For office use only	Team Control Number	For office use only
T1 ________	55238	F1 ________
T2 ________		F2 ________
T3 ________	Problem Chosen	F3 ________
T4 ________	D	F4 ________

2017
MCM/ICM
Summary Sheet

With the accelerated development of society, efficiency becomes more and more essential in our daily lives. The issues that airport encountered are common around us. Therefore, solving these several problems can enhance our capability of solving analogous matters, which means it has a universal value for us to research.

To begin with, we take advantage of the theoretical deduction to complete the Queuing Theory smoothly, which establishes the solid basis for the latter models, and we call it QS model by using the abbreviation.

After that, we accomplish the significant model called CPL (The Computational Model Based on Programming Language), which completes a variety of valuable fittings by modulating different variables and experiencing multiple debugging. After adjusting the parameters that we set repeatedly, we find the time consumed in average converge to a constant 35.3058 [average waiting time] (s), whose preparatory conditions are listed in the macro definition of our program. Also, we seek out some vital bottlenecks in that system, mainly concentrating in the Zone B.

To be more precise, we model another one called SA (The Simulation Model Based on Arena), which can implement more powerful efficacy and solve some deficiency encountered in prior model. The results of this model are also convergent, proving the validity and availability of it. After adjusting the parameters we think can improve the conditions, the average time consumed in the whole process decreased by 33%, which we think is accountable and feasible under our current hypothesis.

Meanwhile, we collect numerous data in order to draw the general tendency of the time spent in this process. Through the fitting of two integrated models, we fundamentally accomplish this task and make some valuable charts ae well as figures to help us find the potential elements.

Finally, all of us analyze the data thoroughly and find out some crucial bottlenecks when we research the influence the cultural factors exert in this system.

From the data tables, various images and our statement, it is surely true that our three models possess universal value, meaning that they can be applied to the analogous issues to help more and more people solve the trouble.

Key words: Queuing Models in Series(QS), The Computational Model Based on Programming Languages (CPL), The Simulation Model Based on Arena (SA)

Content

Quantitative Analysis of the Congestion Issue

1 Introduction

1.1 Background

As a thought-provoking proverb goes, Life is just like the river water, can only flow to and cannot flow back. And it is also true for something precious to us, especially time and security. Today, the U.S. Transportation Security Agency came under tension between desires to maximize security while minimizing inconvenience to passengers, which exists a contradiction to be solved. For instance, The TSA estimated a wait time of up to two-hours at Midway Airport's main security checkpoint. [1] which, in our opinions, largely impedes the passengers'trips. And fortunately, due to the increased security staffing at the airports and better communication between the TSA and airline and airport officials, things now get better, but remain various problems to be solved, which is tightly integrated with all the travelers. Hence, our tasks have its unprecedented significance all over the world nowadays.

Interested in queueing issues like airport security checkpoints, several methods have been adopted to roughly describe it. One of the classic model is Queueing theory [2], and a Jackson network is a class of queueing network where the equilibrium distribution is particularly simple to compute as the network has a product-form solution. [3] Another illustration is a G-network [4], which ulteriorly partition customers into several types: positive customers, negative customers and "triggers". Admittedly, those theories are quite impressive and of great value, but still exists various limitations:

- The potential hypotheses of these theories are usually excluded from the real world

- Several correlative models frequently assume infinite passengers and volume of lines
- The comparatively biggish disparity between the real situations and the marginal probability as well as valus of expectation
- The ambiguous range of application

Therefore, there is an urgent requirement for a complete scientific model. Based on them, our team establish some pragmatic as well as highly serviceable models to analyze and try our best to resolve those problems.

1.2 Our work

To further demonstrate our analyses and solutions, we arrange our paper as follow:

- In the last part of section 1, we will give out the concrete and reliable assumptions and justifications
- In section 2, we will give out three concrete and reliable models to analysis the problems.
- In section 3, we will put forward some supplementary analyses on the model
- In section 4, we will raise the model implementation and some useful results
- In the last several sections, some essential sensitivity evaluation will be adjusted by us and then put forward various advice based on the models we construct.

1.3 Assumptions(CPL)

We have several forms of certain models, which are progressive and connected. The following assumptions are mostly inclined to the basic one, thus adjoining the theory rather than the reality, which will be our main mission to construct a pragmatic as well as highly serviceable model to deeply analyze issues and then put forward valuable measures and suggestions.

The accuracy of our models rely on various certain keys: considering real conditions as many as possible and simplifying assumptions so as to abut against reality. These assumptions are listed below:

- Each passenger in this basic computational model is equivalent (without regard to cultural difference, which will be particularly discussed in the following improved and relatively integrated model)
- Ignore the time spent on the aisle in CPL model, but consider it in SA model

(the average time consumed on the aisle between two adjacent Zones are usually stabilized)

- Suppose the number of passengers is sufficiently large to test the situation when the system verges to the limit.
- Each passenger in this basic computational model is equivalent (without regard to cultural difference, which will be particularly discussed in the following improved and relatively integrated model)

1.4 The Narration of the Certain Parameters

Table 1. Notation

Symbol	Meaning
N(t)	The number of customers in the system at t moment
p_n	P(N(t)=n), n: the number of customers
id	The Serial number
L_s	The Length of Line (Average)
L_q	The Length of Service Line (Average)
W_s	The Sojourn Time (Average)
W_q	The Waiting Time (Average)
T_b	The Busy Time
R_f	The Rate of Fast people
R_n	The Rate of Normal People
R_s	The Rate of Slow People

2. The Models

2.1 Queuing Models in Series (QS)

To a queuing model where exists s service counters, we stipulate N(t) to be the n customers in this system, $p_n = P(N(t)=n)$ If $N(t)=n$, then the expectation of the number of arrival passengers in per minute after the moment of t is labelled as λ_n ($n \in N$). The expectation of the number of leaving passengers in per minute is labelled as μ_n ($n \in N$)

$$\begin{aligned}
&\mu_1 p_1 = \lambda_0 p_0 \\
&\lambda_0 p_0 + \mu_2 p_2 = (\lambda_1 + \mu_1) p_1 \\
&\lambda_1 p_1 + \mu_3 p_3 = (\lambda_2 + \mu_2) p_2 \\
&\ldots\ldots \\
&\lambda_{n-1} p_{n-1} + \mu_{n+1} p_{n+1} = (\lambda_n + \mu_n) p_n \\
&\ldots\ldots
\end{aligned}
\Rightarrow
\begin{aligned}
&p_1 = \frac{\lambda_0}{\mu_1} p_0 \\
&p_2 = \frac{\lambda_1 \lambda_0}{\mu_2 \mu_1} p_0 \\
&\ldots\ldots \\
&p_{n+1} = \frac{\prod_{i=0}^{n} \lambda_i}{\prod_{i=1}^{n+1} \mu_i} p_0 \\
&\ldots\ldots
\end{aligned}$$

Mark $C_n = \frac{\prod_{i=0}^{n-1} \lambda_i}{\prod_{i=1}^{n} \mu_i} (n \in \mathbb{N}^*), C_0 = 1$, then $p_n = C_n p_0$. ($\sum_{n=0}^{+\infty} p_n = 1$, $p_0 = \frac{1}{\sum_{n=0}^{+\infty} C_n}$)

Because of existing s service counters $\lambda_n = \lambda$, $\mu_n = \begin{cases} n\mu & n = 1, 2, \cdots, s \\ s\mu & n = s+1, s+2, \cdots \end{cases}$

$$C_n = \begin{cases} \frac{(\lambda/\mu)^n}{n!} & n = 1, 2, \cdots, s \\ \frac{(\lambda/\mu)^n}{s! s^{n-s}} & n = s+1, s+2, \cdots \end{cases} \Rightarrow p_n = \begin{cases} \frac{(\lambda/\mu)^n}{n!} p_0 & n = 1, 2, \cdots, s \\ \frac{(\lambda/\mu)^n}{s! s^{n-s}} p_0 & n = s+1, s+2, \cdots \end{cases}$$

($p_0 = \frac{1}{\sum_{n=0}^{s-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!(1-(\lambda/s\mu))}}$)

The average length of queue: $L_q = \sum_{n=s+1}^{+\infty} (n-s) p_n = \frac{p_0 (\lambda/\mu)^s (\lambda/s\mu)}{s!(1-\lambda/s\mu)^2}$,

$$L_s = \sum_{n=0}^{+\infty} n p_n = L_q + \frac{\lambda}{\mu}, W_s = L_s/\lambda, W_q = L_q/\lambda = W_s - \frac{1}{\mu}$$

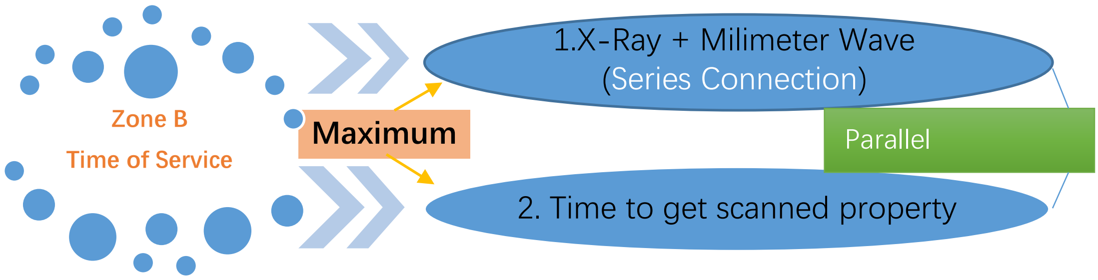
2.2 The Computational Model Based on Programming Language (CPL)

2.2.1 The Model Construction(Some)

Due to the reason that we construct it by using several computer languages, we state it in a unique way that is understandable as well as convincing.
First of all, we add some essential rules to this model and set the probability distributions that are aforementioned.

Then, two figures display the general process of the Zone A and Zone B.
Configuration and Typology of the System:
Figure 1. Flow Chart in Zone A and B

Figure 2. The Concrete Structure of the Fourth Section



Emphasis: The output of Zone A is the input pf Zone B, which is similar to the real situation and is quite crucial to the series connection of two systems.

Afterwards, the process in CPL is constructed by two main organizations: Zone A and Zone B, as it has been shown above. Next, we restate the Mathematical meanings of these variables in detail:
Ls (the Mathematical expectation of the numbers of the passengers in the system)
L_q (the Mathematical expectation of the numbers of the passengers who receive the service in the system)
W_s (The average time passengers spend in this system)
W_q (the Mathematical Expectation of the numbers of the passengers who are in the queue in the system)
Tb (the Mathematical Expectation of the busy time of the system)
In the program CPL, we set several essential macro definitions based on the data.

```
#define MU1 10.1889      #define SIGMA1 2.9793      #define MU2 12.5286
#define SIGMA 24.5313 #define BALANCE 0.5      #define MINILAMBDA 0.0859
#define XRAYLAMBDA 0.1505
#define SPMU 28.6207     #define SPSIGMA 14.0901 #define MAXROUND 3000
#define ZONE_B_NUMBER 6                    #define ZONE_A_REGULAR 5
#define ZONE_A_PRECHECK 2
```

We also create a significant vector <individual> to prepare for the next procedures to adjust some certain variables. Also, two main processes are operated in the class zone A and class zone B in our CPL program.

2.2.2 The process to test the model

As we can see in the macro definition: #define MAXROUND 3000, there we set an end to the whole program. Meanwhile, we configure three constants (6,5,2) to three different sections in Zone A and Zone B, which is straightforward for us to modify the variables in the parameter-adjusting process.
(Explanation: id 0 refers to the Regular-check line in Zone A; id 1 refers to the Pre-check line in Zone A; id 2 to 7 refer to six entrances of Zone B.) The results of each row verge to stabilization, thus they converge to several certain constants, which also verifies validity of our model (CPL). Some detailed analyses will be demonstrated in the next section combined with some bottlenecks we have found.

Table 2. The Results of Fitting (Excerpts: Round 2999- Round 3000)

round: 2999						
>>Zone A:						
	id: 0	Ls:0.98799	Lq:0.00033	Ws:9.84559	Wq0.00367	Tb:20.6923
	id: 1	Ls:0.89996	Lq:0.09003	Ws:11.1216	Wq1.21622	Tb:19.573
>>Zone B:						
0	id: 2	Ls:1.81894	Lq:0.84828	Ws:65.7895	Wq36.4632	Tb:171.235
1	id: 3	Ls:1.68556	Lq:0.75025	Ws:65.7753	Wq35.3034	Tb:116.875
2	id: 4	Ls:1.59887	Lq:0.69556	Ws:72.0263	Wq37.4737	Tb:108.36
3	id: 5	Ls:1.37846	Lq:0.48416	Ws:62.3671	Wq29.443	Tb:74.5
4	id: 6	Ls:1.1964	Lq:0.37012	Ws:53.7625	Wq23.8875	Tb:60.439
5	id: 7	Ls:1.01034	Lq:0.26909	Ws:52.8824	Wq21.4559	Tb:54.2195
round: 3000						
>>Zone A:						
	id: 0	Ls:0.98866	Lq:0.00033	Ws:9.84559	Wq0.00367	Tb:20.7033
	id: 1	Ls:0.9	Lq:0.09	Ws:11.1216	Wq1.21622	Tb:19.5843
>>Zone B:						
0	id: 2	Ls:1.819	Lq:0.84833	Ws:65.7895	Wq36.4632	Tb:171.294
1	id: 3	Ls:1.68533	Lq:0.75	Ws:65.7753	Wq35.3034	Tb:116.917
2	id: 4	Ls:1.59867	Lq:0.69533	Ws:72.0263	Wq37.4737	Tb:108.4
3	id: 5	Ls:1.37833	Lq:0.484	Ws:62.3671	Wq29.443	Tb:74.5278
4	id: 6	Ls:1.19633	Lq:0.37	Ws:53.7625	Wq23.8875	Tb:60.4634
5	id: 7	Ls:1.01033	Lq:0.269	Ws:52.8824	Wq21.4559	Tb:54.2439

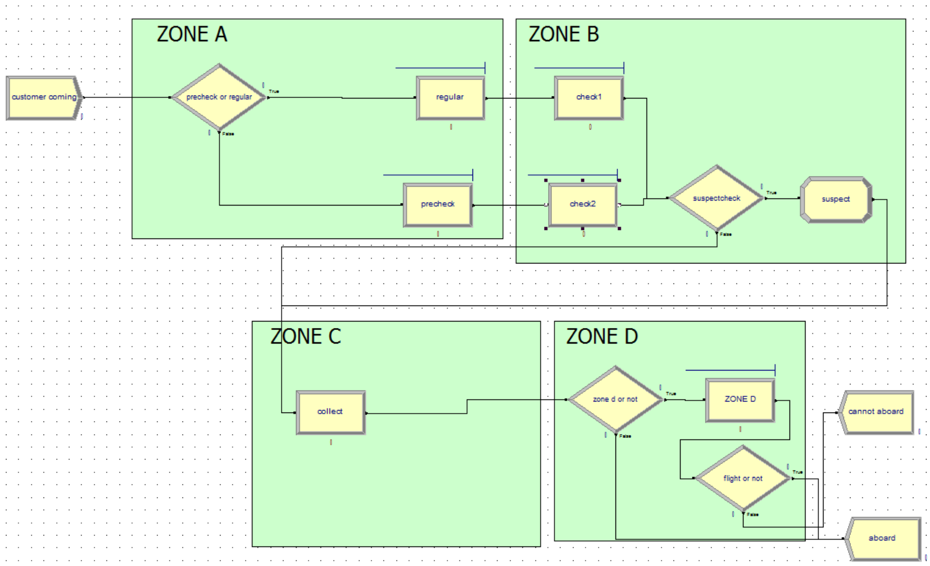
2.3 The Simulation Model Based on Arena (SA)

2.3.1 The Structure of the Simulation

The reason why we bring in this powerful and useful model (SA) is that in the CPL model, we have not paid much attention to the Zone C and Zone D, which is deficient to some extent. Thus, we have spent plenty of time researching the simulating process, acquiring various visualized and valuable data and information.

To verify the assumptions above, we also use a software, Arena, to simulate the actuality in our life. Arena is a software developed by Rockwell Software Company. It is widely used in management science and industrial simulation to get the best design of a process.

Figure 3. The Overall System of SA Model



The basic flow chart is designed above. The process in the left is a customer creation module. The intervals between two customers' coming moments obey the exponential distribution. The mean is 11.1, which is from the analysis of given excel data. After the customer creation, the process goes into a judgement to divide the customer into the regular ones and pre-check ones. 80% customers will be divided into regular ones and goes the regular document-check process. The regular document-check process contains 5 workers and each customer needs one worker to get checked. The remaining 20% customers go to the pre-check process and this process has only 2 workers. After checking in Zone A, the customers will enter the Zone B area, which is baggage and body screening. For regular customers, they need to check everything they carried. However, a pre-check customer only needs to check metal and electronic objects, which needs a shorter time. So the process for regular customer is designed to obey the normal distribution with the mean of 60 and standard deviation of 16, while the process for per-check customer has the mean of 40. These values are from calculation of excel data and some modification in the real life. After the screening check, the customers will also be divided into two parts. The 92% will be the normal customers, while the remaining 8% will be labeled as suspect which need the examination of Zone D. Then all the customers will go to zone C to collect their scanned baggage. This process follows the normal distribution having the mean of 28.6 and standard deviation of 14.0901. They are calculated from excel data. In zone D, if the customer is labeled as suspect, he will receive the examination from zone D. Zone D also obeys the normal distribution, which has the mean of 20 and standard deviation of 1. After the examination of Zone D, 10% passengers still cannot get passed and be divided into cannot aboard groups. Other 90% and customers not labeled as suspect will get aboard successfully. Because of the lacking of data in zone D process, the values we set are get from the real life and some reports about TSA.

2.3.2 Run the Model and Find the Bottleneck in the Process

The simulation will run 10 times to get a robust result. Every simulation has 1000 seconds to run. These are the result. Table 3

	average	half width	minimum average	maximum average	minimum value	maximum value
va time	104.38	1.84	101.43	110.37	26.6623	182.72
wait time	69.2366	24.73	34.5012	131.07	0	253.81
total time	173.62	24.48	137.12	232.9	50.8061	374.61

Va time is the abbreviation of value-added time, representing the time of processes of the service. Wait time is the time of waiting in a line. It happens when all the service desks are occupied. Total time is the time of one customer spent to pass this TSA check.

Because the replication number is 10, so we have different numbers of average and value. Half width represents the range in 95% of repeated trials. It is like the confidence interval in statistics. And we can regard this number as a deviation of the specific statistic. Table 4

waiting time	average	half width	minimum average	maximum average	minimum value	maximum value
check1.queue	75.9705	25	40.4371	139.76	0	253.81
check2.queue	70.1764	22.85	39.9087	124.3	0	239.47
Precheck.queue	0.1858	0.18	0	0.7863	0	16.9782
Regular.queue	0.058071	0.06	0	0.2559	0	10.4924
zone d.queue	0	0	0	0	0	0

This sheet represents the different waiting time in queues. Precheck and regular are in zone A. check1 and check2 are in zone B. Table 5

waiting number	average	half width	minimum average	maximum average	minimum value	maximum value
check1.queue	6.1512	2.29	2.7365	12.4356	0	21
check2.queue	1.4473	0.48	0.5658	2.8686	0	8
precheck.queue	0.004226	0	0	0.017298	0	2
regular.queue	0.00476	0.01	0	0.020216	0	2
zone d.queue	0	0	0	0	0	0

Like the sheet above, this sheet represents the waiting number in these queue. We can find that the most important queue is check1, which most of the passengers will go through. The next is the check2. Zone B need to be modified. Table 6

number busy	average	half width	minimum average	maximum average	minimum value	maximum value
machine	4.6347	0.15	4.3074	4.8625	0	5
precheck staffing	0.4196	0.05	0.2781	0.5093	0	2

regular staffing	1.5996	0.12	1.3566	1.8394	0	5
staffing	9.2695	0.29	8.6148	9.7249	0	10
zoned staffing	0.081161	0.03	0.040185	0.1572	0	2

This sheet represents the busy number of different machine and staffing. Table 7

scheduled utilization	average	half width	minimum average	maximum average
machine	0.9269	0.03	0.8615	0.9725
precheck staffing	0.2098	0.02	0.1391	0.2547
regular staffing	0.3199	0.02	0.2713	0.3679
staffing	0.9269	0.03	0.8615	0.9725
zoned staffing	0.040581	0.01	0.020092	0.07858

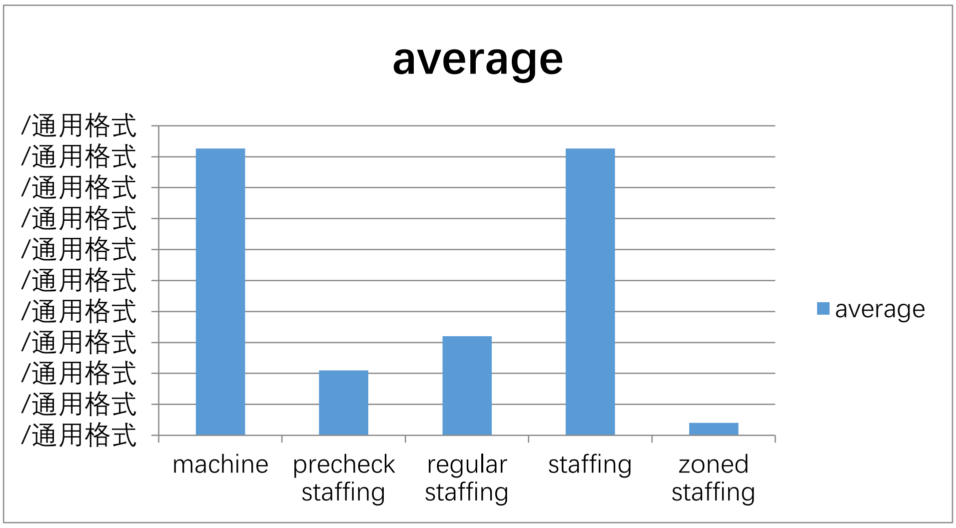


Figure 4

This sheet represents the scheduled utilization of the machine and staffing. This is calculated by its busy number over its total working number.

3. Supplementary Analyses on the Model

3.1 Some Theoretical Emphases in the CPL Model

The average length of queue: $L_q=\sum_{n=s+1}^{+\infty}(n-s)p_n=\frac{p_0(\lambda/\mu)^s(\lambda/s\mu)}{s!(1-\lambda/s\mu)^2}$,

$L_s=\sum_{n=0}^{+\infty}np_n=L_q+\frac{\lambda}{\mu}$, $W_s=L_s/\lambda$, $W_q=L_q/\lambda=W_s-\frac{1}{\mu}$ (The derivation process has been shown in the section 3.1 above)

3.2 The deep analysis on the CPL model

3.2.1 Quantization

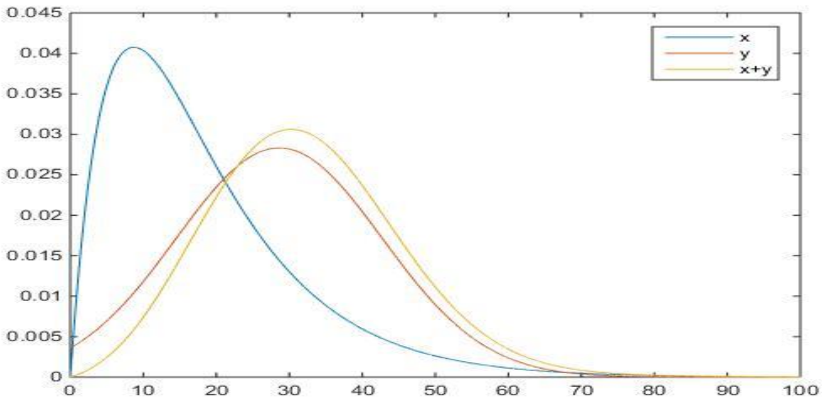


Figure 5

Blue line：x-ray，micro wave Red line：luggage register

As shown in the figure above, the average value of blue line is relatively smaller than that of red line, which means individuals are likely to waste time in waiting for their luggage. Actually, the expectation of blue line is 18.2860, whereas the expectation of red line is 28.2607.

Let x denotes the random variable whose probability distribution is the blue line and y denotes the random variable whose probability distribution is the red line. Z = max(x,y) is the random variable which means the time consumed in zone B.

E[x] = 18.286, Var[x]=179.6728; E[y]=32.3468, Var[y]=174.4101

Probability mass function of x is:

$$\mathrm{x}=\frac{\mu_1\mu_2}{\mu_1-\mu_2}\times\left(e^{-\mu_2 x}-e^{-\mu_1 x}\right)$$

While probability mass function of y is:

$$y=\frac{1}{\sqrt{2\pi}}\times e^{-\frac{(x-\mu)^2}{2o^2}}$$

Then, we can deduce the probability function of z:

$$f(z=\max\{x,y\})=\frac{\mu_1\times\mu_2}{\mu_1-\mu_2}\times\left(e^{-\mu_2 x}-e^{-\mu_1 x}\right)\times\frac{1}{2}\times\left[1-erf\left(\frac{x-\mu}{\sqrt{2}\times\sigma}\right)\right]+\frac{\mu_1\times\mu_2}{\mu_1-\mu_2}\left(\frac{e^{-\mu_1 x}-1}{\mu_1}-\frac{e^{-\mu_2 x}-1}{\mu_2}\right)\times\frac{1}{\sqrt{2\pi}\sigma}\times e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

The possibility of that x is less than y is:

$$P(x\le y)=\iint_{x\le y}\frac{\mu_1\times\mu_2}{\mu_1-\mu_2}\times\frac{1}{\sqrt{2\pi}}\left(e^{-\mu_2 x}-e^{-\mu_1 x}\right)\times e^{\frac{-(y-\mu)^2}{2\sigma^2}}dxdy=\int_0^{+\infty}dx\int_x^{+\infty}\frac{\mu_1\times\mu_2}{\mu_1-\mu_2}\times\frac{1}{\sqrt{2\pi}}\left(e^{-\mu_2 x}-e^{-\mu_1 x}\right)\times e^{\frac{-(y-\mu)^2}{2\sigma^2}}dy$$

$$=\int_0^{+\infty}\frac{\mu_1\times\mu_2}{\mu_1-\mu_2}\times\left(e^{-\mu_2 x}-e^{-\mu_1 x}\right)\times\frac{1}{2}\times\left[1-erf\left(\frac{x-\mu}{\sqrt{2}\times\sigma}\right)\right]dx=0.7284$$

3.2.2 Data Graphicalization

Table 8. The Average Waiting Time and The Total Number of People
(Excerpts: Round 5965- Round 5980)

A	B	C	D	E
5965	2	5	0.453713	29.1063
5966	1	5	0.453252	29.0899
5967	1	5	0.453252	29.0899
5968	2	5	0.453252	29.0899
5969	3	5	0.453252	29.0899
5970	3	5	0.453252	29.0899
5971	4	5	0.453252	29.0899
5972	4	5	0.453252	29.0899
5973	4	5	0.453252	29.0899
5974	4	5	0.453252	29.0899
5975	4	4	0.453252	29.0704
5976	4	4	0.453252	29.0704
5977	4	3	0.453252	29.0877
5978	4	3	0.453252	29.0877
5979	2	5	0.455375	29.0877
5980	2	5	0.455375	29.0877

Figure 6. The Average Waiting Time

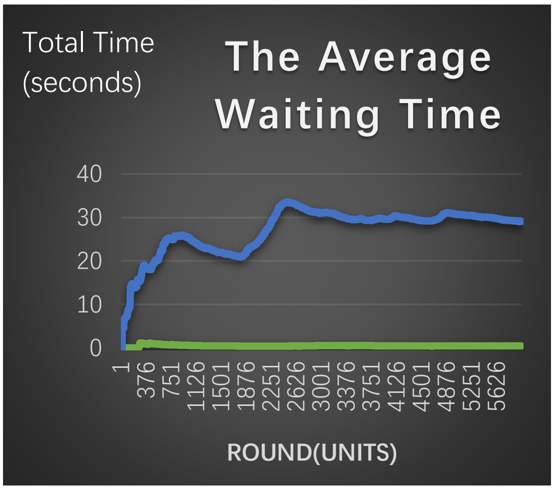
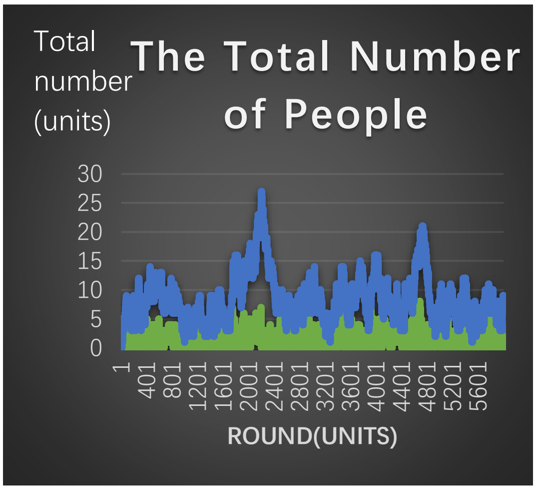


Figure 7. The Total Number of People



When we modulate the variable 'ZONE B NUMBER' in the CPL model to a bigger one than 10, the time that the system tends to converge will largely be shortened. Therefore, we guarantee the stabilization and astringency of the model. Also, we can easily find several bottlenecks from the tables and the figures that are unambiguous as well as visualized:

- The handling capacity of Zone A is highly larger than it of Zone B.
- The number of service counters is comparatively small in Zone B.
- A lot of time consumed in waiting the luggage.
- The inconsiderate mechanism of the Parallel Connection in Zone B
- The unconscionable distribution of proportion between Pre-Check and Regular-Check (Now the ratio is 45% to 55%)

- The inconsiderate mechanism of the Parallel Connection in Zone B
- There exist too many clerks in the Zone D, which can be concluded from SA.

3.3. The deep analysis on the SA model (Modifications)

We can see that the busiest area is zone B. the machine and workers there have a utilization figure bigger than 0.9. However, staffing in zone D only has a utilization of 0.05, meaning that it is not fully used. But every convey belt in zone B needs one machine and two workers. So we move two workers in zone d and pre-check staffing to zone b. and buy a machine to operate in zone b. then run the simulation again.

Table 9	average	half width	minimum average	maximum average	minimum value	maximum value
va time	104.1	1.95	99.09	109.1	29.045	193.16
wait time	28.9174	13.16	4.7699	64.187	0	160.99
total time	133.02	14.06	103.86	167.73	44.3704	268.26
waiting time	average	half width	minimum average	maximum average	minimum value	maximum value
check1.queue	29.4321	12.78	5.2034	58.2959	0	143.8
check2.queue	28.4247	16.95	5.7975	71.9767	0	132.1
precheck.queue	4.8826	1.6	0.4688	7.7118	0	39.1035
regular.queue	0.1554	0.1	0.006839	0.4517	0	12.9832
zone d.queue	0.6413	0.97	0	3.3653	0	20.3932

We can find that there is no significant change in va time. But the change in waiting time is significant. The total time reduce from 173 to 133. The waiting time in zone B decrease from 70 to 29.

Table 10

scheduled utilization	average	half width	minimum average	maximum average
machine	0.8652	0.05	0.7254	0.9602
precheck staffing	0.3695	0.07	0.237	0.5093
regular staffing	0.3413	0.02	0.2974	0.3849
staffing	0.8652	0.05	0.7254	0.9602
zoned staffing	0.085855	0.03	0.020764	0.1426

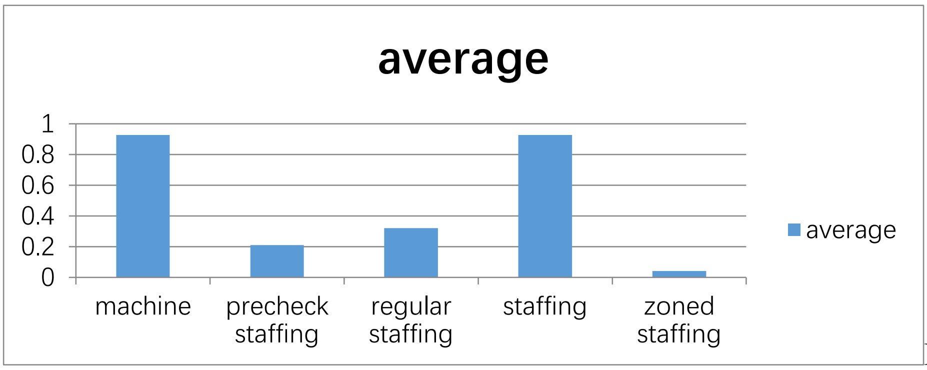


Figure 8

The utilization of machine and staffing in zone B also reduce below 0.9.

4 Model Implementation and Amelioration with Computer

4.1 Modulating the Variables in Zone A

4.1.1 Altering the Number of Counters

Table 11. The Relation Schema(Excerpts)

(Regular-check counters, Pre-check counters) (units)	Time needed(s)
(3,1)	7.674016
(3,2)	0.654537
(4,2)	0.511809
(5,2)	0.477226
(6,2)	0.467401

After analyzing the data and the relationship between two rows scrupulously, we consequently seek out the big disparity between the first line and the second line, which can be clearly illustrated in the table. Meanwhile, after weighing the pros and cons by combining a variety of factors, the optimal solution is (3,2), and the Time needed is 0.654

4.2 Modulating the variables in Zone B

4.2.1 Changing the Number of Service Counters

First and foremost, we transform the number of service counters ranging from 6 to 16, because we have already verify the astringency scope by simulating a variety of times.

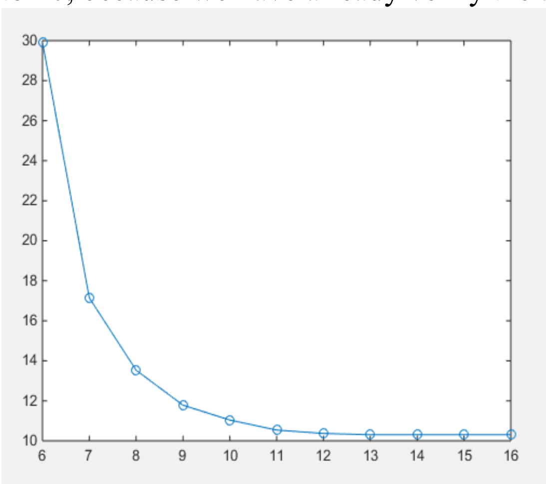


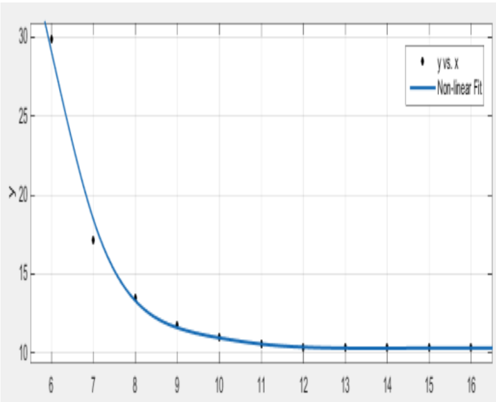
Figure 9

The Average Time of Queuing(s)

From this vivid and clear figure, it is

simple for us to find that the tendency is like inverse proportion. Therefore, we can directly get the point that the time consumed on that place is inversely proportional to the number of service counters, which means the increase of that number can enhance the convenience of passengers on condition that the number is under the limit that is directly illustrated in the figure above.

Figure 10 The Results of Fitting



Then we use Smoothing spline to further fit these data, as is seen on the right part of the above figures. f(x) = piecewise polynomial computed from p, where x is normalized by mean 11 and std 3.317

Smoothing parameter: p = 0.99696368

Goodness of fit: SSE: 2.498 R-square: 0.9929 Adjusted R-square: 0.9809

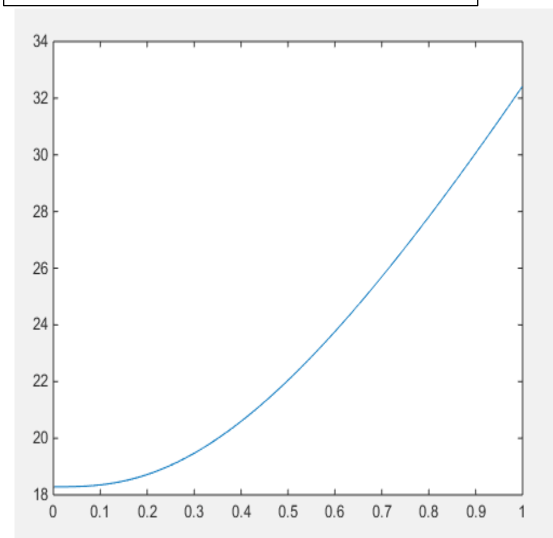
RMSE: 0.8192

Changing the Number of Service Counters

Next, we control other parameters unchanged and alter the time that passengers spend in waiting the luggage.

Figure 11

The Average Time of Queuing(s)



The Compressibility Factor

Supplementary instructions in allusion to the meaning of coordinate axis: The Compressibility Factor (λ) reflects the condensing proportion of each datum in the Normal Distribution.

From this image, this function reflects the direct ratio, and with the decrease of λ, the time consumed in that section is sharply abbreviated. The dependent variable's data are 18.2860, 18.3541, 18.7200, 19.4719, 20.5964, 22.0454, 23.7636, 25.7004, 27.8122, 30.0638, 32.4268 in proper order when the independent variable changes from 0 to 1 with the interval of 0.1.

$$\frac{\Delta y}{\Delta x}_{\max} = \frac{32.4268 - 30.0638}{0.1} = 23.63(s)$$

The Modification of SA Model

We can see that the busiest area is zone B. the machine and workers there have a utilization figure bigger than 0.9. However, staffing in zone D only has a utilization of 0.05, meaning that it is not fully used. But every convey belt in zone B needs one machine and two workers. So we move two workers in zone d and pre-check staffing to zone b. and buy a machine to operate in zone b. then run the simulation again.

Table 12	average	half width	minimum average	maximum average	minimum value	maximum value
va time	104.1	1.95	99.09	109.1	29.045	193.16
wait time	28.9174	13.16	4.7699	64.187	0	160.99
total time	133.02	14.06	103.86	167.73	44.3704	268.26
waiting time	average	half width	minimum average	maximum average	minimum value	maximum value
check1.queue	29.4321	12.78	5.2034	58.2959	0	143.8
check2.queue	28.4247	16.95	5.7975	71.9767	0	132.1
precheck.queue	4.8826	1.6	0.4688	7.7118	0	39.1035
regular.queue	0.1554	0.1	0.006839	0.4517	0	12.9832
zone d.queue	0.6413	0.97	0	3.3653	0	20.3932

We can find that there is no significant change in va time. But the change in waiting time is significant. The total time reduce from 173 to 133. The waiting time in zone B decrease from 70 to 29.

Table 13

scheduled utilization	average	half width	minimum average	maximum average
machine	0.8652	0.05	0.7254	0.9602
precheck staffing	0.3695	0.07	0.237	0.5093
regular staffing	0.3413	0.02	0.2974	0.3849
staffing	0.8652	0.05	0.7254	0.9602
zoned staffing	0.085855	0.03	0.020764	0.1426

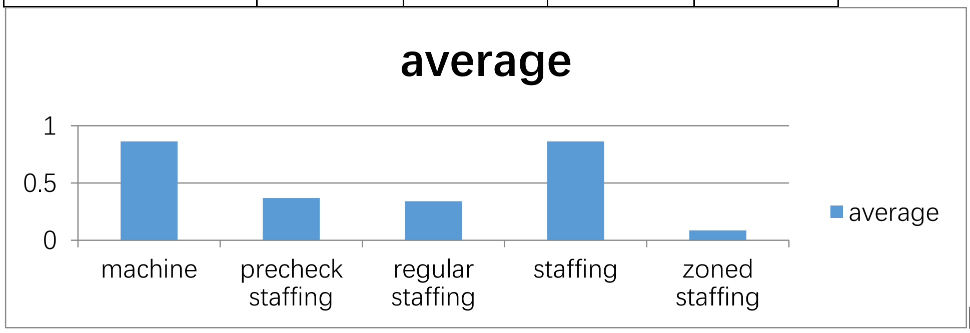


Figure 12

The utilization of machine and staffing in zone B also reduce below 0.9.

5 Sensitivity Evaluation of the Model under Different Cultural Differences

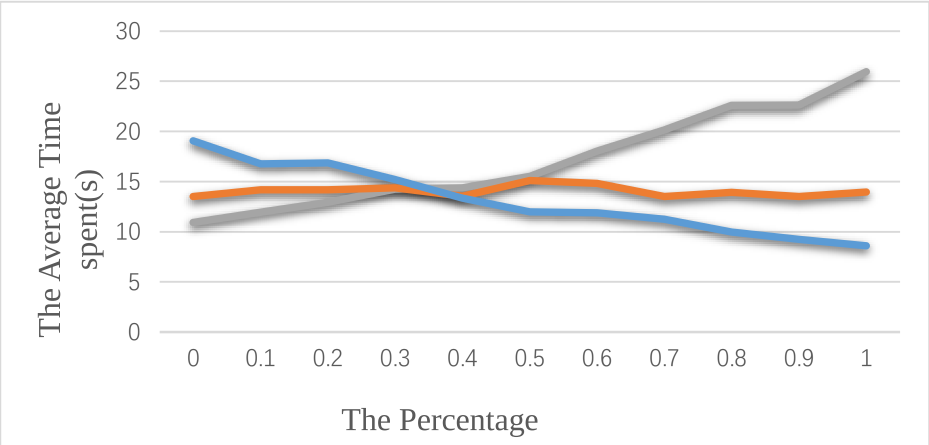
5.1 The Variation of CPL Model

In the first step, we set three kinds of people: fast people, slow people and normal people, their rates range from 0 to 1. And the restricted conditions are $R_f + R_n + R_s = 1$, $R_f \in [0,1], R_n \in [0,1], R_s \in [0,1]$. Then, we will change the exact ratio of them so as to test a variety of situation so as to optimize our model by this sensitivity evaluation.

#define ZONE B NUMBER $6 \to 8$

Then we set a quite important hypothesis that when one variable changes, the other two remain the same ratio, for it may be complicated and not visual to find the potential relationship among the three parameters

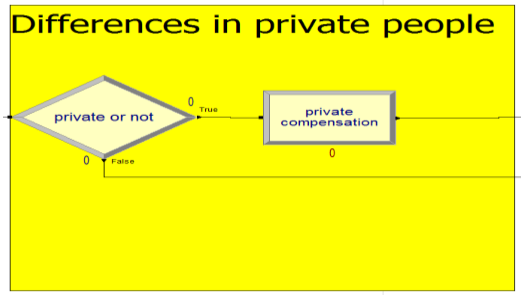
Figure 13. The Overall Demonstration of Three Curves Above

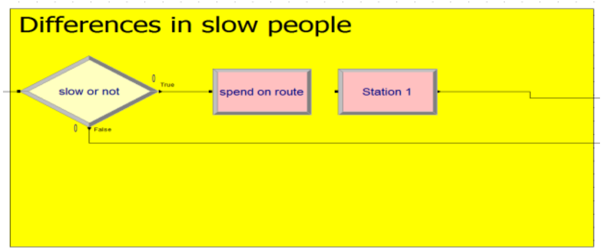


After researching those four figures and three tables and understanding the influence that different cultures and customs will exert, we can safely conclude that it is clearly that the more Chinese style people, the less time they will spend on it in average, and vice versa.

5.2 The Variation of SA Model

Figure 14 & 15





To test the differences in all kinds of people, we add another two modules to the flow chart. The left one is used to test the private people. We assume that 40% people will be private ones. they will notice whether their privacy is invaded. So they will spend more time in the normal check. We add another process called private compensation for these people. It obeys a normal distribution having the mean of 15 and standard deviation of 3.

The right one is designed for some slow people. They cannot move as fast as other people. They will spend more on the route between two processes. So we add this process for these slow people. They comprise the 40% of the total passengers. People in this process will have 15 seconds more on the route than other people.

We run the model again and get the result. Table 14

	average	half width	minimum average	maximum average	minimum value	maximum value
va time	109.7	2.37	103.92	114.29	23.8936	186.91
wait time	37.878	13.71	10.6194	67.9423	0	183.47
transfer time	6.1436	0.7	5.1515	8.3505	0	15
total time	153.72	12.6	131.42	181.69	50.3687	290.43

We can see that the total time increase from 133 to 154. We add 15 seconds for slow people and 15 seconds for private people. The sum of added time is bigger than the increase of total average time. Table 15

waiting time	average	half width	minimum average	maximum average	minimum value	maximum value
check1.queue	37.4415	13.67	9.4439	67.8668	0	162.79
check2.queue	38.9859	15.29	10.9034	83.8547	0	160.83
precheck.queue	7.1034	4.77	2.281	21.9121	0	76.7697
regular.queue	0.116	0.09	0	0.3406	0	13.927
zone d.queue	0.4757	0.68	0	2.8577	0	17.1462

scheduled utilization	average	half width	minimum average	maximum average
machine	0.899	0.04	0.8115	0.9613
precheck staffing	0.4489	0.07	0.3218	0.6135
regular staffing	0.3397	0.02	0.2727	0.3685
staffing	0.899	0.04	0.8115	0.9613
zoned staffing	0.1038	0.02	0.057872	0.1425

The waiting time in the queues and the scheduled utilization don’t change much. So the differences of private and slow people don’t affect the operation of the original model. We can use different increase of these people and test the impact to the total waiting time.

To test which factor has a more significant impact on the total time, we make a sheet on different private people and slow people. The result shows below.The time of slow range from 0 to 40 and the private time is the same. We can find that the time of slow has a more important impact on the total time than private people. So the increase of private people will not make the average pass time longer. But the increase of slow people does.it means that the culture prioritizing the personal space, which is described as private here, doesn’t affect the total pass time very much. But the culture without carefulness about efficiency, which is described as slow here, does affect the total efficiency of the airport. Table 16

slow / private	0	5	10	15	20	25	30	35	40
0	133.02	136.64	132.17	137.33	142.35	143.98	151.4	152.11	152.15
5	141.72	138.95	142.27	147.32	153.46	152.42	153.94	152.99	151.43
10	131.49	133.43	133.53	140.1	138.01	138.09	141.22	151.94	143.83
15	149.33	154.24	156.56	153.72	152.46	166.53	160.99	163.21	165.06
20	139.87	148.36	140.66	142.96	154.46	156.99	149.17	149.19	149.03
25	140.08	141.62	143.17	145.36	143.64	147.72	150.99	155.63	154.18
30	133.76	140.95	144.42	141.5	137.31	141.88	149.26	153.06	151.69
35	148.08	140.06	147.68	149.62	149.91	156.29	157.13	158.14	163.52
40	148.82	147.25	148.28	163.02	154.08	151.31	155.69	157.32	158.89

6 Ideas for Improvement (Future Work).

Our three different models go forward one by one, and each one settles out some of the defects of the front one. However, there exists so many factors influencing the real circumstances at that place that we cannot put forward a fully complete model to solve all the problems, which does not mean that we have no idea what to do with this kind of issue. Conversely, what we should bear in mind is that it is wise to single out and tackle the principal contradictions and factors and put away the minor ones. As for us, our work is mainly on the queuing fitting and the sensitivity evaluation of the model under different cultural differences. The future work could be focused on some details on people, such as moods, the attitudes to privacy and so on. The CPL model's codes can further be optimized and adjusted in order that it can take more useful variables into consideration, which can ulteriorly approach the real situations.

7. Policy and Procedural Recommendations for the Security Managers Based on Our Model

Based on the analyses and data we received above, we can safely put forward several suggestions and Procedural Recommendations:

• Now the load carrying capacity of Zone A and D far outweighs it of Zone B, so it is wise for us to increase the number of counters in Zone B and assign more employees from Zone A and D to Zone B to relieve the congestion.

• According to the CPL model, a lot of people wait for their luggage rather than the opposite. Here is the data in Some Theoretical Emphases in the CPL Model section: The expectation of blue line is 18.2860, whereas the expectation of red line is 28.2607. From the digits, we can easily find the bottleneck of this system. The useful solution can be quickening the speed of conveyor belts.(**Blue line :x-ray+ micro wave Red line :luggage register)**

• Like the rating system distinguishing the pre-check counters from the regular-check counters, a feasible proposal is that we can divide some people to the VIP level in the pre-check counters who can receive relatively few examinations through the process

• It is advisable to set two kinds of passageways for the slow one like elderly people and children and the fast one for the employees as well as other office workers. Meanwhile, arranging more staff in the fast section than the slow one to enhance the efficiency of the whole system.

• According to the peak hours and off-peak hours, we can allocate numerous staff to deal with the former ones and fewer to manage the latter ones.

8. Conclusions

From our continuous endeavor, we successfully fit the real situation under some essential hypotheses. Through adjusting some certain parameters in the airport, the real situations will largely be enhanced. We successfully solve all the given assignments by taking advantage of three models. In CPL and SA models, we can conclude that the bottlenecks mainly lie in Zone B. And the relevant results in the prior one is that with the increase of proportion of slow people, the average of time is surly to be lengthened. The decrease of the number of Zone A does little to the result for Zone A has not some huge bottlenecks. The results of SA model reflect the similar conclusion that Zone B is the key point for us to largely adjust. At the same time, we can also assign the employees from Zone A and D to Zone B to keep the system operating efficiently.

9. Strengths and Weaknesses

9.1 Strengths

• The QS model tamp the powerful theoretical basis for our later modelling.

• The CPL model properly fit the series connection of Zone A and Zone B, which provides us with a variety of useful data that we can use to analyze problems

• The SA model has fitted a relatively integrate system of the queues and the service, decreasing some limits that we set on CPL model, whose results can be fully convincing as well as valuable.

• The solving processing and solution is stable.

• The result of CPL and SA models is visible and easy to understand. (Our models are based on both subjective and objective methods)

• Three different models go forward one by one, remedying the defects one another, which make up a comparatively intact system to fit the reality.

9.2 Weakness

• The theoretical model (QS) has not solved the series connection of several queuing.

• The CPL model may not take some complicated factors in the reality like emergency circumstances into consideration.

• The CPL model do not consider the time consumed in Zone D, but we improve this in the SA model.

• The CPL model's solution to the cultural issues may be relatively simple

• The SA model enhance the above weakness, but it has produced numerous complicated data so as not to commendably screen out the ration of different factors

• The statistical data used in implementing of model are not sufficiently enough.

10. References

[1]http://wgntv.com/2016/07/13/extremely-long-lines-reported-at-chicago-midway-airports-tsa-checkpoint/
[2]http://www.chicagotribune.com/news/ct-tsa-airport-security-lines-met-20160823-story.html
[3]https://en.wikipedia.org/wiki/Queueing_theory
[4]https://en.wikipedia.org/wiki/G-network

11. Appendices

11.1 The Analysis of Data

It is universally acknowledged that computer programming is so powerful and pragmatic that we can take full advantage of the certain language, like c, to adjust various parameters, simulating authentic circumstances.

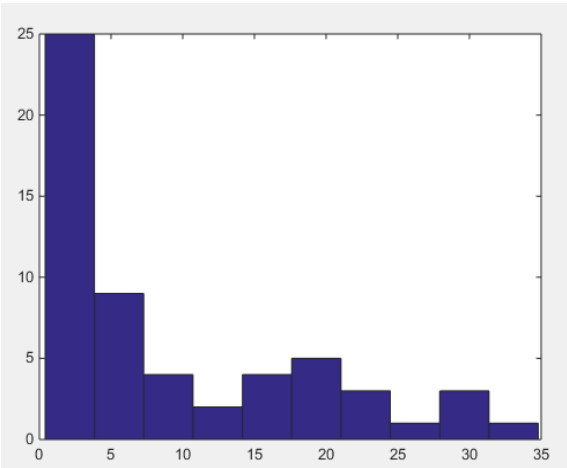
11.1.1 For the Row A (TSA Pre-Check Arrival Times)

First and foremost, we apply calculus of differences to those data, thus obtaining the time intervals of them.

Table 17 The result of calculus of differences(A)

11.2000	1.3000	1.1000	1.4000	9.6000	9.3000	20.5000
1.6000	18.6000	1.7000	27.3000	5.1000	15.4000	22.1000
28.2000	3.3000	1.3000	2.1000	4.9000	3.0000	1.4000
10.1000	1.1000	12.8000	18.4000	24.4000	17.9000	0.4000
1.7000	0.6000	28.4000	6.6000	23.8000	5.3000	3.9000
17.5000	3.2000	4.8000	34.8000	0.7000	1.9000	1.2000
16.3000	0.8000	20.1000	9.1000	4.4000	0.7000	0.7000
4.8000	28.9000	6.9000	2.1000	0.8000	1.7000	15.7000
0.9000						

Figure16:The Graphical Representation(A)



According to this image, we can directly use exponential distribution to fit those numerals.

The parameter λ(lambda)=0.1088[1]

The cumulative distribution function is given by

$$F(x;\lambda) = \begin{cases} 1 - e^{-\lambda x} & x \ge 0, \\ 0 & x < 0. \end{cases}$$

Hence, we can know the probability distribution of the numbers of passengers who arrive at the Pre-check site.

Table 18. The Probability Distribution(A)

0	1	2	>=3
0.8969	0.0976	0.0053	0.0002

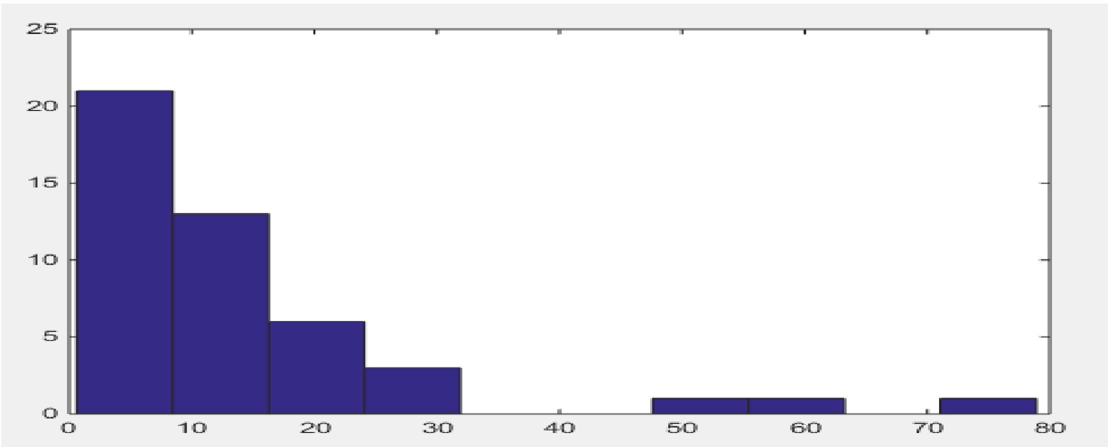
11.1.2 For the Row B (Regular Arrival Times)

We apply the same probabilistic method to these data

Table 19 The result of calculus of differences(B)

9.1000	0.6000	1.6000	1.5000	1.5000	1.6000	10.9000
30.0000	24.3000	54.9000	7.6000	3.5000	15.6000	1.5000
21.4000	7.2000	2.5000	11.5000	2.5000	57.2000	15.9000
5.4000	11.8000	9.9000	30.6000	16.6000	3.7000	19.5000
78.9000	12.0000	10.0000	0.9000	2.5000	1.4000	12.0000
2.2000	1.1000	0.7000	11.2000	12.8000	8.5000	1.7000
17.4000	21.2000	18.5000	2.6000			

Figure16:The Graphical Representation(B)



According to this image, we can also use exponential distribution to fit those numerals.

The parameter λ(lambda)=0.0772

[1] https://en.wikipedia.org/wiki/Exponential_distribution

Hence, we can know the probability distribution of the numbers of passengers who arrive at the Regular Entrance.

Table 20. The Probability Distribution(B)

0	1	2	>=3
0.9257	0.0715	0.0028	0.0001

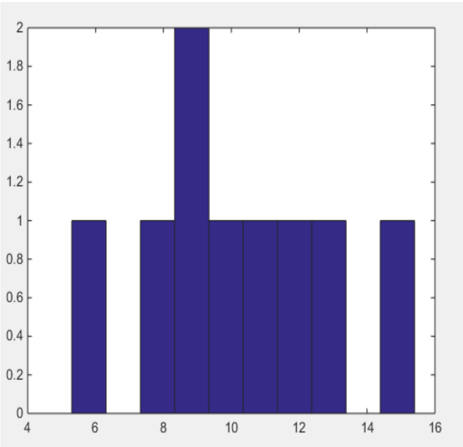
11.1.3 For the Row C and Row D (Two Kinds of ID Check Process)

Table 21. The first ID Check Process

7.5	5.3	11.1	10	9.1	8.8	12.6	15.4	11.9

For these series of numbers, we use another distribution (**Gaussian distribution**) to fit them due to the symmetry and the total shape. After comparing several fitting methods scientifically, we consequently choose this way to match the data, which fortunately receive the satisfying results.

Figure17.The Graphical Representation(C)



The probability density of the Gaussian distribution is: [2]

$$f(x \mid \mu, \sigma^2) = \frac{1}{\sqrt{2\sigma^2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

μ (the mean value) = 10.1889,
σ (the standard deviation) =2.9793

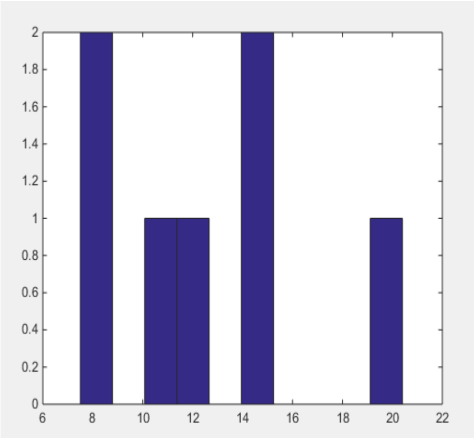
Table 22. The second ID Check Process

14.6	11.8	14.8	20.4	7.7	7.5	10.9

We use the same method to analyze the above numbers owing to the same reasons.

[2] https://en.wikipedia.org/wiki/Normal_distribution

Figure18.The Graphical Representation(D)



Every Gaussian distribution is a version of the standard normal distribution whose domain has been stretched by a factor σ (the standard deviation) and then translated by μ (the mean value):

$$f(x \mid \mu, \sigma^2) = \frac{1}{\sigma}\phi\left(\frac{x-\mu}{\sigma}\right)$$

μ= 12.5286, σ=4.5313

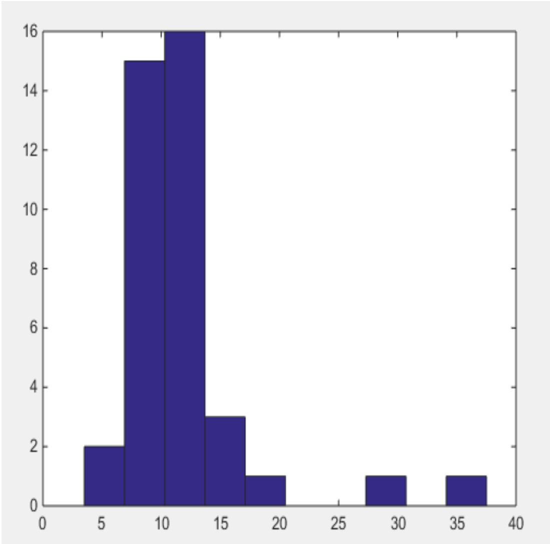
11.1.4 For the Row E (Milimeter Wave Scan times)

We apply calculus of differences to the original data, thus obtaining the time intervals.

Table 23. The result of calculus of differences(E)

11.3000000000000	12.4000000000000	3.50000000000000	7.50000000000000
8.20000000000000	12.9000000000000	11	9.10000000000001
7.70000000000000	10.7000000000000	15.1000000000000	11.0000000000000
17	13.4000000000000	7.70000000000002	6.69999999999999
11.6000000000000	19.4000000000000	8.59999999999999	37.5000000000000
11.3000000000000	12.4000000000000	12	13.2000000000000
11.1000000000000	7.29999999999995	8.10000000000002	14.3000000000000
7.09999999999997	11	9.60000000000002	27.5000000000000
8.60000000000002	9.69999999999999	11	9.69999999999999
8.60000000000002	12	7	

Figure 19.The Graphical Representation(E)



Then we illustrate two main means (the exponential distribution and the Gaussian distribution) to dispose the information received.

The Exponential Distribution:
The parameter λ(lambda)= 0.0859

The Gaussian Distribution:
μ (the mean value) = 11.6359,

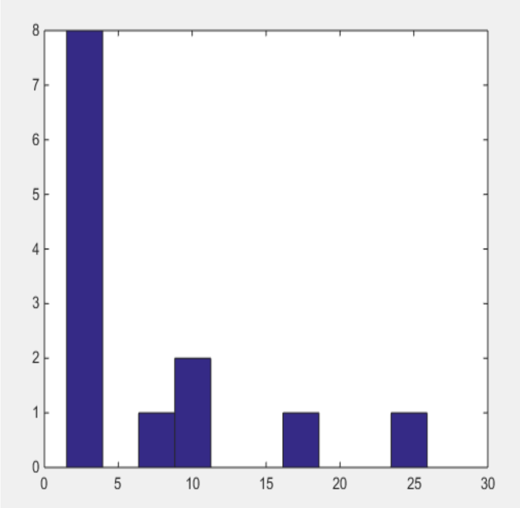
σ (the standard deviation) =:5.8711.5 For the Row F and Row G (Two Kinds of X-Ray Scan Time)

The Exponential Distribution
Table 24. The result of calculus of differences (F and G)

3.10000000000	1.700000000000
2.00000000000	10.80000000000
2.30000000000	2.100000000000
16.7000000000	25.90000000000
1.70000000000	9.100000000000
1.50000000000	2
7.50000000000	

The parameter λ(lambda)= 0.1505

Figure 20. The Distribution of the Results of Difference (F and G)



11.1.5 The Statics of Time to Get Scanned Property

Table 25. The result of Row H

48	45	28	25	22	24	17	3	8	10
26	32	21	37	68	40	18	26	8	21
23	28	50	28	48	28	36	27	5	

μ (the mean value) = 28.6207,

σ (the standard deviation) =14.0901

Figure 21. The Distribution of the Results of Row H