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T2 ________		F2 ________
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Summary Sheet

Summary

The tension between desires to maximize security and convenience for passengers is a complex problem for the airport security checkpoint. This paper proposes 3 models to identify the bottlenecks of the passenger flowing and optimize the throughput with a low variance.

Firstly, we build a Multi-Line Model to figure out the bottlenecks of the passenger flowing in the airport security checkpoint. Passenger flow is divided into two basic processes in Zone A and Zone B. Both of them can be considered as a classical Multi Server Waiting Model (M/M/1) based on the Queuing Theory. We introduce the basic concept of M/M/1 and define 3 indicators to evaluate the flowing throughput and variance in wait time. We explore the passenger flowing process with the given data. The results show that the bottlenecks exist in Zone B, especially in the process of X-ray scanning.

Next, we consider the passenger types and build a Multi-Level Model to solve the problem in Zone B. We design a passenger classifying mechanism to specifically guide different passengers to enter the different lines of security scanning in Zone B. Both Multi-Level Model and Multi-Line Model are calculated with the data from the Terminal 1 of Beijing Capital International Airport. The results show that the Multi-Level Model successfully improves the throughput of the security checkpoint and reduce variance.

Then, we propose a Single-Line Model to further optimize the throughput of passenger flow. So the structure of the security checkpoint is revised. We set a control gate in front of lines in both Zone A and Zone B. Based on the characteristics of M/M/n system in the Queuing Theory, the Single-Line Model performs better than both Multi-Line Model and Multi-Level Model, which is also demonstrated by the results of calculation.

Finally, we perform a sensitivity analysis considering the ratio α of different passenger types and the efficiency factor e in different cultures. Both α and e will affect the variance and the average time passengers spent getting through the lines. Our simulation indicates that Single-Line Model has the best anti-jamming ability among all models when α or e changes.

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1 Introduction

As we all know, the security screening procedure has undergone significant change since September 11, 2001. Many airports have made considerable efforts to protect the nation from terrorist threats by policy improvement, equipment acquisitions and screening staff training. The Transportation Security Administration (TSA) was established to evaluate the security screening strategies and expand the list of potential threats. While these multifarious threats evaluations uncovered numerous terrorist attack, passengers and airports had to face the inevitable problem: endless long line. It was reported that Denver's airport had had the 10 busiest days in its history last summer. At Chicago O'Hare, passengers were stuck overnight in terminals after missing flights in May. The TSA has invested abundant capital in scanners and staff equipment, but these methods were not fit the diverse flow of passengers.

Check procedure optimization was put into a meaningful position to improve passenger throughput and reduce variance in wait time. This paper is intended to figure out the tension between security maximization and inconvenience minimization to passengers.

2 Assumptions

We make the following assumptions of the process in this paper.

- Suppose that passengers arrive independently and followed from to a Poisson distribution[6] with rate $\lambda > 0$.
- Assume the time spent in the ID check procedure conforms to a normal distribution with a very small variance.
- Millimeter Wave Scan time is generally consistent with the normal distribution.
- We neglect the passengers who fail to pass the security checkpoint.
- We assume that those who finish the X-ray scanning will not affect other passengers when packing their personal belongings.

3 A Model of Multi-Line Passenger Flowing

3.1 Multi-Line Passenger Flowing

3.1.1 Multi-Line Passenger Flowing Characteristics

This section focusses on exploring a general model of Multi-Line passenger flowing problems. By analyzing the data, we can figure out the bottleneck position of passenger throughput in the process of airport security.

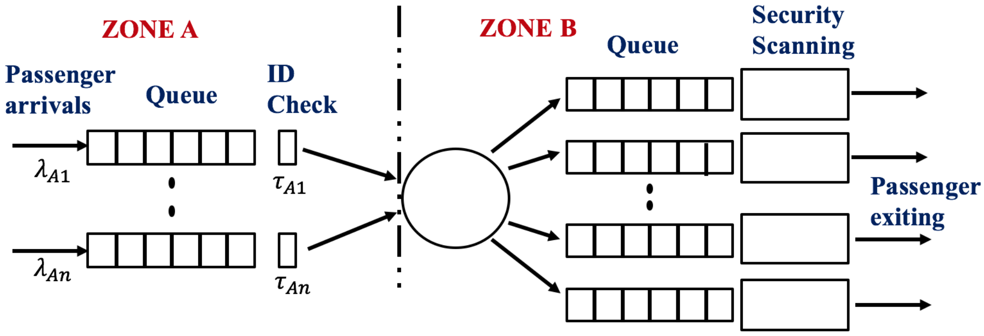


Figure 1: Porcess of Multi-Line Model

First of all, the security check process can be divided into two parts, which is illustrated in Figure 1.

The first part describes the events happening in the zone A. It includes passengers' random arrival, queuing in n lines and getting their identification inspected by the security officers. As the graph indicates, there are two key points in time and one period. One of the key time points is the passengers' arrival time t_{Ai}, and the number of coming passengers of each line per minute conforms to Poisson distribution with rate $\lambda_{Ai}, i = 1, 2, ..., n$. To simplify the model, we suppose that $\lambda_{A1} = \lambda_{A2} = ... = \lambda_{An}$.The other time point represents the accomplishment of identification check. The period between these two points includes queuing and identification, which are defined as $t_{Ai}, i = 1, 2, ...n$. According to the data given and the assumption above, $t_{Ai}(i = 1, 2, ..., n)$ conform to a same normal distribution with a very small variance.

The next part describes the events happening in zone B, where passengers line up m team, waiting for security scanning. The whole security scanning contains two parallel processes. After moving into the front of the queue, passengers prepare all of their belongings for X-ray screening, while they get through a millimeter wave scanner. However, in real life, passengers may have very different behaviors regarding to security scanning especially X-ray scanning. For example, passengers who flying for work usually carry less baggage and generally have more flight experience. On the contrary, there are some travelers, with less experience on their flights, tend to take longer time to pass X-ray scanning, and may require more guidance of the airport staff. So we divide passengers into j different categories. The proportions of these j types of passengers are $\alpha_1, \alpha_2, ..., \alpha_j$ respectively. The passengers then proceed to the conveyor belt on the other side of the X-ray scanner to collect their belongings and depart the security scanning area.

3.1.2 Model Building

As mentioned above, the Multi-Line Model contains two processes and each of them can be considered as a Multi server waiting model[2] (M/M/S) in Queuing Theory[3].

L_q(average number of queuing passengers), W_s (total time passengers cost) and $Var(t)$ (variance) are 3 key parameters to discribe this model. To compute these parameters, we firstly need to know the number of service stations s, the average passengers arriving per minute λ and the average-served passengers per minute μ.

Two parameters ρ and ρ_s are set to solve the model. Let $\rho = \frac{\lambda}{\mu}, \rho_s = \frac{\rho}{s} = \frac{\lambda}{s\mu}$. If $\rho_s \geq 1$,L_q, W_s and $Var(t)$ satisfy the following formula:

$$L_q = W_s = Var_s = \infty$$

This is because when $\lambda > s \cdot \mu$, the efficiency of service is less than the speed of the arrival of passengers, and ultimately, the queue's length will become infinite. However, when $\rho_s < 1$, the formulas of these parameters can be considered as:

$$L_q = \frac{c \cdot \rho_s}{1 - \rho_s} \tag{1}$$

$$L_s = L_q + \rho \tag{2}$$

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

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

$$Var(t) = (\mu - E(t))^2 \cdot e^{\rho} p_0 + \sum_{n=s+1}^{\infty} \frac{\rho^n}{n!} * p_0 \cdot ((n - s + 1) \cdot \mu - E(t))^2 \tag{5}$$

Intermediate parameters such as c and p_0 will be defined later.

To prove above conclusion, we firstly need to compute the possibility p_n of n passengers queuing or being served.

According to Queuing Theory, we have

$$p_0 = [\sum_{n=0}^{s-1} \frac{\rho^n}{n!} + \frac{\rho^s}{s!(1 - \rho^s)}]^{-1} \tag{6}$$

$$p_n = \begin{cases} \frac{\rho^n}{n!} p_0 & \text{n = 1, 2, ..., s} \\ \frac{\rho^n}{s! s^{n-s}} p_0 \cdot \mu & \text{n = s+1, s+2, ...} \end{cases} \tag{7}$$

Let $c = \frac{\rho^s}{s!(1-\rho_s)} p_0$, then:

$$L_q = \frac{c \cdot \rho_s}{1-\rho_s} \tag{8}$$

$$L_s = L_q + \rho \tag{9}$$

The time t from one's arrival to his leave is:

$$t = \begin{cases} \mu & \text{n = 1, 2, ..., s} \\ (i-s+1)\cdot\mu & \text{n = s+1, s+2, ...} \end{cases} \tag{10}$$

Finally, we get the average W_s and variance $Var(t)$ by t:

$$W_s = E(t) = \sum_{n=1}^{s} p_n \mu + \sum_{n=s+1}^{\infty} p_n \mu \cdot (n-s+1) = \frac{L_s}{\lambda} \tag{11}$$

$$W_q = W_s - \frac{1}{\mu} = \frac{L_q}{\lambda} \tag{12}$$

$$Var(t) = \sum_{n=1}^{s} p_n(\mu - E(t))^2 + \sum_{n=s+1}^{\infty} p_n((n-s+1)\cdot\mu - E(t))^2 \tag{13}$$

$$= (\mu - E(t))^2 \cdot \sum_{n=1}^{s} \frac{\rho^n}{n!} * p_0 + \sum_{n=s+1}^{\infty} \frac{\rho^n}{n!} * p_0 \cdot ((n-s+1)\cdot\mu - E(t))^2 \tag{14}$$

$$= (\mu - E(t))^2 \cdot e^{\rho} p_0 + \sum_{n=s+1}^{\infty} \frac{\rho^n}{n!} * p_0 \cdot ((n-s+1)\cdot\mu - E(t))^2 \tag{15}$$

Though variance $Var(t)$ can be solved mathematically and gracefully, we still use Brute Force method to calculate it directorly for convinience.

With regard to Multi-Line Model, parameters $\lambda_A, n_A, n_B, t_{ID}, t_{X1}, t_{X2}, t_{MMW}, \sigma_{t-mmw}$ and α are neccessary to research the model and solve the problem.

Zone A Zone A can be considered as a queuing system containing several independent M/M/1 subsystems, and the total number is s. For each service window, the average number of arrival passengers per unit time is λ/s ($\lambda = \lambda_A/n_A$, $\mu = \frac{1}{t_{ID}}$) . Substituting $s = 1$ into (8) (11) (15), we can get the value of L_{Aq}, W_{As} and Var_A.

Zone B In Zone B, parameter x_{MMW} is the time consumed for Milimeter Wave Scanning, and it obeys normal distribution.Parameters x_{X1} and x_{X2} represent X-ray Scanning time for experienced and inexperienced passengers respectively.

In addtion, we have

$$\lambda_B = \begin{cases} \frac{n_A}{t_{ID}} & \frac{\lambda_A}{n_A} > \frac{1}{t_{ID}} \\ \lambda_A \end{cases} \tag{16}$$

$$t_B = E(max(t_X, t_{MMW})) \tag{17}$$

$$= \alpha \cdot max(x_{X1}, x_{MMW}) + (1-\alpha) \cdot max(x_{X2}, x_{MMW}) \tag{18}$$

$$= \alpha * (t_{MMW} + normcdf(t_{X1}, t_{MMW}, \sigma_{MMW}) * (t_{X1} - t_{MMW})) \tag{19}$$

$$+ (1-\alpha) * (t_{MMW} + normcdf(t_{X2}, t_{MMW}, sigma_{MMW}) * (t_{X2} - t_{MMW})) \tag{20}$$

It should be noted that $normcdf(x, \mu, \sigma)$ is the Cumulative Distribution Function of Normal Function, with its mean μ and standard deviation σ. Substituting $\lambda = \lambda_B / n_B$,$\mu = \frac{1}{t_B}$ and $s = 1$ as before, L_{Bq}, W_{Bs} and Var_B can be calculated.

Combine After the calculation above, the results of Zone A and Zone B can be combined to get the overall evaluating parameters.

$$L_q = n_B * L_{Bq} + n_A * L_{Aq} \tag{21}$$

$$W_s = W_{As} + W_{Bs} \tag{22}$$

$$Var(t) = Var_A + Var_B \tag{23}$$

3.2 Model Calculating and Simplifying

3.2.1 Parameters Calculation

It's also significant to estimate the necessary parameters from the given statistical data and their hypothetical distribution mentioned above. In order to compute the parameters, we convert the given data to a frequency distribution histogram and curve-fit it by MATLAB.

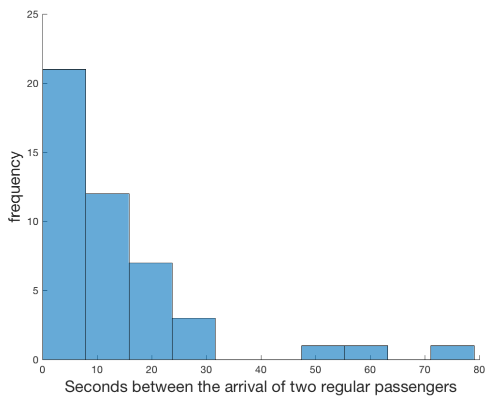


Figure 2: Passengers' arrival time

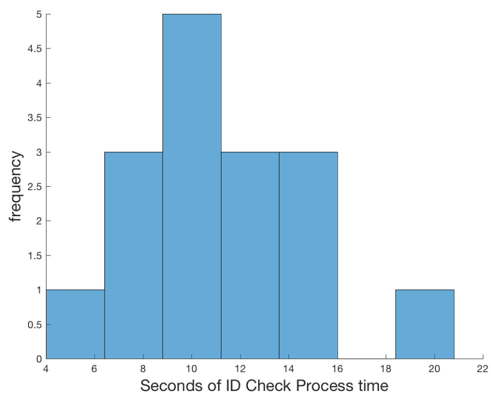


Figure 3: Service time distribution

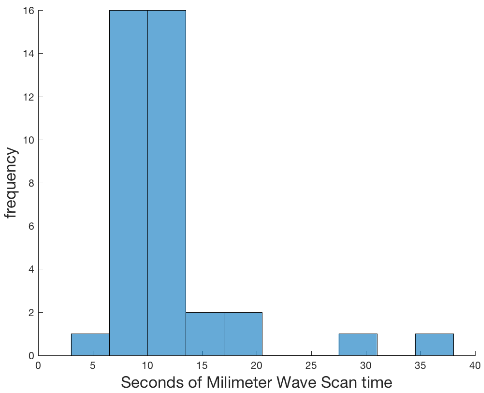


Figure 4: Millimeter Wave Scan time

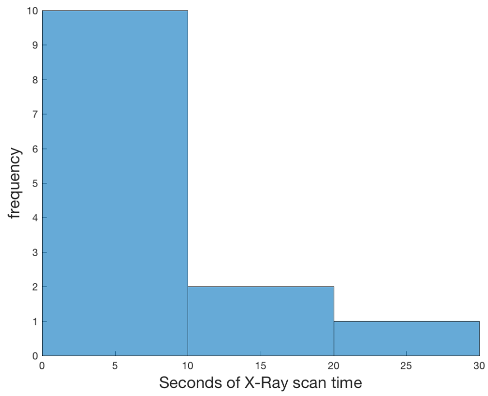


Figure 5: X-ray Scan time

Figure 2 is used to demonstrate passengers' arrival time. From this frequency histogram, we can see that the time interval between passengers arriving at the airport obeys the Poisson distribution. After curve fitting and calculation, we figure out that the value of λ_A is 9.6892.

Figure 3 depicts the service time distribution of ID checks, which can be seen following the normal distribution through the graph. The average service time of the ID inspection service is calculated by curve fitting, and the result is 11.3588.

Conclusion drawn from Figure 4 is that the Millimeter Wave Scan time is basically consistent with the above mentioned hypothesis of the normal distribution, and through the curve we compute that the mean is 11.6359. The figure shows that there are two data much larger than most of the data values, so we can think of these two events as small probability events. After removing the data of these two small probability events, the average value obtained is 10.568. Therefore, 10.568 is the corrected mean.

As to other parameters t_{XF} and t_{XP} , we firstly calculate the time X-ray Scan cost by the given data. It can be found that the numerical value of the data has obvious distribution rule. When these data are presented as frequency histograms, we notice that there is an obvious dividing line between the data. As the security scan description mentioned ,the smaller part of the data is considered as the time required for experienced passengers finishing the X-ray examination, whereas the larger values correspond to the time inexperienced passengers spend in this period. Setting whether the number is less than 3 as the boundary condition for data grouping, we can estimate that experienced passengers use 3.0413 seconds to pass the examination, while the others use the average of 10.5081 seconds.

All the parameters and their value mentioned above are shown in Table 1.

Parameter	Value
λ_A	9.6892
μ_A	11.3588
μ_M	11.6359
t_{XP}	3.0413
t_{XF}	10.5081

Table 1: Model parameters

3.2.2 Simplified Model Calculation

For ease of analysis, we simplify the model by setting the lines of ID-check and security-scanning as 2. Besides, we also categorize the passengers into two types: experienced one and inexperienced one, which account for α and (1-α) respectively. Finally, we set parameters n, m and j as 2 simultaneously, and finish building a simplified Multi-Line passenger flowing model.

In this condition, we combine the resulting parameters to solve the model. The results are listed in the Table 2.

Parameter	Value	Parameter	Value
L_{Aq}	0.702020	L_{Bq}	0.767168
W_{As}	14.305615	W_{Bs}	15.633186
Var_A	559.735354	Var_B	624.168357

Table 2: result of Multi-Line Model

3.2.3 Result Analysis

Analysis of the above data shows that under the given model, the expected queue length L_{Aq} is less than L_{Bq} of zone B. Besides, the time W_{As} for passengers entering zone A to finish the ID-check is less than W_{Bs} passengers spend queuing and completing the security-scanning in zone B.

In conclusion, under the established Multi-Line passenger flowing model, zone B is more likely to be the bottleneck of the passenger throughput due to the longer time spent in this area and the longer queue. All the conclusion is based on the assumption (n, m, j) = (2,2,2).

4 A Model of Multi-Level Passenger Flowing

4.1 Multi-Level Passenger Flowing

4.1.1 Multi-Level Passenger Flowing Characteristics

In order to build the Multi-Level passenger flowing model[1], we suppose that the database of aviation system contains the historical information of each passenger's flight. According to flight information, such as flight number and security records, we rate the passengers and classify them into j levels $Type_i(i = 1, 2, ..., j)$ based on the ratings. The proportion of $Type_i$ is $\alpha_i, i = 1, 2, ..., j$. We assume that there is a negative correlation between passengers' flight number and the time of X-ray scanning. That is, the more flight passengers take, the more familiar they are with aviation rules and security process and the less expectation time μ_{Xi} they spend on X-ray scanning.

In the above premise, we modify the new flow chart as shown in Figure 6

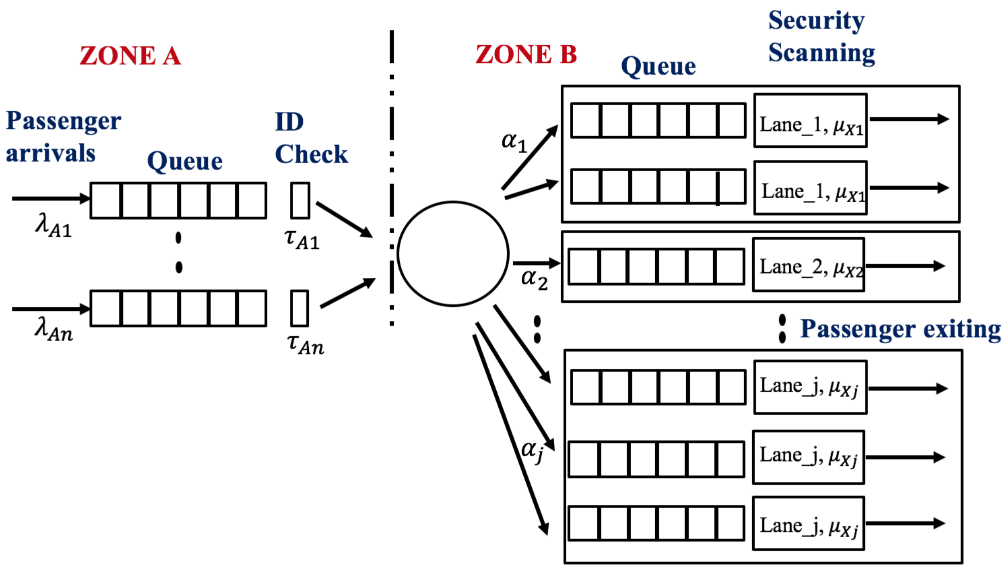


Figure 6: Porcess of Multi-Level Model

Assuming that the number of security lines in Zone B is m. We can divide these m lines into j types $line_1$, $line_2$, ... , $line_j$, considering the number of each level passengers and the average time they cost in scanning examination. The line number of $line_i$ is set to be m_i. To better explain the relationship of these quantity, we give the following equations.

$$m_i = k * mu_{Xi} * \alpha_i \qquad \text{i=1,2,...,j, and k is constant} \tag{24}$$

$$m = m_1 + m_2 + ... + m_j \tag{25}$$

In the Multi-Level passenger flowing model, we assume that passengers of $Type_i$ will be directed to a corresponding $line_i$ of m_i channels to complete the security procedure.

4.1.2 Model Building

As mentioned above, we express the proportion of two types of passengers as α and $1-\alpha$.

Besides, we have gotten the value of the parameters $t_{B1}, t_{B2}, t_{M1}, t_{M2}, t_{X1}, t_{X2}, \sigma_{M1}, \sigma_{M2}, n_{B1}$ and n_{B2} in the parameter calculation. According to the definition of α, we have the expression

$$\lambda_{B1} = \lambda_B * \alpha \tag{26}$$
$$\lambda = \lambda_{B1} \tag{27}$$

Combining

$$t_{B1} = t_{M1} + normcdf(t_{X1}, t_{M1}, \sigma_{M1}) \tag{28}$$
$$\mu = \frac{1}{t_{B1}} \tag{29}$$
$$s = n_{X1} \tag{30}$$

we can compute L_{Bq2} and Var_{B2}.

$\lambda_{B2}, t_{B2}, L_{Bq2}, W_{Bs2}$ and Var_{B2} can be computed with same methods. Finally, we have the total index of zone A and zone B.

$$L_{Bq} = L_{Bq1} + L_{Bq2} \tag{31}$$
$$W_{Bs} = \alpha W_{Bs1} + (1-\alpha) W_{Bs2} \tag{32}$$
$$Var_B = Var_{B1} + Var_{B2} \tag{33}$$

4.2 Model Calculating and Simplifying

4.2.1 Simplified Model Calculation

To facilitate the analysis, the above model will be simplified. Passenger's categories and proportion of each type are defined the same as those in mode1. Table 3 is the passenger throughput data and the number of safe passageways of Terminal 1 of Beijing Capital International Airport.

Terminal 1 Design Year Passenger throughput	9 million
Terminal 1 design peak-period passenger throughput	1500 passengers
Terminal 1 number of the security scanning lines	17

Table 3: Data of Beijing Capital International Airport[4].

From the data above, it can be calculated that interval λ_A of arriving passengers peak time is 2.4s, and we assume that the number of ID-check is the same as that of secure channels, with n = m = 17. The additional data are the same as the data mentioned in mode1. Under these conditions, the Multi-Line Model and Multi-Level Model are both calculated. The results are as follows:

Multi-Line Model	value	Multi-Level Model	value
L_{Aq1}	0.107411	L_{Aq2}	0.107411
W_{As1}	15.741174	W_{As2}	15.741174
Var_{A1}	241.006272	Var_{A2}	241.006272
L_{Bq1}	0.114553	L_{Bq2}	0.001709
W_{Bs1}	559.735354	W_{Bs2}	11.786194
Var_{B1}	259.578889	Var_{B2}	346.937239
L_{q1}	3.773395	L_{q2}	1.827698
W_{s1}	32.083453	W_{s2}	27.527368
Var	500.585161	Var	587.943511

Table 4: comparison of Multi-Line Model and Multi-Level Model

Single-Line-Model	Type1	Type2
L_{Bq}	0.000976	0.000734
W_{Bs}	8.828938	16.518112
$Var_B(t)$	75.994519	270.942720

Table 5: Result of Multi-Level Model in Zone B

4.2.2 Result Analysis

Comparing the results of Multi-Line Model and Multi-Level Model, the calculations of the two models are equal in Zone A, because there is no Multi-Level optimization in this region. After the Multi-Level optimization of the passenger flowing in Zone B, for Passenger1 who is familiar with the aviation rules and security processes, the variance and the average time spent in whole task(W_s) significantly reduce, while for Passenger2 those characteristics improve a little. As a result, W_s is significantly reduced in both Zone B and the whole process according to the Single-Line Model, while the variance becomes higher, which is due to the fact that Single-Line Model significantly improves the Passenger1's throughput.

5 A Model of Single-Line passenger Flowing

5.1 Single-Line passenger flowing

5.1.1 Single-Line Passenger Flowing Characteristics

According to queuing theory, M/M/n system is superior to the simple superposition of n M/M/1[5] systems. When adopting the model of Multi-Level passenger flowing, not only the queue length, queuing time and the variance of passenger flow time are reduced, but the potential bottleneck is solved to some extent .However, the M/M/n/(Infinity) queuing system still has more advantages. Therefore, this part will establish the model of Single-Line passenger flowing based on M/M/n queuing system.

To establish the Single-Line passenger flowing model, we need to improve the layout of the airport in Zone B. As shown in Figure **??**, we assume that there is a passenger

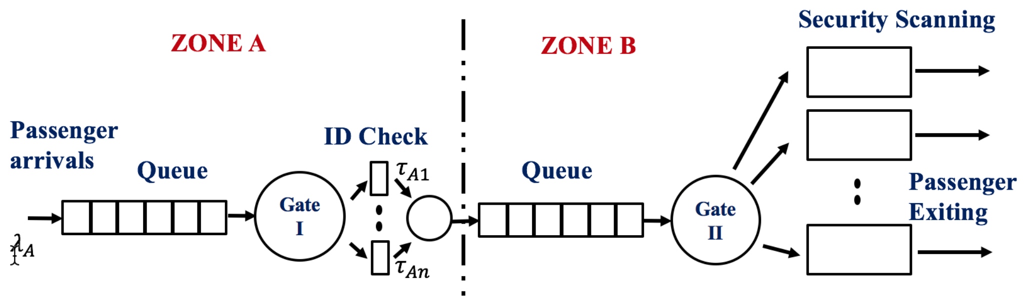


Figure 7: Porcess of Single-Line Model

security flow gate controlled by the airport staff. All passengers have to queue in front of this gate when arriving at Zone B. Only when there exists one or more empty security channels will the passengers be allowed to get through the gate. In this way, we achieve Single-Line passenger flowing model in the design. The classification of passengers still exists and the security examination time of different types of passengers named $\mu_X i$ is still of different value. However, we won't set dedicated lines for different types of passengers.

5.1.2 Model Building

- Zone A: To figure out parameters L_{Aq}, W_{As} and Var_A in Single-Line Model, we only need substitute $\lambda = \lambda_A, \mu = \frac{1}{t_{ID}}$ and $s = n_A$ into the expression of the M/M/S model analysis above.
- Zone B: The calculation method of λ_B and t_B is the same as that of Multi-Line Model and will not be repeated here.

With $\lambda = \lambda_B, \mu = \frac{1}{t_{ID}}$ and $s = n_B$ taken into the expression, the final results including L_{Bq}, W_{Bs} and Var_B can be calculated.

5.2 Model Calculating and Simplifying

5.2.1 Simplified Model Calculation

For easy analysis, we simplify the model as before. Categories and proportions of passengers are the same as Multi-Line Model, which indicates that experienced and inexperienced passengers occupy ratios of α and (1-α) respectively.

The analysis is still based on data from Terminal 1 of Beijing Capital International Airport.

5.2.2 Result Analysis

From the calculated data, Single-Line Model is superior to Multi-Line Model and Multi-Level Model in both zone A and zone B and the total results of zone A and zone B considering parameters of L_q and W_s. In addition, the variance of the time required for passengers to accept security is also significantly reduced in Single-Line Model. These show that compared to Multi-Line Model and Multi-Level Model, Single-Line Model has obvious advantages. It can be concluded that adding security control gate and setting single-queue Multi-Line mode are effective methods to improve throughput and reduce the variance of passenger security time.

6 Analysis

6.1 Sensitivity analysis

6.1.1 Passenger Type Ratio

In real life, the percentage of different types of passengers may be constantly changing. For example, during holidays, especially Christmas, there will be more passengers carrying more luggage, so the proportion of passengers who spend longer time through security checks will increase. In the working days, however, the proportion of business passengers will be larger. Parameter α represents the occupancy rate of the shorter time-consuming passengers. The Multi-Line Model and the Single-Line Model are used to analyze the sensitivity of the change of passenger type ratio. The results of L_q, W_s and Var of Multi-Line Model and Multi-Level Model are obtained and are demonstrated in the figure 8, 10 and 9.

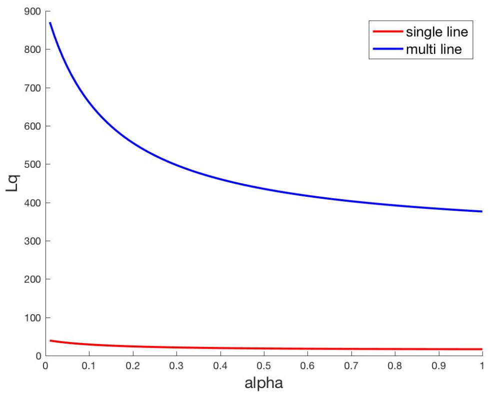


Figure 8: $L_q - alpha$ curve

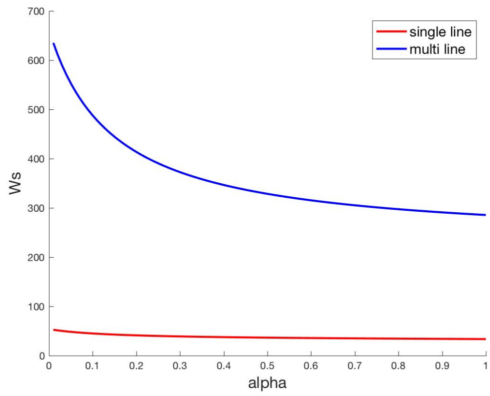


Figure 9: $W_s - alpha$ curve

It can be seen from the figure 8, 9 that for the entire passenger-flowing process, when α becomes larger, the values of L_q and W_s will be significantly reduced both in Multi-Line Model and Single-Line Model. This is due to the fact that the increase in the proportion of passengers with shorter time will significantly reduce the average time of receiving service and the length of queuing, ultimately improving throughput. This is in line with the actual. What is more important, however, is that for an arbitrary α, Single-Line Model's W_s and L_q values are less than Multi-Line Model, which further demonstrate the superiority of Single-Line Model in improving the throughput. In addition, Single-Line Model's throughput changed with α is significantly less than that of Multi-Line Model, further indicating the superiority of improving throughput in Single-Line Model.

Besides, It is shown in Figure 10 that the variance of Single-Line Model is significantly lower, demonstrating that in Single-Line Model, different types of passengers experience more consistent security examinations.

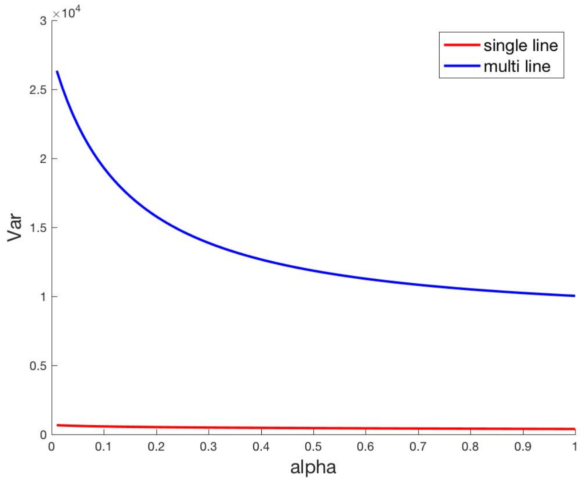


Figure 10: $Var - alpha$ curve

6.1.2 Different culture

Considering the different cultures, the airport security-scanning time usually exists some differences. Some countries that care less on high efficiency tend to have longer security-scanning time, and countries with a high level of personal efficiency values, such as Japan, may have shorter security checks. In addition, the severity of the security process varies from country to country. The more complicated security process to ensure safety also increases the time consumed. For example, America has much more detailed process compared to China. Therefore, in order to explore the sensitivity analysis of the model under different cultures, a new parameter e (negative efficiency factor) is introduced, and the higher the value of e is, the lower the efficiency is. The e is defined as 1 in the former parts of paper. The sensitivity analysis of Multi-Line Model and Single-Line Model on efficiency parameters is performed below in figure 11, 13 and 12,

Figure 11, 12 shows that the changes W_s and L_q in whole passenger-flowing process for both Multi-Line Model and Single-Line Model. When e becomes larger, the efficiency becomes low. The values of L_q and W_s are both increased, which is consistent with the actual situation. Similarly, Single-Line Model effectively improves the throughput. regardless of e. The value of W_s and L_q in Single-Line Model are less than Multi-Line Model. In addition, the change of L_q and W_s in Single-Line Model is much less than that

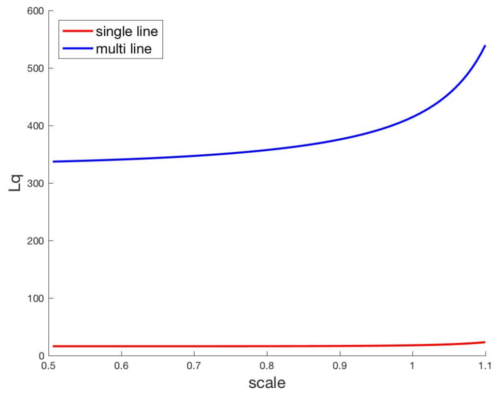


Figure 11: $L_q - scale$ curve

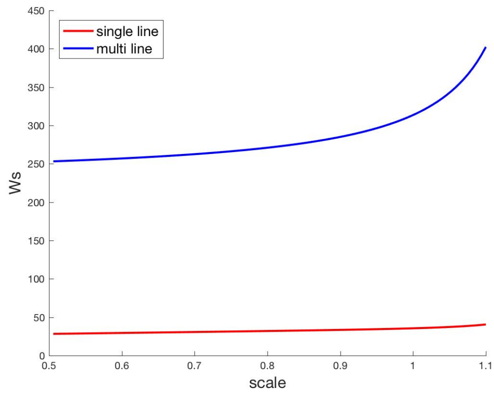


Figure 12: $W_s - scale$ curve

of Multi-Line Model as e becomes larger, which indicates that Single-Line Model has better anti-jamming ability for the different security efficiency of passengers of different cultural types.

Besides, It is shown in Figure 13 that the variance of Single-Line Model is significantly lower, demonstrating that in Single-Line Model,passengers in different cultures experience more consistent security examinations.

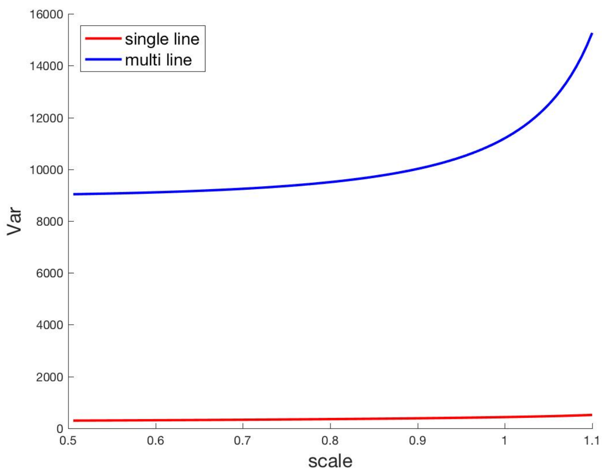


Figure 13: $Var - scale$ curve

7 Conclusion

7.1 Strengths

1. Based on the queuing theory, we set three models: Multi-Line Model (Multi-Line Model), Multi-Level Model (Multi-Level Model) and Single-Line Model (Single-Line Model). Multi-Line Model is abstracted from the reality of the given process,

while Multi-Level Model and Single-Line Model is the further optimization and improvement to it. This paper has proved that Single-Line Model is the best one for its high passenger flowing output and low stable variance.

2. Difference of passengers' behaviors are considered. We divide passengers into different types and give a further discussion on how their proportion changes influence our model. We have also proved that Single-Line Model is able to reduce the impact of it significantly.

3. Cultural impact is also mentioned. A new factor called efficiency factor is added to evaluate the difference of the security scanning time due to different culture.

7.2 Weaknesses

1. All of the passenger flowing models are simplified when calculating. For example, passengers are only divided into two categories while the behaviors are much more complicated in real life.

2. Some processes are neglected when building the model. We ignore the pre-checks, but they take really a large part actually in America. And the probability of the passenger failed to pass the security scanning is not considered, too.

3. When evaluating the Multi-Level Model and Single-Line Model, the economic effect is not mentioned.

7.3 Ideas for improvement

1. The case of passenger failing to pass the security scanning needs to be added into the process to give a more reliable model.

2. Considering the economic factors and space, the Single-Line Model can be adjusted. For example, one gate may control not all but several service windows and security scanning lines. However, their number and ratio need to be calculated with regard to the economic factors, space , throughput and variance.

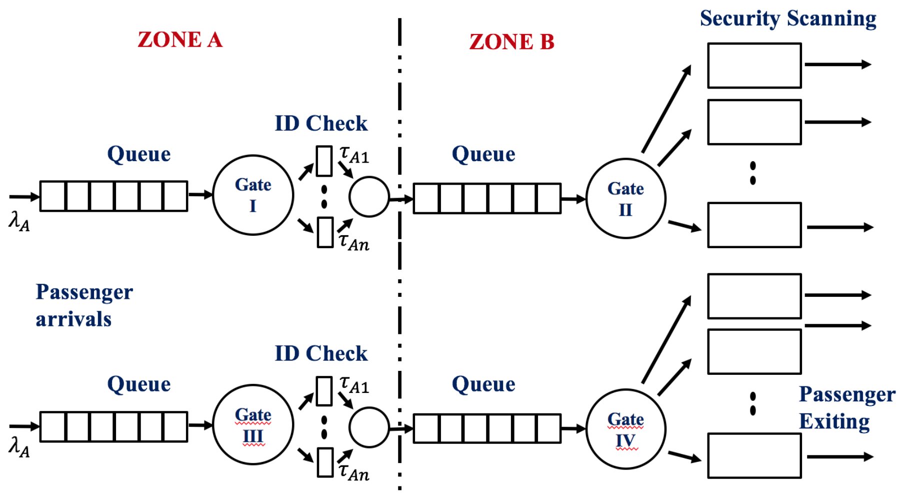


Figure 14: Process of ajusted Single-Line Model

8 Policy recommendation letter to the security managers of the airport

Dear security managers of the TSA:

During 2016, the U.S. Transportation Security Agency (TSA) came under sharp criticism for extremely long lines. According to the report, Large airports, such as O'Hare and small airports in some areas, incidents of unexplained and unpredicted long lines both occurs sometimes, which seriously affected the passenger's experience and the normal operation of the airport. Therefore, We made a number of policies and our policy recommendations consist of two aspects:

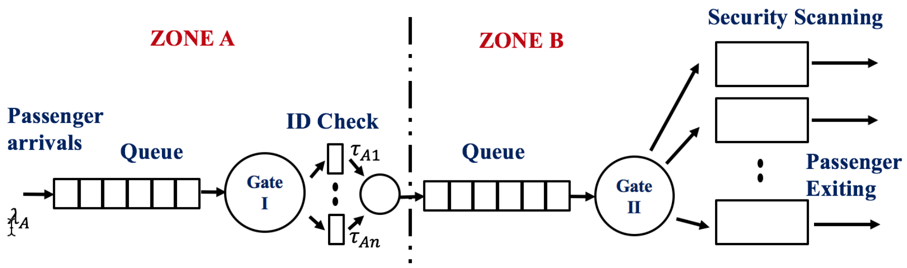
1. Changes of the airport security process structure

   Two new passenger flow control center(Gate I and Gate II) are set in front of the service window and lines. Passengers arrived in front of the queue, the airport staff controls the flowing of them, which means they are only allowed to get into the next zone when the ID Check service window and Security Scanning lines is able to give the instant service.

   This simple adjustment has been proved much more efficient than the uncontrolled passenger queues that waiting before each service window and Security Scanning lines.

2. Other recommendations to improve the speed of the passenger flowing:

   (a) In the queue in the Zone B, the airport staff can push a small cart to carry garbage and remind the passengers to throw their liquids in it.



(b) In Zone B, staff can help passengers to classify their baggage to improve the speed of Security Scanning.

(c) Set up dedicated areas after security scanning in the Zone B, so the passenger can package their baggage their and will not impact other passengers.

Hope our policy recommendations can help you to solve the problem of the passenger flowing.

Yours sincerely

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