Queuing Theory – based Modeling and Analysis of an Airport's Customs Facility

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ABSTRACT

According to Queuing Theory, a waiting line can be defined in terms of the arrival rate of customers, the rate at which customers are served by service providers, and the number of service providers [1]. Analysis of waiting lines leads to reduction of waiting time, which results in increased customer service and decreased lead time [2]. The configuration and operation of waiting lines of the US Customs area of the major US international airports is a complex process. First, the arrival rate of customers (travelers) varies constantly during the day. Second, more than 250 passengers can arrive in a single flight. Third, the waiting lines are dynamic in nature, which reflects the addition of US Customs and Border Protection (CBP) officers when a massive amount of travelers arrive at the same time. This paper introduces a Queuing Theory-based modeling and analysis of the US Customs area of the Chicago O'Hare International airport conducted to evaluate, in terms of waiting time, the level of service provided by CBP officers. Recommendations to configure and operate the US Customs area of the Chicago O'Hare International airport in order to maximize the flow of travelers, reduce waiting time, and enforce security procedures are also provided.

Keywords: Queuing theory, waiting line, arrival rate of customers, service rate, and customs.

1. INTRODUCTION

1. Waiting lines analysis

Humans and transportation equipment transporting materials, products, supplies, etc. spend significant amount of time waiting in line. A quick service is an important component of quality customer service. A basic premise of waiting line analysis is the trade-off between the costs from making customers wait and the cost of improving service (i.e., reducing waiting time). Figure 1 shows the cost trade-offs for service levels.

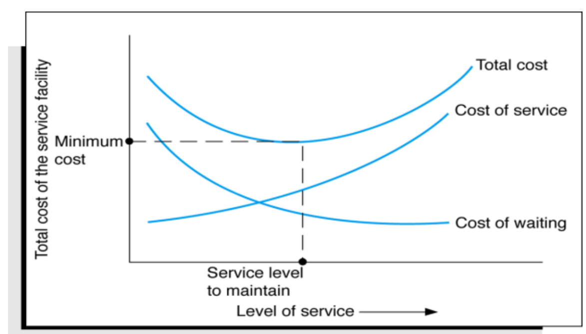

Figure 1. Cost trade-offs for service levels [2].

The results of waiting line analysis are referred to as operating characteristics. They are used by to make design decisions in manufacturing and logistics facilities, for instance, facility layout, number of servers, etc.

Waiting lines are continually increasing and decreasing in length. Decisions concerning the configuration of waiting lines are based on several factors. The most common are:

the arrival rate of customers, the service rate, the number of servers, the queue discipline (e.g. first come, first served), and the nature of the calling population.

The commonly followed assumptions of the single-server queueing analysis are: An infinite calling population, a first-come, first-served queue discipline, Poisson arrival rate, and Exponential service time.

Some of the common configurations of waiting lines are:

- Single server
- Undefined / constant service time
- Finite / Infinite calling population
- Finite queue length
- Multiple server

The nomenclature frequently used in waiting line analysis is the following:

λ: Arrival rate (average number of arrivals per time period)

μ: Service rate (average number served per time period)

For the case of a multiple-server model (two or more independent servers) the following parameters should be considered:

c: number of servers

c μ: mean effective service rate for the system

The formulas to calculate the operating characteristics of the multiple-server model are [2]:

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=c-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c \left(\frac{c\mu}{c\mu-\lambda}\right)} = \text{probability no customers in system}$$

$$P_n = \frac{1}{c!c^{n-c}}\left(\frac{\lambda}{\mu}\right)^n P_0 \quad \text{for } n>c$$

$$P_n = \frac{1}{n}\left(\frac{\lambda}{\mu}\right)^n P_0 \text{ for } n< c = \text{probability of n customers in system}$$

$$L = \frac{\lambda\mu(\lambda/\mu)^c}{(c-1)!(c\mu-\lambda)^2} P_0 + \frac{\lambda}{\mu}\mu = \text{average customers in the system}$$

$$W = \frac{L}{\lambda} = \text{average time customer spends in the system}$$

$$L_q = L - \frac{\lambda}{\mu} = \text{average number of customers in the queue}$$

$$W_q = W - \frac{1}{\mu} = \frac{L_q}{\lambda} = \text{average time customer is in the queue}$$

$$P_w = \frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c \frac{c\mu}{c\mu-\lambda} P_0 = \text{probability customer must wait for service}$$

Section 2 shows the application of the multi-server model in the operation of the of the US Customs area of the Chicago O'Hare International airport

1.2 Background

An airport is an aerodrome with facilities for flights to take off and land. Airport often have facilities to store and maintain air raft, and a control tower. An airport consists of a landing area, which comprises an aerially accessible open space including at least one operationally active surface such as a runway for a plane to take off, and it often includes adjacent utility buildings such as control towers hangars, and terminals. An international airport has additional facilities for customs and immigration.

U.S Customs and Border Protection is the largest federal law enforcement agency of the United States Department of Homeland Security. This agency takes care of enforcing U.S regulations regarding immigration. For the purpose of this project the Chicago O'Hare International Airport was selected to carry on a study on the waiting lines for the customs and immigration process for all international flights arriving to terminal 5 of the airport. The reason the Chicago O'Hare International Airport was selected for this study is because as of 2014 it reclaimed the title of the busiest airport in the world by number of takeoffs and landing, another reason was because as of 2015 it has been considered the fourth busiest airport in the world by passenger traffic.

1.3 Problem Statement

The way US Customs area waiting lines are set up and their form of operation in mayor US International Airports has always been a complex process. The first complexity is that the arrival rate of passengers is constantly changing throughout the day. This arrival rate can significantly change when more than two flights with 250 or more passengers arrive around the same time. Second, the waiting lines are dynamic by nature, since they can be redesign accordingly to the need of space depending on the amount of passengers arriving, and also US Customs and Border Protection officers can be added as needed.

1.4 Objective

The objective of this project is to conduct a Queuing Theory-based model in order to analyze the US customer area of the Chicago O'Hare International Airport, and develop recommendations related passenger waiting time and the level of service provided by the US Customs and Border Protection officers in order to maximize the flow of travelers and reduce waiting time while enforcing security procedures.

2. SIMULATION APPROACH

To model the proposed queuing system, an Excel-based simulation was developed. The purpose of modeling is to promote simulation of multiple different scenarios at the airport. On a large enough scale, a queuing analysis can become very complex, and thus a manual process is not ideal to use in drawing conclusions about a proposed future state. Therefore, a simulation using actual data and real probabilities, with some liberty taken on certain assumptions, is a far more practical approach.

The Excel-based model functions on the following principles:

- Actual 2015 data was used for Chicago O'Hare International Airport (credit http://awt.cbp.gov/, Customs and Border Protection Airport Wait Time).
- Based on the data, a random hour of flight arrivals is simulated. This simulation primarily focuses on the peak airport hours so as to reduce the complexity around probabilities used for flight arrivals. A simple macro button is set up to select the number of flights, where probability aids in the selection process. For example, anywhere from 4 to 8 flights could arrive in one hour, but the probability is weighted more heavily on the *average* flights arriving in an hour based on the data (which is closer to 6 flights per hour).
  - Based on the hour of the day, the data varies greatly throughout the year. Peak hours are used mainly because it is the time of highest demand on the airport terminal, and the data is more consistent than it would be if all the less busy hours were also included. Refer to Table 1 below, which contains AWT data.

			Average			
	Hours	Days	Wait Time (mins)	Passenger	Flights	Booth
PEAK HOURS	1400 - 1500	365	20.14	1670.8	7.89	28.9
	1300 - 1400	365	15.14	1588.8	7.92	29.3
	1500 - 1600	365	19.23	1498.4	7.6	28.43
	1800 - 1900	365	11.9	1113.5	6.8	23.11
	1700 - 1800	365	11.87	944.6	6.04	24.2
	1600 - 1700	364	15.96	1159.9	6.08	28.17
	1200 - 1300	363	10.29	906.2	4.72	26.2
	1900 - 2000	361	11.15	806.7	4.22	21.52

Table 1. AWT data.

The following conclusions and references are made, based on the AWT data (Table 1). Note that the total average number of customers arriving is simulated in the model, and the 1211 number is just used as a point of reference to ensure the model is simulating within an acceptable range that makes sense. Ultimately, the table provides inputs to the total number of booths / servers used, the average number of passengers per flight, and the average number of flights arriving in a peak hour:

- Average passengers arriving during peak hours: 1211
  - This number is to be used as a point of reference only – the model calculates arrival rate in passengers per hour.
- Average booths open during peak hours (each booth has 2 servers): 26
  - The model assumes that 26 booths are available, with two servers at each booth.
- Average passengers per flight: 189
  - This is to be used with probabilities to determine how many passengers are arriving / arrival rate.
- To determine arrival rate λ, another simple macro selects the number of passengers to arrive on each flight selected to arrive. The number of passengers is also based on probability, and is assumed to be 20% plus or minus the annual average number of passengers per flight (which is 189).
- The available booths reported in the AWT data determine the number of servers, c, and a standard service rate, μ, is assumed. Booths are assumed to be staffed by two processing employees each. An average of 26 booths is open during all the peak hours throughout the year. Thus, 52 servers are assumed to be on staff during all peak hours across the board.
- A service rate, μ, of 3 minutes per passenger is assumed.
- Based on the arrival and services rates, the simulation checks if the entire lot will be able to be processed within an hour, c*μ.
- The final output of the simulation portion provides all the necessary inputs (λ, μ, and c) to the queuing theory section at the bottom of the Excel, discussed next in this report.
- Lastly, this simple queuing diagram describes how the booths are assumed to be setup, with two servers at each booth, following a "Multiple Server" queuing theory model. See Figure 2 below.

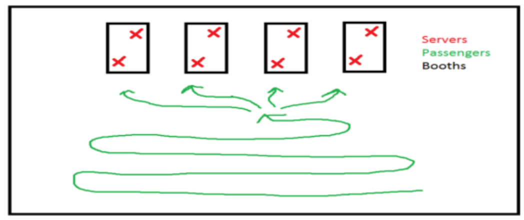

Figure 2. Layout of Customs area.

With arrival rate, servers, and service rate defined by running the simulation, the Excel has provided the needed inputs to the queuing theory part of the project.

The simulator model created in the excel sheet allows us to generate a random number of flights / hr. and also a random number of passengers for each of those flights, all random numbers are based on a probability distribution with values in the interval [0, 1].

The fixed inputs generated from the random models are the arrival rate, which is the number of passengers arriving per hour at the customs terminal (λ**).**

To solve for the queuing analysis we had to assume the total number of servers, for this problem we assumed that 52 is the total number of servers available to assist passengers **(**c**).**

If it will take each server 3 minutes to process 1 passenger, the resulting service rate will be 20 customers / hr. / server, **(μ).**

Generating the MS Excel random simulator, the following inputs were recorded:

λ: 733 (# of passengers arriving per hour)
c: 52 (Total servers available)
μ: 20 (Each server can process 20 passengers per hour or 3 minute processing time)

Service rate is $\mu * c = 1040$ passengers / hr.

Since all the data in the Random Simulator was based on actual numbers obtained from the AWT site for 2015 (from Jan, 2015 to Dec 31, 2015), the only variable that is being modified is the number of servers. Increasing the number of servers per booth will allow the queuing system to receive more passengers per hour.

Current	Future
λ : 733	λ : 733
c: 52	c: 70
μ : 20	μ : 20
Service rate : μ * c = 1040	Service rate : μ * c = 1400

While the current state queuing model was solved, the processing time for an officer to process 1 passenger is 3 mins, this includes the time for the optic checks and the passport check by the officer, increasing the number of servers will improve the overall service rate by 360 passengers per hour.

Increasing the number of officers will reduce the average time passengers spend in the queue, which allow the Chicago O'Hare international airport to receive more international flights.

3. CONCLUSION

The customs and immigration process in a country like the United States of America is delicate and complex process in which the custom officers on duty must evaluate many factors. In order to achieve the highest level of security in this process, officers must be in place and that is why machines for passengers to do the process on their own should not replace them, or at least not completely replace them.

As mentioned in the Current state Vs. Future State, in order to reduce the waiting time in the customs lines at the Chicago O'Hare International Airport the number of servers must be increased during the peak times so more passengers can be processed at the same time.

A cost analysis must also be done in order to determine the cost feasibility of increasing the number of custom officers during peak times.

REFERENCES

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