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2017
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

Summary

In order to explore the flow of passengers at the airport to address the bottlenecks in the airport security system, reduce the difference in passengers' waiting time and maintain the same standard of security level, our group develops three models. The first one explores the flow of passengers, the second and the third solve the bottlenecks as well as reducing variance in waiting time and improve throughput. Sensitivity analysis is also taken into account by our group.

In the first model, our group fully takes advantage of the data in Excel and selects columns A and B as our data source. We denote time passengers' arrival times as x, and the throughput recorded by the airport checkpoint as y. Besides, the throughput at moment 0 is regulated as 1. According to the regulations, we draw a data distribution figure by MATLAB. By observing and analyzing the distribution of data, we adopt linear fitting to get the fitting figure. Subsequently, we successfully explore the throughput at the airport with a deep analysis on the two fitting straight-lines.

In the second model, we primarily analyze the four zones in the entire screening process. By using Petri net as a tool, we build the P/T network diagram and develop it into the GSPN model. After that, we simplify the GSPN model to focus our attention on the research of MC model under the theoretical support that a GSPN model is isomorphic to a MC model of continuous time. On this basis, we offer three evaluation indicators of the model's performance: average token number, transitions usability, and the marked velocity of transitions. After that, we use the data from column C~G in the Excel to calculate the value of several evaluation indexes and explore the bottlenecks in the process.

In the third model, our group adopts the random algorithm to solve the task. Referring to the given data in Excel, we use Python to simulate the average waiting time that a stream of visitors spend when passing the overall security system in queues. Then we loop this process for several times. Through comparing the offset between the maximum and average value of waiting time, the variance is reflected distinctly, thus realizing the optimization goal.

Finally, we also carry on sensitivity analysis on consideration of the variety of passengers. By means of changing the proportion of a certain group of people with special preferences, we found out the influence of changing the proportion of the certain group's population by means of process simulation. The evaluation of our model indicates its outstanding stability, accommodation and universality.

Contents

1 Introduction

1.1 Problem Background

Ever since the astounding Sept 11 attacks, the level of airport security check has been highly enhanced throughout the US, especially in the part of security checkpoints, which act as a crucial and effective way of freeing passengers from hijacking or destroying aircraft by excluding latent dangerous items

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"Screening checkpoints and the screeners who operate them are a key line of defense against the introduction of dangerous objects into the aviation system" (General Accounting Office 2001). However at times, security screening for domestic flights at airports throughout the United States is a source of additional delay for passengers, causing them to miss connecting flights, miss appointments, lose personal time, and as a result spend too much time waiting and in queues. This causes air travel to be experienced as unpleasant and stressful; costly for both passenger and industry, and crowding in terminal halls is in itself a potential security risk. [1]Several pieces of news happened last year show the severity and emergency of this situation as follows:

●During the spring-break week of March 14-20, nearly 6,800 American passengers missed flights because of checkpoint delays, with the worst cases occurring in Los Angeles, Miami, Atlanta, Dallas and Philadelphia. "As we approach spring and summer, we are concerned that these lines will grow even longer," American spokesman Ross Feinstein said.[5]

●In Chicago, long lines were back at Chicago Midway Airport's TSA checkpoint one morning in July while it is unknown what caused the long lines. [4]

●In Atlanta, the masses criticized that they hate it when the whole line stops for one suspicious bag in the X-ray machine, and it's also annoying when you have to wait for someone to take off their shoes. [6]

●The TSA advises arriving two hours early for domestic flights and three hours early for international flights. For all you stressed out Pre-Check smarty-pants folks, Delta Air Lines spokesman Morgan Durrant still advises arriving early." If you have Pre-Check, I can recommend 90 minutes -- if you're like me and don't want to be in a rush to the departure gate."[3]

Due to the lowered price of oil, the accumulating number of tourists resulting from the rapid economy development and the relatively deeply-reduced staff, the issue of long airport security checkpoint lines is an inevitable woe of the US.

1.2 Previous Research

The problem existing in the airport security checkpoint in the US has called for a national concern. Because the "severe" lines at airports in the US, especially O'Hare International Airport, the U.S. Transportation Security Agency (TSA) has received sharp criticism and has been pushing to shorten the security check lines. To help find out the barriers and methods of optimizing the passenger throughput at an airport security checkpoint, we have made a lot of previous research on the measures made by the TSA.

New system

The TSA has built a new system which promises to eliminate those pesky holdups and more, specifically from three aspects:

●Bins with suspicious bags are automatically rerouted to a separate conveyor belt to keep the lanes moving.

●Baggage bins automatically recirculate after they move through the security machine, saving staff time.
●The lanes include areas where passengers can take off shoes at their own pace, which will speed up lanes.
Chad Wolf, a former TSA assistant administrator said nobody knows how much time the new setup will save, but the biggest time saver will likely be rerouting suspicious bags. However, it is regrettable that this new system won't fix the current wave of security line traffic jams, according to a TSA spokesman. It's looking years ahead -- more like five years from now. [6]

The My TSA app
The My TSA app provides passengers with 24/7 access to the most commonly requested TSA information, including the security wait times. [8]Currently, the app's wait times are reported by travelers, making its accuracy sometimes less than trustworthy. [6] Some of the wait times seemed at odds with the TSA's pronouncement that it had gotten airport queues under control thanks to some quick fixes (more staff and money). But at some major airport hubs, travelers were continuing to post wait times of an hour or more—which would suggest TSA has a way to go before taming the mess at security. It is that TSA is working on a more accurate mechanism for disseminating wait times.[7]

Pre-Check
TSA Pre-Check is an expedited security screening program managed and operated by the TSA, allowing certain travelers to move through security more quickly and easily when departing from participating airports in the US without removing shoes, belt, light outerwear, laptop and bag with liquids. There is often a separate line, which is usually shorter and faster. [9][10]

Nevertheless, it is noted that Pre-check lines are now sometimes longer than the general boarding lines because passengers without relative qualifications are also randomly accepted in these lines. [11]

1.3 Our work

We are asked to build one or more models to explore and solve the bottlenecks in passenger throughput as well as to reduce variance in wait time considering cultural differences or traveler styles in a realistic, sensible, and applicable way.

To begin with, in order to depict the flow of passengers through a security check point, we extract the data of TSA Pre-Check Arrival Times in column A and Regular Arrival Times in column B and use them to make a visual figure. Through the process of Matlab, we successfully got an idea demonstration of the flow of passengers and built our own Flow-Time (F-T)model. The causes of the difference between regular and pre-check passengers as well as feasible solutions are also taken into account.

Next, when considering how to identify bottlenecks in the airport security check point, we connected this problem with the procedure optimization in business management. Based on this connection, we considered process optimization and control as the method of developing the first model. Generalized stochastic Petri network (GSPN) model is a tool that is often used in the process optimization analysis of business management. By using flow diagrams to represent the process of airport security check and considering a certain amount of time every process occupied, we can use a GSPN to indicate the whole process.

Last but not least, we are required to do the sensitivity analysis to explore how to accommodate some difference to expedites passenger throughput and reduce variance.

According to the task to be solved, we thought of the Queuing Theory in operational research and extracted the arithmetic from it to create the readily comprehensible Line up (LP) Model. Python helped us deal with the data and made complete conclusions.

1.4 The construction of airport security checkpoint

According to the information provided, the current process for a US airport security checkpoint can be divided into four zones as Figure 1 indicates, that is document check(Zone A), baggage and body screening(Zone B), collect items and exit(Zone C), additional screening(Zone D).

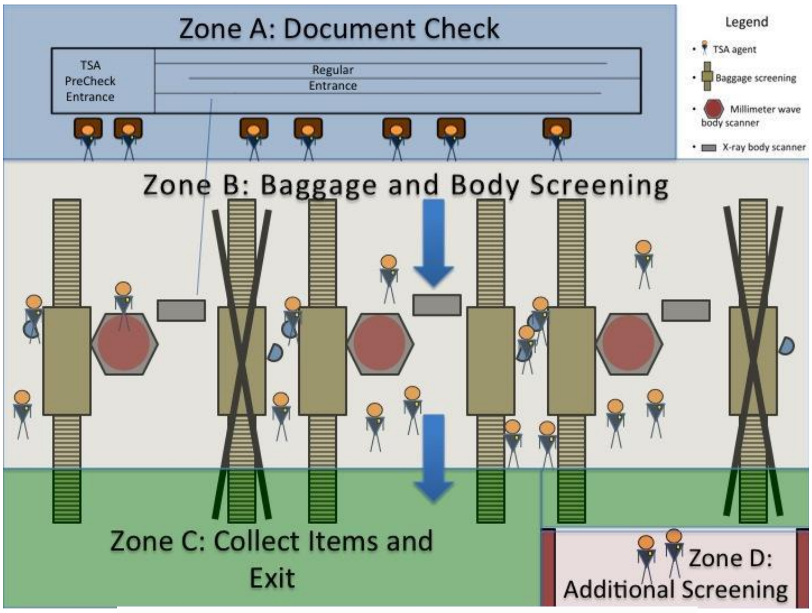

Figure 1. The airport security checkpoint

2 General Assumptions

- Pre-Check and regular passengers have no difference in Zone A
- Time spent between every two zones is neglected
- Time spent in Zone C is neglected
- Cost in improvement measures is not considered
- The throughput of passengers in the same length of time is constant
- The flow of passengers is steady and continuous

3 The flow of passengers

3.1 The Flow-Time (F-T) model

To explore the flow of passengers through a security check point, we choose to make full use of the data in the Excel. Based on TSA Pre-Check Arrival Times in column A and Regular Arrival Times in column B, we decided to draw a figure to indicate the function relationship between historical passenger flow and arrival time. At this point, historical passenger flow stands for the number of passengers into the security check queue which is recorded by airport checkpoint, and arrival time represents the time where passengers enter the security check queue.

After entering data into Matlab, we get Figure 2.

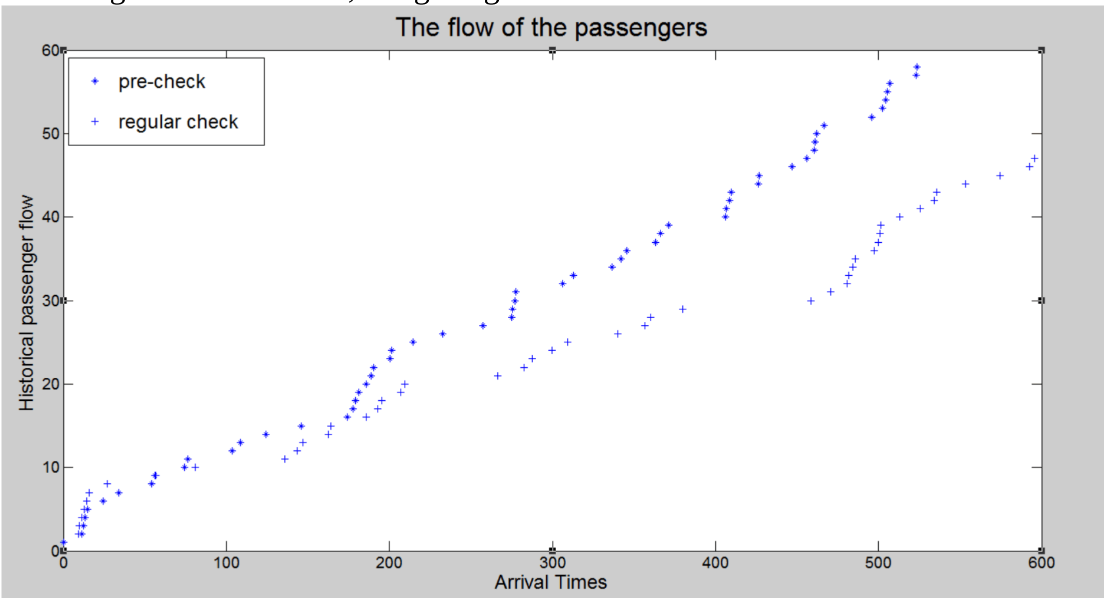

Figure 2. Historical passenger flow of regular passengers and pre-check passengers

In Figure 2, it is clearly displayed that the discrete dots approximately form two lines , so we made a reasonable assumption that the rate of rise of the passenger numbers with time flowing is a quantity for both types of passengers. Then we got two equations:

$$\frac{df}{dt} = k \tag{3.1}$$

$$f = kt + c \tag{3.2}$$

where:

f is historical passenger flow

k_1 is the rate of rise of the regular passenger numbers

k_2 is the rate of rise of the pre-check passenger numbers

On account of our assumptions, we got Figure 3 through data fitting by Matlab.

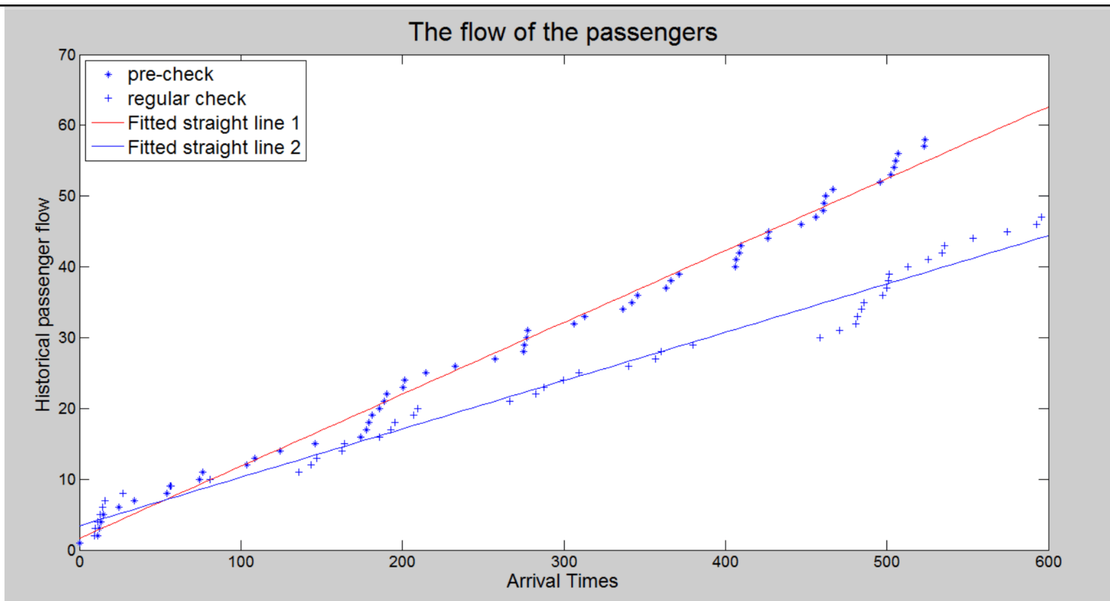

Figure 3. The flow of passengers

3.2 Results of the (F-T) model

From Figure 3, it can be observed that the rate of rise of the pre-check passenger numbers is larger than that of the regular passenger numbers.

After combining the result and the premise that about 45% passengers registered pre-check project, we concluded that reasons can be attributed to a higher frequency of checking-in for pre-check passengers. That is to say, although the proportion of pre-check passengers in less than 1/2, the tremendous difference in the frequency increase the person-time of pre-check remarkably. It is perhaps caused by different passenger types (e.g. Businessmen travel frequently by air and their route are always timed-scheduled)

4 Bottlenecks of Passenger Throughput

4.1 Symbol Description

i: passengers who have finished check-in process (boarding documents ready)

o: passengers ready to enter the next zone

p_i: place, Pi∈P = { P1, P2, …, P9}

t_i: transition, ti∈T = { t1, t2, …, t 11 }

λ_i: the average trigger rate

α_1: The probability of triggering immediate transition t4

α_2 : The probability of triggering immediate transition t8

p_1: passenger depart from Zone A

p_2: baggage ready for X-ray screening

p_3 : baggage after X-ray screening

p_4: baggage with suspicious objects;

P5 : uncollected baggage

P6: passenger ready to process through either a millimeter wave scanner or metal detector
P7: passenger that processes through either a millimeter wave scanner or metal detector
P8: passenger that fails to process through either a millimeter wave scanner or metal detector
P9: passenger ready to collect their baggage
t1: inspect identification and boarding documents
t2: passenger ready to enter Zone B
t3: check baggage with X-ray machine
t4 : baggage with suspicious items
t5: baggage in Zone D
t6: baggage with no suspicious items
t7: passengers process through millimeter wave scanner or metal detectors
t8: millimeter wave scanners or metal detectors don't alarm
t9: millimeter wave scanners or metal detectors alarm
t10: passengers in Zone D
t11: passengers in Zone C

4.2 P/T model of single channel

Petri net is an effective modeling tool in describing and analyzing systems that features concurrence and synchronization, which is always used for discrete event system modeling.[13]

According to the definition of a Petri net [14], combined with, set up a simple single-channel screening we processed a Petri net model with the combination of the passenger security screening process in the Terminal, that is, modeling under the condition of only one authentication, a millimeter wave scanner or metal detector, one X-ray machine, a security officer for pat-down inspection, as shown in Figure 1.

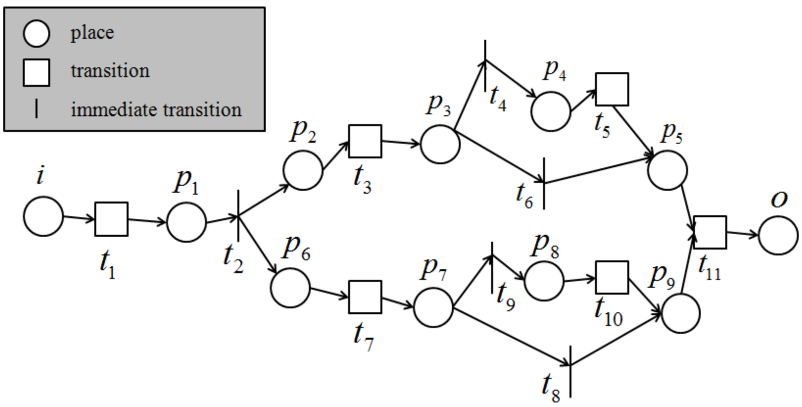

Figure 4. Petri net

Among the transitions, immediate transitions are t2, t4,t6,t8,t9,t11.

4.3 GSPN model

Based on Petri nets, we replaced the corresponding timed transition and immediate transition on the reachability graph with statistical time data and probability distribution and added timed transition t and the average trigger rate λ between input place i and output place o to obtain a generalized stochastic Petri nets (GSPN). To establish a stochastic Petri net model with additional time parameters, we need to introduce a delay time which obeys the exponential distribution for every timed transition in the system. On this basis, depending on the practical significance of the security system, it is also required to identify a probability for each immediate transition in the system. GSPN model of passenger screening system is shown in Figure 5.

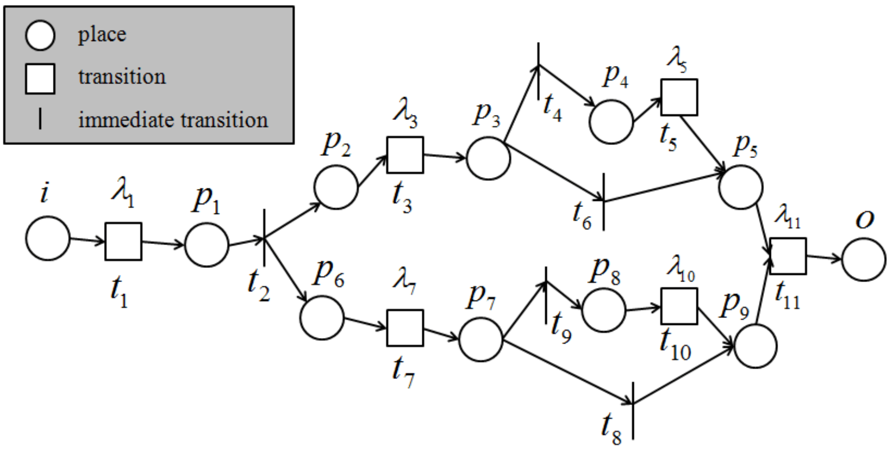

Figure 5.GSPN model

In the GSPN model, time transition set is $Ta = \{t_1, t_2, \ldots, t_{11}\}$.To identify each time transition with a trigger speed $\lambda_a = \{\lambda_1, \lambda_2, \ldots, \lambda_{11}\}$ and immediate transition set $T_b = \{T_4, T_6, T_8, T_9\}$.

If place P3 has token, then immediate transition t_4, t_6 are both under the enforceable

4.4 MC model

A GSPN is isomorphic to a Markov chain (Markov Chain, MC) of continuous time. By analyzing the existential state of token in place, we got the state matrix showed in

	i	p_2	p_4	p_5	p_6	p_8	p_9
M_0	1	0	0	0	0	0	0
M_2	0	1	0	0	1	0	0
M_4	0	1	0	0	0	0	1
M_5	0	1	0	0	0	1	0
M_{10}	0	0	1	0	1	0	0
M_{12}	0	0	1	0	0	0	1
	0	0	1	0	0	1	0
M_{14}	0	0	0	1	1	0	0
M_{16}	0	0	0	1	0	0	1
M_{17}	0	0	0	1	0	1	0

Figure 6. The state matrix

According to the state matrix, the transforming relationship in each state is available.

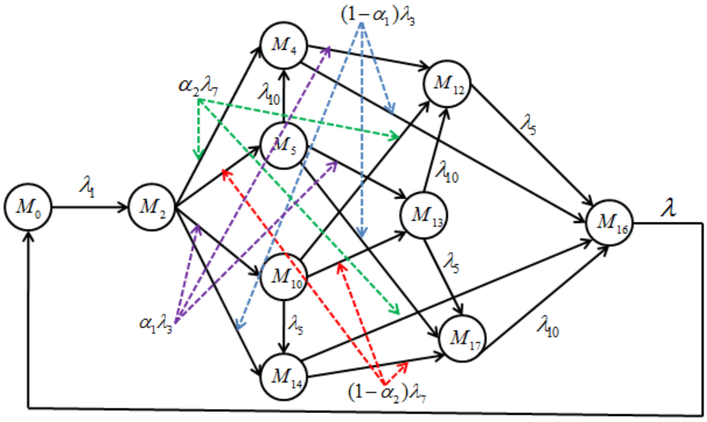

Figure 7.MC

Where there are two kinds of states:

●tangible state: $(M_0, M_2, M_4, M_5, M_{10}, M_{12}, M_{13}, M_{14}, M_{16}, M_{17})$

●vanishing state: $(M_1, M_3, M_6, M_7, M_8, M_9, M_{11}, M_{15}, M_{18})$

Vanish state can be even divided into two kinds due to the judgement method. One When there exists stationary distribution in the constructed MC, the steady state probability of the system can be worked out. Then identify the steady state probability with row vectors $X = (x_1, x_2, \cdots, x_n)$. According to the relative theorems of $\begin{cases} xQ = 0 \\ \sum_i x_i = 1 \end{cases}$ the stationary distribution of the Markov chain and C-K equation, we got the equation set as follows:

Solve the equation and we got the steady state probabilities P[M]of each state of Based on the stability probability, we analyzed the following performance

a. The average token number in position $Ni=ui$,that is to say, the average token number Sj of a transition set $Sj \subseteq S$ is the sum of the average token numbers in every position $si \in sj$,in which

$$\bar{u}_i = \sum_j j \times P[M(s_i) = j]$$

$\bar{u}_i$ Indicates the average token number that position Si has in any accessible token under a steady state.

b. The utilization rate of transition:

$$U(t) = \sum_{M \in E} P[M]$$

that is the utilization of U (t) is equal to the sum of stability probability of all tokens that make t enforceable.

c. The marked velocity of transition: $R(t,s)=W(t,s)\times U(t)\times\lambda$, that is to say, the marked velocity of $t \in T$ refers to the average token number of the rear position S that flows into t in per unit of time.

Refer to the equations above; we solved the average token of each place and the

place	Average of tokens	transition	Utilization of transitions
p_1	0.0989	t_1	0.0989
p_2	0.0495	t_3	0.0495
p_4	0.0824	t_5	0.0824
p_5	0.7692	t_7	0.0989
p_6	0.0989	t_{10}	0.2447
p_8	0.2447		
p_9	0.5575		

Table 1.

From Table 1, we found that P5 and P9 have much more tokens than others, and it is At the same time, the average token number in GSPN can be solved out:

$$N=u2+u4+u5+u6+u8+u9=1.8002$$

The marked velocity into the subsystems:

$$R(t1,p2)=W(t1,p2)\times U(t1)\times\lambda 1=0.4945$$

Assume $\bar{T}$ as waiting time. According to the Little rules and equilibrium principle, we calculated the average delay time

$$\bar{T}=\frac{\bar{N}}{\lambda}=3.64(\text{min})$$

of the system. In other words, the average working time is 3.64min.

5 Line Up (LP) Model based on stochastic simulation

We are required to do the sensitivity analysis to explore how to accommodate some difference to expedites passenger throughput and reduce variance. According to the task to be solved, we thought of the Queuing Theory in operational research and extracted the arithmetic from it to create the readily comprehensible Line Up(LP)Model.

First, we define the symbols as follows:

Xi	The internal time between two passengers
Yi	Time of a passenger passing this system
Wi	Waiting time of passenger i
Oi	Time occupied by system
ai	Arrived time
fi	Finished time
si	Start time
Ii	Idle time
D	Finished time of passenger i-1 minus the arrived time of passenger i
Wave	The average of waiting time

Wmax	The maximum time of waiting time
L	Maximum waiting time minus average waiting time

Initially, we considered the situation of only one person. Just take one security checkpoint as an example. From the moment the airport put into operation, when the number of people waiting in the queue is zero, to the moment that the first passenger arrives, the time between two moments is the interval time of random variable. We define the interval as X1 and passenger's waiting time as W1=0.Then the idle time of the checkpoint is the period of time before the first passenger arrives. Namely, I=a1=X1.Therefore, the whole time spent till the departure of the first passenger is f1=a1+Y1.

Then we considered the situation of the i th passenger. We can easily draw that Ai=ai-1+Xi.In order to learn about whether the i th passenger needs to queue up,we need to calculate the difference D=ai-fi.If D>=0, the i th passenger doesn't need to wait, the wait time equals zero. However,if D<0, the waiting time is unavoidable.It equals –D.

By this means, the moment of the i th passenger beginning one's security is the total of ai and Wi, and fi equals the sum of si and Yi.

Next, we use Python to translate the arithmetic above into computer language, with a circulation of i from 2 to 100.

Afterwards, Wsum=xigema Wi（i=1…to）and Wave=Wsum/100.

By comparing all the value of Wi, we got Wmax.

After six independent experiments and calculations of the average of Wave and the average of Wmax, we got L by calculating their difference.

According to the data from Excel,we assumed that X is a uniform distribution of random variable from 1 to 30 and Y is that from 8 to 50.

The results of six independent experiments are presented as follows:

times	1	2	3	4	5	6	average
W_{ave}	549.66	676.56	842.68	499.75	657.94	600.71	637.88
W_{max}	1255	1500	1623	1092	1314	1345	1354.83
L	705.34	823.44	780.32	592.25	656.06	744.29	716.95

Table 2

6 Sensitivity Analysis

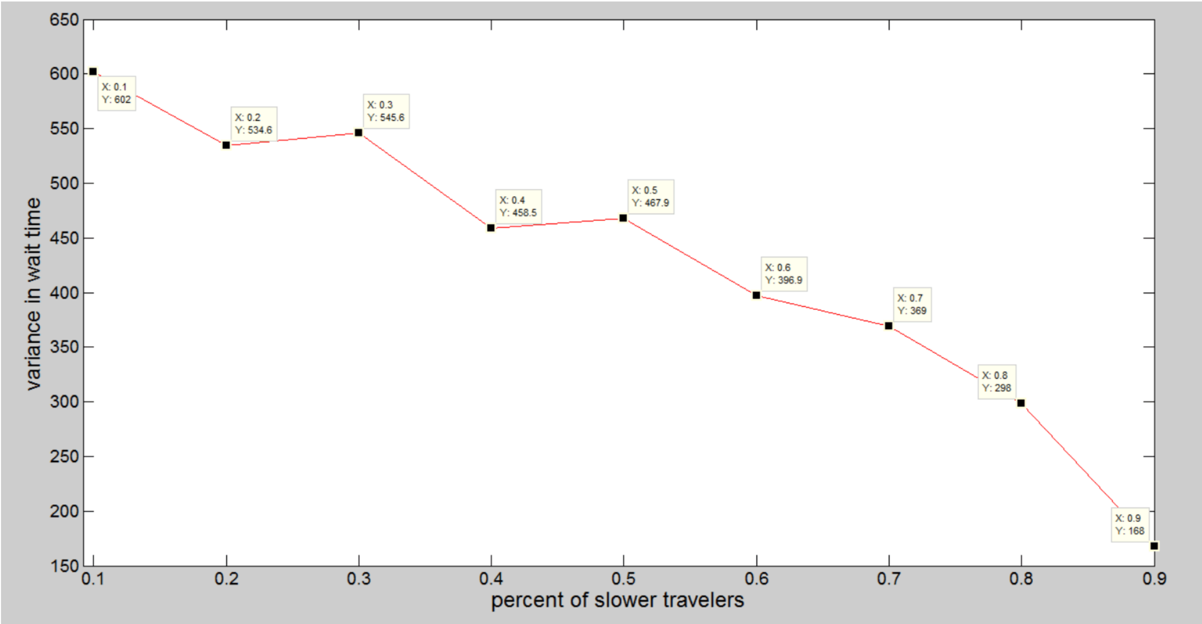

Figure 8

7 Strengths and Weaknesses

7.1 Model 1

Strengths

1、Make full use the provided data;
2、Be able to observe the variation trend in a direct way;
3、Be flexible to do comparisons and reach the conclusions.

Weaknesses

The residual of linear fitting is relatively large, so it fails to explain some dense data that deviates from the fitting straight-line.

7.2 Model 2

Strengths

1、The model has explicit structure, thorough relevancy and substantial theoretical foundation;
2、The model reflected the process of practical problem in an integrated way and the result well reflected the reality;
3、The model included a comprehensive performance analysis, which pointed out the bottlenecks and problems in practical situation from all perspectives.;
4、The model is pretty reliable, thus possessing universality and extrapolation to some extent to solve some kinds of related problems.

Weaknesses

That the neglect of the time consumed in zone transition the time out of the screening process, and the time of queuing up is not correspondent with practice. It will cause variance between the results and the reality.

7.3 Model 3：

Strengths

1、The model accepts the idea of random, using intervals to depict the interval time that passengers arrive as well as the time for waiting, to reflect the reality as much as possible. By this means, the error tolerance and reliability of the model is improved；
2、The model repeatedly examine the screening process to a certain group of passengers. It tried its best to point out the main parts that affect passenger satisfaction and time-consuming, and provided data support for increasing passenger throughput as well as reducing waiting time;
3、The model has good stability and accommodation to passengers of certain travel types. The relevant measures can be quickly achieved by sensitivity analysis.

Weaknesses

1、The assumption that security check process is continuous, that is to say, without interrupt is not completely in conformity with the reality;
2、The model has default in reflecting dual effects of both multi-culture difference and traveler styles.

8. Policies and suggestions

8.1From Model 1：

According to the problem indicated in Figure 3, our group recommends to modify the original 3R+1P line arrangements into the 2R+2P mode. We suggest strengthening the qualifications of pre-check project and properly adding more staff in each line.

8.2 From Model 2:

Through the analysis, we found that the average token in P5,P8 and P9 is relatively larger and it is easy to form bottlenecks. In terms of this situation, the suggestions offered by our group is to increase the staff number in Zone D to improve the efficiency of OOBA(out of box edit)and frisking. In addition, it is also advised to increase the staff in Zone C to guide the pack up process.
By noticing the incredible 3.64 minutes spent during the whole process, our group considers that a large amount of time is wasted on both the transition part and the long lines. We suggest to add guide staff between every two zones.

8.3 From Model 3

Considering the queuing time has huge fluctuations, we propose to cut down the variance between the maximum and average value of wait time. The concrete scheme is that by improving the inspection efficiency (such as increasing inspectors and standardize the operating skill of the staff) in P5,P8 and P9 to reduce time spent in the three points to achieve the goal of shorten wait time.

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Appendix

The code of Model 3 run in Python:

```
def solve(n):
    between = randint(1, 30)
    unload = randint(8, 50)
    arrive = between
    HARTIME = unload
    MAXHAR = unload
    WAITIME, MAXWAIT, IDLETIME = 0, 0, arrive
    finish = arrive + unload
    for i in range(1, n):
        between = randint(1, 30)
        unload = randint(8, 50)
        arrive += between
        timediff = arrive - finish
        if timediff >= 0:
            idle = timediff
            wait = 0
        else:
            wait = -timediff
            idle = 0
        start = arrive + wait
        finish = start + unload
        harbor = wait + unload
        HARTIME += harbor
        if harbor > MAXHAR:
            MAXHAR = harbor
        WAITIME += wait
        IDLETIME += idle
        if wait > MAXWAIT:
            MAXWAIT = wait
    HARTIME = HARTIME / n
    WAITIME = WAITIME / n
    IDLETIME = IDLETIME / finish
    L = MAXWAIT-WAITIME
    print('WAITIME: {}\nMAXWAIT: {}\nL:{}\n'.format(WAITIME, MAXWAIT,L))

for i in range(6):
    solve(100)
    print('*'*10)
```

Python 3.6.0 Shell

File Edit Shell Debug Options Window Help

```
Python 3.6.0 (v3.6.0:41df79263a11, Dec 23 2016, 07:18:10) [MSC v.1900 32 bit (In
tel)] on win32
Type "copyright", "credits" or "license()" for more information.
>>>
============== RESTART: C:\Users\Administrator\Desktop\test.py ==============
WAITIME: 751.05
MAXWAIT: 1524
L:772.95

**********
WAITIME: 724.47
MAXWAIT: 1446
L:721.53

**********
WAITIME: 681.55
MAXWAIT: 1350
L:668.45

**********
WAITIME: 744.55
MAXWAIT: 1522
L:777.45

**********
WAITIME: 632.6
MAXWAIT: 1282
L:649.4

**********
WAITIME: 714.07
MAXWAIT: 1351
L:636.93

**********
>>>
```

Ln: 35 Col: 4