Mathematical Model for the Optimization of the Airport Self-Service Kiosks System

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Abstract
This paper studied the effectiveness of airports self-service kiosks by using the data analysis. The queuing systems taking place in various service situations in our daily life. Reasonable use of queuing theory can significantly improve the efficiency of the queuing system and system performance. The service system, queuing system and queuing model is suggested. The queuing theory in the area of service science, the corresponding mathematical model of the airport self-check-in system is established. After analyzing the collected data, it is conclude that the overall proportion of time that the kiosk is idle is quite high at the Vienna airport, especially during the weekdays. Furthermore, the suggestions for the airport self-service system are offered.

Keywords 1
Self-service kiosk, data analysis, effectiveness, servers, information, service.

1. Introduction

In this study we analyze the service system of airport check-in kiosks by using the data we collected from the Vienna International Airport. The kiosks observed were used by Star Alliance Airlines. The service system and queueing models are made for single server and multiple server cases and compared with each other. In addition, some relevant calculations were made and the difference between a normal weekday and a weekend is recognized.

The data we observed is connected with some relevant literature. After analyze is done we suggest some improvements and ways to optimize the service systems of Airport check-in kiosks.

The aim of this study is developing the mathematical model for the optimization of the airport self-service kiosks system.

2. Related work

To identify service system, we first need to define the concept of "service". Service is usually "defined as an act of beneficial activity" [1], which is intangible, not stored and does not result in ownership. Also, recommendation system [2] are actual fields in investigation. Examples of services include the transfer of goods, such as the postal service delivering mail, and the use of expertise or experience, such as a person visiting a doctor. There are "five essential elements involved in a service" [1], namely:

- Resource. Resources can be in a physical, soft, or hybrid form,
- Provider. A service is purposely performed by a service provider,
- Customer. A service consumer is usually a human being who consumes, acquires, or utilizes a service offered and performed by a service provider

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- Benefits. A performed service surely generates certain benefits.
- Time. Small or big, simple or complex, a service certainly takes time to get per- formed to realize the desired benefits.

In 2008, Spohrer and Maglio point out that service system are value co-creation configurations of people, technology, value propositions connecting internal and external service systems, and shared information. Service science is researches which try to sort and interpret various service systems that exist. Furthermore, service science discusses how service systems interact and evolve to co-create value [3].

Nowadays, the use of self-service is becoming more and more frequent in our daily lives. Self-service technologies [4, 5] have been introduced in many fields, such as self-service banking, self-service cashier in supermarkets as well as self-service ticket vending machine etc.

The main promising assumption is that automation will drive efficiency to a higher level and hence cut remarkable amount of costs for the service industry.

Queues happen when there are more people wanting the service than the servers are capable to serve on that given time. To manage this there has to be a queueing system. Queuing systems consist of customers arriving for the service [6], waiting for the service and finally exiting the system after being served. In queueing theory real life situation are modelled and performance is measured by different calculations. The aim is to shorten the queueing time and optimize the system.

Queueing theory [7, 8] is important for service businesses since problems in queueing situations usually lead to dissatisfaction with a service. Poorly functioning queue may even result in losing customers and thus cause economic losses. Queueing theory includes queueing disciplines, models and calculations.

Main types of queueing disciplines are FIFO and LIFO, from which LIFO is not as commonly used. First in first out (FIFO) system is a typical system where the first customer to enter the service system is also the first to exit it. In example, this is how queues in supermarkets work.

On the other hand last in first out (LIFO) is the exact opposite to FIFO: the latest to arrive the system is served first. Sometimes when talking about service models the term first come first served (FCFS) might be used. However, this is essentially the same model as FIFO.

Queueing models are important part of queueing theory and their main purpose is to model a real life situation accurately. Some examples of the queueing models are: single queue and one server, single queue and several servers, several queues and one server, and several queues and several servers. While all of these models can be served using the FIFO mechanism there can also be different systems. One of those systems being high priority and low priority queues, where the low priority queue is served after the high priority one. Taking this same model a little further there is also a class systems model – serving the first class first, then the second class and so on. For example, many hospitals with first aid work like this serving the more urgent cases first.

Below you can see an example of basic queueing model

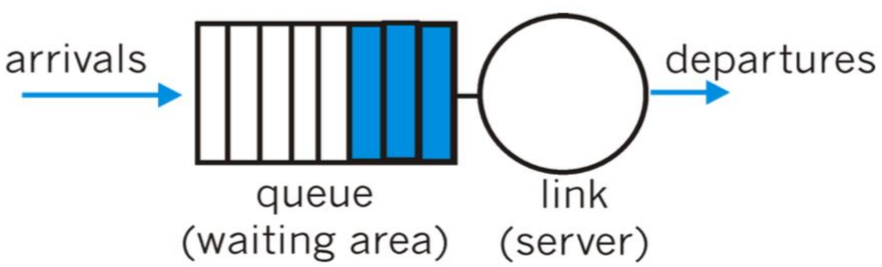

Figure 1: The basic queueing model

Queueing behavior can be analyzed mathematically. Typical characteristics calculated are average time spent in the queue, average number in the queue, average serving time, and the probability of that the queue is full or empty.

Although, in some systems there are no limit for the fullness of the queue, it can be assumed that a too long queue will result in customers leaving the system before served.

3. Analysis and modelling the airport self-service kiosks system

There are three typical ways for checking in a plane ticket: check-in counter, self-check-in on the internet and self-check-in kiosks. In our work we are focusing on the latter. The check-in kiosks are workstations usually located near the check-in counter [9, 10]. Using the kiosks a boarding pass and a baggage tag can be printed without the need of a service employee. After the kiosk a passenger proceeds to the baggage drop-off if he/she has any baggage. Otherwise they can go straight to the security check.

Using check-in kiosks starts with selecting the airline and then deciding how to identify oneself. Typical options are [11-13]: reference no., frequent flyer card no, E-ticket no., or a passport scan. After that the flight details are confirmed and a boarding pass and possible bag-tag can be printed. This process is fairly simple but the speed of checking in depends on the passengers' familiarity with the kiosks and if the needed information is already on hand (i.e. reference no.). Pictures from the check-in kiosk Austrian airlines uses appendix 1.

Depending on the queue to check-in counters, the kiosks might save passengers a significant amount of time – especially if travelling without baggage so that the baggage drop line can be avoided. However, in all cases the kiosks cuts costs from the airlines. The cost of checking in with an agent is 3.68 US dollars while the cost of using a self-check-in kiosk is only 0.16 US dollars [14].

Below you can see a queue model for check-in kiosks:

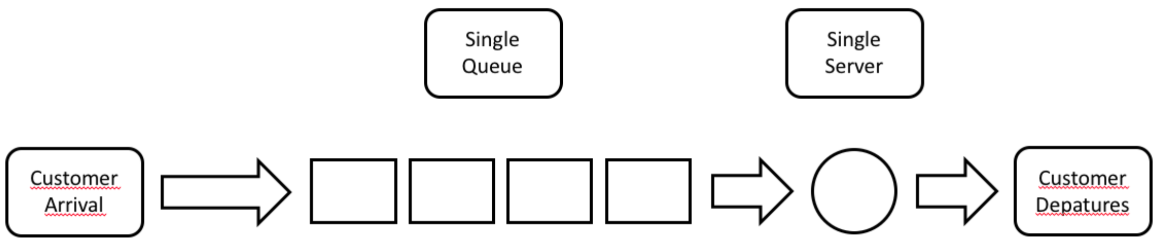

Figure 2: Single Server

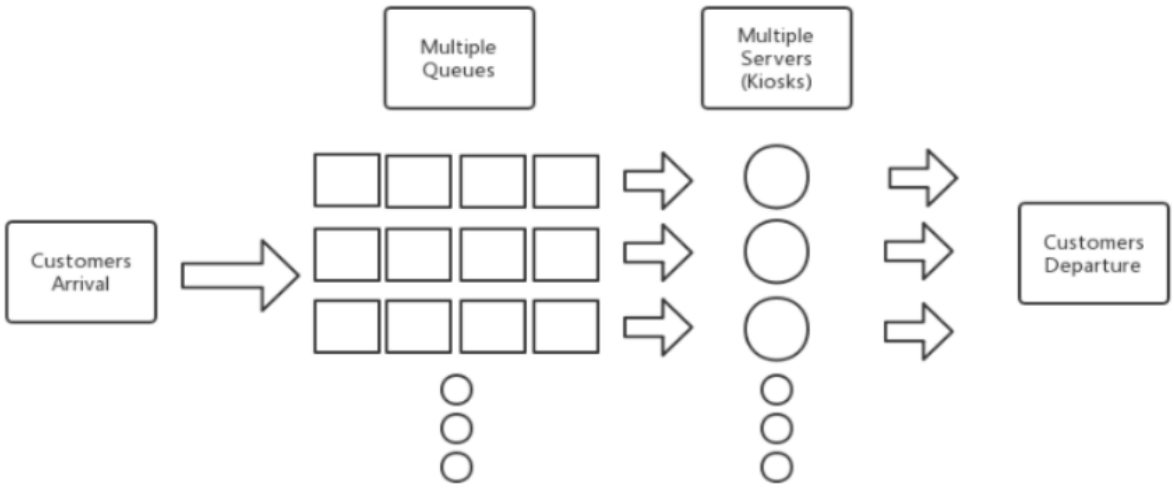

Figure 3: Multiple Servers

When the customer arrives the system, if there is an idle kiosk, the customer will be accepted immediately. If not, the customer will enter shortest queue and wait for the service. However, if they queues are considered too long the customer might move to a check-in counter instead [16, 17]. In this system the customers are served by the first in first out (FIFO) method. There are several kiosks [18] which are independent from each other and serve customers parallel. In our work we assume that the capabilities of each kiosk are the same.

Furthermore, we assume that customer arrivals are random and independent and the source of customers is unlimited. In addition, there is no limit on the system capacity and the arrival distribution is assumed as a Poisson process. Customers may move between different queues while waiting for the service [19].

After successfully check-in the customer, if he/she has baggage, moves to a baggage-drop queue. This system usually has single queue with a single server served as FIFO. However, in some cases there might be multiple queues and multiple servers – in which case the queue model is similar to the one of check-in kiosks.

3.1. Data collection

In this section, we will introduce the data collection process of this report. The data have been mainly collected at the Vienna International Airport on 20.11.2018 (weekday) and 24.11.2018 (weekend) between 18.00-18.30. There are check-in machines located in each terminal for passengers checking in at the airport to print their boarding passes. Our data are collected at Terminal 3 by some observations. The main items collected are the arrival time and departure time of each customer. We have observed the queueing state at kiosks No.361 and 362 to establish the modelling with one server by only applying the data collected at kiosk No.361 and then with more servers by applying data collected [20] at all 2 machines.

Our original data are recorded in following tables:

Data collected on 20.11.2018 (weekday)

Table 1

Machine 361: weekday

Customer	Arrival time	Departure time	Service time
1	18.00	18.02	2
2	18.04	18.06	2
3	18.07	18.08	1
4	18.09	18.11	2
5	18.13	18.14	1
6	18.16	18.17	1
7	18.20	18.21	1
8	18.22	18.23	1
9	18.26	18.27	1
10	18.30	18.31	1

Table 2

Machine 362: weekday

Customer	Arrival time	Departure time	Service time
1	18.01	18.02	1
2	18.04	18.06	2
3	18.06	18.09	3
4	18.10	18.11	1
5	18.13	18.14	1
6	18.17	18.18	1
7	18.22	18.24	2
8	18.26	18.28	2
9	18.29	18.30	1

Data collected on 24.11.2018 (weekend)

Table 3
Machine 361: weekend

Customer	Arrival time	Departure time	Service time
1	18.00	18.01	1
2	18.03	18.06	3
3	18.06	18.08	2
4	18.09	18.11	2
5	18.11	18.12	1
6	18.14	18.15	1
7	18.17	18.18	1
8	18.21	18.22	1
9	18.24	18.26	2
10	18.26	18.28	1
11	18.29	18.31	2
12	18.30	18.32	1

Table 4
Machine 362: weekend

Customer	Arrival time	Departure time	Service time
1	18.00	18.02	2
2	18.03	18.04	1
3	18.05	18.06	1
4	18.08	18.09	1
5	18.12	18.14	2
6	18.16	18.18	2
7	18.18	18.20	2
8	18.19	18.21	1
9	18.22	18.24	2
10	18.25	18.26	1
11	18.28	18.30	2
12	18.30	18.31	1

3.2. Modeling with data

As previously discussed, we can describe the self-service kiosks system by (M/M/c) (∞/FIFO) [15], which denote that:

- There are c identical servers working in the system
- The customer arrives at the Poisson flow
- Both the inter- arrival time and service time are exponentially distributed. The inter-arrival time is exponentially distributed with a mean of λ minutes and the service time is also exponentially distributed with a mean of μ minutes.
- The system capacity is infinite, and the arrival and service are independent of each other
- Customers are served on a first-in-first-out basis

In addition, we have gotten some queueing formulas from the lecture, which can be applied in our case. First of all, we will list the notations of the queueing formulas.

(1) Notation

- λ: mean rate of arrival. It is equal to 1/E[Inter-arrival-Time] where E[.] denotes the expectation operator.
- μ: mean service rate. It is equal to 1/E[Service-Time].
- $\rho = \lambda/\mu$ for single server queues: utilization of the server; also the probability that the server is busy or the probability that someone is being served.

- c: number of servers.
- L: Mean number of customers in the system.
- Lq: mean number of customers in the queue.
- W : mean wait in the system.
- W_q: mean wait in the queue.

(2) Formulas

Single-server (M/M/1)

- L=λW; Lq =λWq.
- W = Wq +$\frac{1}{\mu}$
- For the M/M/1 queue, we can prove that
- Lq =$\frac{\rho^2}{1-\rho}$
- Multiple-server (M/M/c)
- ρ=$\frac{\lambda}{c\mu}$
- Lq=$\frac{P_0(\frac{\lambda}{\mu})^c\rho}{C!(1-\rho)^2}$,

Where P_0=1/ $[\sum_{m=0}^{c-1}\frac{(c\rho)^m}{m!}+\frac{(c\rho)^c}{c!(1-\rho)}]$, which denotes the probability that there are 0 customers in the system.

3.3. Single-server queues

For the single-server queues case, we can describe it by (M/M/1) (∞/FIFO) [15]. The data collected at kiosk No.361 will be used in this part.

First, we will take a look at the weekday data. There are 10 customers within 30 minutes in our data, where we can assume that the customers' arrival at the kiosk No.361 follows a Poisson distribution [16] and the numbers of arrival would be 10 people every 30 minutes. Therefore, the inter-arrival time is exponentially distributed with a mean of 3 minutes. Furthermore, by computing the mean of service time we assume that the service time is also exponentially distributed with a mean of 1.3 minutes.

Now we have an M/M/1 system. We also have: $\lambda=\frac{1}{3}$; $\mu=\frac{10}{13}$. Hence, $\rho=\lambda/\mu=\frac{13}{30}$

Number in the Queue = $L_q=\frac{\rho^2}{1-\rho}\approx 0.33$

Wait in the Queue = $W_q = L_q/\lambda \approx 0.99$ mins

Wait in the System =W= $W_q + 1/\mu \approx 2.29$ mins.

Number in the System =L=λW ≈ 0.76

Proportion of time the server is idle = 1 − ρ≈ 0.57

Then we will turn to discuss the data collected at weekend. By applying the same approach as before, the inter-arrival time is assumed to be exponentially distributed with a mean of 2.5 minutes. Furthermore, by computing the mean of service time we assume that the service time is also exponentially distributed with a mean of 1.5 minutes.

Now we have an M/M/1 system. We also have: λ = 0.4; $\mu=\frac{2}{3}$. Hence, $\rho=\lambda/\mu=0.6$

Number in the Queue = $L_q=\frac{\rho^2}{1-\rho}=0.9$

Wait in the Queue = $W_q = L_q/\lambda = 2.25$ mins

Wait in the System =W= $W_q + 1/\mu = 3.75$ mins.

Number in the System =L=λW = 1.5

Proportion of time the server is idle = 1 – ρ = 0.4

3.4. Multiple-server queues

For the multiple-server queues case, we can describe it by (M/M/c) (∞/FIFO) [16]. The data collected at kiosk No.361 and 362 will be used in this part.

First, we will take a look at the weekday data. There are 19 customers in total within 30 minutes in our data, where we can assume that the customers' arrival at the kiosk follows a Poisson distribution and the numbers of arrival would be 19 people every 30 minutes. Therefore, the inter-arrival time is exponentially distributed with a mean of $\frac{30}{17}$ minutes. Furthermore, by computing the mean of service time we assume that the service time is also exponentially distributed with a mean of $\frac{27}{19}$ minute.

Now we have an M/M/c system, where c equals to 2. We also have: $\lambda = \frac{17}{30}$; $\mu = \frac{19}{27}$,

Hence, $\rho = \frac{\lambda}{c\mu} \approx 0.4$

$P_0 = 1/ [\sum_{m=0}^{c-1} \frac{(c\rho)^m}{m!} + \frac{(c\rho)^c}{c!(1-\rho)}] \approx 0.43$

Number in the Queue = $L_q = \frac{P_0(\frac{\lambda}{\mu})^C \rho}{C!(1-\rho)^2} \approx 0.15$

Wait in the Queue = $W_q = L_q / \lambda \approx 0.27$ mins

Wait in the System = $W = W_q + 1/\mu \approx 1.69$ mins.

Number in the System = $L = \lambda W \approx 0.96$

Proportion of time the server is idle = $1 - \rho = 0.6$

Then we will turn to discuss the data collected at weekend. By applying the same approach as before, the inter-arrival time is assumed to be exponentially distributed with a mean of 1.25 minutes. Furthermore, by computing the mean of service time we assume that the service time is also exponentially distributed with a mean of 1.5 minutes.

Now we have an M/M/2 system. We also have: $\lambda = 0.8$; $\mu = \frac{2}{3}$, c = 2

Hence, $\rho = \frac{\lambda}{c\mu} = 0.6$

$P_0 = 1/ [\sum_{m=0}^{c-1} \frac{(c\rho)^m}{m!} + \frac{(c\rho)^c}{c!(1-\rho)}] = 0.25$

Number in the Queue = $L_q = \frac{P_0(\frac{\lambda}{\mu})^C \rho}{C!(1-\rho)^2} = 0.675$

Wait in the Queue = $W_q = L_q / \lambda \approx 0.84$ mins

Wait in the System = $W = W_q + 1/\mu \approx 2.34$ mins.

Number in the System = $L = \lambda W \approx 1.875$

Proportion of time the server is idle = $1 - \rho = 0.4$

4. Analysis of the results

From the previously discussed data, we can summaries the items in the following table:

Table 5
Analysis of the results

Customer	Single-server		Two-server	
	weekday	**weekend**	**weekday**	**weekend**
Mean inter-arrival time/min	3	2.5	1.76	1.25
Mean service time/min	1.3	1.5	1.42	1.5
Number in the Queue	0.33	0.9	0.15	0.675
Wait in the Queue/min	0.99	2.25	0.27	0.84
Wait in the System/min	2.29	3.75	1.69	2.34
Number in the System	0.76	1.5	0.96	1.875
Proportion of time the server is idle	0.57	0.4	0.6	0.4

Mean service time is basically very similar both at weekday and weekend, but the inter-arrival time at weekend is below the inter-arrival time at the weekday, which implies that there are more customers arriving within a time unit during weekend. That's why proportion of the time the server is idle during weekend is approximately 40%, while achieves about 60% during the weekday. Therefore, we can conclude that the overall proportion of time that the kiosk is idle is very high at the Vienna airport, especially during the weekdays.

In fact, there are more than 10 identical self-service kiosks in our observation area and in most cases; they lie unused, because each customer only needs about 1.5 minutes to complete the self-check in process. Generally, on the one hand, we suggest that the airport can shut down some of the machines to improve the service system. On the other hand, we noticed that some of the airline companies recently have promoted the self-drop off machine of Baggage. If more and more passengers would like to accept the self-service of Baggage drop off, then the machine could be taken a better advantage of.

5. Conclusion

There are queuing systems taking place in various service situations in our daily life. Reasonable use of queuing theory can significantly improve the efficiency of the queuing system and system performance. In this study we first introduce the service system, queuing system and queuing model. Then, through the queuing theory in the area of service science, the corresponding mathematical model of the airport self-check-in system has been established. After analyzing the collected data, we conclude that the overall proportion of time that the kiosk is idle is quite high at the Vienna airport, especially during the weekdays. Furthermore, we have put forward some suggestions for the airport self-service system.

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