Optimize passenger throughput at airport security checkpoints

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Abstract

We improved the traditional queuing theory model and used the deviation of actual length of the queue and the estimated one to find the bottleneck of the airport security, in order to reduce the possibility of too long queue. We also used polynomial fitting and Petri net, WF-net to improve the airport passenger throughput, and analyzed the impact of different cultures on the model. Finally, we put forward practical suggestions to the airport according to the results of Gray System Theory analysis. Through the actual data simulation we found that millimeter wave and X-ray detection is more likely to exist bottlenecks. The largest number of passengers in a day is about 7a.m. to 8 a.m.. In addition, cultural differences between different countries also have an impact on the simulation.

Keywords

Throughput, queuing theory,Polynomial fitting, Petri net and WF-net, the Gray System Theory.

1. Introduction

Today, airport security has become an indispensable task before boarding. How to reduce the waiting time of airport security queuing is of great significance. Our model is used to check the problems at airports, and to take measures to avoid passengers waiting too long to improve the passenger throughput. We also consider the impact of different cultural differences in different countries in the model, and propose suitable and feasible suggestions for airport managers.

Recently the airport security issue has received wide attention by the whole society. Many researchers published the relevant academic papers. Prof. Gao Jinhua and Prof. Li Jie of Civil Aviation University of China used the knowledge of stochastic process and queuing theory to analyze the performance of Erlang's queuing model and solve the parameters, and give the application range in airport passenger terminal building.

Queuing theory is also applied to other fields. Professor Jiang Yong and Professor Yang Lili of Guangdong University of International Business and Economics have put forward queuing theory and its three components and corresponding performance indexes, and use queuing model in system theory to analyze the waiting problem of personal banking service system. Then from the perspective of operational research and economics, the paper analyzes the sensitivity of the service time and the number of service desks as the main variables, puts forward the corresponding optimization system and improves the policy recommendations.

Our approach is:

Firstly, we analyzed the principles of queuing theory and improved the queuing theory.

We abstracted this problem into a multi-window service in parallel, multi-link se rvice model in series and we believed each window service time obeys the Erlang Distribution .

We measured the results by the length of the queue rather than the number of people in the queue, which was more convenient for the airport staff to know when to take measures.

We introduced the two basic variables, service intensity ρ and order k, and calculated the estimated value of ideal queue length. When $\rho > 1$, the queue length becomes longer, and when $\rho < 1$, the queue length becomes shorter. K is the order of the Erlang distribution.

When the (actual length - theory length) / theory length more than a certain value N, we believed that if continue to queue up, the waiting time will be too long for passengers and causes dissatisfaction. To avoid this situation, the staffs should take timely measures.

Then, we considered the actually situation finding that under the guidance of the airport staff the variance of waiting time is reducing rapidly.

We used the polynomial fitting method to estimate the airport passenger throughput at different times of the day, and used Petri net and WF-net model to improve the throughput.

We analyzed the influence of different cultures on the model.

Finally, we used the Gray System Theory model to calculate the factors that affect the passenger satisfaction, and made recommendations to the airport staff.

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3. Organization of the Text

3.1 Assumptions

Each passenger arrival time obeys the Erlang distribution, each customer arrival time interval obeys the exponential distribution.

The number of passengers is greater than the number of open windows. Under ordinary circumstances, the number of passengers is always more, so the assumption is reasonable.

One link is not related to next link, we believe each window and link is independent. As there are many windows, so each window, each link does not exist connection between each other.

From 6a.m. to 10p.m., it was assumed that an aircraft will take off at an average of two minutes. Data show that there are more aircrafts during 6a.m. to 10p.m., from 11p.m. to 6a.m. there are less flights.

Different people need same time to check out the items.

Ignore the very special cause of a window may be closed.

Under normal circumstances, ordinary people required for 0.8 * 0.8 square meters to line up.

3.2 Definitions

variables	The meaning of variables
μ_1	The number of people who passed per unit time during the ID check
μ_2	The number of items per unit time passed during millimeter wave inspection
μ_3	The number of people who passed per unit time during X-ray examination
$1/\mu$	Average service duration
s	The number of queues
λ	The number of people who arrived in the airport per unit time
L_{q0}	The estimated length of the queue
L_f	The actual length of the queue
L	The length of the conveyor belts
v	The velocity of the conveyor belts
ρ	Service intensity

3.3 Model 1 : Found the airport security bottlenecks, avoid too long queue

When passengers enter the airport, the process illustration is as follows:

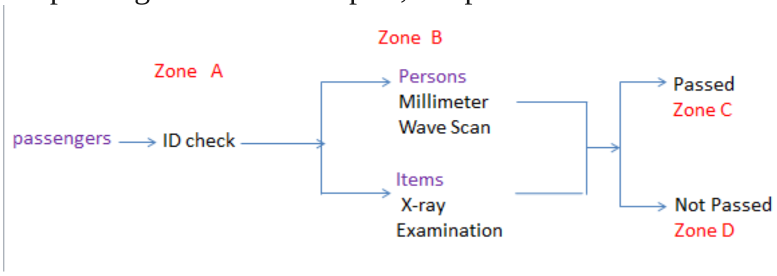

Figure 1 the process illustration

3.4 Zone A(the length of the queue for ID check)

Table 1 the time of ID check

ID Check Process Time 1 (Column C)	ID Check Process Time 2 (Column D)
00:07.5	00:14.6
00:05.3	00:11.8
00:11.1	00:14.8
00:10.0	00:20.4
00:09.1	00:07.7
00:08.8	00:07.5
00:12.6	00:10.9
00:15.4	
00:11.9	
Average 10.1889	Average 12.5286

Table 2 Number of departures and add passengers at different times of the day

Time	The number Of aircrafts	The number of people	Time	The number Of aircrafts	The number of people
0-1 o'clock	25	4000	12-13 o'clock	59	9440
1-2 o'clock	36	5760	13-14 o'clock	81	12960
2-3 o'clock	26	4160	14-15 o'clock	65	10400
3-4 o'clock	15	2400	15-16 o'clock	67	10720
4-5 o'clock	15	2400	16-17 o'clock	78	12480
5-6 o'clock	24	3840	17-18 o'clock	66	10560
6-7 o'clock	116	18560	18-19 o'clock	66	10560
7-8 o'clock	139	22240	19-20 o'clock	65	10400
8-9 o'clock	113	18080	20-21 o'clock	75	12000
9-10 o'clock	91	14560	21-22 o'clock	62	9920
10-11 o'clock	65	10400	22-23 o'clock	34	5440
11-12 o'clock	75	12000	23-24 o'clock	11	1760

3.4.1the Pre-Check passengers

According to the known data, the average time Pre-Check passenger used during the ID check is $1 / \mu_1 = 12.5286$, time $var(1 / \mu_1) = 1 / (k_1\mu_1^2) = 20.5324$; (the Pre-Check passengers need to show the "trust certificate" and other related documents, then the ID check takes longer time, so we think that the Column D represents the Pre-Check passengers time.)

So k_1=（12.5286）^{2}/20.5324=7.6448； $\rho_1=\lambda/s\mu_1$; (1)

According to information we find that the conventional airport will open 20-40 security port at the same time, here calculated by 30, that s equals 30.

Different types of aircraft carry different numbers of passengers, generally 100-400 people, here we calculated by 200 people, and the statistical data shows that the aircraft seating rate is generally 80% , So each plane accommodates about 160 people.

According to the data provided by the airline official website, we can approximate that from 7a.m. to 10p.m. in 16 hours the total number of flights n equals 1283, the passengers reach the airport in every second

$$\lambda = n * 160 / (16 * 60 * 60) = 3.56 \quad (2)$$

And the Pre-Check passengers accounted for 45% of the total number of passengers, the Pre-Check channels accounted for 1/4 of the total number of channels, so

$$\rho = 0.45\lambda/\frac{1}{4} s\mu_1 \quad (3)$$

The estimated length of the queue

$$Lq0 = 0.8\left\{\frac{\rho^2}{1-\rho} - \frac{(k-1)\rho^2}{2k(1-\rho)}\right\} \quad (4)$$

Metrics: When（Lf_1- L_{q0}）/ L_{q0} > N, that is, the actual length of the queue compared to the ideal estimated value more than a certain standard N, we believed this part of the problem, the infrared devices installed outside the queue area will make some kind of warning so that the staff can take appropriate measures to prevent the long queue. (According to the data given in the table, we found that the ID check time is relatively stable so that the parameter N of this link is small, take 10%).

3.4.2the ordinary passengers

Similarly, according to the known data, the average time ordinary passengers

used during the ID check is 1 / μ1=10.1889, time var (1 / μ1) = 1 /$_1$(k1μ 2) =8.8761; So k1=(10.1889)2/8.8761=11.6959； ρ1=λ/sμ1;

And the ordinary passengers accounted for 55% of the total number of passengers, the ordinary channels accounted for 3/4 of the total number of channels, so

$$\rho = 0.55\lambda/\frac{3}{4} s\mu_1 \quad (5)$$

The estimated length of the queue

$$Lq0 = 0.8\left\{\frac{\rho^2}{1-\rho} - \frac{(k-1)\rho^2}{2k(1-\rho)}\right\} = 3.600 * 0.8 = 2.8803 \quad (6)$$

According to the given data, ID check time is basically the same, we can approximated that there is a very small probability of accidents leading to too long queues. If blockings occurs, 1 / μ1 increases, ρ1 increases, so that the length of queue increases.

3.5 Zone B(Millimeter-wave and X-ray examination at the same time)

Table 3 millimeter wave scan time and X-ray scan time

Millimeter wave inspection time(two neighboring numbers take subtraction）	Millimeter Wave Scan times	X-ray examination time(two neighboring numbers take subtraction）(Ordinary)	X-Ray Scan Time (Column F)	X-ray examination time(two neighboring numbers take subtraction）(Pre-Check)	X-Ray Scan Time (ColumnG)
11.3	00:08.8	3.1	00:02.5	1.5	00:00.0
12.4	00:20.1	1.7	00:05.6	2	00:01.5
3.5	00:32.5	2	00:07.3	7.5	00:03.5

7.5	00:36.0	10.8	00:09.3	average 3.667	00:11.0
8.2	00:43.5	2.3	00:20.1		
12.9	00:51.7	2.1	00:22.4		
11	01:04.6	16.7	00:24.5		
9.1	01:15.6	25.9	00:41.2		
7.7	01:24.7	1.7	01:07.1		
10.7	01:32.4	9	01:08.8		
15.1	01:43.1	average7.5	01:17.9		
11	01:58.2				
17	02:09.2				
13.4	02:26.2				
7.7	02:39.6				
6.7	02:47.3				
11.6	02:54.0				
19.4	03:05.6				
8.6	03:25.0				
37.5	03:33.6				
11.3	04:11.1				
12.4	04:22.4				
12	04:34.8				
13.2	04:46.8				
11.1	05:00.0				
7.3	05:11.1				
8.1	05:18.4				
14.3	05:26.5				
7.1	05:40.8				
11	05:47.9				
9.6	05:58.9				
27.5	06:08.5				
8.6	06:36.0				
9.7	06:44.6				
11	06:54.3				
9.7	07:05.3				
8.6	07:15.0				
12	07:23.6				
7	07:35.6				
average11.345	07:42.6				

The understanding of the process: people need to test their own items placed in the container, and then through the millimeter wave, the items are sent by the conveyor belt to X-ray inspection at the same time. The speed of people and items should be matched, otherwise:

People too fast will make the accumulation phenomenon occurred when people pack their things and lead to obstruction;

Items too fast will make the items blocked, give people trouble to pack, and increase the time passengers pass the security port, reducing satisfaction.

Therefore, the time exams passengers and the time exams items should be substantially equal. Due to the need to ensure adequate security, we'd better not change the scan time, so we should change the speed of the conveyor belt to adjust the speed of the items be transferred. As for how to adjust the conveyor speed, the analysis will be mentioned later.

Define the time when person remove and pack the items which need to be checked as t0 (the time when items be pulled to the belt ignored), according to the information that ordinary passengers cost 16.89s to remove items, packing time is 18.04s , With the help of the staff, that each person uses the same time.

Under the conditions that the length of conveyor belt is not changed, the time object on the belt is t = L / v; according to the flow of people to adjust the conveyor belt and make v match.

So

$$1/\mu B=\max(1/\mu 2,\ 1/\mu 3+L/v)+t0; \qquad (7)$$

Observing the data in the table, the data given in the question is the end of the check time, so the subtraction between the upper and lower values is the time cost for inspection. Considering the Pre-Check passengers need to receive less inspection items and cost less time, so that the Column G stands for the Pre-Check passengers check time, Column F stands for ordinary passengers check time.

3.5.1the Pre-Check passengers

As a result of the Pre-Check passengers have conducted a background investigation, they do not need to take off shoes and some checks, so the t0 for Pre-Check passengers is smaller (approximately take removing items costs 10s, packing time is 12s), and the belt speed should be increased.

It is mentioned in the assumptions that each link can be regarded as independent of each other because of the large number of open windows , so λ is still the same value as the ID check.

According to information that the conveyor speed v is generally 0.22m / s, conveyor belt length L take 2 meters. And according to the actual situation that this part of the opening windows will be less compared to the ID check, so take s equals 15;

According to the given data, we can calculate that

$$1/\mu B=34.7576 \qquad (8)$$

$$var(1/\mu B)=1/(k2\mu\ 2)=11.0833 \qquad (9)$$

$$k2=109.1 \qquad (10)$$

$$\rho 2=0.45\lambda/\frac{1}{4}s\mu_B \qquad (11)$$

The estimated length of the queue:

$$Lq0=0.8\left\{\frac{\rho^2}{1-\rho}-\frac{(k-1)\rho^2}{2k(1-\rho)}\right\}=2.4333*0.8=1.9466 \qquad (12)$$

Metrics: When(Lf1- Lq0)/ Lq0 > N, we believed this part of the problem, here, we take N as 20%.

3.5.2Oridinary passengers

Compared to the Pre-Check passengers, the t0 of this part will be more and the 1/μB will be more ,the length of the queue will be longer . The remaining data sources and thoughts are the same as the Pre-Check passengers.

$$1/\mu B=51.5209 \qquad (13)$$

$$var(1/\mu B)=1/(k2\mu B2)=20.5324 \qquad (14)$$

$$k=129.2788 \qquad (15)$$

$$\rho 2=0.55\lambda/\frac{3}{4}s\mu_B \qquad (16)$$

$$Lq0=0.8\left\{\frac{\rho^2}{1-\rho}-\frac{(k-1)\rho^2}{2k(1-\rho)}\right\}=2.4333*0.8=1.9466 \qquad (17)$$

Passengers in general will coordinate with the security staff, if an accident occurs,

such as refusing to be checked, then the parameter t0 will increase, ρ2 will increase, so that the queue will be longer. Another case is carrying prohibited items, the alarm device will make an alarm, the staff will make passengers with their luggage to the D area for further inspection, which will make the service time and queue longer inevitably.

Then we discuss how to determine the speed of the conveyor to match the inspection speed in the following discussions.

Let's take ordinary passengers as an example. When the speed of two inspections match, the length of the queue does not change, we set it to a fixed value 10 and calculate the function relationship between the number of passengers and speed of the conveyor belt:

$$a=0.0034*\lambda*\lambda-3.7716*\lambda \quad (18)$$

$$b=\sqrt{(4*0.0356*0.1778*\lambda\text{^}5)} \quad (19)$$

$$c=2*0.0356*\lambda*\lambda \quad (20)$$

$$v=(-a+b)/c \quad (21)$$

We make an image of the belt speed v varying with the number of passengers λ :

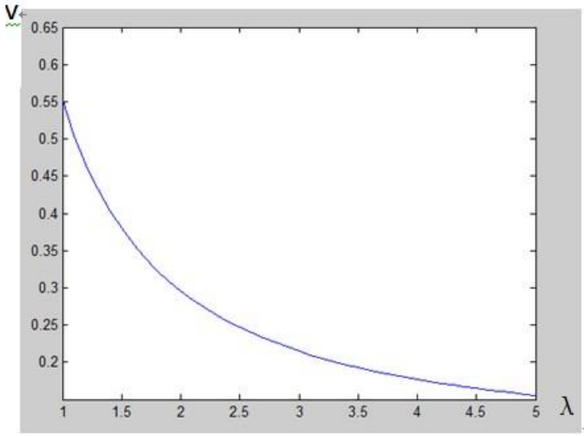

Figure 2 how the belt speed v varying with the number of passengers λ

According to the image, v should be reduced with the increase of λ, or when the number of passengers is too large, the phenomenon of accumulation will occur. The airport staff can adjust the conveyor belt speed based on the number of passengers to avoid blocking phenomenon.

Conclusion: There are five steps in the security check procedures, which can be divided into two links, we can establish infrared security checkpoints to observe the length of the queue in the two links. If Lq1 exceeds, we can conclude that the ID check is of problem; when Lq2 becomes larger, we can conclude that the second link is of problem.

The significance of the first model is that the model is more accurate than the human eyes. When the human eyes be able to see that the queue is too long, it's late for airport to take measures. And the model plays a certain role in the prediction.

3.6 Model 2 :Increase guidance to passengers and reduce the variance between each queues

Assuming that the security gate is symmetric about the entrance, according to the characteristic that people will give priority to the nearest channel, it can be abstracted into a normal distribution model in the case of no guidance. And it can be abstracted into a uniform distribution model under the guidance of the staff. Uniform distribution can make the service time variance become less than the normal distribution, so that the order k increases, Lq0 reduces and waiting time is reduced.

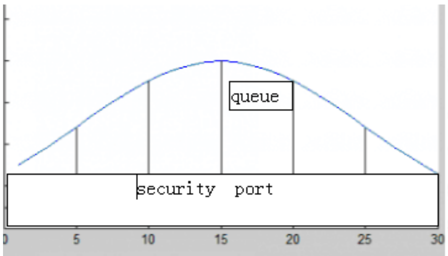

Figure 3 without the guidance

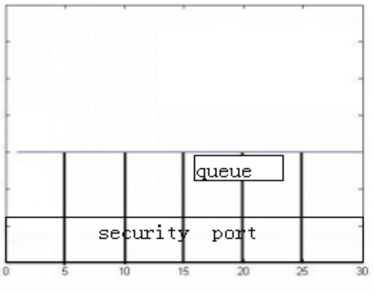

Figure 4 under the guidance

3.7 Model 3 :Forecast the changes of the population in the airport during the day, take measures to increase passenger throughput

According to the data provided by the airline's official website, we can know the number of flights taking off each hour, and the number of passengers in per flight is 160, the two can be calculated by the hourly throughput of the airport. With the help of matlab and excel, we can use the polynomial fitting to get how throughout varies with the time in the form of scattered plot diagram and curve. The functional relationship is:

$$f(x)=p1*x8+p2*x7+p3*x6+p4*x5+p5*x4+p6*x3+p7*x2+p8*x+c \quad (22)$$

other , p1=-0.001, p2=0.106,p3=-4.478,p4=99.98,p5=-1261,p6=8890,p7=-32500,p8=53610, c=-24790;

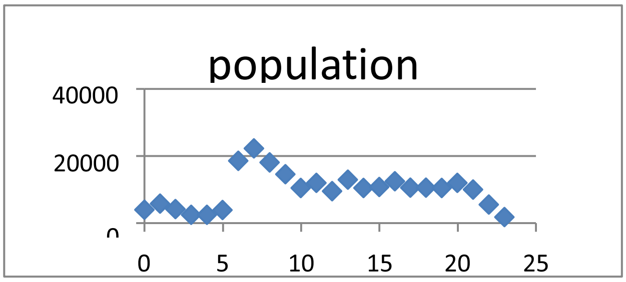

Figure 5 Throughput at different times of the day

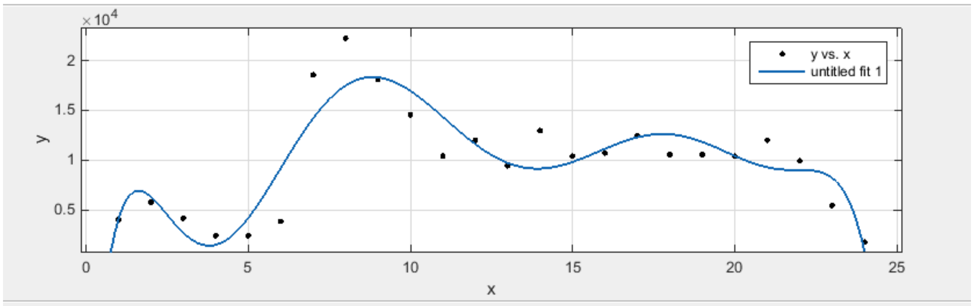

Figure 6 Throughput curve fitting at different time of day

According to the fitting curve, the slope represents the number of passengers per hour enter the airport, we make its slope curve with matlab:

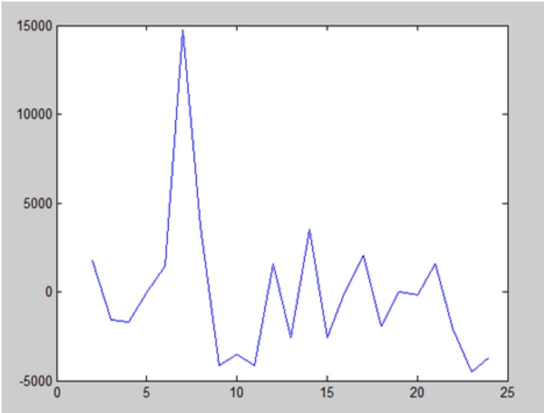

Figure 7 Number of passengers adding in one hour at different times of the day

Access to information that when increasing 1800 new people per hour the airport needs to open a new window and reduce a window when decreasing 600 people per hour, according to the figure, airport staff can open or close service windows timely.

3.8 Model 4 :Use the Petri net and MF-net model to increase the throughout

3.8.1 Definitions

Petri net: A model that combined with graphics, can be a good description of the process problem, is concerned about the impact of changes on the system.

random Petri net SPN={P T F M0 λ }

P: A finite set of places

T: a finite set of transitions

F: the flow relationship between the places and the transitions M0: the initial identification of the network

λ= {λ1, λ2, ⋯, λm}: The set of Initiation rate per unit time of the corresponding index change

WF-net: Petri net that satisfies the following two conditions at the same time:

3.8.2Model changes

Specify the initiation rate of each ti in the Petri net as λi, then the original model becomes the SPN model

There is no instantaneous transition in the security service. GSPN model can be obtained with a given delay time.

The SPN model obeying the exponential distribution is isomorphic to the Markov chain with continuous time.

3.8.3Explanation of measurement standards

The average number of tokens refers to the transition time of different states. The larger the average tokens, the longer it takes.

The greater the utilization rate of transition, the population of waiting for the activities the larger, the queue longer.

3.8.4Calculations

State equation: A set of equations of number n is established based on the average rate of the inputs and outputs of each state and its associated transitions, with all probability sums being 1.

Probability: The probabilities of the Token number i are obtained by summing the stable probabilities of the same Token number.

Average Token Count: Multiply the probabilities by the number of tokens of i, and then sum up the cases.

Transition utilization: The sum of the probabilistic probabilities of all the state identifiers with the transition time in an enforceable state.

3.8.5Improvement program

3.8.5.1Program 1

Based on the GSPN model of security service flow, the reachable identification table of security process GSPN model is listed and the reachable label is obtained.

The table is as follows:

	i	p_1	p_6	p_7	p_{10}	p_{14}	o
M_0	1	0	0	0	0	0	0
M_1	0	1	0	0	1	0	0
M_2	0	0	1	0	1	0	0
M_3	0	0	0	1	1	0	0
M_4	0	0	0	1	1	0	0
M_5	0	1	0	0	0	1	0
M_6	0	0	1	0	0	1	0
M_7	0	0	0	1	0	1	0
M_8	0	0	0	1	0	1	0
M_9	0	0	0	0	0	0	1

Table 4 GSPN model reachability table

Graphic as follows:

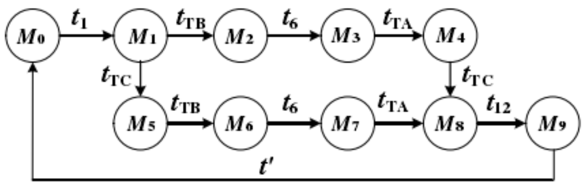

Figure 8 GSPN model reachability diagram

Because there is no instantaneous transition then there is no disappearance of the state, without simplifying the model we can establish the Markov chain that isomorphic with the previous model, the structure shown in Figure 9:

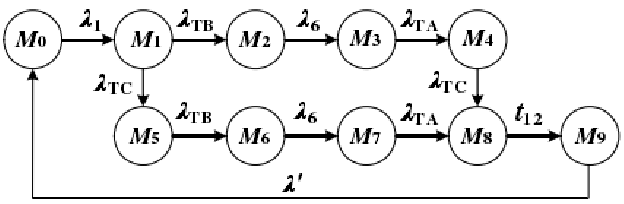

Figure 9 Markov chain

Give λ={λ1,λ6,λ12,λTA,λTB,λTC} the assignment,X is the set of probability values for the stable state, X={x0,x1,x2,….,x9}, establish the state equation,The stability probability of each reachable identity is obtained.

The stable probability distributions are shown in the following table:

Table 5 Security service flow LCIOWF model of the steady state probability distribution

variable	Probability	variable	Probability	variable	Probability
X_0	0.04907	X_4	0.15677	X_8	0.02748
X_1	0.12354	X_5	0.01373	X_9	0.19922
X_2	0.20175	X_6	0.16476	——	
X_3	0.00883	X_7	0.00485	——	

Use the formula of the average number of tokens and the change in the utilization to calculate its value. The calculation results are shown in Table 6

Table 6 Average Token Count and Utilization

Places	Tokens number	transition	Utilization
i	0.04907	t_1	0.13907
P_1	0.03727	t_6	0.25184
P_6	0.25184	t_{12}	0.07748
P_7	0.15403	t_{TA}	0.01368
P_{10}	0.10439	t_{TB}	0.03727
P_{14}	0.26082	t_{TC}	0.20194
o	0.21242	——	

3.8.5.2Program 2

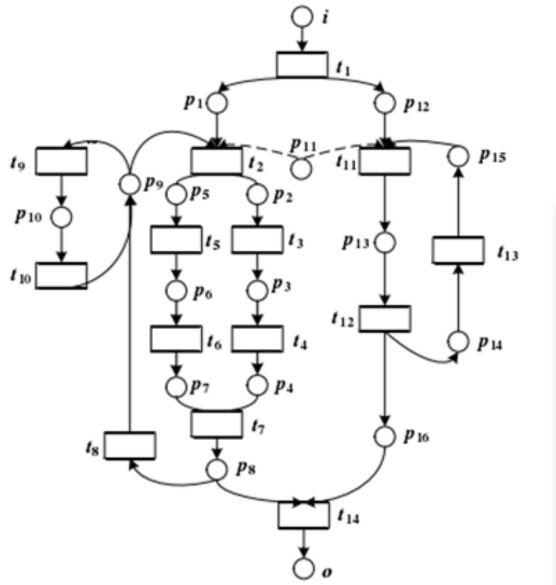

Figure 10 flow chart

t represents the corresponding time

t1 Identification of passengers' identity documents, t2 carry baggage at two disposal,

t3carry-on luggage and items placed on the 1st service, t4 carry-on luggage and items over X-ray machine,

t5 carry-on luggage and items placed on the 2nd service, t6carry-on luggage and items over 2 X-ray machine, t7view X-ray machine display,

t8 security system alarm, t9 test items in question,

t10 remove the problem items,

t11 passengers into the security door, t12 passengers for artificial security, t13 remove suspicious items,

t14 The passengers pack their belongings

In order to simplify the model, we use the complex transition tTA instead of t9, t10, tTB instead of t5, t6, tTC instead of t3 and t4, tTD instead of t11, t12, t13, simplified model as follows:

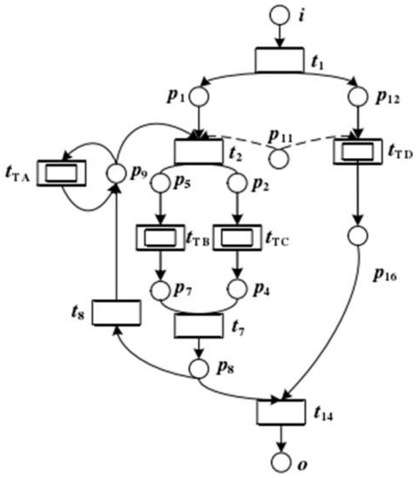

Figure 11 simplified model

There is no instantaneous transition, so only a given set of time-varying random distribution of the delay time can be drawn GSPN model. List the identity table on the basis of the previous statement as follows:

Table 7 reachability table of Program 2

	i	p_1	p_2	p_4	p_5	p_7	p_8	p_9	p_{12}	p_{16}	o
M_0	1	0	0	0	0	0	0	0	0	0	0
M_1	0	1	0	0	0	0	0	0	1	0	0
M_2	0	0	1	0	1	0	0	0	1	0	0
M_3	0	0	1	0	0	1	0	0	1	0	0
M_4	0	0	0	1	1	0	0	0	1	0	0
M_5	0	1	0	1	0	1	0	0	1	0	0
M_6	0	0	0	0	0	0	1	0	1	0	0
M_7	0	0	0	0	0	0	0	1	1	0	0
M_8	0	0	0	0	0	0	0	1	1	0	0
M_9	0	1	0	0	0	0	0	0	0	1	0
M_{10}	0	0	1	0	1	0	0	0	0	1	0
M_{11}	0	0	1	0	0	1	0	0	0	1	0
M_{12}	0	0	0	1	1	0	0	0	0	1	0
M_{13}	0	0	0	1	0	1	0	0	0	1	0
M_{14}	0	0	0	0	0	0	1	0	0	1	0
M_{15}	0	0	0	0	0	0	0	1	0	1	0
M_{16}	0	0	0	0	0	0	0	1	0	1	0
M_{17}	0	0	0	0	0	0	0	0	0	0	1

Make use of the reachability table we can get the reachability diagram, as shown:

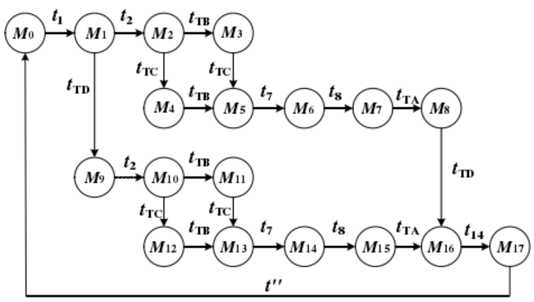

Figure 12 the reachability diagram

Because there is no instantaneous transition then there is no disappearance of the state, without simplifying the model we can establish the Markov chain that isomorphic with the previous model, the structure shown in Figure 13:

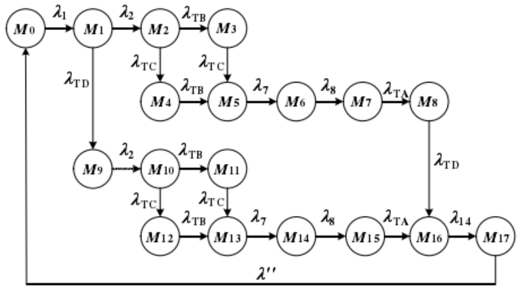

Figure 13 the Markov chain

Giveλ={λ1,λ2,λ7,λ8,λ14,λTA,λTB,λTC,λTD} the assignment , X is the set of probability values for the stable state, X={x0,x1,x2,….,x17}, establish the state equation,The stability probability of each reachable identity is obtained.

The stable probability distributions are shown in the following table:

Table 8 Probability distribution

variable	Probability	variable	Probability	variable	Probability
X_0	0.06266	X_6	0.0311	X_1	0.01285
X_1	0.031	X_7	0.00096	X_{13}	0.217
X_2	0.02155	X_8	0.00242	X_{14}	0.217
X_3	0.00155	X_9	0.217	X_{15}	0.0057
X_4	0.00155	X_{10}	0.01075	X_{16}	0.04133
X_5	0.0311	X_{11}	0.01075	X_{17}	0.08366

From the above table data and the formula of average number of tokens and changes in the utilization, we can calculate the data shown in the following table:

Table 9 Average Token Count and Utilization

Places	Tokensnumber	transition	Utilization
i	0.08366	t_1	0.08366
P_1	0.248	t_2	0.25685
P_2	0.0248	t_7	0.248
P_4	0.2404	t_8	0.248
P_5	0.0248	t_{14}	0.04233
P_7	0.2604	t_{TA}	0.00773
P_8	0.248	t_{TB}	0.0248
p9	0.05148	t_{TC}	0.0248
p12	0.12313	t_{TD}	0.08608
p16	0.27869	——	
o	0.08366	——	

3.8.5.3Comparison and analysis of two Programs

Table 10 Token number comparison

	former				
Places	Tokens number		Program1		Program2
i	0.25	i	0.14907	i	0.08266
P_1	0.0375	P_1	0.03727	P_1	0.248
P_2	0.23438	P_6	0.25184	P_2	0.0248
P_4	0.05625	P7	0.13403	P_4	0.2604

P_{10}	0.28125	P_{10}	0.20439	P_5	0.0248
P_{11}	0.14063	P_{14}	0.26082	P_7	0.2604
o	0.375	o	0.23242	P_8	0.248
				P_9	0.05348
				P_{12}	0.10313
				P_{16}	
				o	

According to the table, the former larger tokens numbers are i, p10, o. Larger tokens in Program 1 are p6 p14, compared to the original maximum reduction is 30.45% on average. Larger tokens in Program 2 are p4 p7 p14, compared to the previous maximum reduction is 25.68% on average. Therefore, the Program 1 and Program 2 reduce the waiting time than the previous model , a greater degree to enhance the flow rate.

Table 11 Utilization contrast

	former				
transition	Utilization		Program1		Program2
t_1	0.25	t_1	0.14907	t_1	0.08266
t_{TA}	0.01875	t_6	0.25184	t_2	0.25685
t_{TB}	0.075	t_{12}	0.07748	t_7	0.248
t_{TC}	0.1875	t_{TA}	0.01368	t_8	0.248
t_9	0.125	t_{TB}	0.03727	t_{14}	0.04133
		t_{tc}	0.19194	t_{TA}	0.00773
				t_{TB}	0.0248
				t_{TC}	0.248
				t_{TD}	0.08708

According to the table can clearly see that the improved program compared to the previous model do not significantly enhance, the use of resources is still relatively tight, which is the shortcomings of the two improved methods.

3.9 Sensitivity analysis: Discuss the influence of cultural differences on the above models

3.9.1different conceptions of time

Some countries are more punctual, the concept of time is strong, such as Germany, these countries may arrive at the airport ahead of schedule, so the airport passengers peaks in these countries will appear early; and other countries, such as France, the nature of freedom, their concept of time is not too strong, so passengers peaks in these countries will appear later. General changes in the situation as shown.

The airport begin to make the security check at 45-120 minutes before the departure of the aircraft, the security time is 120-45 = 75 minutes, the arrival of passengers similar to the Poisson distribution, different countries arrived early and late fluctuations in half an hour or less, so the range of 30/75 = 40 %

Airport staff should be in accordance with the habits of different countries, ahead of time or later to increase the number of windows to increase throughput.

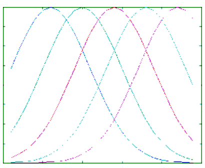

Figure 14 Time-distribution curve for passengers arriving at airports in different countries

3.9.2different queuing habits

The country that take the collective efficiency into priority will be consciously line up, but the country who give priority to personal interests may not line up or even jump the queue, which may cause disputes and increase the individual waiting time.

Assuming there is one person to jump the queue before one window on average, each members in the queue waiting time increased by 1 / μ.

We can arrange supervisors for windows to prevent the queue jump situation. If found jump queue phenomenon, the person can be fined to reduce the occurrence of this phenomenon. Or we can install fence that only allows a single person through or single column through to maintain the queue order.

3.10 Different lifestyles or because of social discrimination

The United States prefer to keep a certain distance between people. Physical contact when queuing is very sensitive to such people in the queue. People like this will inevitably increase the distance between others which makes the queue looks longer (that is, even if the infrared device alarms, the number actually does not reach the corresponding value) Such a country should open the window after a period of time when the device alarms, or adjust the theoretical length of the queue.

In some countries, there is ethnic discrimination. When discriminated ethnic groups are in the queue, the local residents will choose to stay away from them and choose other queues, resulting in that unequal length of each queue. In this regard, the relevant staff should increase efforts to persuade and reduce such cases.

3.11 Model 5 :Use Gray System Theory to analyze the impact of different factors on passenger satisfaction.

According to the survey data that the factors which influence the passengers of different ages as follows:

Table 12 Security efficiency Satisfaction survey

Age distribution	Security queuing time satisfaction	Physical examination satisfaction	Open package inspection satisfaction	Inspector's inspection seriousness	Convenience of securityscreening equipment
18--25	3.6	3.8	3.5	4.1	3.4
25--34	2.7	2.9	3.2	3.8	3.1
35--44	2.8	3.1	3.4	3.6	2.9
45--54	2.5	3.2	2.8	3.1	2.8
55--64	2.3	3	2.7	2.9	3.2
>=65	2	3.3	2.3	2.7	2.6

We analyze the main contents of the Gray System Theory, take the queuing time as the reference sequence.

And the correlation coefficient is

$$\xi_i(k)=\frac{\min_s\min_t|x_0(t)-x_s(t)|+\rho\max_s\max_t|x_0(t)-x_s(t)|}{|x_0(k)-x_i(k)|+\rho\max_s\max_t|x_0(t)-x_s(t)|}$$

x0 stands for the reference sequence, xk stands for the comparison series, here take the resolution coefficient ρ equals 0.5

Correlation $r_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$

Make the gray relational analysis for the satisfaction degree of security service and obtain the correlation matrix as shown in the following table.

Table 13 Correlation matrix

	Security queuing time satisfaction	Physical examination satisfaction	Open package inspection satisfaction	Inspector's inspection seriousness	Convenience of security screening equipment
Security queuingtime satisfaction	1	0.646	0.686	0.503	0.674
Physical examination satisfaction	0.646	1	0.704	0.686	0.75
Open package inspection satisfaction	0.686	0.704	1	0.711	0.731
Inspector's inspection seriousness	0.503	0.686	0.711	1	0.781
Convenience ofsecurity screening equipment	0.674	0.75	0.731	0.781	1

It is not difficult to see that the main factors that influence the service satisfaction are the waiting time for security queues, physical examination, out of the box to check and the convenience of security screening equipments .

Recommendations:

We can play some music under the situation that does not affect the normal flight, which can alleviate the anxiety of passengers waiting to a certain extent

Make regular training and assessment for airport security staffs and implement the work system of "short-term, multi-section", which can ensure that employees at work in the best condition and improve work efficiency.

Implement the corporate philosophy of full PR management thoroughly, pay attention to the way of talking with passengers and ways to enable passengers to enjoy the best quality service.

Make the regular maintenance and replace the old equipment and avoid technical mistakes bring unnecessary trouble to passengers .

4. Conclusion

How to find bottlenecks in the airport?

·In the crowd-intensive area we need to install the infrared device and calculate the estimated length according to the model, when a bottleneck occurs, the passengers blocking is about to occur, the infrared device alarm, to remind staff to take appropriate measures.

How to improve airport throughput and reduce the waiting time difference between different queues?

Strengthen the crowd comb, so that the queue length change from the normal distribution into uniform distribution, waiting time is significantly reduced.

According to the established model to estimate the number of passengers at different times in a day, take timely manner to open or close the window;

Increase the security personnel according to the established model or increase the number of inspection devices at each window.

How do cultural differences in different countries affect the above model?

Cultural differences in different countries have an impact on passengers to reach the airport time, queuing, waiting time and so on.

What advice would the airport manager need to make?

As far as possible to improve work efficiency, pay attention to the way solving the problem, pay attention to the timely repair equipment to ensure maximum satisfaction to passengers.

5. Discussions

5.1 Advantages

Erlang model with the order k can simulate a variety of changes in distribution. When k = 1, it becomes an exponential model. When k approaches to infinity, it becomes uniform distribution. The flexibility of distribution makes it possible to apply it to a variety of distributions.

We measured the results by the length of the queue rather than the number of people in the queue, which was more convenient for the airport staff to know when to take measures.

According to the number of flights a day, we use eight degree polynomial to calculate at different times the number of passengers, just know the time will be able to predict the number of passengers, which is simple, convenient and quick.

LCIOEF is developed on the basis of the WF-net, with synchronous coupling and cross-organizational characteristics, not only to better meet the basic requirements of the security service process, but also a good reflection of the security process of passenger and baggage of the inspection is in a large security process and the synchronization of a work process.

The Gray System Theory is used to calculate the effect of different factors on

passenger satisfaction, which is more obvious than the questionnaire survey.

5.2 Weaknesses

Erlang model does not take the "nearest to the principle" of the passenger selection service window into account, that is, the relationship between the passenger distribution and the window position;

However, the curves fitted by the polynomial are much the same as those of the original data curve, but they are more likely to be different when the precision reaches a certain hour, which is a big error prediction method.

Due to the lack of relevant data, the results of calculation are contingent, and there may be fluctuations in different airports.

The assumptions are too ideal.

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