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T1 ________	65679	F1 ________
T2 ________	Problem Chosen	F2 ________
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T4 ________		F4 ________

2017

MCM/ICM

Summary Sheet

“I do not wanna wait at a long line!”

In this paper, we address the problem associated with maintaining airport security and reducing passengers’ waiting time. Since September 11, 2001 terrorist attacks in the United States, the world's airport security issues are of great concern. However, maximizing safety and minimizing inconvenience to passengers is still a big problem. To help us better understand and deal with this problems effectively, we developed a model of bottleneck Recognition, based on cellular automata to explore where passengers passes through security checkpoints and bottlenecks that may occur.

Firstly, we analyzed data of the security screening process and quantified the factors that affect waiting time, and establish a model of bottleneck Recognition. We have come to the conclusion that the current security check process will occur bottlenecks in Pre-check lane Zone B and Regular lane Zone B.

Secondly, we develop a multi-objective optimization model by using the queuing theory of single-queue multi- channel waiting system, use computer simulation to calculate the result, which makes it possible to increase the security channels and reduce the average waiting time. Analysis of security channel and the number of security officers, the model of the second question takes the first model to judge the bottleneck region as the premise. And this calculation combines the macroscopic and microscopic perspective, which is using Single Queue Multi - channel Waiting Model to Simulate. Finally we calculated that there increase 2 security channels..

Thirdly, task three requires to conduct a sensitivity analysis on model, but as a matter of fact, those indicators have little effects on our model, although different traveler types will influence the security time, but it has been proved our optimization model can still maintain a dynamic balance.

Admittedly, what we have discussed in this study is far from complete. In our further study, we hope to make some improvements, including: Quantify cultural norms that may affect our model ,Simulating the time of different traveler style when they remove things from the body is different.

Finally, we summarize the advantages and disadvantages of the model, and there is an interesting microcosmic idea, the cellular automaton model can be used as an independent validation of our other models. We can consider to increase one mm-wave Scanners and two X-ray Scanners.

Keywords: Bottlenecks Recognition Model Cellular Automata Queuing Theory Multi-objective Optimization Model Computer Simulation

Contents

1 Introduction.. 1
1.1 Background of the Problem 1
1.2 Restatement of the Problem 1
1.3 Our work 2
2 Assumptions.. 3
3 Symbol Descriptions 3
4 TaskI: Bottleneck Model Based on Cellular Automata 4
4.1 Data Analysis 4
4.2 Bottlenecks Recognition Model.. 5
4.2.1 Analysis and Simulation of Airport Environment 5
4.2.2 Define Bottleneck Evaluation Standard.. 6
4.2.3 Model Establishment and Solution 6
4.2.4 Results.. 8
5 TaskII: Multi-objective Optimization Model Based on Queuing Theory 9
5.1 Single Queue Multi-channel Waiting System Model 9
5.2 Optimization Model 10
5.2.1 Optimization model Establishment.. 10
5.2.2 Optimization model Solution 11
5.3 Optimization Model Verification.. 13
5.4 Results.. 13
6 Task III: Sensitivity analysis 15
7 Task Ⅳ: Advices.. 16
8 Model Extension 17
8.1 The United States Summer Vacation Security Check Point Long Line Problem................ 17
8.2 Adapt to Chinese Spring Festival travel rush in the subway security check points optimization model 17
9 Analysis of the Model 18
9.1 Strength 18
9.2 Weakness 18
10 References.. 18
Appendix 19

1 Introduction

1.1 Background of the Problem

Globalization of economic has improved the development of national economy all over the world, more and more people are tend to take an airplane to travel. In O'Hare International Airport. The total number of people taking the plane in recent three years is 77960588, 76949504 and 70075204. The growth rates is 1.91%, 9.81% and 4.45%. In addition, cargo tonnage totals is 1726361.6 tons, 1742500.8 tons and 1578330.8 tons.an increase of -0.93%, 10.40%, 10.01%, compared with year to date respectively. In 2014, aircraft lift totals of O'Hare International Airport was 881933 sorties, ranking first in the world.

The continuous development and perfection of the air transportation system has improved the people's life quality. The airport, as an important part of the air transportation system, has maintained the balance and safety of ground traffic and the air traffic. As a result, construction and planning of airport are critical to the transport system. Airport managers can improve the service equality and safeguard equipment of the airport through good planning which can reduce constraints of bottleneck, moreover, the rational allocation of resources, which can save production costs and realize the optimal use of resources, can help managers to achieve the scheduled flights safety the while ensuring that production tasks can be finished on time. Although air transport system bring about great convenience for people, there is still a great security risk. The tragic called "911" has a profound impact on the international aviation, and airports all over the world have increased security efforts from then on. Therefore, security check for passengers is essential before they take plane.

The passenger flow is the interaction between people, hence there is too much uncertainty. It is the huge passenger totals that cause not only congestion but also long time used in security check In the O'Hare International Airport, Chicago of the United States. The time used in security check is too long to make the more and more passengers feel unsatisfied when they take airplanes besides the resources of the airport cannot be reasonably allocated and used. Therefore, there is of great practical significance to solve the problems related to security check of passengers and airport management by qualitative and quantitative analysis.

1.2 Restatement of the Problem

Passengers must accept security check by airport security inspectors before they take plane. In order to ensure the passengers' safety. Due to large passenger totals, many international airports usually appear the phenomenon that passengers have to use many extra time on security check. Such as Chicago O'Hare Airport. During 2016, Transportation Security Agency (TSA) invested in several modifications to the checkpoint equipment and procedures and increased staffing in the more highly congested airports. While these modifications are successful in reducing waiting times, it is also unclear how much cost the TSA incurred to implement the new measures and increase staffing. There is no guarantee for the passengers' airplane experience. The flow chart of security check in US is shown in Figure 1.2. By understanding this process, we have to solve some problems. Scientific and rational airport process planning can improve the airport system's security capabilities. It can make the daily operation of the airport system level to achieve the best condition, make sure the airport in a cost-effective way to meet current and future air transport needs.

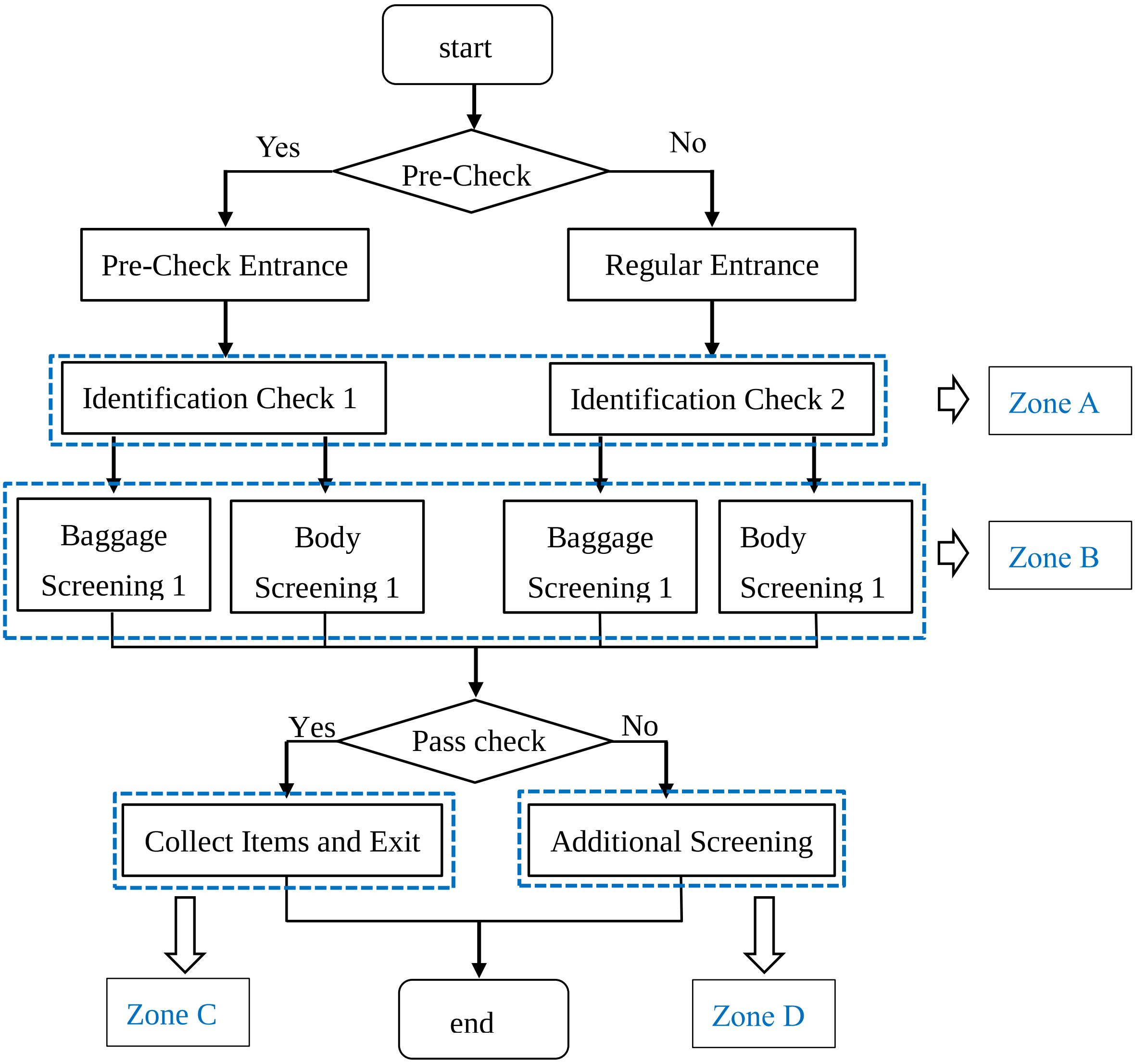

Figure 1.2 The US security check flow chart

For optimizing the passenger throughput at an airport security checkpoint, we ought to do some things. First of all, we need to establish a model to explore the passengers totals through the security checkpoint and identify the bottleneck and found that the current problems in the area of the case. Secondly, we need to find ways to increase passenger totals and reduce waiting time. The influence of the model on the process is illustrated by the model. Thirdly, the passengers from various countries, so we need find the different cultural norms have what impact on the model and analysis sensitivity of the model. Finally, we will give some suggestions to manager of the airport security department.

1.3 Our work

First, we spend many time in analyzing the known data, we use Python to transform data form, make a data flow diagram , and extract the most valuable information.

Second, we quantify the factors that affect waiting time for safe waiting, and establish a model of the bottlenecks identification based on Cellular Automata .

Third, we build Single Queue Multi - channel Waiting Model , use this optimization model to expedites passenger throughput and reduces variance. And we use some datas from Chicago’s O’Hare international airport made a simulation to find out the optimized result. Based on the comprehensive evaluation criteria, the optimization model of equipment staffing was established, and the sensitivity analysis of our model was carried out.

Last, we summarize the advantages and disadvantages of the model, then propose policy and procedural recommendations for the security managers based on our model.

2 Assumptions

● Passengers who are pre-checked will not choose a regular entrance.
● Passengers follow the queuing rules of First Come First Service (FCFS) and the queue is not lost.
● Forty-five percent of the passengers take the pre-check lane for security.
● The total cost of the facilities at the airport is within acceptable range.
● The movement of passengers is not affected by the circumstances behind them.

3 Symbol Descriptions

In the section, we use some symbols for constructing the model of follows.

Table 1. Description of symbol in model

Symbol	Description
P	The number of Pre-Check lane
R	The number of regular lane
N	The number of passengers to check security
A	Comprehensive evaluation index
μ	The service rate of the system
λ	The service rate of the passenger
G_1	The throughput of regular lane
G_2	The throughput of pre-check lane
$W_{S(i)}$	Average length of the passengers stay in the security system
$W_{q(i)}$	Average waiting time of passengers in Security System
L_{qi}	The average length of waiting queue

4 Task Ⅰ: Bottleneck Model Based on Cellular Automata

In recent years, with the rapid development of air transport system, the aircraft's speed, comfort and other advantages make the trunk airport traffic surge. At the same time, due to the internal equipment and layout of the airport does not match. Airport security has exposed serious bottlenecks. Not only reduces the airport collection and distribution efficiency, but also affect passenger travel efficiency and safety.

4.1 Data Analysis

By analyzing the known data, the resulting data flow diagram is shown in the figure. By analyzing the known data, the resulting data flow diagram is shown in the figure 4.1.

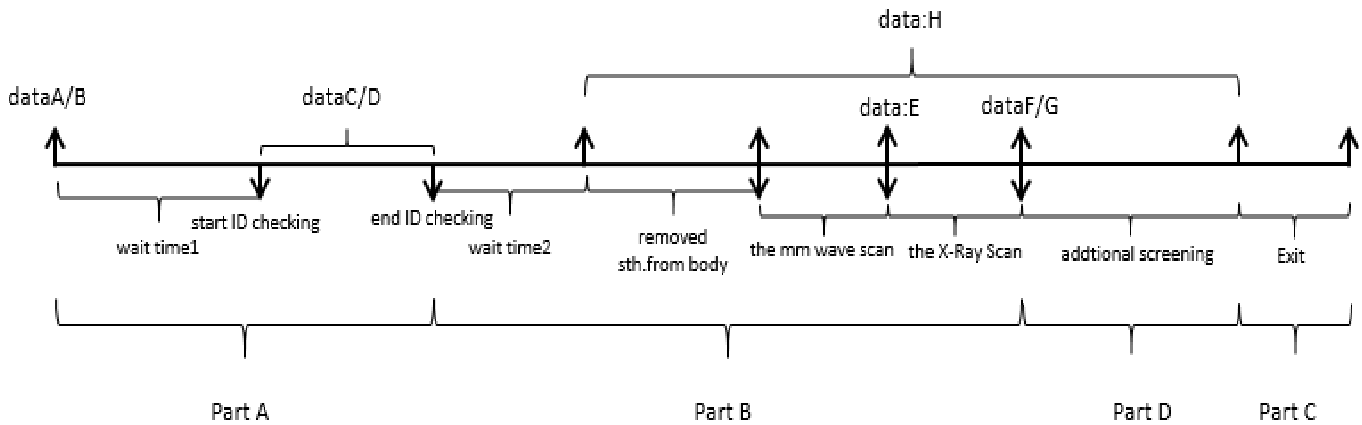

Figure 4.1 data flow diagram

Explain:

1. Data A represents the time point of 58 Pre-check passengers that arriving at the security checking system. So Pre-check passengers arrival rate is 9.2 per second.
2. Data B represents the time point of 48 regular passengers that arriving at the security checking system. So regular passengers arrival rate is 12.9 per second.
3. Data C represents the ID check time of pre-check passengers, their average examination time is 10.2 seconds.
4. Data D represents the ID check time of regular passengers, their average examination time is 10.2 seconds.
5. Data E represents the milimeter wave scan times, Due to mechanical automatic scanning,the average scanning time of pre-check passengers is as same as regular passengers, It’s 11.6 seconds.
6. Data F represents the ending time of Pre-check passengers that passing X-Ray scan, their average ending time is 7.1 seconds.
7. Data G represents the ending time of regular passengers that passing X-Ray scan, their average ending time is 3.7seconds.
8. Data H represents the time that passengers pass zone B, and their average examination time is 28.0 seconds. Summarized as shown in the information table 4.1.1

Result:

Table 4.1.1 Information Sheet

Item	Information
Pre-check passenger arrival rate	9.2 per second
Regular passenger arrival rate	12.9 per second
The ID check time of the pre-check passenger	10.2 seconds
The ID check time of the regular passenger	12.6 seconds
The Milimeter Wave Scan time of the passenger	11.6 seconds
Each pre-check user passes the X-ray time	7.1 seconds
Each regular user passes the X-ray time	3.7 seconds
The time for a passenger to pass the B zone	28.0 seconds

4.2 Bottlenecks Recognition Model

4.2.1 Analysis and Simulation of Airport Environment

Cellular automata is suitable for the study of complex time system. We use the principle of cellular automata to carry out computer simulation. Programming in matlab software platform. To simulate bottlenecks in the security process.

Analysis and simulation of airport environment :

(1) According to the data analysis we know that the number of passengers arriving, obey the Poisson distribution over time. The number of people taking the pre-check lane accounted for 45% of the total number, and the number of people taking the regular lane accounted for 45% of the total number. We build the model through the number of cells produced in time t follows the Poisson distribution. We set the lane entry ratio is 45% and 55% to simulate the ratio of the two lanes.

(2) The airport has two kinds of lanes, during the security check, both them have to pass four zones. There are five check points belong to regular lane, and two check points belong to pre-check lane in Zone A. There are two check points belong to regular lane, and one check point belong to pre-check lane in Zone B.

(3) By analyzing the environment, we can obtain a conclusion that Line A is a single queue, and line B is a multiple queues.

According to the above airport environment analysis, we simulate the following diagram as the airport security environment:

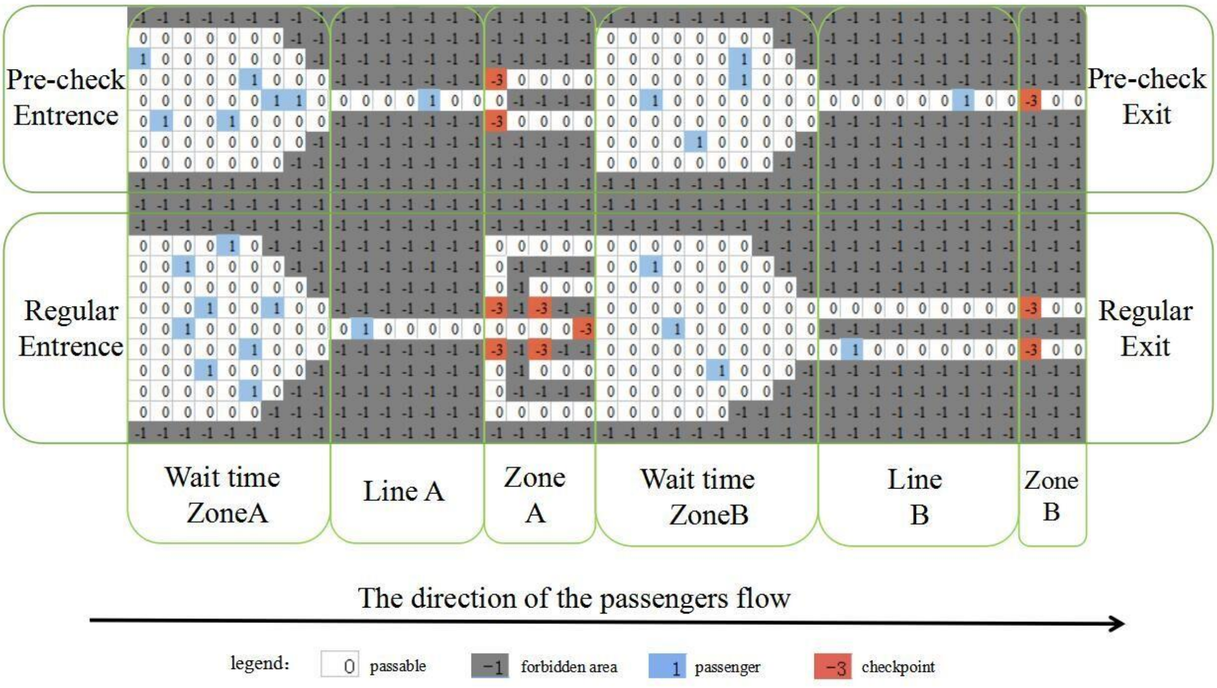

Figure 4.2.1 simulation of security check environment

We will use the cellular automaton ideas to achieve the specific process in airport. In order to facilitate the simulation, simplify the measurement. Set the weight of the free cell in the attribute to 0, the weight of the cell neighbor region is set to -1, the weight of the state transition is set to 1, the checkpoint weight is set to -3.

The black area is denoted as a not accessible area. Blue square represents the unit cells and indicate the passenger moving in the queue. The red squares are represented as security lanes. The white squares are represented as accessible area.

4.2.2 Define Bottleneck Evaluation Standard

1 Bottleneck causes

Due to the low rate of the maximum flow.at security channels. Passengers' demand circulation rate is much larger than the maximum flow rate in the check are, resulting in reduced passenger flow.

2 Bottleneck definition

The passengers is bigger then the load-bearing capacity of security channels.

3 Bottleneck effect

For airport security, the location that have possibility to make bottlenecks is the inspection port.

4 According to the bottleneck effect, define the bottleneck evaluation standard.

$$Q(i,j) = \frac{M(i)}{N(i)}$$

Represents at the time of t(j), the percentage of queuing number to capacity.

4.2.3 Model Establishment and Solution

Simulation formula:

$$\text{Min } j$$

j represents the earliest time of bottleneck occurred. In order to find the area of the bottleneck, we should find Min j.

limitation factor:

St1:

$$R_{(i,j)} = \frac{P(i)}{N} = 1$$

Where the $P(i)$ represents at the time of $t(j)$, the area i holds the number of people, And N represents the capacity of each inspection port. $R_{(i,j)}$ represents at the time of $t(j)$, the capacity of the area i.

St2：

(1) The way of passenger discern：

Based on the direction of passenger flow, we have simplified the consistent identification method, that is expressed by, the movement of passengers is not affected by the circumstances behind them. Shown as Figure 4.2.3.1

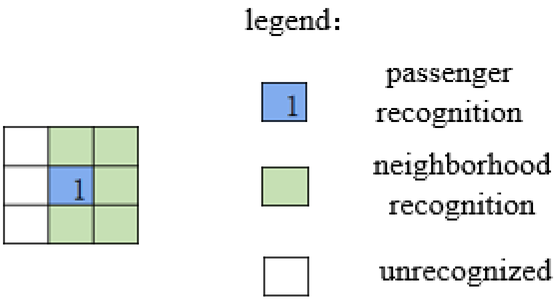

Figure 4.2.3.1 cell neighborhood recognized diagram

In the figure, the blue part is the passenger position, the green part is the neighbor position recognized by the passenger, and the white part is the unrecognized area.

(2) The way the passengers walk：

Assume each passenger behaves in the same way， so the passenger can walk in the not checked area (Zone A, Zone B) .As the following figure.

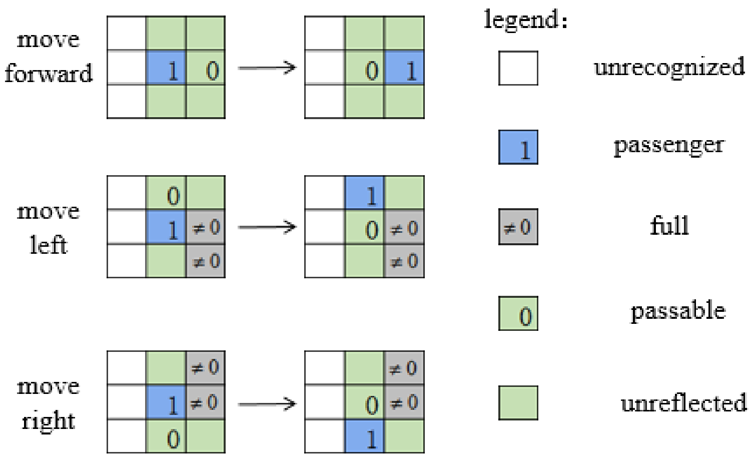

Figure 4.2.3.2 cell regular evolutionary process diagram

According to the summary of *"No Consider"* in the chart, the part with figures is the areas that should be practically considered. The chart express the conditions that passengers should go straight, turn left, or turn right.

In addition to movement rules of passengers in the regions of inspection, movement rules of passengers in the regions of non-inspection, was shown as following figure.

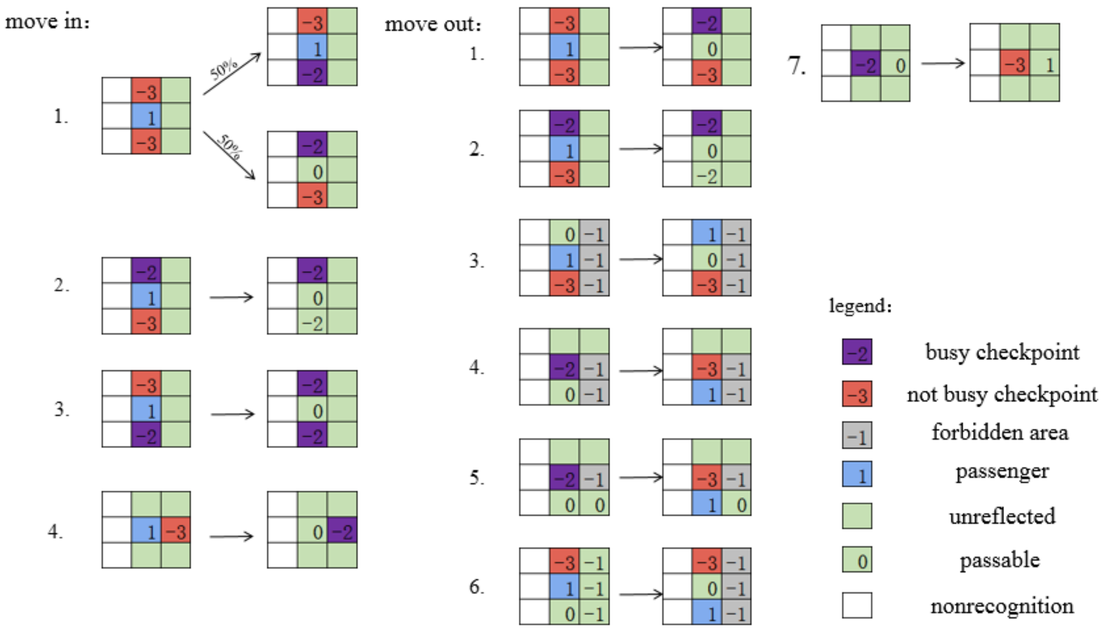

Figure 4.2.3.3 Be tested area evolutionary process diagram

This chart shows six ways to move into security checkpoint, and seven ways to move out security checkpoint are shown. There are two kinds of mobile situations in the first way to move into security checkpoint, and the probability of each of the mobile situation is equal, which is 0.5.

4.2.4 Results

Although the result of each simulation modeling cannot be coincident, we find out (that part) meet conditions (how many) times by statistical analysis.

Solution of the results of simulation modeling: although the states of the results are different, the conclusion is the same through the cellular automata simulation. That is to say Zone B of pre-check lanes and regular check lanes may first cause bottleneck effect. The results of four times simulation are shown as following.

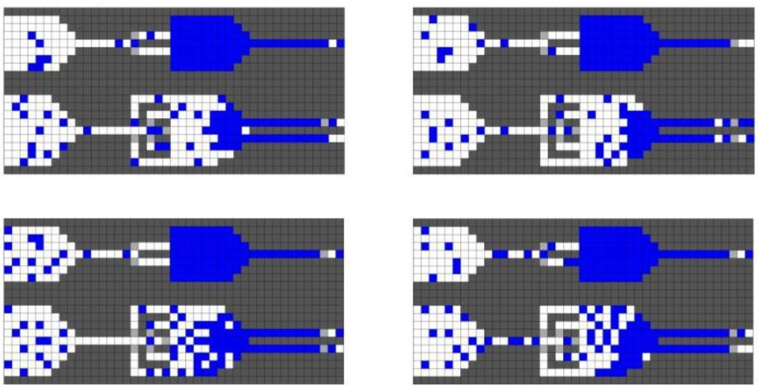

Figure 4.2.4 simulation result

The above figure shows the results of the four times cellular simulation, the higher channel in each picture is pre-check channel, the lower channel is the regular channel. Through the image, we can obtain that the Zone B of pre-check and regular lanes are bottlenecks.

5 Task Ⅱ: Multi-objective Optimization Model Based on Queuing Theory

5.1 Single Queue Multi-channel Waiting System Model

A queuing network for passenger security checked, Multi-desk waiting for the lanes are built into the a queuing system. The network construction is shown in Figure 5.1.

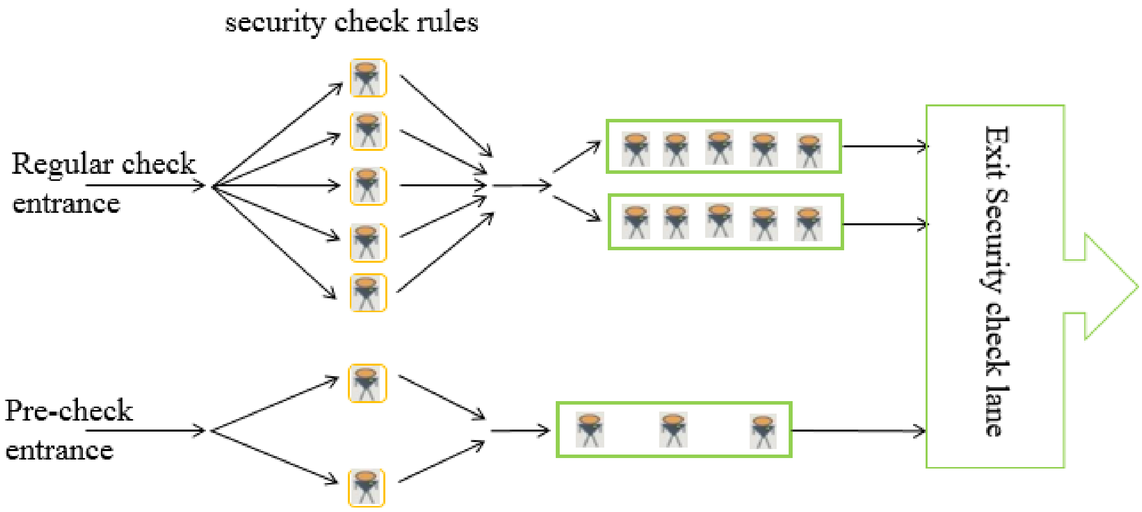

Figure 5.1 Queuing Network Diagram

Let N is the number of customers arriving within the time interval [0, t) (t> 0), Let $P_n(t_1,t_2)$ denote the probability that n (≥ 0) customers arrived in the time interval $[t_1,t_2),(t_2>t_1)$, is expressed by

$$P_n(t_1,t_2)=P\{N(t_2)-N(t_1)=n\} \quad (t_2>t_1,n\geq 0)$$

1 Since the number of customer arrivals is independent of each other in the non-overlapping time interval, we call this property no-after-effect.

2 For a sufficiently small Δt, the probability of a customer arriving within the time interval [t, t + Δt) is independent of t, And it's approximately proportional to the interval length Δt.

$$P_1(t,t+\Delta t)=\lambda\Delta t+o(\Delta t)$$

when $\Delta t\to 0$, o(Δt) is infinitesimal of higher order about Δt. λ > 0, λ is a constant. It represents the probability of a customer arriving per unit of time, called the probability intensity.

3 For a sufficiently small time , The probability of two or more customers arriving within the time interval [t, t +Δt) is so small that it can be ignored, that is

$$\sum_{n=2}^{\infty} P_n(t, t+\Delta t) = o(\Delta t)$$

The time starts at 0, Abbreviated as

$$P_n(0,t) = P_n(t)$$

Through 1 and 2 we can obtain

$$P_0(t, t+\Delta t) = P_0(t)P_0(\Delta t)$$

$$P_n(t, t+\Delta t) = \sum_{k=0}^{n} P_{n-k}(t)\, P_k(\Delta t), \qquad n = 1,2,\ldots$$

Through 1 and 2 we can obtain

$$P_0(\Delta t) = 1 - \lambda\Delta t + o(\Delta t)$$

Express as

$$\frac{P_0(t, t+\Delta t) - P_0(t)}{\Delta t} = -\lambda P_0(t) + \frac{o(\Delta t)}{\Delta t}$$

$$\frac{P_n(t, t+\Delta t) - P_n(t)}{\Delta t} = -\lambda P_n(t) + \lambda P_{n-1}(t) + \frac{o(\Delta t)}{\Delta t}$$

In the above two formulas, limiting Δt tend to zero, when the function involved is assumed to be derivative, We can get the following differential equation group:

$$\begin{cases} \dfrac{dP_0(t) - P_0(t)}{dt} = -\lambda P_0(t) \\ \dfrac{dP_n(t)}{dt} = -\lambda P_n(t) + \lambda P_{n-1}(t), \quad n = 1,2,\ldots \end{cases}$$

Take the initial value $\mathrm{P}_0(0) = 1$, $P_{\mathrm{n}}(0) = 0(\mathrm{n} = 1,2,\ldots)$, the result is $P_0(t) = \mathrm{e}^{-\lambda t}$. And then let $P_{\mathrm{n}}(t) = U_{\mathrm{n}}(t)\mathrm{e}^{-\lambda t}$, we can obtain $U_0(t)$ and other $U_{\mathrm{n}}(t)$ to suit the differential equations.

$$\begin{cases} \dfrac{dU_n(t)}{dt} = \lambda U_{n-1}(t), n = 1,2,\ldots \\ U_0(t) = 1, U_n(t) = 0 \end{cases}$$

Thus, a result can be easily obtained

$$P_0(\mathrm{t}) = \frac{(\lambda\mathrm{t})^n}{n!} e^{-\lambda t}, \ \ \mathrm{n} = 1,2\cdots$$

$\{N(\mathrm{t}) = \mathrm{N(s+t)} - \mathrm{N(s)}\}$ obey to Poisson distribution,

$$E[N(t)] = \lambda t; \ \ \mathrm{Var}[N(t)] = \lambda t$$

Passengers arrive at the airport individually, with successive arrival times subject to a negative exponential distribution with a parameter λ.

5.2 Optimization Model

5.2.1 Optimization model Establishment

In order to seek the maximum A, G_1 represents the regular lane throughput, G_2 represents the regular Pre-check lane throughput.

$$\text{s.t.}\begin{cases} T_s = \max\left[\left[G_1 * W_{S(1)} + G_2 * W_{S(2)}\right],\ \left[G_3 * W_{S(3)} + G_4 * W_{S(4)}\right]\right] \\ G < 24 * 60 * 60 \\ T = \frac{G_1 * W_{q(1)} + G_1 * W_{q(2)} + G_2 * W_{q(3)} + G_2 * W_{q(4)}}{G_1 + G_2} \\ G = G_1 + G_2 \\ S_i \epsilon 1,2,3,4 \\ Q_i = \mathrm{S}_i * M_i \end{cases}$$

T_s represents the work time of a security staff, the time passenger stay is the work time of security check:

$$T_s = \max\left[\left[G_1 * W_{S(1)} + G_2 * W_{S(2)}\right],\ \left[G_3 * W_{S(3)} + G_4 * W_{S(4)}\right]\right]$$

Where G_1 is the total passenger throughput of regular channels, G_2 is the total passenger throughput of pre-check channels, and $\mathrm{G} = G_1 + G_2$ is the total passenger throughput of whole airport.

T_L represents the average waiting time of all passengers at airport.

$$T_L = \frac{G_1 * W_{q(1)} + G_1 * W_{q(2)} + G_2 * W_{q(3)} + G_2 * W_{q(4)}}{G_1 + G_2}$$

Where S_1 is the number of information desk in Zone A of Regular channels regions, S_2 is the number of information desk in Zone B of Regular channels regions,S_3 is the number of information desk in Zone A of pre-check channels regions, S_4 is the number of information desk in Zone B of pre-check channels regions.

Where M_1 is the cost of one information desk in the Zone A of regular channels regions.M_1 is the cost of a personnel, M_2 is the cost of a information desk in the Zone B of regular channels regions M_2 is the cost of five personnels add cost of facilities.M_3 is the cost of a information desk in the Zone A of pre-check channels regions M_3 is cost of a personnel, M_4 is the cost of a information desk in the Zone B of pre-check channels regions M_4 is the cost of five personels add cost of facilities

Total cost: $Q_i = S_i + N_i$

So comprehensive evaluation indexes combine with the following formulate

$$T_L = \begin{cases} \frac{G_1 * W_{q(1)} + G_1 * W_{q(2)} + G_2 * W_{q(3)} + G_2 * W_{q(4)}}{G_1 + G_2} \\ G = G_1 + G_2 \\ Q_i = S_i * M_i \end{cases}$$

The expression of A is obtained as shown in the following formula:

$$A = \frac{G}{T * Q} = \frac{(G_1 + G_2)^2}{[G_1 * W_{q(1)} + G_2 * W_{q(2)} + G_3 * W_{q(3)} + G_4 * W_{q(4)}] * \sum_1^4 Si * Mi}$$

The A is a comprehensive evaluation index. And it has the greater value, the results will be better. We strive to achieve the maximum passenger throughput of security channels while the average waiting time is minimum.

5.2.2 Optimization model Solution

In the model of queuing theory, the law of passengers arrive at checkpoint is the distribution of Poisson. And the law of time used in security check belong to negative exponential distribution. There are S security checkpoint, and the capacity of the system is infinite waiting system. In Poisson distribution, the λ was used to describe the average number of passengers who are arrival per unit time. The $\frac{1}{\lambda}$ describes the average arrival time interval of per passenger, and this agree with the meaning of ET. Moreover, the μ called average service rate express the number of passengers who have finished security check per unit time. And the $\frac{1}{\mu}$ express the average time a passenger pass through the security check.

We use known data to compute these: λ=11.05 μ=6

For improving the largest passenger throughput of the security lanes, and reducing variance in waiting time, we analysis the location in inspection process that may cause bottleneck effect by the cellular automaton model. And the location is the beginning of causing waiting time. Moreover, we use the computer simulation of queuing theory to reduce variance in wait time. Through simulation, we obtain the average wait time of passengers and the intensity of security system. Through the computer simulation of queuing theory by the Matlab software, we can obtain the average waiting time of passengers and the load intensity of system work.

Firstly, we only use the model of the single queue and single lane to simulate and calculate the average waiting time of passengers and the load intensity of a unit security system, and make an evaluation criterion according to this model. Secondly, we utilize the model of the single queue and multi-lanes to simulate the average waiting time due to the lanes sequentially increase. The simulation outcome of the single queue and single lane was shown as following：

working intensity of security system: 0.653,the average waiting time of passengers: 13.29s

According to the simulation outcome of queuing theory, we can reduce the average waiting time by increasing the number of security lanes and security staffs. As long as the result of modification is less than the simulation outcome, we are successful.

For stochastic optimization problems, we can obtain results only through procedure simulation. We study the Chicago O'Hare International Airport in United States. The airport is one of the busiest airport in the world. According to the date released by O'Hare International Airport, the number of landing flight was 2700. And the annual passenger throughput reached 70 million 80 thousand in 2014, the passenger throughput of a day reached up to 192 thousand.

We use the model of the single queue and single lane to simulate, and part of the results are shown as following table.

Table 5.2.2 Simulation results

Number of security lane	Passenger throughput	Average waiting time	Security lane work intensity	Simulation time
3	2000	2000	0.94021	1500
5	9277	1820	0.87530	2500
10	9301	1580	0.85100	5000
50	11012	1201	0.80122	25000
100	20225	980	0.73789	50000
150	25026	854	0.71036	75000
250	42302	741	0.68432	125000
300	48652	546	0.65301	150000
400	56503	443	0.53246	200000

450	60145	361	0.51235	225000
500	72563	220	0.51026	250000
800	99658	112	0.51641	400000
1000	142350	68	0.50230	500000

5.3 Optimization Model Verification

We validate the established optimization model， by using the method of computer simulation, Through the analysis of known data, make the data into this optimization model, Compare the optimized model and un optimized ,the radio of passengers to average waiting time varies with time as shown in the Figure 5.3

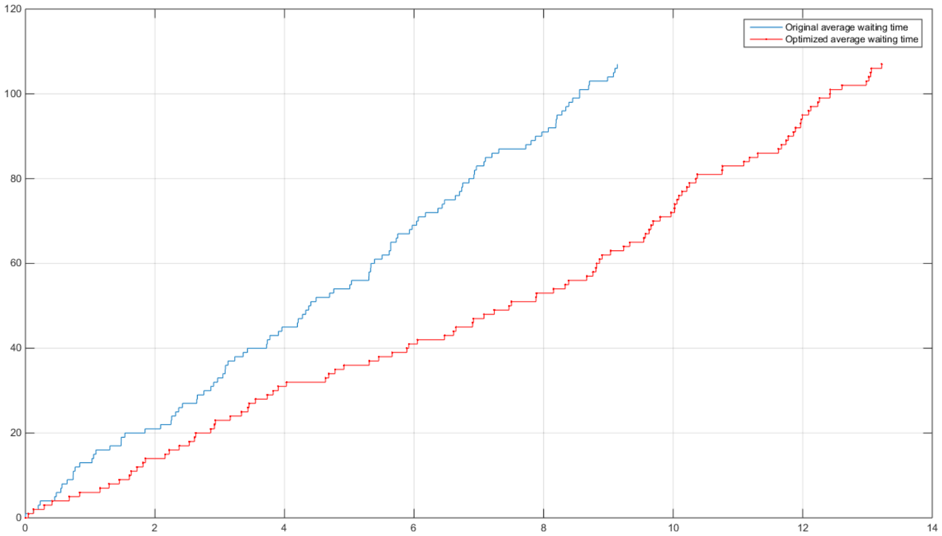

Figure 5.3 Optimization model validation diagram

This red curve represents the rate of original model, the blue curve represents the rate of optimized model. We can find the rate rises obviously, this process verificates the optimization model is feasible.

5.4 Results

According to the date shown in the above table, we can obtain that the number of security-check lanes is positively related to passenger throughput while negative related to the average waiting time. Then combined with the waiting model of single queue and single lane, we acquire the indexes (the average waiting time and working intensity of security check lanes) by comparison. We establish an optimal mathematical model under the premise of warranty cost by combining with the related factors including passenger throughput per unit time, the average waiting time, cost of construction of security lanes, and employment cost of security staffs, if less than the indexes. The model was shown as following：

We can obtain an optimal solution by using the optimal model. We can obtain the minimum average waiting time while the number of security channels increase. That is to say, we can obtain the maximum passenger throughput of security channels.

To achieve the constraint conditions of the optimal, we have to consider the effect of the cost of construction of increasing the security channels and cost of hiring security staffs on comprehensive evaluation indexes. Hence we carry on the comparative analysis of linear correlation of estimated costs.As shown as Figure 5.4.1.

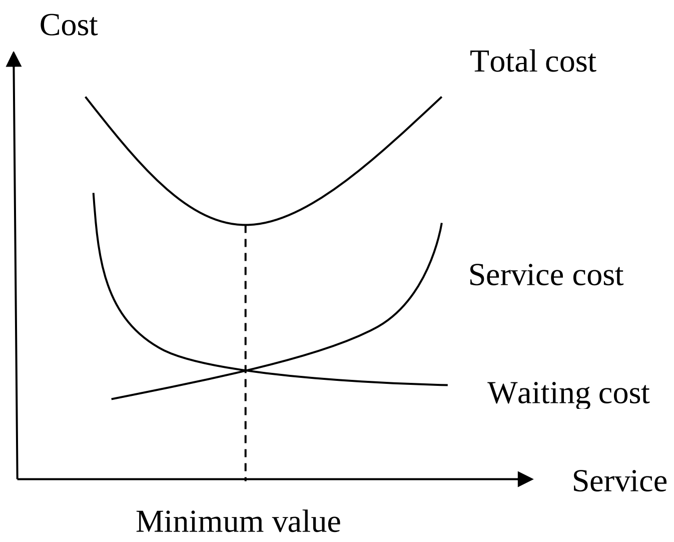

Figure 5.4.1 System cost

It can be seen that the higher the security cost, the smaller the loss caused by waiting time, and the minimum value when the function curve intersects.

The cost of each security channel per unit time is C_s Each customer in the system to stay in the unit cost C_w , The expected cost per unit of time (Service costs and pending charges) is

$$z = C_s c + C_w L_s$$

In this case,

$$L_s = L_s(c)$$

It is related to the service desk C. So the total cost is

$$z = z(c)$$

The optimal value of Z in mind C is C, Then

$$z = (c^*)$$

is the lowest cost .Since

$$z(c)$$

can only take integers, that is, discrete functions So the marginal analysis method can only be used to solve, in fact, according to

$$z = (c^*)$$

for the minimum, can obtain

$$\begin{cases} z(c^*) \leq z(c^* - 1) \\ z(c^*) \leq z(c^* + 1) \end{cases}$$

$$z = C_s c + C_w L_s$$

by

$$\begin{cases} C_s c^* + C_w L_s(c^*) \leq C_s(c^* - 1) + C_w L_s(c^* - 1) \\ C_s c^* + C_w L_s(c^*) \leq C_s(c^* + 1) + C_w L_s(c^* - 1) \end{cases}$$

Through Simplifying can obtain

$$L_s(c^*) + L_s(c^* + 1) \le \frac{C_s}{C_w} \le L_s(c^* + 1) - L_s(c^*)$$

We can get

$$c^*$$

And

$$c^*=2$$

Through this model, we can get an optimal solution. From a macro point of view, when the passenger's throughput is maximum, we could increase 2 security check points.

6 Task Ⅲ: Sensitivity analysis

Task three requires to conduct a sensitivity analysis on our model. Now we consider how the differences impact our model. In the context of the security channel, based on different cultural backgrounds and different types of passengers can only be one by one security, this randomization in the security process caused by a Stage of the phenomenon of long lines.

At the same time, when we balance the influences of various factors we tend to neglect the impact of certain incidents. We perform a sensitivity analysis on the influencing factors based on arrival rate and service rate

$$\rho_i = \frac{\lambda_i}{S_i \mu_i,}$$

μ represents the number of passengers in unit time that can be checked security，It's the average service rate of the system，Find some factors of influencing arrival rates, such as include passenger types，We divide into the following items of passenger types, It's based on a standard classification in the air transport industry.

Table 2 Description of traveler style

traveler types.	λ_i	μ_i
Plan business travelers	11.2	7
Urgent business travelers	6.1	6
Emergency leisure passengers	5.2	6.5
Plan leisure passengers	12.9	5.8

Different kinds of travelers only can pass through security checkpoint one by one, the time of different kinds of travelers need to accept security check is different. We think the effect factors is related to characterization of culture, aging, sex and big or small and the number of the baggages they carry in addition, the inestimable effect factors include social code of ethics of passengers.

Finally, we should consider if there need hire extra staffs as standby crew for ensuring the safety of passengers and airports. To better characterize the sensitivity of our model to the natural variations and errors present in our initial conditions and simulated components, we have performed this two indicators.

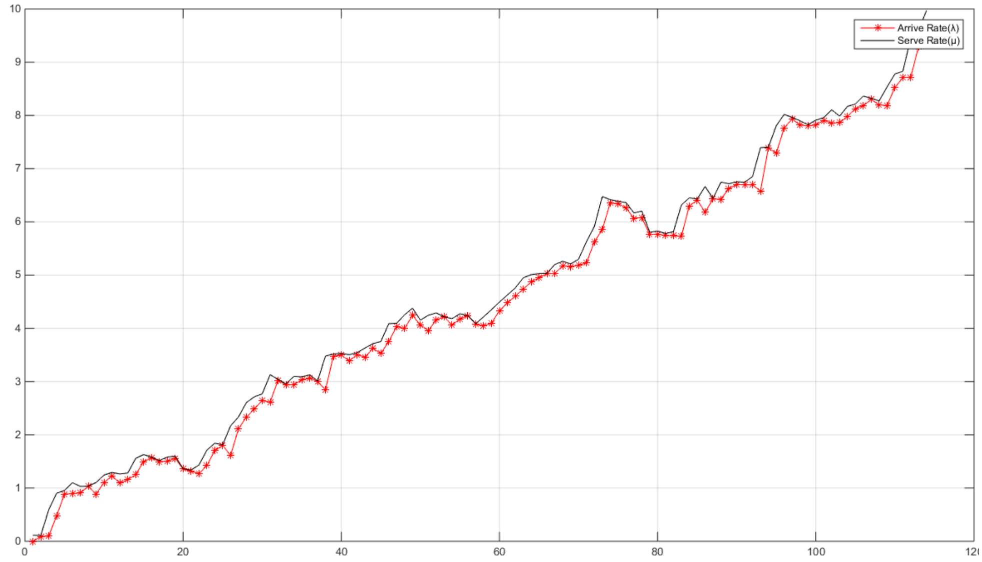

Figure 6

It can be seen that the change of passenger type has little effect on the model, indicating that the model has a certain stability. The model can adapt to many kinds of environments and has the value of promoting .

7 Task Ⅳ: Advices

In the process of building model, we control the throughput by controlling the number of channels. It reflects the influence of the number of channels on throughput and average waiting time. We hope that you can apply it flexibly through our model. For example, you can find annual peak operating hours, and annual peak operating hours for equipment storage, but the use of equipment and staffing are based on recent changes in passenger traffic to be adjusted. In this way, you can according to the statistical annual throughput to decide on specific scenarios for equipment usage and staffing.

Similarly, our model is established to find the bottlenecks region in the system, for example, the throughput is cyclical and growth trends over time, In different period, alternately to replace equipment and staff, We can through the model one, find out the bottleneck point in the system。 Try to make a small adjustment to the bottleneck point。 If you meet your expectations, you can choose to wait until the next cycle and then adjust.

Finally, if your airport passenger has obvious characteristics, you can according to your airport passengers, the user waiting area for optimization. For example, the slow pace of the elderly, people in the crowd will affect the people around, the same is likely to delay the aircraft, according to this situation, to ensure safety under the premise of opening up the policy.

Here are some advices as following:

1. Equipment reserves to meet the annual operating peak.
2. Using Multi-objective Optimization Model re-plan the airport at the turn of the throughput cycle.

3. Alternation of throughput cycle variation, fine-tuning the bottleneck of the solution using Bottleneck Recognation Model and abandonment of re-optimization of the number of channels and staffing if expectations are met.

4. To slow down the crowd, set up a separate channel.

8 Model Extension

8.1 The United States Summer Vacation Security Check Point Long Line Problem

During 2016, the U.S. Transportation Security Agency (TSA) came under sharp criticism for extremely long lines. Why still happened this , I think this is not a force majeure. We use the idea of cellular automata to analyze the possible bottleneck areas，to establish an optimal model of multi-security channel mechanism based on queuing theory. We try to improve our optimization model to deal with the long queue congestion caused by large-scale festivals.

Resulting in a long time of the congestion phenomenon, on the one hand is due to large flow of population too late to ease, and the security of the mouth of the load capacity is lower than large-scale passenger flow. Therefore we consider leading factors in dealing with this festive congestion problem. Obviously ,we can not choose to change the large-scale in a short time to change the number of security checkpoints, but we can change the security link into a multi-queue multi-channel loss model optimization model, Because we plan to increase the security officers and the flow of mobile security officers to guide passengers flow from the macro and micro perspective at the same time.

Of course, this requires close monitoring and control center with the action, the use of free movement of the security channel fixed column to plan passenger flow lines. So as to minimize the phenomenon of long lines.

8.2 Adapt to Chinese Spring Festival travel rush in the subway security check points optimization model

We effectively to China during the Spring Festival, brought about by the congestion problem to be considered. In China during the Spring Festival, in Beijing, Shanghai, Guangzhou, Shenzhen and other large cities of the transport hub often produce long queues and congestion problems, which is in our real life is also very concerned about is worthy of our in-depth consideration.

Analysis of a system, we often need from a macro perspective, to analyze the bottleneck caused by the overall flow of people planning, our cellular automata model is based on the airport security bottleneck area to find the model, but we can according to environmental variables Different, set the evolutionary rules for the same flow of people to promote the use of the problem, looking for the system channel bottleneck area. For example, the public subway gate security system, when the peak flow of people per day, the security channel is too small, will result in security channels for the bottleneck area, the same time peak, if the wicket less, wicket will become a bottleneck area. Therefore, when there is a planning problem with the security gate and the ticket gate and the circulation, the problem is just as we model two, considering the number of security channels and the number of security personnel optimization model.

9 Analysis of the Model

9.1 Strength

- Integrity : We comprehensively use all of the data, either for evaluation, or for averaging over a group, understand the meaning of data accurately, making evaluation criteria more credible.
- We successfully quantify various indicators.
- We use a graphical display model to clearly analyze the process.
- Our models are sensitive and show a great adaptability ， and can be applied in different aspects.

9.2 Weakness

- We don't get the exact value of the benefits due to lack of data.
- The results of simulation need to ensure the accuracy of the rules under the premise of the reliability of simulation results.
- Subjective factors of culture norms are not taken into account in the configuration of Task3 which are uncontrollable, such as religious factor.

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Appendix

Code1

```
n=10000;
dt=exprnd(12.3,0.1,n);
st=normrnd(6.5,0,n);
a=zeros(1,n);
b=zeros(1,n);
c=zeros(1,n);
a(1)=0;

for i=2:n
    a(i)=a(i-1)+dt(i-1);
end

b(1)=0;
c(1)=b(1)+st(1);

for i = 2:n
    if(a(i)<=c(i-1))
        b(i)=c(i-1);
    else
        b(i)=a(i);
    end

    c(i)=b(i)+st(i);
end

cost=zeros(1,n);
for i=1:n
    cost(i)=c(i)-a(i);
end

T=c(n);
p=sum(st)/T;
avert=sum(cost)/n;

fprintf(':%6.3f\n',p);
fprintf(':%6.2f seconds\n',avert)
```

code2

```
;  Total_time = 9.2;
N = 1000;
lambda = 11.05;
mu = 6;
arr_mean = 1/lambda;
ser_mean = 1/mu;
arr_num = round(Total_time*lambda*2);
events = [];

events(1,:) = exprnd(arr_mean,1,arr_num);

events(1,:) = cumsum(events(1,:));

events(2,:) = exprnd(ser_mean,1,arr_num);

len_sim = sum(events(1,:)<= Total_time);
events(3,1) = 0;
events(4,1) = events(1,1)+events(2,1);
events(5,1) = 1;
member = [1];
for i = 2:arr_num
if events(1,i)>Total_time
break;
else
number = sum(events(4,member) > events(1,i));
if number >= N+1
events(5,i) = 0;
else
if number == 0
events(3,i) = 0;

events(4,i) = events(1,i)+events(2,i);

events(5,i) = 1;
member = [member,i];

else len_mem = length(member);

events(3,i)=events(4,member(len_mem))-events(1,i);
events(4,i)=events(4,member(len_mem))+events(2,i);
```

```
events(5,i) = number+1;
member = [member,i];
end
end
end
end
stairs([0 events(1,member)],0:len_mem);
hold on;
stairs([0 events(4,member)],0:len_mem,'.-r');
legend(' ',' ');
hold off;
grid on;
figure;
plot(1:len_mem,events(3,member),'r-*',1: len_mem,events(2,member)+events(3,member),'k-');
legend(' ',' ');
grid on;
```