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The Optimizing of the Passenger Throughput at an Airport Security Checkpoint

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Abstract

In order to increase checkpoint throughput and reduce variance in waiting time, the current security process of an airport in the United States has been taken as an example. Depending on the survey data, we use the queuing model to review airport security checkpoints and staffing and to identify potential bottlenecks which disrupt passenger throughput. And the method of improving the traffic volume and reducing the waiting time is deduced by the mathematical formula. The influence of the cultural difference of the passenger security process is analyzed by sensitivity. Based on the security optimization model, the security system is put forward to a certain extent to adapt to different cultural differences. The model takes into account the impact of parameter changes on the airport security process.

Keywords

Safety Engineering, Airport Security Process, Queuing Theory, Passenger Throughput, Cultural Differences

1. Introduction

In recent years, the number of air travelers is in explosive growth [1], and airport security checkpoints are critical component in protecting airports and passengers from terrorist threats. But there is a tension between desires to maximize security while minimizing inconvenience to passengers, and the U.S. Transportation Security Agency (TSA) has come under sharp criticism for extremely long lines. Passengers have become more dissatisfied with the security screening process about the longer time they wait to be screened [2]. And it is unclear that short waiting times also make unexplained and unpredicted long lines at other airports [3] [4] [5] [6] [7].

1.1. The Questions We Face

In order to alleviate the tension between airport security checkpoints and passengers, we developed several models to figure out the possible bottlenecks of airport security check process based on the current US security process, which is shown in Figure 1 [3].

1.2. Our Approach

In order to determine the possible bottlenecks of scattered traffic flow from the review of the airport security check point and staff, we need to divide security checkpoint into three small queuing systems according to the A, B, C area based on the US security process which is shown in Figure 1, and analyze the bottleneck of airport security inspection by using the queuing theory based on the data for passengers through security process in the table [3].

First, we analyze the current security process of the zone A where passengers arrived at the security gate and waited in line to check their identity cards and registration documents.

The Zone A (Document Check) has two types of entries: one is Pre-Check Entrance and the other is Regular-Check Entrance.

1.3. Theoretical Knowledge

Assuming that the airport security system is in accord with the standard queuing theory model M/M/c/∞/∞, the operating parameters of the queuing system are as follows:

The probability of the system that is idle:

$$P_0 = \left[\sum_{k=0}^{c-1} \frac{1}{k!} \left(\frac{\lambda}{\mu} \right)^k + \frac{1}{c!} \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu} \right)^c \right]^{-1} \tag{1-1}$$

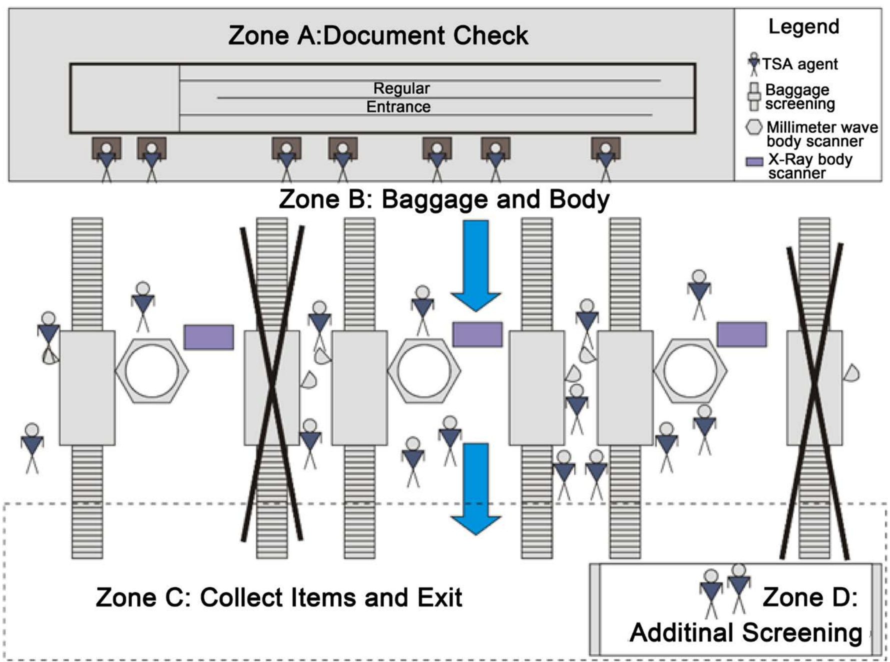

Figure 1. Illustration of the TSA Security Screening Process.

Average queue length:

$$L_q = \frac{(c\rho)^c \rho}{c!(1-\rho)^2} P_0 \tag{1-2}$$

The number of customer in the queuing system:

$$L_s = L_q + \frac{\lambda}{\mu} \tag{1-3}$$

Average waiting time:

$$W_q = \frac{L_q}{\lambda} \tag{1-4}$$

Average time the passenger spent in the queuing system:

$$W_s = \frac{L_s}{\lambda} \tag{1-5}$$

Assuming c is the number of security channel at airport, β is the ratio of Pre-Check and Regular-Check channels, the number of Pre-Check Entrance is:

$$C_1 = \frac{\beta}{1+\beta} c \tag{1-6}$$

The number of Regular-Check Entrance is:

$$C_2 = \frac{1}{1+\beta} c \tag{1-7}$$

- For Zone A: Pre-Check Entrance

According to the equation in the standard queuing model M/M/c/∞/∞, the corresponding indexes of the Pre-check Entrance queuing system in Zone A are derived as follows:

The Probability of Pre-Check Entrance system being in idle state in Zone A:

$$P_0 = \left[\sum_{k=0}^{\frac{c}{1+\beta}-1} \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c}{1+\beta}} \right]^{-1} \tag{1-8}$$

Average queue length in Pre-Check Entrance service system:

$$L_q = \frac{\left(\frac{c\rho}{1+\beta}\right)^{\frac{c}{1+\beta}} \cdot \rho}{\left(\frac{c}{1+\beta}\right)!(1-\rho)^2} P_0 = \frac{\left(\frac{c\rho}{1+\beta}\right)^{\frac{c}{1+\beta}} \cdot \rho}{\left(\frac{c}{1+\beta}\right)!(1-\rho)^2} \cdot \left[\sum_{k=0}^{\frac{c}{1+\beta}-1} \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c}{1+\beta}} \right]^{-1} \tag{1-9}$$

The number of customers in Pre-Check Entrance service system:

$$L_s = L_q + \frac{\lambda}{\mu} = \frac{\left(\frac{c\rho}{1+\beta}\right)^{\frac{c}{1+\beta}} \cdot \rho}{\left(\frac{c}{1+\beta}\right)!(1-\rho)^2} \cdot \left[\sum_{k=0}^{\frac{c}{1+\beta}-1} \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c}{1+\beta}} \right]^{-1} + \frac{\lambda}{\mu} \tag{1-10}$$

Average waiting time in Pre-Check Entrance service system is:

$$W_q = \frac{L_q}{\lambda} = \frac{\left(\frac{c\rho}{1+\beta}\right)^{\frac{c}{1+\beta}} \cdot \rho}{\left(\frac{c}{1+\beta}\right)!(1-\rho)^2 \lambda} \cdot \left[\sum_{k=0}^{\frac{c}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c}{1+\beta}}\right]^{-1} \tag{1-11}$$

Average time spent in the Pre-Check Entrance queuing system:

$$W_s = \frac{L_s}{\lambda} = \frac{\left(\frac{c\rho}{1+\beta}\right)^{\frac{c}{1+\beta}} \cdot \rho}{\left(\frac{c}{1+\beta}\right)!(1-\rho)^2 \lambda} \cdot \left[\sum_{k=0}^{\frac{c}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c}{1+\beta}}\right]^{-1} + \frac{1}{\mu} \tag{1-12}$$

The same indicators of Regular-Check Entrance service system can be obtained in Zone A.

According to the equation in the standard queuing model M/M/c/∞/∞, the corresponding indexes of the Regular-Check Entrance queuing system in Zone A are derived as follows:

The Probability of Regular-Check Entrance system being in idle state in Zone A is:

$$P_0 = \left[\sum_{k=0}^{\frac{\beta c}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} \tag{1-13}$$

Average queue length in Pre-Check Entrance service system is:

$$L_q = \frac{\left(\frac{c\rho\beta}{1+\beta}\right)^{\frac{c\beta}{1+\beta}} \cdot \rho}{\left(\frac{c\beta}{1+\beta}\right)!(1-\rho)^2} P_0 = \frac{\left(\frac{c\rho\beta}{1+\beta}\right)^{\frac{c\beta}{1+\beta}} \cdot \rho}{\left(\frac{c\beta}{1+\beta}\right)!(1-\rho)^2} \cdot \left[\sum_{k=0}^{\frac{c\beta}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} \tag{1-14}$$

The number of customers in Pre-Check Entrance service system:

$$L_s = L_q + \frac{\lambda}{\mu} = \frac{\left(\frac{c\rho\beta}{1+\beta}\right)^{\frac{c\beta}{1+\beta}} \cdot \rho}{\left(\frac{c\beta}{1+\beta}\right)!(1-\rho)^2} \cdot \left[\sum_{k=0}^{\frac{c\beta}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} + \frac{\lambda}{\mu} \tag{1-15}$$

Average waiting time in Pre-Check Entrance service system is:

$$W_q = \frac{L_q}{\lambda} = \frac{\left(\frac{c\rho\beta}{1+\beta}\right)^{\frac{c\beta}{1+\beta}} \cdot \rho}{\left(\frac{c\beta}{1+\beta}\right)!(1-\rho)^2 \lambda} \cdot \left[\sum_{k=0}^{\frac{c\beta}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} \tag{1-16}$$

Average time the passenger spent in the Pre-Check Entrance queuing system:

$$W_s = \frac{L_s}{\lambda} = \frac{\left(\frac{c\rho\beta}{1+\beta}\right)^{\frac{c\beta}{1+\beta}} \cdot \rho}{\left(\frac{c\beta}{1+\beta}\right)!(1-\rho)^2 \lambda} \cdot \left[\sum_{k=0}^{\frac{c\beta}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{1}{1-\rho} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} + \frac{1}{\mu} \tag{1-17}$$

System service strength ρ:

$$\rho = \frac{\lambda}{c\mu} \tag{1-18}$$

Substituting Equation (1-18) into Equation (1-19):

$$W_s = \frac{L_s}{\lambda} = \frac{\left(\frac{\lambda\beta}{(1+\beta)\mu}\right)^{\frac{c\beta}{1+\beta}} \cdot c\mu}{\left(\frac{c\beta}{1+\beta}\right)!(c\mu-\lambda)^2} \cdot \left[\sum_{k=0}^{\frac{c\beta}{1+\beta}-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \left(\frac{1+\beta}{c\beta}\right)! \cdot \frac{c\mu}{c\mu-\lambda} \cdot \left(\frac{\lambda}{\mu}\right)^{\frac{c\beta}{1+\beta}}\right]^{-1} + \frac{1}{\mu} \tag{1-19}$$

The variables in Equation (1-19) are c, μ and β, λ is a constant.

1.4. Parameters Calculation

Analyzing the relative information of Pre-Check Entrance in Zone A:

a) Nearly 45% of passengers register for a project called a pre-screening for a reliable passenger [3].

b) These passengers need to pay $ 85 for background checks and are eligible for a five-year separate inspection process; Pre-Check passengers and their baggage pass the same inspection process with Regular-Check which just make some improvements in the speed of the design compared to the Regular-Check process.

c) Pre-Check passengers need to remove electronic and medical equipment and fluids for inspection without removing shoes, belts, thin jackets, or removing the computer from the bag.

Set λ_{A1} as the average arrival rate of Pre-Check customers, μ_{A1} as the average service rate of the customer, ρ_{A1} as the service intensity;

λ_{A2} as the average arrival rate of Pre-Check customers, μ_{A2} as the average service rate of the customer, ρ_{A2} as the service intensity;

- For Pre-Check Entrance:

The average arrival time of the customer: (second/person)

$$523.80/57 = 9.19\ \text{s/p} \tag{1-20}$$

Average customer arrival rate: (person/hour)

$$\lambda_{A1} = 57/523.80 = 0.11\ \text{p/s} = 396\ \text{p/h} \tag{1-21}$$

Average customer service times:

$$97/9 = 10.78\ \text{s/p} \tag{1-22}$$

Average customer service rate:

$$\mu_{A1} = 9/97 = 0.09\ \text{p/s} = 324\ \text{p/h} \tag{1-23}$$

- For Regular-Check Entrance:

The average time of arrival of the customer:

$$596.10/46 = 12.96\ \text{s/p} \tag{1-24}$$

The average customer arrival rate:

$$\lambda_{A2} = 47/596.10 = 0.08\ \text{p/s} = 288\ \text{p/h} \tag{1-25}$$

Average customer service times:

$$99.5/7 = 14.21\ \text{s/p} \tag{1-26}$$

Average customer service rate:

$$\mu_{A2} = 7/99.5 = 0.07\ \text{p/s} = 252\ \text{p/h} \tag{1-27}$$

Assumed that the arrival time interval of Pre-Check customers obeys Poisson distribution, which can be obtained C_1 = 1, C_2 = 3 from **Figure 1**: Illustration of the TSA Security Screening Process.

According to the M/M/C model, we can see that the Pre-Check queuing system in accord with the standard M/M/1 model:

$$\rho_{A1} = \frac{\lambda_{A1}}{C_1\mu_{A1}} = \frac{396}{324} = 1.22 > 1 \tag{1-28}$$

Pre-Check Entrance queue will be discharged to infinite, Pre-Check personnel in TSA will be 100% busy.

Similarly, according to the M/M/C model, we can see that the regular-check queuing system accord with the standard M/M/c model:

$$\rho_{A2} = \frac{\lambda_{A2}}{C_2\mu_{A2}} = \frac{288}{3\times 252} = 0.38 < 1 \tag{1-29}$$

And the probability that the TSA personnel in Regular-Check in idle state can be obtained by Equation (1-11):

$$P_0 = \left[\sum_{k=0}^{c-1} \frac{1}{k!} \left(\frac{\lambda}{\mu} \right)^k + \frac{1}{c!} \cdot \frac{1}{1-\rho_{A2}} \cdot \left(\frac{\lambda}{\mu} \right)^c \right]^{-1} \tag{1-30}$$

So $P_0 = 0.31$, that is Regular-Check in the TSA staff will be 69% of the time in the busy state, 31% of the time in the idle state.

The operation indexes of regular-check system are as follows:

Average queue length:

$$L_q = \frac{(c\rho_{A2})^c \rho_{A2}}{c!(1-\rho_{A2})^2} P_0 = \frac{(3 \times 0.38)^3 \times 0.38}{3!(1-0.38)^2} \times 0.31 = 0.08 \text{ Person} \tag{1-31}$$

Average Captain:

$$L_s = L_q + \frac{\lambda}{\mu} = 1.22 \text{ Person} \tag{1-32}$$

Average waiting time:

$$W_q = \frac{L_q}{\lambda} = \frac{0.08}{0.08} = 1 \text{ Second} \tag{1-33}$$

Average length of stay:

$$W_s = \frac{L_s}{\lambda} = \frac{1.22}{0.08} = 15.25 \text{ Second} \tag{1-34}$$

- In Zone B: Baggage and Body Screening queuing system

Set λ_B as the average arrival rate of Pre-Check customers, μ_B as the average service rate of the customer, ρ_B as the service intensity; Take the average customer arrival rate of customers into the security system as the average customer arrival rate of Zone B, which can be got by sum the average customer arrival rate of Pre-Check Entrance and the average customer arrival rate of Regular-Check Entrance; Since baggage check and body check are carried out simultaneously in Zone B, it is necessary to use the maximum value between these two time as the customer service time of B queuing system. Because the time of baggage check is longer than body check, the mean of the time to get scanned property in Zone B is approximated as the average service rate of the B queuing system μ_B.

The average arrival rate of customers in Pre-Check Entrance λ_{A1} and the average arrival rate of customers in Regular-Check Entrance λ_{A2} can be used to obtain the average customer arrival rate of Zone B:

$$\lambda_B = \lambda_{A1} + \lambda_{A2} = 676 \text{ p/h} \tag{1-35}$$

among them

$$\lambda_{A1} = 396 \text{ p/h}, \lambda_{A2} = 280 \text{ p/h} \tag{1-36}$$

This can be calculated customer Baggage-Check in Zone B

Average service time:

$$830/29 = 28.62 \text{ s/p} \tag{1-37}$$

Average service rate:

$$\mu_B = 29/830 = 0.03 \text{ p/s} = 108 \text{ p/h} \tag{1-38}$$

Assumed Zone B: Baggage and Body Screening time accord with Poisson distribution, the number of devices can be seen from Figure 1 $c = 4$.

According to the M/M/C model, we can see that the queuing system in Zone B accord with the standard M/M/4 model:

$$\rho_B = \frac{\lambda_B}{c\mu_B} = \frac{880}{4 \times 108} = 2.04 > 1 \tag{1-39}$$

Pre-Check Entrance queue will be discharged to infinite, Pre-Check personnel in TSA will be 100% of the time in busy state.

1.5. Conclusion

1) In actual life, the proportion of Pre-Check Entrance and Regular-Check Entrance is smaller, so the number of Pre-Check Entrance cannot meet the needs of customers, which leads to the phenomenon of infinite queuing;

2) Under the assumption that the A Zone queuing system meets the standards of the M/M/c queuing model, the service personnel working strength calculation shows that security personnel of SAT Pre-Check queuing system will have been busy. According to queuing theory model (1 - 9) can be seen that the average arrival rate of customers and the average service rate are fixed. In order to reduce service strength can only through changing the number of C, that is, increasing the number of security personnel can solve the bottlenecks of the service system.

3) In the Zone B, from the Equation (1-39) can be seen, to solve the problem of infinite queue need to increase the value of c and μ_B, that is, it need to increase the number of devices or reduce the average service time of the package inspection.

2. Methods to Improve Passenger Throughput and Reduce Variance in Wait Time

2.1. The Questions We Face

Two or more potential modifications to the current process must be built to improve passenger throughput and reduce variance in wait time. And the model must reflect the influence of the change of parameters on the airport security check process.

2.2. Our Approach

a) The method to increase passenger throughput in the security check service system is equal to reduce the time of customer stay in the system or increase the number c of security channels, analyze the relationship between W_s and other variables;

b) The method to reduce variance in wait time is equal to reduce the average time of customer stay in the Pre-Check Entrance service system and Regular-Check Entrance service system in Zone A, and reduce the average time of Baggage Screening and Body Screening in Zone B.

2.3. Solving Process

1) Analysis of the relationship between W_s and the variable c

For the analysis of the change regularity of W_s with variable c, we take β, μ as constant. By the Little equation, analysis of the change regularity of W_s with variable c is equivalent to the analysis of the changing rules of L_s in Equation (1-3) with the variable c.

Firstly, analysis variation of P_0 with variable c, the specific analysis process is as follows:

Let

$$P'(c)=\left[P_0(c)\right]^{-1}=\sum_{k=0}^{c-1}\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k+\frac{1}{c!}\cdot\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^c \tag{2-1}$$

Then,

$$\begin{aligned}P'(c+1)-P'(c)&=\sum_{k=0}^{c}\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k+\frac{1}{(c+1)!}\cdot\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^{c+1}\\&\quad-\sum_{k=0}^{c-1}\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k+\frac{1}{c!}\cdot\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^c\\&=\frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c+\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^c\left[\frac{1}{(c+1)!}\frac{\lambda}{\mu}-\frac{1}{c!}\right]\\&=\frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c+\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^c\cdot\frac{1}{c!}\cdot\left(\frac{\lambda}{c\mu}-1\right)\\&=\frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c\left[1+\frac{1}{1-\rho}\left(\frac{\lambda}{c\mu}-1\right)\right]\\&=0\end{aligned} \tag{2-2}$$

That is,

$$P'(c+1)=P'(c) \tag{2-3}$$

Therefore, it can be seen that the value of P_0 has nothing to do with c.

Secondly, let

$$Q(c)=\frac{(c\rho)^c\rho}{c!(1-\rho)^2}=\frac{\left(\frac{\lambda}{\mu}\right)^c}{c!\left(1-\frac{\lambda}{c\mu}\right)^2} \tag{2-4}$$

Then,

$$Q(c+1)=\frac{\left(\frac{\lambda}{\mu}\right)^{c+1}}{(c+1)!\left(1-\frac{\lambda}{(c+1)\mu}\right)^2} \tag{2-5}$$

Then,

$$\frac{Q(c)}{Q(c+1)}=\frac{\dfrac{\left(\frac{\lambda}{\mu}\right)^{c}}{c!\left(1-\frac{\lambda}{c\mu}\right)^{2}}}{\dfrac{\left(\frac{\lambda}{\mu}\right)^{c+1}}{(c+1)!\left(1-\frac{\lambda}{(c+1)\mu}\right)^{2}}}=\frac{\mu}{\lambda}\cdot\frac{c^{2}}{c+1}\cdot\left[\frac{(c+1)\mu-\lambda}{c\mu-\lambda}\right]^{2} \tag{2-6}$$

- **Discussion and analysis**

a) when $c=1$, the average arrival rate of customers in Pre-Check Entrance is: $\lambda_{A1}=0.11\ \text{p/s}$ (one person per second, p/s),the average customer service rate is: $\mu_{A1}=0.09\ \text{p/s}$, take them into Equation (2-6), we got $\frac{Q(c)}{Q(c+1)}=5.01>1$;

b) when $c>1$, for $(c+1)\mu-\lambda>c\mu-\lambda$, then $\left[\frac{(c+1)\mu-\lambda}{c\mu-\lambda}\right]^{2}>1$, therefore, $\frac{Q(c)}{Q(c+1)}>\frac{\mu}{\lambda}\cdot\frac{c^{2}}{c+1}$, obviously, we can see Equation (2-7) is a monotonically increasing function,

$$\frac{c^{2}}{c+1}=\frac{1}{\frac{1}{c}+\frac{1}{c^{2}}} \tag{2-7}$$

As a result, when $c=2$, we can get the minimize value 4/3, then $\frac{Q(c)}{Q(c+1)}\geq\frac{Q(2)}{Q(2+1)}>\frac{\mu}{\lambda}\cdot\frac{4}{3}\cdot 1$.

The average arrival rate of customers in Pre-Check Entrance is:

$$\lambda_{A1}=0.11\ \text{p/s};$$

The average customer service rate is:

$$\mu_{A1}=0.09\ \text{p/s};$$

We can get,

$$\frac{Q(c)}{Q(c+1)}>1.$$

- **Conclusion**

Since $Q(c)$ is a monotonically decreasing function, it can be seen that the value of P_0 has nothing to do with c. Therefore, L_q is monotone decreasing function with variable c.

Additionally,

$$W_s=\frac{L_q}{\lambda}+\frac{1}{\mu} \tag{2-8}$$

Then we can get W_s is monotone decreasing function with variable c.

Therefore, increasing the number of c that the time of customers stay in the service system can be reduced, which can increase the passenger throughput in

Pre-Check Entrance service system in Zone A.

2) Analysis of the relationship between W_q and the variable c

For

$$W_q = \frac{L_q}{\lambda} \tag{2-9}$$

We can get, W_q is monotone decreasing function with variable c. Therefore, increasing the number c of TSA agents, the average waiting time of the customers in the system can be shortened.

3) Analysis of the relationship between W_s and the variable μ

For the analysis of the change regularity of W_s with variable μ, take β, λ as one constant. By the Little equation, analysis of the change regularity of W_s with variable μ is equivalent to the analysis of the changing rules of L_s in Equation (2-3) with the variable μ.

Firstly, analysis variation of P_0 with variable μ, the specific analysis process is as follows:

a) when $c=1$, it is satisfied the standard queuing theory model M/M/1/∞/∞, for the Little equation,

$$W_s = \frac{1}{\mu - \lambda} \tag{2-10}$$

We can get that W_s is monotone decreasing function with variable μ.

b) when $c>1$,

$$P_0(\mu) = \left[\sum_{k=0}^{c-1} \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \frac{1}{c!}\cdot\frac{1}{1-\rho}\cdot\left(\frac{\lambda}{\mu}\right)^c\right]^{-1} \tag{2-11}$$

$$Q(\mu) = \frac{(c\rho)^c \rho}{c!(1-\rho)^2} = \frac{\left(\frac{\lambda}{\mu}\right)^c \frac{\lambda}{c\mu}}{c!\left(1-\frac{\lambda}{c\mu}\right)^2} = \frac{\lambda^{c+1}}{c!c\mu^{c-1}\left(\mu - \frac{\lambda}{c}\right)^2} \tag{2-12}$$

Obviously, $Q(\mu)$ is a monotone decreasing function with respect to the variable μ.

According to Equation (2-12),

$$W_s = \frac{Q(\mu)\cdot P_0(\mu)}{\lambda} + \frac{1}{\mu} \tag{2-13}$$

and

$$\begin{aligned} W_s &= \frac{Q(\mu)\cdot P_0(\mu)}{\lambda} + \frac{1}{\mu} \\ &= \frac{(c\rho)^c \rho}{\sum_{k=0}^{c-1} \frac{c!}{k!}\cdot(1-\rho)\cdot\left(\frac{\lambda}{\mu}\right) + (1-\rho)\left(\frac{\lambda}{\mu}\right)^c} + \frac{1}{\mu} \\ &= \frac{1}{c}\cdot\frac{1}{\sum_{k=0}^{c-1} \frac{c!}{k!}\cdot\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{\lambda}{c\mu}\right)^{k-c-1} + \left(1-\frac{\lambda}{c\mu}\right)\left(\frac{\lambda}{\mu}\right)^{-1}} + \frac{1}{\mu} \end{aligned} \tag{2-14}$$

Let

$$h(\mu)=\sum_{k=0}^{c-1}\frac{c!}{k!}\cdot\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{\lambda}{c\mu}\right)^{k-c-1}+\left(1-\frac{\lambda}{c\mu}\right)\left(\frac{\lambda}{\mu}\right)^{-1}$$
$$=\sum_{k=0}^{c-1}\frac{c!}{k!}\cdot\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{\lambda}{c\mu}\right)^{k-c-1}+\left(\frac{\mu}{\lambda}-\frac{1}{c}\right) \tag{2-15}$$

make $\mu'>\mu$,

$$h(\mu')-h(\mu)=\sum_{k=0}^{c-1}\frac{c!}{k!}\cdot\left(1-\frac{\lambda}{c\mu'}\right)^2\cdot\left(\frac{\lambda}{c\mu'}\right)^{k-c-1}+\left(\frac{\mu'}{\lambda}-\frac{1}{c}\right)$$
$$-\sum_{k=0}^{c-1}\frac{c!}{k!}\cdot\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{\lambda}{c\mu}\right)^{k-c-1}+\left(\frac{\mu}{\lambda}-\frac{1}{c}\right)$$
$$=c!\cdot\lambda^{k-c-1}\sum_{k=0}^{c-1}\frac{1}{k!}\left[\left(1-\frac{\lambda}{c\mu'}\right)^2\cdot\left(\frac{1}{c\mu'}\right)^{k-c-1}\right.$$
$$\left.-\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{1}{c\mu}\right)^{k-c-1}\right]+\frac{\mu'-\mu}{\lambda} \tag{2-16}$$

for $\mu'>\mu$, so $\mu'-\mu>0$ and $c!\cdot\lambda^{k-c-1}>0$.

Let

$$g(\mu)=\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{1}{c\mu}\right)^{k-c-1} \tag{2-17}$$

Then,

$$\frac{g(\mu')}{g(\mu)}=\frac{\left(1-\frac{\lambda}{c\mu'}\right)^2\cdot\left(\frac{1}{c\mu'}\right)^{k-c-1}}{\left(1-\frac{\lambda}{c\mu}\right)^2\cdot\left(\frac{1}{c\mu}\right)^{k-c-1}}=\left(\frac{c\mu'-\lambda}{c\mu-\lambda}\right)^2\cdot\left(\frac{\mu}{\mu'}\right)^{k-(c-1)} \tag{2-18}$$

Because, $\mu'>\mu$, $k\le c-1$, so that, $c\mu'-\lambda>c\mu-\lambda$, then, $\frac{c\mu'-\lambda}{c\mu-\lambda}>1$ and $\frac{\mu}{\mu'}<1$ for $k-(c-1)\le 0$, so that $\frac{g(\mu')}{g(\mu)}>1$, $h(\mu')-h(\mu)>0$, then we can get $h(\mu)$ is an increasing function, taking $h(\mu)$ to the equation W_s,we know that W_s is a monotone decreasing function with respect to the variable μ. Which also means L_s is a monotone decreasing function with respect to the variable μ. Therefore, reducing the average service time of the customer in the service system is equivalent to increasing the throughput of customers in Pre-Check Entrance service system in Zone A.

4) To analysis the relationship between W_q and the variable μ in the similar way.

For

$$W_q=\frac{L_q}{\lambda} \tag{2-19}$$

We can get W_q is a monotone decreasing function with respect to the variable μ. Thus reducing μ is to reduce the average waiting time of the customer in the service system.

2.4. Conclusion

- For Zone A:Regular-Check Entrance

1) In Regular-Check Entrance service system, increasing the number c of SAT agents or reducing the average service time can reduce the time of customer stay in the service system, and increase the throughput of customers in Regular-Check Entrance service system.

2) For the average service time for customers in Pre-Check Entrance service system is less than the Regular-Check Entrance service system, we can increase the number c of SAT agents or reducing the average service time in Regular-Check Entrance to reduce the waiting time variance between Pre-Check Entrance service system with Regular-Check Entrance service system.

- For Zone B:Baggage and Body Screening

According to equations of the standard queuing model M/M/c/∞/∞, the corresponding indexes of the Regular-Check Entrance queuing system in Zone B are derived as Equations (1-1)-(1-5);

The following conclusions can be drawn:

1) For the Baggage and Body Screening service system in Zone B, It can be proved that W_s and W_q are monotone decreasing functions of variable c; increasing the number c of their checkpoint equipment in Zone B can reduce the stay time of customers in the service system, which can increase the throughput of customers in Baggage and Body Screening service system in Zone B;

2) To reduce the average waiting time variance between Baggage Screening service system with Body Screening service system, we can increase the number c of checkpoint equipment (or SAT agent) or reduce the average service time for each customer.

3) For the Baggage and Body Screening service system in Zone B, we take c, λ as a constant in Equations ((1-1), (1-2) and (1-5)), W_s and W_q are monotone decreasing functions about the variable μ; in order to increase the throughput of customers in Baggage and Body Screening service system, we can reduce the average service time for customer.

3. The Influence of Culture Variance

According to equations of the standard queuing model M/M/c/∞/∞, the corresponding indexes of the Regular-Check Entrance queuing system in Zone A and Zone B are calculated, we take parts of variables in Equation (1-19) as a constant which value are given in 1.4 Parameters Calculation, while analyzing the relationship between W_s and variables μ and β in different situation. Then we use Matlab soft to show the relationship between the average service rate μ of the customer and the average stay time of the customer in the security system in the case of changes in the number of security personnel and the relationship between the average stay time of passengers in the system W_s and the ratio of pre-check and regular-check β.

Sensitivity Analysis

Figure 2 shows the relationship between the average service rate μ of the customer and the average stay time of the customer in the security system in the case of changes in the number of security personnel.

From the chart one, we can see that when the number of security personnel is a fixed value, customer average stay time in security system decreases with the increase of average customer service rate. When c increases, the average stay time decreased. When c increased from 4 to 8, the average customer staying time decreased obviously. However, when c increased from 8 to 12, the average staying time of the customers is basically unchanged.

This can be seen:

1) The increase of average service rate is inversely proportional to the average stay time of customers, that is, the average service time of customers is proportional to the average stay time. Therefore, reducing the average service time of customers can significantly reduce the average stay time of customers in the system and increase the customer throughput of the airport.

2) When c is small, increasing the value of c can significantly reduce the service time of customers in the system; when c is large, the increase has little effect on stay time of customers. From a practical point of view, we can see that when the number of security personnel is little, security personnel has less free time. When the c reaches a certain value, the increase of the number of security personnel will cause redundant personnel, high security personnel idle rate, which result in cost loss to the airport.

Figure 3 shows the relationship between the average stay time of passengers in the system W_s and the ratio of pre-check and regular-check β. As can be seen from the figure, β and W is inversely proportional. So the passenger of regular-check security inspection mode into the channel of pre-check case can reduce the average stay time of customers in the security system effectively.

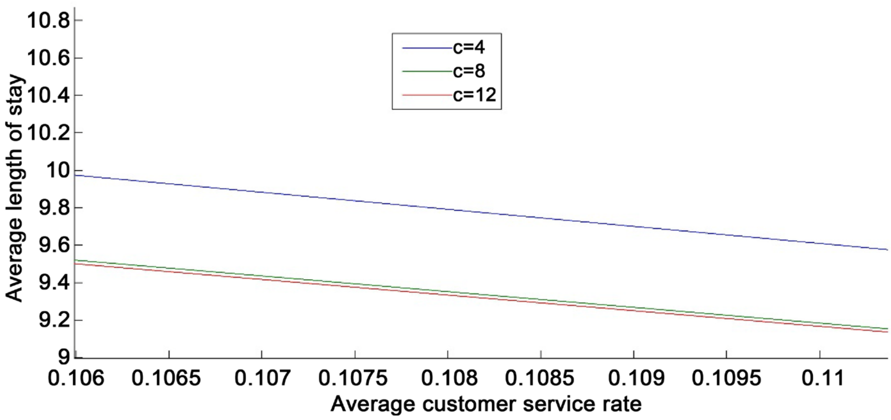

Figure 2. Sensitivity analysis.

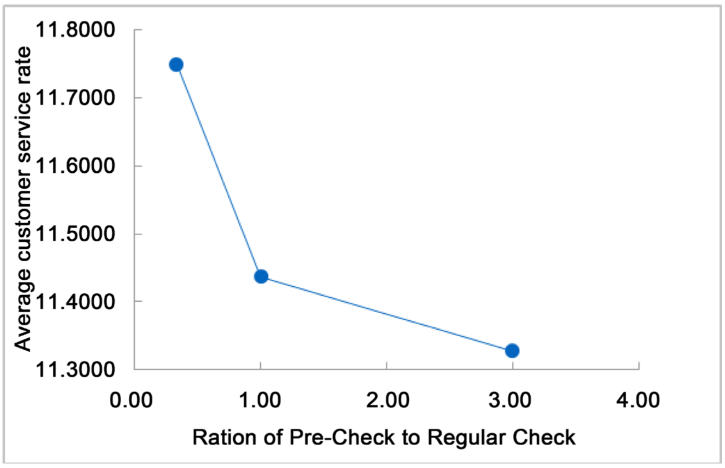

Figure 3. Sensitivity analysis.

From the above, we can see that the rate of W_s decreases is faster when the β is changed from 0 to 1; When W_s changed from 1 to 3, the rate of decline slowed down. Therefore, when the β reaches a certain value, increasing the proportion of pre-check security checks has little effect on the reduction of the average stay time of passenger in the system. From the actual situation, it has been able to meet the need of the number of customers which accept traveler's check pre trust plan when the pre-check security channel is enough. At this point, the increase of pre-check security channel will cause the increase idle probability of pre-check security channel, which is not conducive to improving the airport customer throughput.

1) Consider the collective efficiency as the priority principle

Queuing model with collective efficiency for priority consideration mainly aim to increase the number of passengers which is handled by security check. According to the conclusion of the second question, increasing the number of security equipment, the number of security personnel, and reduce equipment service time can meet the corresponding demand.

2) Consider private space as the priority principle

The main difference between normal queuing model and the queuing model considering private space as priority principle is the distance between people is longer. Thus, increasing the customer walk distance is equivalent to increase the average queue length of customers in the system and the time customer through security checkpoint costs. From Equation (2-8) can be seen, W_s is a monotonically increasing function of variable μ. Therefore, this is tantamount to reducing the passenger throughput.

Specific response measures

a) Increase the number of devices and security personnel

b) Reduce service time of equipment

c) Consider the individual efficiency as a priority principle

Consider personal efficiency as priority principle equivalent to the customer use pre-check security mode more frequently. It can be seen that increasing the number of security personnel of pre-check security and security equipment and improves the proportion of pre-check channel can improve the efficiency of individual effectively according to the second question (the number of).

The objective function (1) is to minimize the travel time, (2) is to minimize the number of death among all the refugees. Constraints (3) are the variable initialization. Constraints (4) ensues that all the refugees in the Middle East depart successfully. Constraints (5) determine the death in the flows of refugees. Constraints (6) (7) and (8) impose the refugees whose asylum requests are not be approved, and have to leave the current country to another available country. Constraints (9) restrict the total number of the refugees in Europe, and the number of the refugees crossing in current country, and refugees resettled are limited by Constraints (10) and (11). Constraints (12) define the scale of the refugees and constraints (13) ensure the range of parameters and variables.

4. Policy and Procedural Recommendations

Several Recommendations

1) The encourage policy to Pre-check security check mode

a) Popularize the knowledge of pre-check

b) Reduce pre-check security costs

c) Improve the proportion of pre-check channels

2) Increase the number of security equipment and service personnel, reduce security equipment service time

3) Reduce the length of service channel assess and weaknesses, and propose ideas for improvement (future work).

5. Strengths and Weaknesses

5.1. Strengths

Each model is discussed by using scientific and accurate methods and the relationship between each parameter and each variable is obtained.

This paper makes a sensitivity analysis of the customer's stay time in the system, and discusses the influence of each variable on the W_s and explained the reason of this effect from the practical point of view

5.2. Weaknesses

We only consider the relationship between each parameter and the individual variable by setting other variables as fixed value. But in the actual situation, each variable is constantly changing, and they have a better combination to optimize the parameters. This paper has not discussed their combinatorial optimization, so that the conclusion is non-optimal and we need to strengthen the research of this aspect in the future work.

6. Conclusions

In order to increase checkpoint throughput and reduce variance in waiting time, we divide the current process of a US airport security checkpoint into two phases: Zone A for Document Check by Pre-Check Entrance or Regular-Check Entrance, Zone B for Baggage and Body Screening. First, we analyze the type of the airport security process of the two phases, including the customer reach time interval distribution and service time distribution. Second, we check out the effect of a variable on objective function by set other variables to a fixed value. Through the test results, we can find the bottleneck of the security check process and take corresponding measures to improve the passenger throughput and reduce customer waiting time variance. Third, we discuss the effect of national cultural differences on the process of passages pass through checkpoint. And we give the corresponding suggestions to increase customer throughput to reduce the impact of cultural differences. Finally, we put forwards to strategies and measures that apply to the world in order to optimize airport security system process.

Through the analysis of the airport security process, we can provide reference for the airport to improve customer throughput. We will further improve the paper to meet the actual security process better.

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