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Problem Chosen

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MCM/ICM

Optimizing the Passenger Throughput at an Airport Security Checkpoint

Summary

The airport security system sometimes have congestion problems, cause inconvenience to the passengers. In this paper, we identify problem areas and potential bottlenecks through analyzing passenger traffic, establish the optimization model based on **M/M/C** queuing theory to increase throughput. Giving some suggestions on the allocation of airport security resources.

Firstly, we process the data, calculate the time interval based on timestamp to get passenger traffic in a certain period of time. Then set up the model to describe the inflow and outflow of passengers, through comparative analysis we can find area B is more likely to be a **problem area**, X-ray machine and millimeter wave scanner is **potential bottleneck**.

In order to modify the current process, based on M/M/C and relevant information, we take different weighting coefficient for queuing length and waiting time, build an **optimization model** which aim at passenger dissatisfaction minimum. When the passenger dissatisfaction is the least, the passenger throughput is the biggest and the waiting time variance is the least. Based on this model, we make some modification of airport security resource allocation: For pre-check lane, add one staff member in area A and one lane in area B; For regular lane, add one lane in area B.

Next, we analyze different passenger's demand which caused by cultural differences. Take different weighting coefficient for queue length, waiting time and queue time variance to get a single target, For example, for the Chinese people who pay attention to personal efficiency, we should increase the weight of the queuing time.

Based on the above research results, we give some propose for the security managers. For example, open channels and arrangements staff based on passenger traffic, improve the quality of security personnel and so on.

Key Words: optimization; M/M/C queuing theory; Passenger throughput

Contents

1 Introduction

1.1 Problem Background

In recent years, the rapid development of the aviation industry have bring convenience to people's lives, but at the same time terrorist attacks in the airport also made people aware of the importance of airport security, So the airport set up security checkpoints to prevent passengers carrying dangerous goods on board aircraft and ensuring the safety of all passengers.

But the airport-related security resources become tense with the increase in passenger traffic, which may lead to passengers waiting for too long, stranded and the service quality of airport dropped. For example, in 2016, The US Transportation Security Administration (TSA) has been criticized for its long lines in the security process, especially at the Chicago O'Hare International Airport. Due to the impact of this public event, TSA invests in improving their checkpoint equipment, increased number of staff in highly congested airports. To some extent, these modifications have succeeded in reducing the waiting time, but TSA has also invested a lot of assets. In addition to the O'Hare airport, there are also some long queues that are queued for shorter-duration airports for unknown reasons, unpredictable. This high degree of instability have bringing a lot of trouble to passengers.

The efficiency of security screening often can influence whether the passengers can travel smoothly and airport quality of service, the rational allocation of security resources can make resource utilization rate rise, reduce service cost.

The existing US airport security check process is shown below:

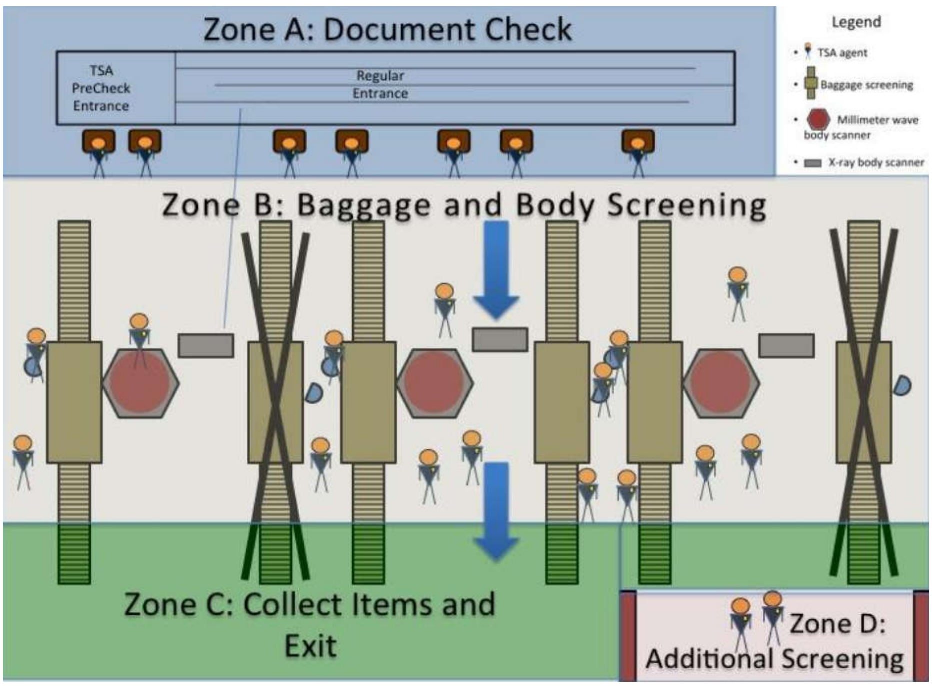

Figure 1 The existing US airport security check process

1.2 Our Task

Combined with the US airport security process and EXCEL data to examine potential bottleneck in airport security checkpoint which affect the passenger throughput.

Task **a**: establish one or more models to analyze the traffic passing through the security spot, thereby finding potential bottlenecks in the current process and clearly identify the problem area

Task **b**: make two or more improvements to the current process to reduce latency, improve throughput and reduce latency instability and demonstrate how our changes affect the security process

Task **c**: because of the differences in cultural and social interactions in different parts of the world, consider how these differences affect our model and make a sensitivity analysis, based on genuine cultural differences, or may be based on a particular individual. Reflecting how the model accommodates this variability, improving passenger throughput and improving stability.

Task **d**: make recommendations to the security sector based on the model.

2 Basic Assumptions

- The data given is accurate, can accurately reflect the passenger security process
- The same security equipment have the same performance
- The queuing order is arranged in the order in which the passengers arrive first
- Different airport security process is basically the same

3 Symbol Description

Symbol	Meaning
Q_{Inflow}	the passenger inflow
Q_{outflow}	the passenger outflow
λ	average arrival rate of passengers
μ	expected service hours
L_q	passenger queuing length
w_q	passenger waiting time
D_q	passenger waiting time variance
c	number of the open security lane
n	number of staff

4 Problem analysis and Model preparation

4.1 The analysis of airport security resource allocation

In order to find potential bottlenecks in the security process， we first analyze the entire security process of resource allocation combine with the topic. The whole process is divided into A, B, C three regions now. A area for file inspection, divided into pre-check entrance and regular entrance two areas, as can be seen from the picture pre-check entrance there are two staff (The number of staff here represents the scale, the actual number depends on the size of the airport), regular entrance have five staff; Area B is the personal and baggage inspection area, including a pre-check entrance and two common entrance. Each conveyor belt by the two staff responsible, each millimeter wave detector has a total of three staff members. Pre-check entrance configuration is basically same with the regular channel, but the millimeter detector only has one staff member; Area D is the retest area by two staff members. The entire security process of pre-check passengers shown in Figure 2[1][2].

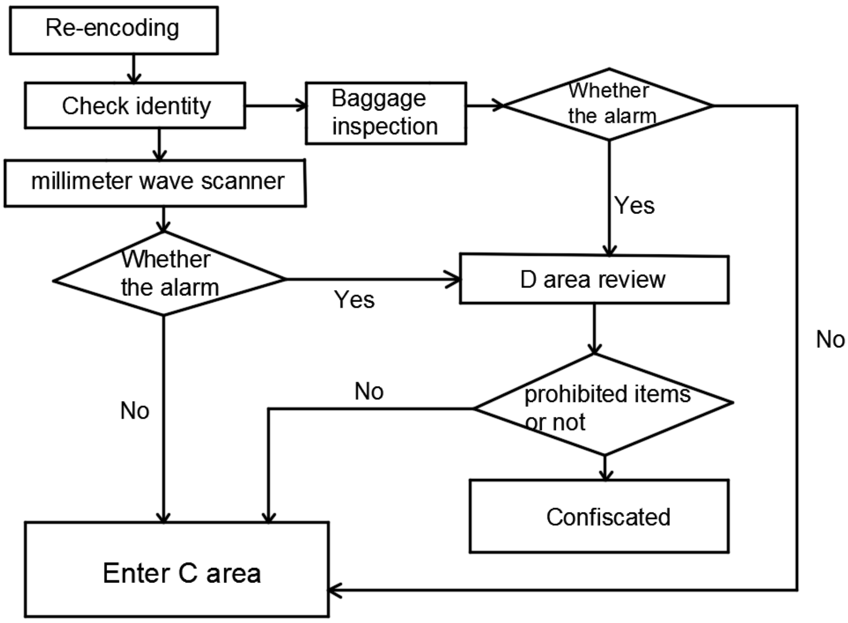

Figure 2 The Security process of pre-check passengers

Regular passengers of the security process is basically the same as above, but need to drag off the shoes clothes, take out laptop to check. Approximately 45% of passengers enroll in the program called Pre-Check for trusted travelers. These passengers pay $85 to receive a background check and enjoy a separate screening process for five years. So there will be about 45% of the passenger pre-check entrance, 55% of the passengers through the regular entrance. Combined with relevant information and experience, We set that the passengers entering the D-zone review account for 1% of the total number of passengers.

4.2 Data processing

The data sheet given in the subject has a total of eight rows of data, among them, column A representative the time stamps as airport checkpoint recoding individuals entering the pre-check queue, column B representative the same time stamps like A column of regular queue. The interval between adjacent timestamps is the time required for one passenger to encode, we use this to reflect the traffic into the airport, that inflow. Columns C and D are the time required for different staff to check IDs, the difference in staff is a factor in the variance of queuing time. E columns and F columns, G columns are the millimeter-wave detection and X detection time stamp, the adjacent time interval reflects the passenger flow entering the C area through security screening, which reflect the passenger outflow Column H reflects the time it takes for the baggage to be carried on the conveyor belt to retrieve the baggage, that is, the passenger's queue time in zone B.

Columns A, B, E, F, G data processing, figure out the time interval between adjacent timestamps respectively, using random number method to complement inadequate data.

$$\Delta t_i = t_{i+1} - t_i$$

In the formula, t_i is number i data time value, t_{i+1} is number $i+1$ data time value, Δt is time interval between t_i and t_{i+1}.

Columns C, D data processing:

$$\bar{t} = \sum_{i=1}^{N} \frac{t_i}{N}$$

In the formula, $\bar{t}$ is the average value of staff check ID. The data processing results are as follows:

Table 1 The result of data processing

Columns A	Columns B	Columns E	Columns F	Columns G
0.5	7.5	11.3	3.1	1.5
1.6	5.3	12.4	1.7	2
1.5	11.1	3.5	1.9	7.5
1.5	10	7.5	10.8	10.8
1.6	9.1	8.2	2.4	2.3
11	8.8	13	2.1	5.6
30	12.6	11	16.7	4.2
……	……	……	……	……
2.6	11.9	9.7	9.1	6.3

5 The Models

5.1 Build models to explore the current process

5.1.1 A Model to describe passenger inflow

In the model preparation, we have A, B column data into a time interval format, in order to more intuitive reflect the inflow of passengers, we convert the data to the number of people passed in 1 minute intervals to reflect the flow of passenger. Inflow volume is divided into pre-check entrance inflow and regular entrance inflow, both can be calculated using the following formula.

$$Q_{\text{Inflow}} = \frac{60}{\Delta t}$$

Through the above formula to get the converted data:

Table 2 Statistics on passenger inflows

interval1s / channels	interval one	interval two	interval three	interval four	……	……
Pre-check channel inflow	5	46	54	42	……	……
Regular channel inflow	7	100	38	40	……	……

In order to improve the flexibility of the model, transforming the discrete process of arriving passengers into a continuous process. Using least square method nonlinear fitting to get the relationship between passenger flow and arrival time.

Here, we use high-order polynomial fitting, make:

$$Q(t) = a_1 t^n + a_2 t^{n-1} + \cdots + a_{n-1} + a_n$$

a_1, $a_2, \cdots$, a_{n-1}, a_n is coefficient to be determined. The value of n is determined by the variation of the data.

Using least squares to make the sum of squares between the various data points in table 1 and curve $y = Q(t)$ is minimal, recorded as:

$$J(a_1, a_2, \cdots, a_n) = \sum_{i=1}^{N} \delta_i^2 = \sum_{i=1}^{N} [Q(t_i) - y_i]^2$$

Combined with the above formula, programming with MATLAB, obtain polynomial coefficients and draw the curve which reflect the relationship between passenger inflows of the pre-check channels and the regular channels and time. As shown in figure 3 and 4.

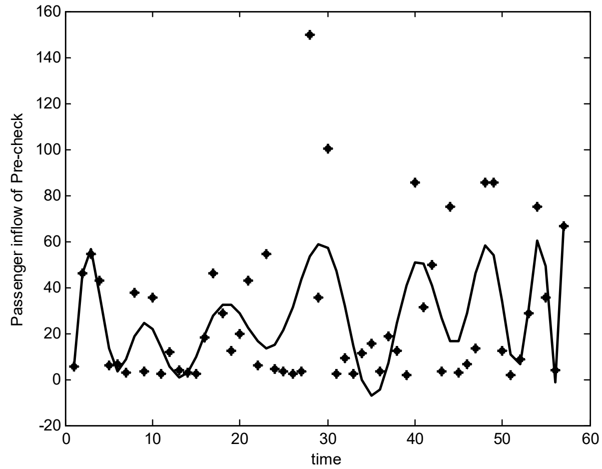

Figure 3 Pre-check lane passenger inflow

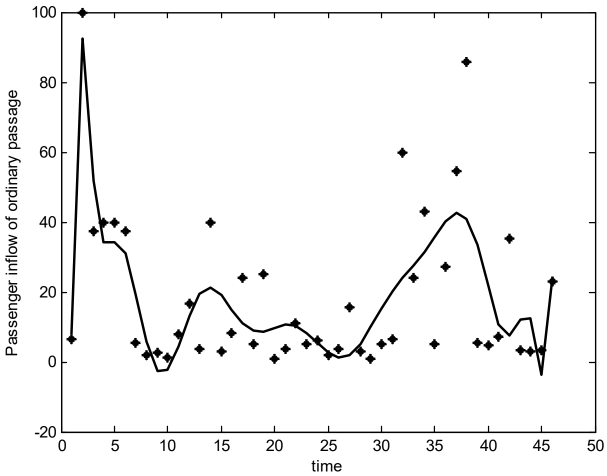

Figure 4 regular lane passenger inflow

5.1.2 A Model to describe passenger outflow

The description is the same as the outflow, converting data into number of people out of the security point in 1 minute. The difference is passenger outflow can also be described by baggage outflow. Combined with common sense, we regulations that security check is over only the baggage and passengers are both out of the security check points, which mark the outflow of passengers. So we make the same deal to the time that baggage pass through the X-ray detector costed. Using the smaller value as traffic flowing out of security checkpoints. Δt_1 representative the time interval for a person to pass the millimeter detector, Δt_2 representative the time interval for luggage passing through the X-ray apparatus. So the outflow of each channel can be expressed as:

$$Q_{\text{outflow}} = \min[\frac{60}{\Delta t_1}, \frac{60}{\Delta t_2}]$$

The converted data tables are as follows:

Table 3 Statistics on passenger inflows

	interval one	Interval two	Interval three	Interval four	……	……
outflow	5	5	17	8	……	……

Fitting method of inflow, using a higher order polynomials to fit. Using the least squares method and MATLAB program to get the coefficients of the outflow model. Drawing curves reflect the relationship between passenger outflow and time, as shown in Figure 5.

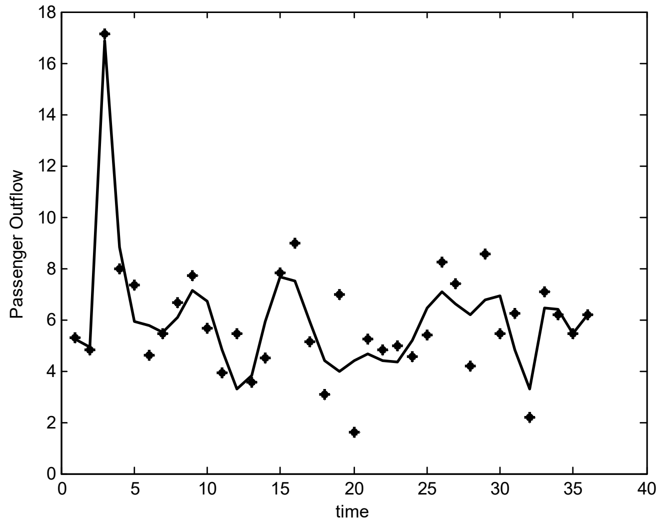

Figure 5 The curves reflect passenger outflow

5.1.3 Potential bottlenecks and Problem areas

Through analysis we can know, causes of congestion phenomenon at airport is passenger inflows and outflows are unbalanced. In order to find potential bottlenecks exist in the current process, we need comparative analysis the inflows and outflows of passengers. We set up $N(t)$ as the D-value between the inflow and outflow of each security channel at a certain time, so:

$$N(t)=Q_{\text{Inflow}}(t)-Q_{\text{outflow}}(t)$$

We can get the D-value between inflow and outflow at a certain time interval by integral $N(t)$. As shown in the following formula:

$$\begin{aligned} P(t) &= \int_0^t N(t)dt \\ &= \int_0^t [Q_{\text{Inflow}}(t)-Q_{\text{outflow}}(t)]dt \end{aligned}$$

We take the regular channel as an example to explore how the problem area is generated.

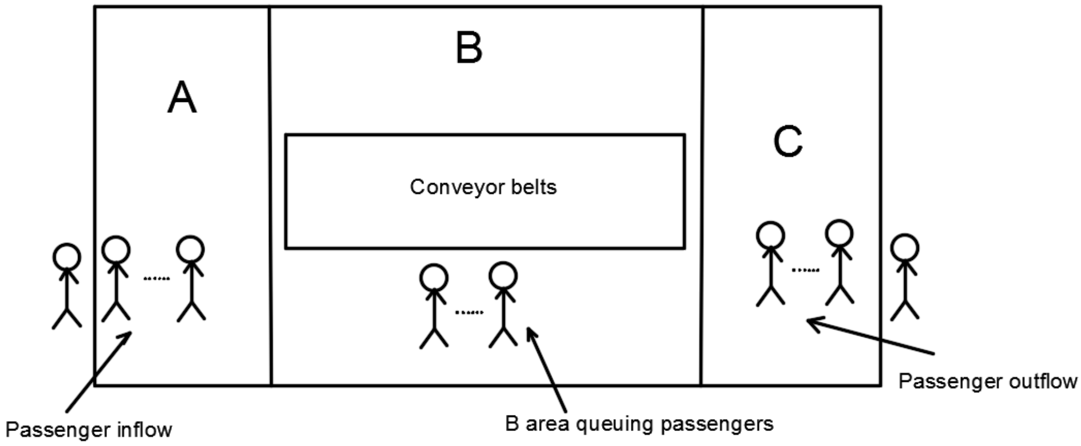

Figure 6 Problem Area Analysis

As shown in Figure 6, the conveyor belt represents a regular channel, Area A has passengers entering, and area C have passengers out of the security point. If the number of passengers flowing into zone A is greater than the number of outbound passengers from zone C, we can say that B zone process is slow, here have problems. On the contrary, if the number of passengers flowing into zone A is less than the number of outbound passengers from zone C, we can say that A zone process is slow. For the D zone, due to the proportion of people entering the re-examination is very small, we believe that the bottleneck cannot be generated in the D area. Area C is the area where passengers leave, the possibility of a bottleneck is very small. This method can be extended to the pre-check channel study.

From the model point of view, if $P(t) > 0$, area B is the problem area; if $P(t) < 0$, area A is the problem area. Drawing Integral Process Image with MATLAB. Reflect the value of $P(t)$ at each moment.

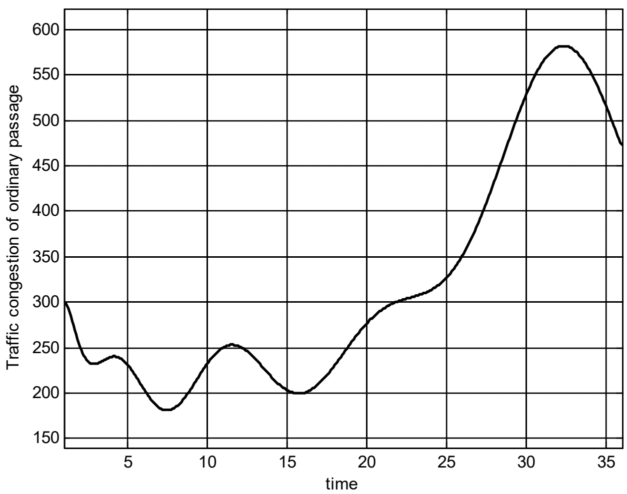

Figure 7 The D-value between inflow and outflow of regular lane

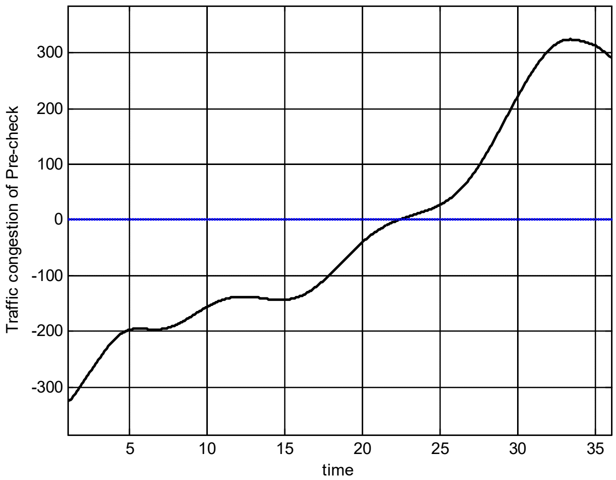

Figure 8 The D-value between inflow and outflow of pre-check lane

It can be seen from Figure 7 that the $P(t)$ of regular lane is positive, the inflow is greater than the outflow, so the problem area is B area, the bottleneck is millimeter wave scanner or X-ray machines. In addition, we can know from Figure 8 that in the early stages of the process the $P(t)$ of pre-check lane is negative, the inflow is less than the outflow, so the problem area is A area, the bottleneck is identity checkpoint. In the latter stages, $P(t)$ is positive, indicating that congestion problems of A area is ease, B area begin to have problems. For this phenomenon we conjecture that the staff of A area have problems in the early stages, resulting in slow inspection, a large number of passengers stranded in area A. The latter may be due to a reduction in the number of pre-check passengers or an increase in staff efficiency, making the A area smooth, the problem is transferred to the B area.

In addition, there is another potential bottleneck, from the subject we can see that the number of pre-check passengers accounted for about 45%, there is often one Pre-Check lane open for every three regular lanes. Due to pre-screening passenger security faster, so two lane security check efficiency is roughly the same. But if the proportion of passengers in a certain period of time does not meet the predetermined proportion. Such as there are all pre-check passengers, the regular lane will be congestion.

From this we conclude that B area is more likely to become the problem area, X-ray detector and millimeter detector is bottlenecks for the current security process.

5.2 Modifications based on M/M/C queuing theory

In Problem a, we have established the model to reflect the passenger flow and the possible problem areas and potential bottlenecks are generated. Based on the model, we combine the M/M/C queuing model to modify the resource allocation in the current process to increase passenger throughput and reduce waiting time. And to demonstrate how these changes work.

5.2.1 Process improvement model based on M/M/C queuing theory

Using χ^2 test, it is found that the number of passengers arriving is in Poisson distribution[5]. Using MATLAB software programming to calculate the average arrival rate λ=18.5823 . The EXCEL table provided by title provides the service interval data for each link. Also using χ^2 test, we find that the service time coincides with a negative exponential distribution. Using MATLAB software, we can solve the expected service time μ=5.9963 . So it is shown that the airport security problem complies with the M/M/C queuing model. Assuming that each security channel service rate is the same, each channel configuration the number of security staff is m , the average service time is μ_0 , service intensity[3] is $P = \frac{\lambda}{\mu_0}$.

If there is a free service desk after the arrival of passengers in accordance with the order of arrival to accept the service, if all the service desk are occupied, the passengers waiting in line. Make $M(t)=i$ to represent the system has exactly i passengers when time is t , and System collection is $\{0,1,2\cdots\}$. It can be proved that $\{N(t), t>0\}$ is the birth and death process, and can be:

$$\lambda_n = \lambda, n = 1,2,\cdots$$

$$\mu_n = \begin{cases} n\mu, & n = 1,2,\cdots \\ c\mu, & n = c+1, c+2,\cdots \end{cases}$$

According to the M/M/C queuing theory, two theorems are obtained

Theorem 1: the smooth distribution of queue length $M(t)$, we set:

$$P_n(t) = P\{N(t) = n\},\ \ P_n = \lim_{t\to\infty} tP_n(t),\ \ n = 1,2,\cdots$$

The stationary distribution of the system is:

$$P_n(t) = \frac{\rho^n}{c!c^{n-c}} P_0,\ \ P_0 = [\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!(1-\frac{\rho}{c})}]^{-1},\ \ 1 < n < c$$

Theorem 2: the main indicators of the system

Queue length in the service system:

$$L_q = \sum_{i=c}^{\infty} (i-c) p_i = \frac{\rho^{c+1} p_0}{(c-1)!(c-\rho)^2}$$

Average waiting time for passengers in the system:

$$w_q = \frac{L_q}{\lambda} = \frac{\mu(\frac{\lambda}{\mu})^2}{(c-1)!(c\mu-\lambda)^2} P_0$$

Average length of stay of passengers in the system:

$$w_s = w_q + \frac{1}{\mu} = \frac{\mu(\frac{\lambda}{\mu})^2}{(c-1)!(c\mu-\lambda)^2} P_0 + \frac{1}{\mu}$$

Average number of passengers in the system:

$$L_s = \lambda w_s = \frac{\rho^{c+1}}{(c-1)!(c-\rho)^2} P_0 + \rho$$

The probability of full system members:

$$P(n=c) = \frac{\rho^c}{c!} P_0$$

In order to improve the throughput and reduce the waiting time variance, we need to reduce the average queue length and average waiting time, for which we can establish a two-objective optimization model[4]:

$$\min \ \mathrm{L}_q = \frac{\rho^{c+1} p_0}{(c-1)!(c-\rho)^2}$$

$$\min \ \ w_q = \frac{L_q}{\lambda} = \frac{\mu(\frac{\lambda}{\mu})^2}{(c-1)!(c\mu-\lambda)^2} P_0$$

$$s.t. \begin{cases} c > 0 \\ n > 0 \\ c, n \in z \end{cases}$$

5.2.2 The modifications for the current process

We have figured out the expected service hours μ=5.9963 , this is the expected service time when the area A staff is two. The expected service hours will change with the change the number of staff. In general, there is a logarithmic relationship between them, we set:

$$\mu(n) = 5.9963 \log_2 n$$

In the formula, n is the number of staff, $\mu(n)$ is service hours of staff. We transform the bi-objective programming problem into a single-objective optimization problem, take a weight coefficient ω between L_q and w_q, we set passenger dissatisfaction R_q as objective:

$$R_q = \omega L_q + (1-\omega) w_q$$

Combined with relevant information and consider the actual situation, we set weight coefficient $w = 0.43$, set up a single-objective optimization model with the aim of minimizing passenger dissatisfaction. When the passenger dissatisfaction is the least, the airport security point throughput is the biggest, and the waiting time variance is the least.

$$\min \quad R_q = \omega L_q + (1-\omega) w_q$$

$$s.t. \begin{cases} \mu(n) = 5.9963 \log_2 n \\ c > 0 \\ n > 0 \\ c, n \in z \end{cases}$$

Substituting the data we get from data processing, Using LIGNO figure out c, n which can make passenger dissatisfaction smallest. The result for pre-check lane is $c=2,\ \ n=3$, that is to say, arrange three staff members in area A, open two lane in area B; For regular lane is $c=3,\ \ n=5$, that is to say, arrange five staff members in area A, open three lane in area B.

5.2.3 The effectiveness of the modifications

In Problem a, we analyze the possible problem areas and potential bottlenecks. We can find that in pre-check lane area A and B maybe have problem both, For the regular lane, Area B maybe have problem. In the result we get from optimization model, the number of staff of area A and lanes of area B should increase, which conformity with the analysis results we obtained before. Regular lane only increase the number of lane in area B, A area staff did not change, also conformity with the analysis results. Indicating that the changes we made can reduce the problem area.

Next, we use MATLAB to make the modified congestion curve，to demonstrate how our changes affect the security process.

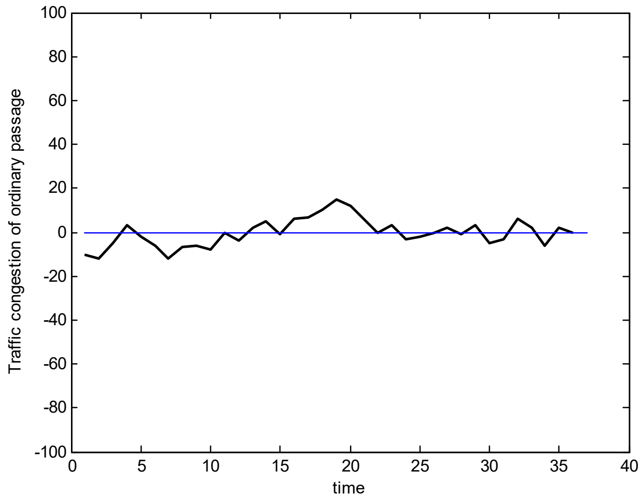

Figure 9 Regular lane congestion amount after modification

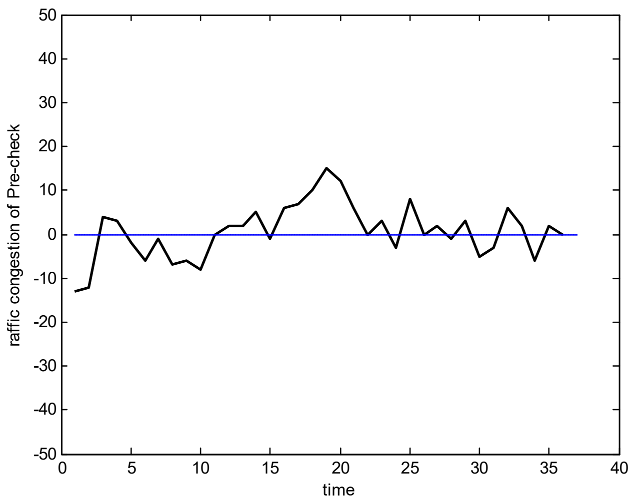

Figure 10 Pre-check lane congestion amount after modification

As we can see in figure 9 and 10, the traffic congestion significantly lower than before, indicating that our changes played a role.

There have also been incidents of unexplained and unpredicted long lines at other airports, including airports that normally have short wait times. This shows that the instability of queuing time is high. Next, we compare and analyze the variance of queuing time before and after modification.

From the model we have known that service times obey a negative exponential distribution: $\mu(t) = 5.9963e^{-5.9963t}$, the function between number of passengers and time is $Q(t)$, It follows a Poisson distribution[6], which is:

$$Q(t)=\frac{18.5823^t}{t!}e^{-18.5823}$$

Replacing λ in w_q by $Q(t)$ and replace μ by $\mu(t)$, so w_q is a time-varying distribution function.

$$w_q(t) = \frac{\mu(t)(\frac{Q(t)}{\mu(t)})^2}{(c-1)!(c\mu(t)-Q(t))^2}P_0$$

The calculation formula of average waiting time:

$$E=\int_0^\infty tw_q(t)dt$$

Waiting time variance is:

$$D_q=\int_0^\infty [t-E]^2 w_q(t)dt$$

Through MATLAB programming, we can get D_q=3.2531×10^2, which is modified wait time variance. Then we compute wait time variance of the original process. Based on the data in EXCEL column H, figure out wait time variance of the original process is 4.3029×10^3.

It can be seen in different time zones, modified wait time variance is small than variance of the original process, which Indicating that our modifications improve the stability.

5.3 Model Sensitivity Analysis

In the previous model, we optimized the allocation of airport security resources to improve passenger throughput and reduce the variance of waiting time, but we did not take into account the differences in the passengers themselves on the security process impact. In real life, there are cultural differences between countries, these differences lead to the diversity of passenger types. In addition to cultural differences between countries, there will be differences between the individual passengers, which requires us to establish the model to have a wide range of applicability, then we have different types of travelers for the sensitivity analysis of the model.

Problem two, we studied the relationship between passenger dissatisfaction R_q with queuing length L_q and queuing time w_q, and now variance of waiting time D_q to be taken into account, we set:

$$R_q = \omega_1 L_q + \omega_2 w_q + \omega_3 D_q$$

Among them:

$$L_q = \frac{\rho^{c+1} p_0}{(c-1)!(c-\rho)^2}$$

$$w_q = \frac{\mu(\frac{\lambda}{\mu})^2}{(c-1)!(c\mu-\lambda)^2} P_0$$

$$D_q = \int_0^{\infty} [t-E]^2 w_q(t) dt$$

We use sensitivity analysis as an example. For Chinese people, they pay more attention to personal efficiency, that is, how to reduce the length of waiting time. So the weight of waiting time should be the biggest when considering Chinese. According to the questionnaire survey, 68% of people who pay more attention to queuing time, 17% of people who pay more attention to variance of queuing time, 15% of people who pay more attention to queuing time. So the weights w_1, w_2, w_3 are 0.15, 0.68, 0.17 respectively.

The optimal model with dissatisfaction R_q as the goal is:

$$\min \ R_q = 0.15 L_q + 0.68 w_q + 0.17 D_q$$

$$s.t. \begin{cases} \mu(n) = 5.9963 \log_2 n \\ c > 0 \\ n > 0 \\ c, n \in z \end{cases}$$

Substituting the relevant data, we get the c, n that minimizes the objective function by LINGO programming. Solution of the number of staff in pre - check lane A: n_1=3 Number of open channels in zone B: c_1=2 . Number of staff in area A of regular lane: n_2=4 . Number of open channels in zone B: c_2=3 .

From the results we can see that the pre-inspection channel and the general channel opening number and staff distribution and the previous airport process solution results are basically the same, but in the ordinary channel number of staff than in the previous one, which should be Cultural differences, but the overall situation is basically the same, so indicating that the model has a certain stability.

For Americans, they give priority to personal space, so the length of the queue will increase. We need to increase the weight of the length of the queue, and in order not to take off their shoes and clothes, The United States apply for pre-seized passengers will be more, so the proportion of pre-screening channels need to increase; for the Swiss,

they focus on collective efficiency, so the waiting time variance need to be lower, and need to wait for a short time while minimizing variance, it can be appropriate reduce the weight of queue length and increase the weight of waiting time variance.
To sum up, for different types of passengers, we need to analyze their needs, and adjusting the proportion of the weight of the airport resources can be the appropriate security configuration.

5.4 Propose policy and procedural recommendations for the security managers

In view of the current airport security problems, by analyzing the changes in traffic, we set a mathematical model for optimizing passenger throughput. Based on this model, We have some suggestions to the security department [7].

- Through analysis, the majority of airport congestion occurs because of unreasonable resource allocation, resulting in a bottleneck. Security departments should do a comprehensive analysis of passenger traffic, forecast the passenger situation during a certain period, open lane and arrange staff reasonable.

- The proportion of the pre-check passage to the common lane shall be in accordance with the number of pre-check passengers and ordinary passengers to avoid congestion because of the different types of passengers.

- Improve the professional quality of security inspectors, in the security process, timely detection and correction security personnel operating irregularities. Such as unnecessary communication in the course of their work, shift time is too long and so on, this greatly reducing the service efficiency. Security inspection system should strengthen the training of staff, improve the operational level of the security inspection staff. To avoid congestion caused by the poor operational capacity of security staff.

- Taking into account regional cultural differences. For example, Americans pay more attention to personal privacy, in order not to take off the shoes and clothes and check the computer, the number of applicants for pre-check should be higher. So we should consider to increase the number of pre-check lane and to increase staff.

6 The evaluation and Model extension

6.1 Strengths and Weaknesses

6.1.1 Strengths

- Through the better processing data, we can get the curve of passenger inflow and outflow with time. And then through their poor integration of the amount of congestion with the time to change the relationship between the maps, a more intuitive reflection of the airport security bottlenecks in the process.

- The M/M/C queuing model is established, and single target optimization is carried out. The bottleneck of the current process is modified to improve the jamming capacity of the passengers and reduce the queuing time.
- The cultural differences between countries and the objective function of the weight of the factors linked to simple and accurate sensitivity analysis can be carried out.
- Problem two model has the significance of guiding the actual production

6.1.2 Weaknesses

- Some data when the data is based on the law of data with a random number to add, and they may differ from the actual situation.
- The test of the model in question d is not particularly clear.

6.2 Model extension

This model can be used in airport security port design, train station, bus station security port design, the number of large supermarket cash register opening and the staff of the service area configuration to solve the problem of hospital queuing. The model can be extended to the actual life of production, the actual production has important guiding significance.

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Appendix

```
RAPT=[9.1 0.6 1.6 1.5 1.5 1.6 11 30 24.3 54.9 7.5...
    3.6 15.6 1.5 21.3 7.2 2.5 11.5 2.4 57.3 15.8 5.4...
    11.9 9.9 30.6 16.5 3.8 19.5 78.9 12 9 1 2.5 1.4 12.0...
    2.2 1.1 0.7 11.2 12.9 8.5 1.7 17.4 21.1 18.6 2.6];
MWST=[11.3 12.4 3.5 7.5 8.2 13 11 9 7.8 10.6 15.2 11.0...
    16.9 13.4 7.7 6.7 11.7 19.4 8.6 37.4 11.4 12.4 12 13.2...
    11.1 7.3 8.1 14.4 7 11 9.6 27.5 8.5 9.7 11 9.7];
TPRT=[11.2 1.3 1.1 1.4 9.6 9.3 20.5 1.6    18.6 1.7 27.3 5.1...
    15.4 22.1 28.2 3.3 1.3 2.1 4.9 3 1.4 10.1 1.1 12.8 18.4...
    24.4 17.9 0.4 1.7 0.6 28.4 6.6 23.8 5.3 3.9  17.5 3.2 4.8...
    34.8 0.7 1.9 1.2 16.3 0.8 20.1 9.1 4.4 0.7 0.7 4.8 28.9...
    6.9 2.1  0.8  1.7  15.7 0.9];
RST=[3.1 1.7 1.9 10.8 2.4 2.1 16.7 25.9 1.7 9.1];
rapt=60./RAPT   %Inflow passenger time interval of Pre-check passenger
mwst=60./MWST;   %Outgoing passenger time interval
tprt=60./TPRT   %Inflow passenger time interval of regular passenger
rst=60./RST;
xlswrite('data.xls',rapt,'Sheet1','A1');
xlswrite('data.xls',tprt,'Sheet1','A2');
xlswrite('data.xls',mwst,'Sheet1','A3');

figure;   %Figure 3
p1=polyfit(1:length(rapt),rapt,15);
y1=polyval(p1,1:length(rapt));
plot(1:length(rapt),rapt,'k*',...
    1:length(rapt),y1,'k-','LineWidth',2);
xlabel('time');ylabel('Passenger inflow of ordinary passage');

figure;   %Figure 4
p2=polyfit(1:length(tprt),tprt,20);
y2=polyval(p2,1:      length(tprt));
plot(1:length(tprt),tprt,'k*',...
    1:length(tprt),y2,'k-','LineWidth',2);
xlabel('time');ylabel('Passenger inflow of Pre-check');

figure;   %Figure 5
p3=polyfit(1:length(mwst),mwst,20);
y3=polyval(p3,1:length(mwst));
```

```
f2=poly2sym(p2);
f3=poly2sym(p3);
f=f2-f3;
intf=int(f);
ezplot(intf,[1,length(mwst)]);
hold on
plot(zeros(1,50))
grid on;
xlabel('time');ylabel('Traffic congestion of ordinary passage');

figure;    %Figure 7
p4=polyfit(1:length(mwst),mwst,20);
y4=polyval(p4,1:length(mwst));
plot(1:length(mwst),mwst,'k*',...
    1:length(mwst),y4,'k-','LineWidth',2);
xlabel('time');ylabel('Passenger Outflow');

xlswrite('data.xls',p1,'Sheet1','A4');
xlswrite('data.xls',p2,'Sheet1','A5');
xlswrite('data.xls',p3,'Sheet1','A6');

function f=fun(x);
RAPT=[9.1 0.6 1.6 1.5 1.5 1.6 11 30 24.3 54.9 7.5...
    3.6 15.6 1.5 21.3 7.2 2.5 11.5 2.4 57.3 15.8 5.4...
    11.9 9.9 30.6 16.5 3.8 19.5 78.9 12 9 1 2.5 1.4 12.0...
    2.2 1.1 0.7 11.2 12.9 8.5 1.7 17.4 21.1 18.6 2.6];
MWST=[11.3 12.4 3.5 7.5 8.2 13 11 9 7.8 10.6 15.2 11.0...
    16.9 13.4 7.7 6.7 11.7 19.4 8.6 37.4 11.4 12.4 12 13.2...
    11.1 7.3 8.1 14.4 7 11 9.6 27.5 8.5 9.7 11 9.7];
rapt=60./RAPT;
mwst=60./MWST;
Lambdahat=poissfit(rapt);
muhat=expfit(mwst);
muhatt=muhat*log2(x(2));
rou=Lambdahat/muhatt;

for i=0:x(1)-1
    fenmu1=fenmu1+rou^i/factorial(i);
end
P0=( fenmu1+rou^x(1)/( factorial(x(1))*(1-rou/x(1)) ) )^(-1);
```

```
f=rou^x(1)*P0/( factorial(x(1)-1)*(x(1)-1)^2 );

x0=[1;1];
[x,fval]=fmincon('fun',x0,[],[],[],[],[1;1],[])
```