency in service delivery systems which as a matter fact provides available customers with timely access to service. For that reason, service providers must examine their current capacity and service levels to guarantee optimal customer slow, reduced lost opportunities and reduced waiting cost. In the results achieved, the model showed that the net profit is dependent on variations in arrival and service parameters. These can call attention to the need for management of service delivery systems to assure that intended decisions on the optimal service rate parameter are critical to obtain a maximization of profit. Additionally, timely delivery and appropriate service packaging is essential to assure that customer's demands are met to reduce any chances of rejection or reprocessing of the service which may in turn minimize overall operating costs of the service delivery system.

In this field, future work includes an advanced exploration of the impact of lost opportunity due to customers drawing out of the system, where additional cost can be applied to the service delivery system, similar customers leaving the system after their waiting time in a queue exceeds a predetermined level. Such as, in emergency rooms, customers often leave the system often after waiting for a long time and are classified as "Leave Without Being Seen" (LWBS) patients.

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