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Wait Time Analysis to Optimize Number of Opened Counters

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ABSTRACT

The Morning Shift (MS) flow of passengers on Thursday is similar to any other day in the week at an urban train station. However, passenger congestion occurring in the Evening Shift (ES) affects the system behaviour. The system has been showing this characteristic over the years. However, only one counter is opened. This counter also sells different types of tickets. Thus, the system is not cost-effective. The study aims to determine the optimal number of counters that should be opened on Thursday. In order to solve this problem, the study has applied Poisson Queuing Simulation (PQ) to the MS and ES data. Findings indicate that running one or two counters in MS maintains the mean of wait time in-queue and in-system at less than one minute, while the mean of in-queue and in-system passengers is also at one person. Extra cost has to be incurred to hire another teller; thus, one counter is optimal. For ES, the service rate was only slightly higher than the arrival rate. Based on the mean number of in-queue and in-system passengers, there was no way that one counter can efficiently service the queue that was formed. A simulation was done to determine if there was a need to set up a two-counter or a three-counter system. Although a two-counter system will be idle 47% of the time, it was not cost-effective for the management to two extra tellers for a three-counter system. The management must take future corrective measures. Based on the findings, one counter is optimal for MS, but cost-effectiveness tests must confirm that two counters are optimal for ES. Besides, the management should also identify actions that can be taken during the 47% idle system time in ES.

Keywords: *minimum time; optimization; performance measures; Poisson; simulation.*

1. INTRODUCTION

What is a sustainable transport? Sustainable transport provides mobility for people in urban areas and gives them the freedom to go anywhere at any time. It is defined as a system that ensures stability to the future generation. It safeguards consistent and basic individual and societal needs in line with human and ecosystem health. It offers efficient and affordable services. It also manages emissions and global waste [1, 2]. Any reduction in time-cost of travel can lead to an increase in demand for travel [2]. Thus, the management needs to be alert in making possible changes to cater to future congestion issues.

One of the most preferred public transports is train. Travelling by train is fast, easy, and cost-effective. A train has seats that are less cramped than in plane cabins. They are usually comfier; more importantly, the passengers can enjoy the scenic views along the way [3].Delays in journeys are almost always associated with time schedules [4-6], maintenance issues [7, 8], in-

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service failures [9] and many more. Inefficient ticket counter services also cause delays. In an inefficient system, a person waits in line for a longer time than necessary. The current study was carried out to model the wait time problem at an urban area train station in Alor Setar, Kedah, a state of the northern peninsular of Malaysia. The wait time problem here has been left unremedied for very long time. By quantifying the counter services' capability, the study aims to determine whether an optimal number of opened counters was operating at the train station.

When a person sets out to travel, he plans ahead of of his time schedule for every trip segment. Missing a train is not part of the plan. Assuming the train is not delayed, he must be assured that he will experience an optimal waiting in-queue time at the ticket counter. Based on researchers' observation, wait time took place when only one opened counter was set up to cater to passengers' overflowing volume. In an addition to the misery, this opened counter also sold different types of tickets. In an attempt to solve this wait time problem, Poisson Queuing Simulation Model (PQ) was used to determine the optimal number of opened counters and the optimal ticket-buying time. However, this article only focuses on the first objective.

2. LITERATURE REVIEW

Waiting is part of everyone's daily life. It takes place in many everyday activities. For example, a person waits to shop for groceries, buy petrol, deposit money at the bank, and purchase a flight ticket.

Queues form in a machine-repair system and a truck-loading queue management system. Congestion also forms when planes await to take-off from a runway; information waits to get through saturated communication networks; manufacturing processes wait to resume work caused by scarce supplies; and services are delayed when they do not comply to schedules and many more [10].

A low-level service can be cost-effective in the short run. However, a system that continuously provides low-level services may suffer high costs in customer discontent and displeasure in the long run. Although a high-level service is more expensive, it helps to lower the chances of customer dissatisfaction. Therefore, any management must determine the optimal level of service to provide at any particular time in a queuing system.

Waiting occurs when a system is not fully equipped and provides low-quality services[11]. Waiting denotes inefficiency. Reducing waiting time may help increase customer satisfaction. Waiting also causes the system to incur high costs. Inefficiency can be corrected, and excessive expenses can be reduced. Nevertheless, waiting cannot be eliminated [12].

How to best manage queues is not a new problem. It has been the focus of previous and present academic and practical research works. Queues affect service quality provided by a system under a variety of conditions. They must be effectively designed and managed. In the current study, only one counter is operating in the system. This system can be considered as a single server infinite length queuing model with the infinite population. The arrivals (λ) and the rate of service (μ) are assumed to follow a Poisson distribution and an exponential distribution, respectively. A system is defined as efficient if the ratio $\left(\frac{\lambda}{\mu}\right) < 1$. Otherwise, it is inefficient with increasing queue length [13].

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A service-related system emphasizes on wait time reduction to improve customer satisfaction. PQ predicts the characteristics of a queue by using the quantitative analysis technique. It is also a simulation model that can measure a system’s performance under various conditions. To find an optimized feasible solution for this study, simulations were carried out to analyze and compare system's performance with one, two or three operating counters. Hence, efficiency and effectiveness can be defined for the system.

How a queuing system operates efficiently and effectively can be determined by a queuing model. A queuing model analyses a queuing system and observes its behaviour. It can optimize service levels, albeit lengthy operating time. Lengthy operating time can be caused by external factors like misunderstanding between staff and customer [14], insufficient staffing issue [15, 16], and many more.

Queuing models have been used to model situations in healthcare facilities [17, 18]. The cited situations in healthcare facilities include evaluating bed assignment policies, improving customer satisfaction in pharmacy applications, and determining the number of operating servers at a healthcare facility.

Queuing models have also solved scarce resource problems at intensive units in busy hospitals [19] and inefficient deployment issues related to private ambulance services[20]. Use of the queuing models also includes measuring the service quality delivered in cloud platforms[21] and evaluating performances in blockchain-based systems[22].

Queuing analysis is carried out to offer a reasonably satisfactory service to customers. The essential elements of a queuing system is defined by an input and output process, queue discipline and method used by arrivals to join a queue [10, 23].

2.1 Input and Output Process

A queue system can assume one of two things, a) one arrival occur at one given instant, or b) more than one arrival can occur at one time. In a restaurant setting, a) cannot be assumed to take place.

The type of population also shapes the model that it is servicing [10, 12, 23]. The population can be drawn from a finite population or an infinite population. In some situations, the rate at which the customer is entering the queue decreases due to crowdedness. Sometimes the population can also be described by a probability distribution.

2.2 Queue Discipline

A queuing model simulates the behaviours of the situation's behaviours in a waiting line issue and suggests possible optimal solutions to the waiting issues. There is an order in which customers are selected. Some examples of discipline types include First Come First Served (FCFS), Last Come First Served (LCFS) and Service in Random Order (SIRO). Some can also be selected based on priority[12].

Wait time is affected by the design of a queuing system. Customers may balk, renege or jockey from a queue. A reneging phenomenon takes place when a person foregoes the long wait. This phenomenon is very synonymous to the healthcare system[17]. It occurs when the system capacity cannot service the surging demand [17]. Reneging can also occur in other systems like the grocery store queues [24, 25]. Besides reneging, customers can also perform balking (simply does not want to join the queue) and jockeying (moving to another line to reduce wait time) [25, 26].

Wait cost (probability of losing customers due to long wait time) may result from these queue behaviours [27]. During the current study's observation period, none of these behaviours (balk, renege and jockey) took place. Here, the focus is on the waiting issues at the ticket counters operating at urban area train stations. Findings from this case study can be used as a reference for bigger scaled waiting for issues at bigger train stations.

3. METHODOLOGY

This section discusses the properties of the queuing model used in this study according to the current queuing system's attributes and a queue's performance measures.

3.1 Attributes of the Current Queuing System

There is a need to specify the input and output process, queue discipline, and method used by arrivals to join the queue in any queuing system.

3.1.1 Input and Output Process

Raw observation data on passenger queue behaviour were collected at a local train station. Data were collected twice a day for two weeks. The observation time was Morning Shift (MS): 6.00 am to 9.00 am and Evening Shift (ES): 4.00 pm to 6.00 pm. Observations were video-recorded.

3.1.2 Queue Discipline

The queuing theory model's performance measures in this study were computed using QM for Windows version 5.2. Here, the counter queuing network was based on FIFO (First-In, First-Out) method in both MS and ES.

It was observed that only one counter was opened during both observation time. No balking and jockeying took place since no more than one arrival can occur at one instant. To describe the queue in this study, a measure of performance like mean queue length, mean wait time and system utilization indicator were used.

3.1.3 Method Used by Arrivals to Join Queue

This article focuses only on the performance indicators for waiting that occurred on Thursday. Thursday is the last working day of the week in the state to the north of Malaysia. Besides catering for passengers' usual flow, it is also the day when students ride the train home from their hostels.

As stated earlier on, only one counter was opened. One opened counter in MS seemed able to cater for the volume of passengers. However, one opened counter in ES seemed packed with so many passengers. Can this counter efficiently cater to the volume of passengers in MS and ES?

3.2 Performance Measures of a Queue

In 1990, A. K. Erlang introduced the queuing theory. Given the arrival rate (λ) and the service rate (μ), he calculated mean server utilization (ρ), mean number of in-queue customers (L_q), mean number of in-system customers (L_s), mean waiting time of in-queue customers (W_q), and mean waiting time of a customer in the system (W_s) for the multi-server channel single-phase (M/M/s) as follows:

The mean server utilization,

$$\rho = \frac{\lambda}{s\mu} \tag{1}$$

The mean number of in-queue customers,

$$L_q = \frac{\rho\left(\frac{\lambda}{\mu}\right)^s}{s!\,(1-\rho)^2} \tag{2}$$

Little's formula relates L_s to W_s (and relates L_q to W_q) in the following manner[12]:

$$L_s = \lambda W_s \tag{3}$$

$$L_q = \lambda W_q \tag{4}$$

From Eqn (4), the mean wait time of in-queue customers,

$$W_q = \frac{L_q}{\lambda} \tag{5}$$

and the mean wait time of in-system customers,

$$W_s = \frac{L_s}{\lambda} \tag{6}$$

By defining mean service time as $\frac{1}{\mu}$, the direct relation between W_s and W_q can be written as:

$$W_s = W_q + \frac{1}{\mu} \tag{7}$$

By multiplying λ on both sides of Eqn (7),

$$L_s = L_q + \frac{\lambda}{\mu} \tag{8}$$

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Here, $\frac{\lambda}{\mu}$ defines the mean number of busy servers, $\bar{c}$ [12].

4. RESULTS AND DISCUSSION

4.1 Performance Measures for one opened counter

Table 1 displays the performance measures for services with only one open counter.

Table 1: Performance Measures for One Opened Counter

Variable	**MS**	**ES**
Arrival rate $(\boldsymbol{\lambda})$	1.043	2.273
Services rate $(\boldsymbol{\mu})$	2.141	2.460
Mean number of in-queue passengers $(\boldsymbol{L_q})$	0.463	11.23
Mean number of in-system passengers $(\boldsymbol{L_s})$	0.95	12.16
Mean wait time (in minutes) of in-queue passengers $(\boldsymbol{W_q})$	0.05	1.4941
Mean wait time (in minutes) of in-system passengers $(\boldsymbol{W_s})$	0.091	5.3476
Utilization indicator of system $(\boldsymbol{\rho})$	51%	7.6%

For the MS, $\lambda = 1.043$ customers per minute is smaller than $\mu = 2.141$ customers per minute. Moreover, the results show that $L_q = 0.463$ (less than one person) and $(L_s) = 0.95$ (less than one person). Thus, MS system was servicing constant customer arrivals with no surge in demand.

Like MS, ES also witnesses $\lambda = 2.273$ customers per minute is smaller (although not distinct) than $\mu = 2.460$ customers per minute. Thus, no queue was formed, and the system was able to meet the demand. However, the mean number of in-queue ES passengers (11.23) is not differentiated from the mean number of in-line ES passengers (12.16). Therefore, the system's behavior could be attributed to an influx of passengers, low server efficiency (here, utilization indicator = 7.6%), and insufficient system capacity [28].

Passengers often associate long wait time to poor quality service [25]. To avoid this stigmatic perception, the management should vary the demand pattern. The management can offer discounts. Other enhancements may include offering better services during a less hectic day or week schedules. Under certain circumstances, there is a need for the management to investigate if the proficiency of the counter employee is causing the problem.

The current study did not consider queue behaviors like reneging, balking or jockeying. As stated earlier on, there was only one operating counter at the train station. In the following sub-section, this study attempts to determine if adding more counters would be an excellent management decision in this situation.

4.2 Optimal Number of Servers

The previous section has shown that there were passengers to be served in the queue and ES system. This study simulated the system behavior and varied the number of counters to determine the optimal number of opened counters to increase service efficiency.

Table 2 provides the mean wait time, queue length and utilization indicator for one-counter and two-counter systems.

Table 2: Performance Measures for One-Counter and Two-Counter Systems

Variable	**System**			
	One-Counter		**Two-Counter**	
	MS	**ES**	**MS**	**ES**
Mean number of in-queue passengers (L_q)	0.463	11.23	0.031	0.251
Mean number of in-system passengers (L_s)	0.95	12.16	0.518	1.175
Mean wait time (in minutes) in-queue (W_q)	0.05	1.4941	0.003	0.110
Mean wait time (in minutes) in-system (W_s)	0.091	5.3476	0.49	0.52
Utilization indicator of system (ρ)	51%	7.6%	75%	53%

The utilization indicator shows the percentage of time the counters were busy. The management needs to determine that the optimal number of opened counters in the system to ensure that wait time is within allowable limits (not too short, not too long) and action is cost-effective.

Analysis of the statistics shows that running one or two counters in MS maintains the mean wait time in-queue and in-system at less than one minute and the mean number of in-queue and in-system passengers also at one person. However, would opening two counters be cost-effective? If $\rho =$ proportion of time the server is busy, then idle service rate is given by $1 - \rho$. From Table 2, idle service time for one-counter system and two-counter system are 49% and 25%, respectively. Cost efficiency cannot be achieved for the two-counter system since the number of tellers will increase. In conclusion, the optimal number of opened counters in MS is one.

At this point in the discussion, the study questioned if a three-counter system would be better than a two-counter system. Table 3 include the mean wait time, queue length and utilization indicator for two-counter and three-counter systems.

As can be seen, wait time in-queue and in-system for two-counter, and three-counter systems are less than 1 minute. The queue length is also 1 (person). Thus, would opening three counters be more cost-effective in ES? The system is idle at 47% and 31% for the two-counter and three-counter systems. When the number of counters increases, the number of tellers also increase, and so will operation costs. Therefore, the suggested optimal number of counters to be opened in ES is two.

Table 3: Performance Measures for Two-Counter and Three-Counter Systems

Variable	**System**			
	Two-Counter		**Three-Counter**	
	MS	**ES**	**MS**	**ES**
Mean number of in-queue passengers (L_q)	0.031	0.251	0.003	0.033
Mean number of in-system passengers (L_s)	0.518	1.175	0.49	0.957
Mean wait time (in minutes) in-queue (W_q)	0.003	0.110	0.003	0.014
Mean wait time (in minutes) in-system (W_s)	0.49	0.52	0.0047	0.015
Utilization indicator of system (ρ)	75%	53%	84%	69%

On the contrary, one counter does not work well for ES. There is not a big difference between the mean number of in-queue and in-system passengers $\left(L_q = 11.23; L_s = 12.16\right)$ but the system was servicing at 7.6%. Based on the statistics in Table 2, both the two-counter and three-counter systems display the mean number of in-queue and in-system passengers to approximately one and a wait time of less than or equal to one minute. However, the two-counter system would be running at 53% capacity. Therefore, the optimal number of opened counters in MS should be two after considering the extra management cost of two added tellers for a three-counter system.

As stated earlier on, the counter was selling both types of tickets. The results will be different if the queues to be developed are based on types of tickets. However, the management must carry out further simulations to ascertain if the queues to be designed should include priority counters based on the type of tickets or specific train schedules.

5. CONCLUSION

This article concerns only the counter services on Thursdays at a train station. The flow of passengers for MS on Thursday is similar to any other day in the week. However, the pattern changes for ES. Congestion of passengers occurs on every Thursday. Although the system exhibits this characteristic, the management has continued to open only one counter. Besides, this counter sells different types of tickets. This study wishes to emphasize that the current system is definitely not cost-effective.

The one-counter system was able to cater to the existing volume of passengers in MS. The service rate was higher than the arrival rate (or the ratio $\left(\frac{\lambda}{\mu}\right) = 0.487 < 1$) and no waiting line was formed. However, the data study told a different story for ES. A passenger taking the ES train on a Thursday needs the assurance that the journey will be smooth with zero delays.

Sadly, data described the system as needing efficiency and effectiveness tests. Efficiency implies the successful accomplishment of an operation using the least available resources, while effectiveness is defined as the degree in success at producing the desired result [29]. The service rate was only slightly higher than the arrival rate, but the ratio $\left(\frac{\lambda}{\mu}\right) = 0.924 < 1$ defines the system as efficient. However, based on the mean number of in-queue and in-system passengers, there was no way that one counter can efficiently service the queue that was formed. Thus, the system is not Simulation done suggested the optimal number of the counter for ES was two.

The question of what corrective measures to take now lies with the management. Would increasing the number of counters to two on a Thursday solve the problem? Or would run a three-counter system work better? This study recommends that the management run experiments check cost-effectiveness of the system for one-counter, two-counter or three-counter systems. A further in-depth study into the relationship between the degree of efficiency from low to high, the mean number of in-queue and in-system passengers has to be carried out.

Any decision-making by the management has to be thorough. Long wait time is almost often associated with poor quality service. Should discounts be offered? Should proficiency of the teller be measured? The study recommends that the management define actions to be taken during the 47% and 31% idle system time for two-counter and three-counter systems.

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