Team Control Number

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T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
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2017
MCM/ICM
Summary Sheet
Optimizing the Passenger Throughput and Average Wait Time at an Airport Security Checkpoint

Today's airport security checkpoints are suffering the bottleneck of passenger throughput and quite long average wait time. Passengers may arrive unnecessarily early or potentially miss their flight because of the great variance in wait time. The maximum of security is contradicted with the minimum of wait time.

We develop three main models for optimizing passenger throughput and reducing variance in wait time. With the simulation results, a series of possible modifications are proposed under basic assumptions.

The first model developed is Single-Lane Model for exploring the flow of passengers and the bottleneck of throughput. With the comparison between mean service time (check time) and arrival time, the throughput of system is no longer elevated when the frequency of arrival equals to or exceeds the serviceability. That is, under the gradual formation of queue for every lane, the system is running into bottlenecks.

In order to explain real situation better, we develop Multi-Lanes Model. We introduce perplex of passengers to interpret why system delay to full throughput when there are more passengers coming to queue. Furthermore, if the system works under full throughput, the average wait time and the variance of it can be reduced effectively by balancing queues. We analyze the system under varied number of queues and the coming frequency of passengers We have performed 'Control' policy with simulations and also discussed the problem of Manpower cost.

In the third model, we focus on internal sorting of the queue. Similar to CPU scheduling in operation system, we attempt to utilize FCFS, SJF, PBS and HRRF scheduling strategies to reducing average wait time as well as accommodating different cultural norms. With the simulation, we conclude that 'cutting' may sometimes effectively improve the mean wait time under some circumstances.

In addition, we refer a model of binary decision-tree for guaranteeing the security of the checkpoint at the cost of security check time and device cost.

In summary, our model provides available modifications of improving throughput, variance of wait time and average wait time including balancing the length of queues, internal sorting as well as optimizing the cost and security.

Contents

I. Introduction

1.1 Backgrounds

Since terrorist attacks on September 11, 2011 in the US, security checkpoints has been enhanced significantly. Passengers arrive at a checkpoint system and enter a wait queue at random. At the beginning passengers are inspected their ID and boarding documents. After that, passengers will get their baggage screened. Meanwhile, they prepare their belongings such as shoes, metal objects, electronics, containers with liquids and etc. for X-ray scanned and process through mm wave scanner in sequence. Furthermore, passengers fail any step will receive a pat-down inspection by a security officer in a special zone.

Airport security checkpoints aim at increasing throughput and reduce variance in wait time at the same time on the basis of maintaining safety and security. Therefore, the process of striking a balance between maximizing security and minimizing inconvenience to passengers can be optimized.

1.2 Our Work

We establish a single line model to explore the flow of passengers through a security checkpoint and identify and improve the bottlenecks

We extend the single line model to multi lanes model and develop some potential modifications to improve passengers throughput and reduce variance in wait time. Also, we demonstrate how the modifications we suggest will impact the security process with the multi lanes model.

Four queueing principles are proposed in queue internal ranking model and they are matched with different parts of the world with different cultural norms. Besides, we accomplish sensitivity analysis on account of queue internal ranking model.

A binary decision-tree model is referred by us to calculate security indicator along with conditional probability.

II. Models

Some variables and their descriptions are defined in order to develop models conveniently as follows:

Table 1: Symbol Table of Models

Variable	Description
Q	number of lanes
T_a	interarrival time
T_s	mean service time
t_{ID}	mean time to get ID check
t_x	mean time to get X-ray scan
t_{mm}	mean time to get mm wave scan
t_{bag}	mean time of baggage screening
TP	throughput
P	passenger's perplex
$E(WT)$	expectation of a passenger's wait time
σ^2	variance in wait time
p_i	probability of a passenger getting into the i^{th} lane
L_i	number of passengers in the i^{th} lane
TP_{real}	throughput without the influence of perplex
TP_{actual}	troughout with the influence of perplex
Δ	difference between TP_{ideal} and TP_{actual}
T_{S_i}	servive time of the i^{th} passenger in the queue
WT_i	wait time of the i^{th} passenger in the queue
$\overline{WT}$	mean waiting time of passengers in one queue
N	total number of the passengers in the queue
η_i	response ratio of the j^{th} passenger

2.1 Task A: Single Line Model

To tackle task a, we develop a single lane model to explore the flow of passengers through a security check point and identify bottlenecks.

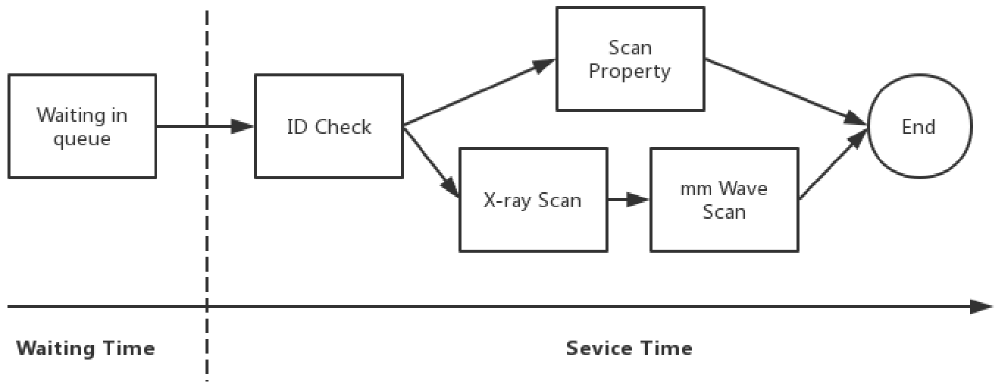


Figure 1-System of Security Checkpoint

In the current process for a US airport security checkpoint, the system consists of two parts-waiting part and service part. In the waiting part, passengers reach at random. Then they move into the service part, where they get ID check, baggage screening, X-ray scan and mm wave scan.

2.1.1 *Assumptions*

To explore and exhibit the flow of passengers through check point simply and clearly, we make some assumptions in the single lane model:

- The arrival rate of passengers follows a uniform distribution, and their interarrival time is T_a.
- All passengers are the same, which means everyone's service time, time to get ID check, X-ray scan, mm wave scan and time of baggage screening are $T_s, t_{ID}, t_x, t_{mm}, t_{bag}$ separately.
- The system obeys to the principle of First Come First Served(FCFS).
- There's only one lane in the single lane model; in other words, $Q = 1$.

2.1.2 *The Foundation of Model*

According to the problem, a passenger gets ID check first, then the passenger gets X-ray scan and mm wave scan meanwhile his or her baggage gets screening. Since t_{bag} and $(t_x + t_{mm})$ are concurrent, T_s depends on the larger one of them. So

$$T_s = t_{ID} + max\{t_{bag}, t_x + t_{mm}\}$$

When $\frac{1}{T_a} < \frac{1}{T_s}$, passengers of new arrival can get served immediately. If $\frac{1}{T_a} \geq \frac{1}{T_s}$, the system is at a full load of serving $\frac{1}{T_s}$ passengers per unit time and passengers may get congested at that time. The throughput of the system is

$$TP = \begin{cases} \frac{1}{T_a}, & \frac{1}{T_a} < \frac{1}{T_s} \\ \frac{1}{T_s}, & \frac{1}{T_a} \geq \frac{1}{T_s} \end{cases}$$

The relation between TP and $\frac{1}{T_i}$ is shown in figure 2, and the maximum of TP is $\frac{1}{T_s}$.

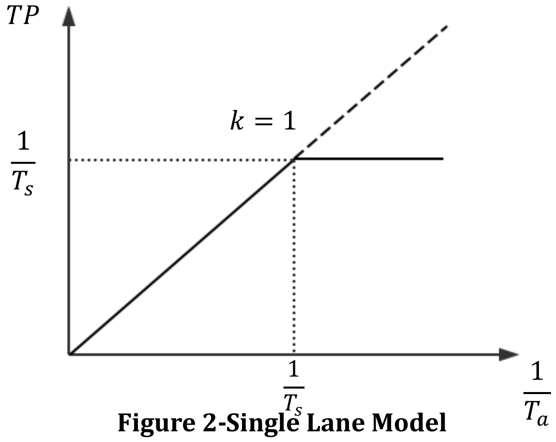


Figure 2-Single Lane Model

2.1.3 *Analysis of the Result*

From figure 3, TP continues increasing linearly with $\frac{1}{T_i}$ before $\frac{1}{T_i}$ increases to $\frac{1}{T_s}$. Obviously, the maximum value of TP is $\frac{1}{T_s}$. Therefore, the bottleneck of the system's throughput is T_s . So if TP is expected to rise, T_s must be reduced under the case of one lane.

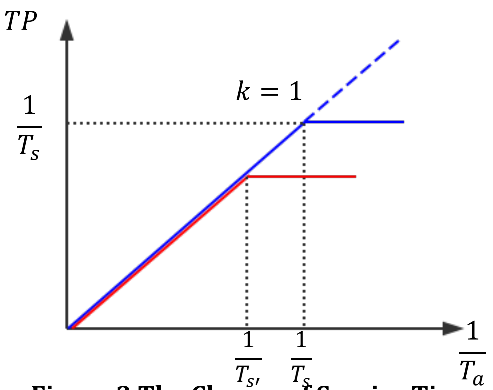


Figure 3-The Change of Service Time

2.2 Task B: Multi lanes Model

To tackle task b, we develop a multi lanes model to find and implement modification so that passenger throughput will be improved and variance in wait time will be reduced. Besides, we will give task a a further talk by using multi lanes model.

2.2.1 *Re-Assumptions*

- The arrival rate of passengers follows a uniform distribution, and their interarrival time is T_a.

- All passengers are the same, which means everyone's service time, time to get ID check, X-ray scan, mm wave scan and time of baggage screening are $T_s, t_{ID}, t_x, t_{mm}, t_{bag}$ separately.
- The system obeys to the principle of First Come First Service.

2.2.2 *The Foundation of Model*

1 Passenger Throughput

TP will also rises as Q becomes more and more as well as T_s is controlled and reduced in task a. The following figure shows this departure process:

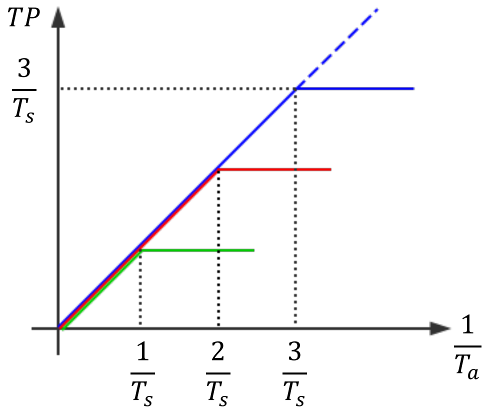


Figure 4-Multi Lanes Model

However, when Q is more than one, the phenomenon of passenger's perplex may occur-for instance, a passenger may get into an occupied lane instead of a vacant lane because of his or her incomplete information. That will delay TP to get to its maximum value.

A passenger's perplex P is influenced by Q :

$$P = P(Q)$$

When there is only one lane ($Q = 1$), pasengers have no perplex, so P equals zero at the case of Q equals one.

Passengers have more perplex at the case of more lanes, so $P(Q)$ is a monotonically increasing function.

Considering $\mathrm{P(Q)}$ has five properties:

$$\begin{cases} 0 \le P < 1 \\ P(1) = 0 \\ \lim\limits_{Q\to\infty} P = 1 \\ P(Q) \ \ is \ \ a \ \ monotonically \ \ increasing \ \ function \\ P(Q) \ \ is \ \ a \ \ concave \ \ function \end{cases}$$

The function that satisfies the five properties above is

$$P = 1 - \frac{1}{Q}$$

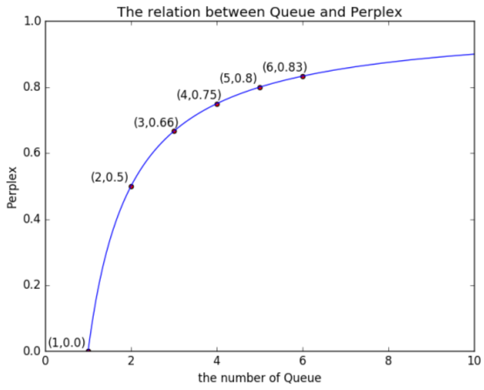


Figure 5

Each Q has a corresponding P,

$$Q_{1,}Q_2, \dots \dots, Q_n$$

$$P_1P_2, \dots \dots, P_n$$

Because of the different dimensions of Q and P, they should be treated to be non-dimensional before calculation with the below equation:

$$Q_i^* = \frac{Q_i - Q_{min}}{Q_{max} - Q_{min}}$$

$$P_i^* = \frac{P_i - P_{min}}{P_{max} - P_{min}}$$

Consequently, TP gets to its maximum value when $\frac{Q}{T_a}$ equals to $\frac{Q^*+P^*}{T_s}$ as figure 4 shows below:

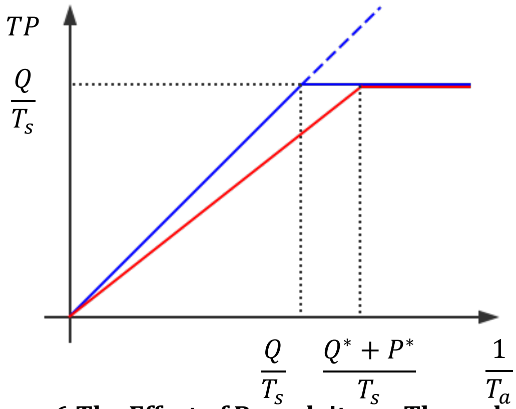


Figure 6-The Effect of Perpelxity on Throughput

In fact, the function of TP_{ideal} has the following 4 properties:

$$\begin{cases} the\ function\ curve\ passes\ (0,0)\ and\ \left(\frac{Q^* + P^*}{T_s}, \frac{Q}{T_s}\right) \\ P(Q)\ is\ a\ monotonically\ increasing\ function \\ P(Q)\ is\ a\ concave\ function \\ TP_{actual} \leq TP_{ideal} \end{cases}$$

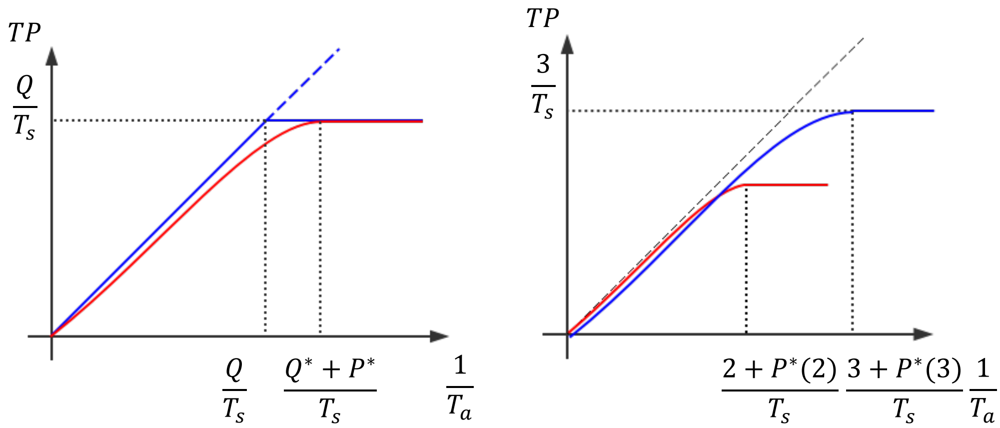


Figure 7-A More Reliable Model

The function that satisfies the four properties above is

$$TP_{actual} = \begin{cases} 1 - \dfrac{1}{k \cdot \dfrac{1}{T_a} + 1}, & \dfrac{Q^*}{T_a} \leq \dfrac{Q^* + P^*}{T_s} \\ TP_{max}, & \dfrac{Q^*}{T_a} > \dfrac{Q^* + P^*}{T_s} \end{cases}$$

Put $\left(\frac{Q^*+P^*}{T_s}, \frac{Q^*}{T_s}\right)$ into TP_{actual}, then we can get $k = k(Q^*, P^*)$. If $k \leq 1$, the function of TP_{actual} is right.

2 Variance in Wait Time

When a passenger arrives at the system, he or she may enter any lane. The different numbers of people in every lane results in an uncertainty and variance in wait time, σ^2. For instance, a passenger may get through the checkpoint very soon in a short wait queue and wait for a long time in a long wait queue.

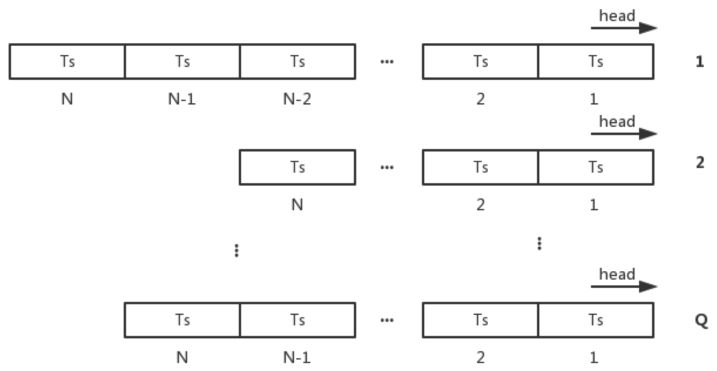


Figure 8-Variance in Length of Queues

The expectation of wait time

$$E(WT) = T_s \sum_{i=1}^{Q} P_i \cdot L_i$$

If a passenger enters different lanes with the same possibility, that is

$$p_i = \frac{1}{Q}$$

E(WT) can be simplified as follows

$$E(WT) = T_s \cdot p_i \sum_{i=1}^{Q} L_i$$

When a passenger arrives at the system, the number of the whole people waiting in front of him or her is certain. Consequently, E(WT) is a constant.

Thus, σ^2 can be defined as

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{Q} (T_s \cdot L_i - E(WT))^2$$

2.2.3 *Modifications to the Current Process*

1 To Improve Passenger Throughput

(1)Increasing Q

The increase of Q will rise TP_{max}. So opening more lanes can improve passenger throughput. When all opening lanes are occupied, it is high time to open another lane and increase Q.

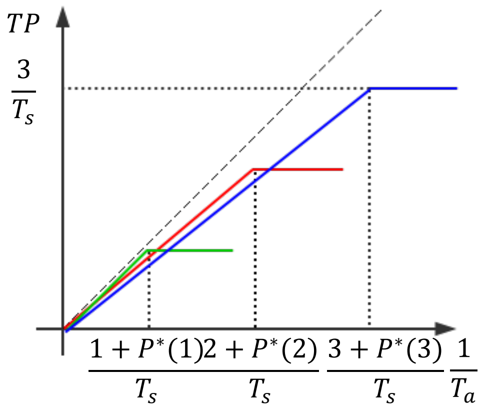


Figure 9-The Change of the number of queues

(2)Reducing T_s

The reduce of T_s will rise TP, the same as single lane model. So improving service efficiency can improve passenger throughput.

Considering the service time T_s,

$$T_s = t_{ID} + max\{t_{bag}, t_x + t_{mm}\}$$

We calculate the duration of passengers' X-ray scan times and mm wave scan times by using timestamps given from problem D data excel. They are exhibited in the following figure as well as bag screening time:

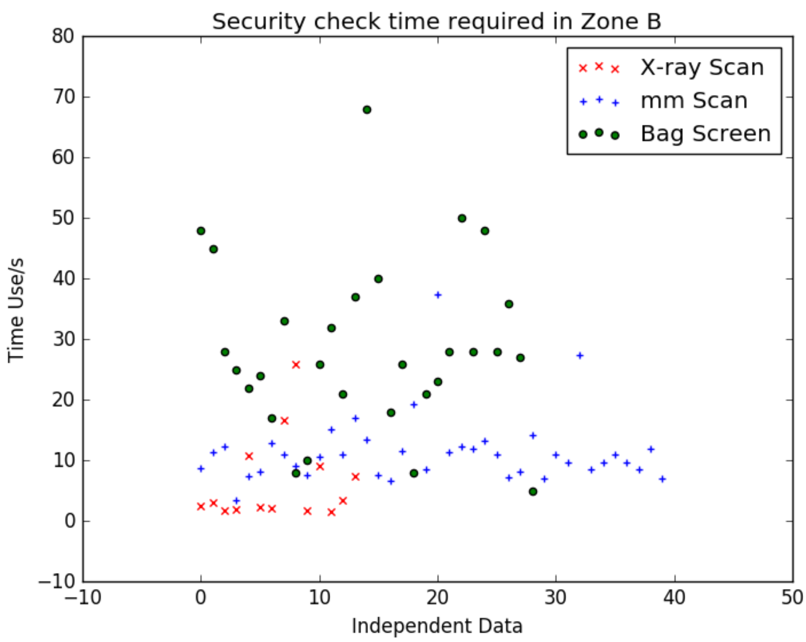


Figure 10-The Data Set

The average of Pre-Check arrival times is 9.35s and the average of Regular Pax arrival times is 13.23s. They are less than t_{bag}, which is a step of all the check. Therefore, it can be concluded that the average of Pre-Check or Regular Pax arrival times TP has got to its maximum value and the system is under congestion.

The value of t_{bag} has the feature of fluctuation, so it is unreasonable to calculate its average time. Apparently, t_{bag} is bigger than $(t_x + t_{mm})$. Thus if t_{bag} is decreased to $(t_x + t_{mm})$, T_s will descend. In addition, the decrease of t_{ID} and $(t_x + t_{mm})$ will also reduce T_s.

Furthermore, passengers can be classified into different lanes with different numbers of check procedures in accordance with their features.

What's more, Pre-Check is essentially a kind of the reduction of T_s.

(3)Passenger Control

Although the increase of Q will rise TP_{max} , it will increase P, which will increase the difference between TP_{ideal} and TP_{actual}, Δ, before TP gets to its maximum value. It means the more lanes open, the more seriously unequal the length of the lane is in reality. So the system should be controlled by either airport staffs or electronic equipments so that it will make sure to allow passengers of new arrival to enter the vacant lane.

Passenger Control can improve passenger throughput as long as the passenger is moved from a waiting lane to a vacant lane. When $\Delta = \Delta_{max}$, namely the maximum difference between TP_{ideal} and TP_{actual}, it is necessary to implement the control.

2 To Reduce Variance in Wait Time

Passenger Control can make every lane more balanced. The more balanced every lane is, the less σ^2 is. When numbers of passengers in every lane are equivalent, σ^2 can be decreased to 0, that's when there's no variance in wait time and a new coming passenger can enter any lane without difference of wait time.

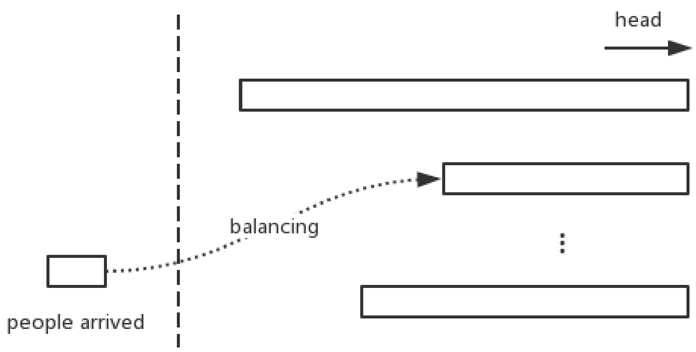


Figure 11-Balancing the Queues

2.2.4 *Simulation*

The process of queue-service is simulated under the utilization of python. In one simulation period, the arrival of passengers and service are under serialization-passengers enters wait queue at a certain frequency and the service ability of every lane is a constant. We assume that passengers reach at the frequency of $\frac{1}{T_a}$ and they are inserted into a lane at random.

In the result of simulation, axis represents the number of simulation round, which is the total duration of the simulation system in this round. After simulation, the ratio of throughput, numbers of full throughput periods divided by numbers of total simulation periods, can be calculated. And full throughput period is defined as in this simulation period any lanes are occupied, which is T_p gets to its maximum value (see single lane model).

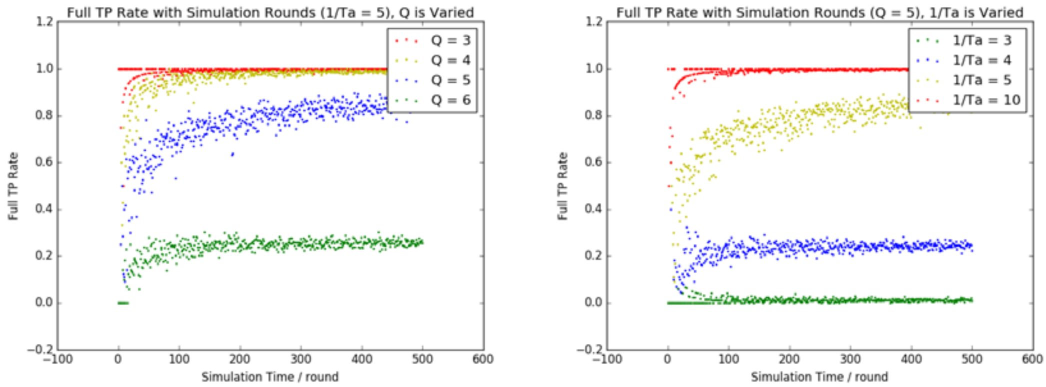


Figure 12-The Change of Q and T_a

1 The change of Q

We assume passengers arrive at a certain frequency. When Q is larger than $\frac{1}{T_a}$, a considerable portion of simulation period is non-full throughput in the whole simulation period. Therefore, when the total number of simulation period increases, the Full Throughput Rate (FTR) converges to a value smaller than 1, and that value decreases as Q decreases.

When Q is smaller than $\frac{1}{T_a}$, the system can maintain at a situation of full throughput. Thus FTR at this situation is much closer to 1 than the situation of a larger Q. As Q decreases further, that tendency becomes more and more apparent-in other words, FTR can converge to 1 soon.

Altogether, though the sustained increase of Q rises the bottleneck of throughput of the system, the system will work at a low level of FTR at most of the time to a certain extent.

2 The change of $\frac{1}{T_a}$

The increase of $\frac{1}{T_a}$ has the similar effect with the decrease of Q. From the green point on the finger we can get that when the number of lanes Q is much greater than actual passenger arrival rate, the value of FTR of the system is close to 0.

3 Implementing passenger control

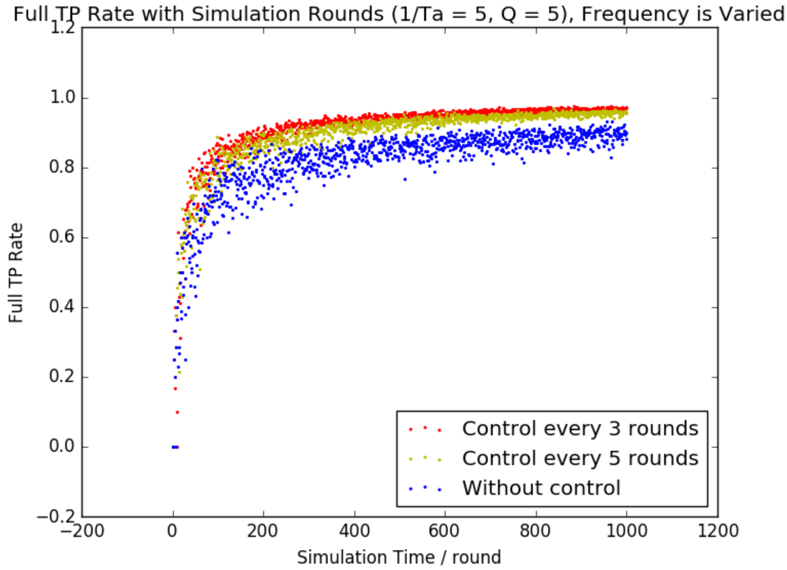


Figure 13-The Control Policy

We assume that Q and $\frac{1}{T_a}$ are constant and in order to discuss conveniently, we make them equivalent, which means the frequency of passengers' arrival and the ability of service time (which can be regarded as Q) are almost identical.

In the simulation system, "Control" can be implemented easily as follows: when the system passes a "Control Period", the system arrange the last passenger of the longest queue to the tail of the shortest one. From a long perspective, it is similar to the purpose of balancing the queue which mentioned before.

From the figure 13, FTR can be obviously improved when introducing 'Control'. That is , with the same number of simulation periods, introducing "Control" will make the value of FTR more close to 1. If the frequency of "Control" is increased (of course, within limits), FTR can be further improved, which is expected more Manpower cost.

2.3 Task C：Internal Ranking Model

To tackle task c, we develop a internal ranking model and implement four different queuing principles on the model so as to discuss how cultural differences may impact the way in which passenger's process through checkpoints.

2.3.1 *Re-Assumptions*

- The arrival rate of passengers follows a uniform distribution, and their interarrival time is T_a.
- TP has got to TP_{max} , and all lanes in the system are occupied all the time.

2.3.2 *The Foundation of Model*

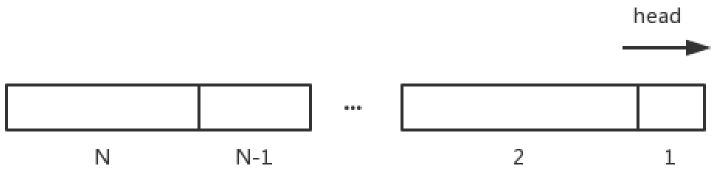


Figure 14-Varied Check Time in Queue

When there are N passengers in one queue waiting, the mean waiting time of passengers $\overline{WT}$ is

$$\overline{WT} = \frac{\sum_{i=1}^{N-1} \sum_{j=1}^{i} T_{sj}}{N}$$

Four different queuing principles-First Come First Served(FCFS), Shortest Job First(SJF), Highest Response Ratio First(HRRF), Priority-Based Scheduling(PBS)-are implemented on the model.

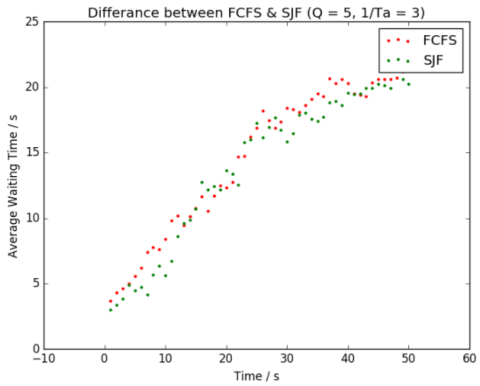
2.3.3 *Solution and Result*

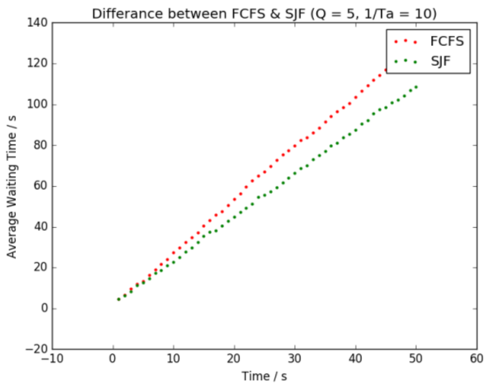
1st queuing principles: FCFS

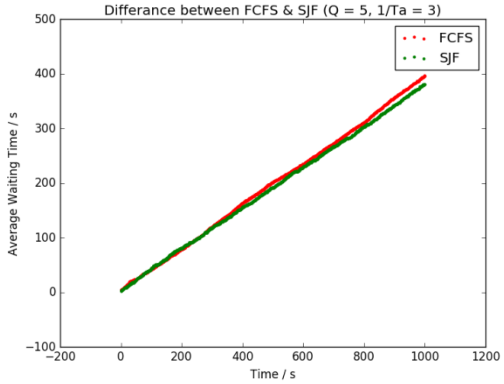
FCFS obeys to sequential service. $\overline{WT}$ is very sensitive under the principle of FCFS. When there's a much large T_{si} at the forefront of a queue, $\overline{WT}$ will rise significantly.

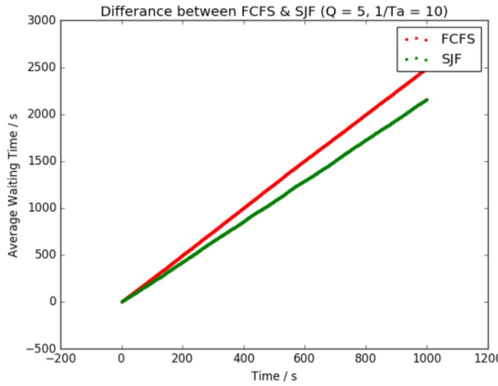
2nd queuing principle: SJF

SJF is the optimized queueing principle, yet it's too ideal to realize in reality. Here are four simulation results of SJF against FCFS:









FCFS and SJF have no obvious differences before TP gets to its maximum value, however, there exists a tendency of difference between FCFS and SJF after TP gets to TP_{max}, namely $\frac{1}{T_a} > Q$.

3th queuing principle: HRRF

We define response ratio of the j[th] passenger η_i as

$$\eta_i = \frac{the\ \ total\ \ waiting\ \ time\ \ passenger\ \ i\ \ has\ \ spent}{T_{sj}}$$

The passenger with higher η will be serviced earlier on the basis of HRRF.

In general, the sequence of the $\overline{WT}$ of the three principles above is:

$$\text{SJF} < \text{HRRF} < \text{FCFS}$$

4th queuing principle: PBS

PBS is similar to HRRF, a passenger with priority has a high η.

2.3.4 *Cultural Norm Analysis*

Americans have a strong social stigma against “cutting” in front of others, thus it is suitable for Americans to implement FCFS. Nevertheless, FCFS is sensitive to large T_s. Accordingly, it is suggested to open a green channel for the aged, the sick, the disabled ,etc.and a special channel for passengers with excessive baggage on purpose, and each system only has one green channel and one special channel. It can expedites passenger throughput. As far as the reduction of variance in wait time, passenger controlling must ensure the total service time of every lane are equal.

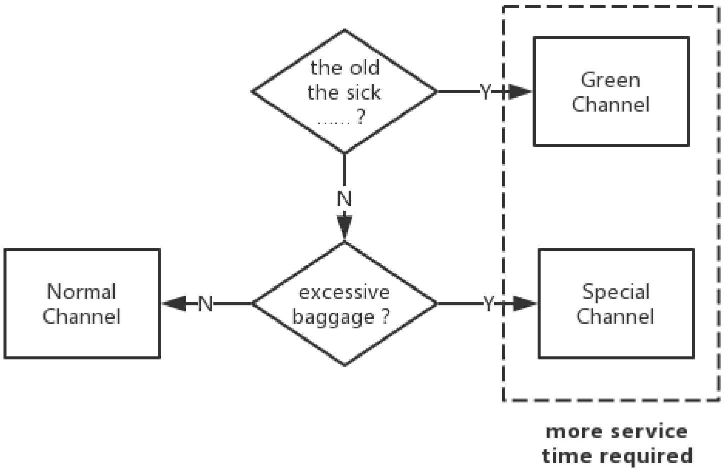


Figure 15-Policy for Special Passenges

Chinese prioritize individual efficiency so much that PBS is suitable for Chinese Airports.

Swiss emphasizes on collective efficiency. As a result, SJF can be implemented on them. But the problem is how to figure out T_{s_i} of every Swiss precisely before they get serviced. An approximate method is to estimate T_{s_i} based on the quantity and size of every passenger.

2.3.5 *Sensitivity Analysis*

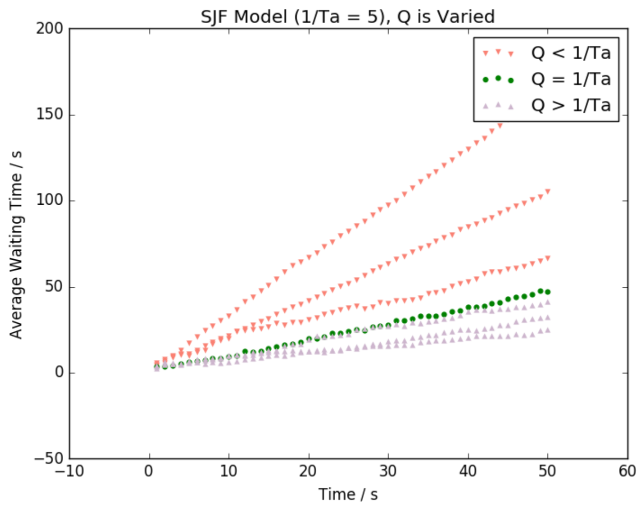


Figure 16-Sensitivity Analysis for SJF Scheduling

Under the assumption of SJF scheduling and $\frac{1}{T_a} > Q$, the increasing of Q (opening new queue) is effective for reducing $\overline{WT}$. If $\frac{1}{T_a} \le Q$, $\overline{WT}$ can not be effectively reduced.

That is, if the airport is able to estimate $\frac{1}{T_a}$, we can save cost as well as maintain $\overline{WT}$ in relatively lower level by choosing the value of Q.

2.4 Task D：Binary Decision-Tree Model

To tackle task c, we develop a queue internal ranking model and implement four different queuing principles on the model so as to discuss how cultural differences may impact the way in which passenger's process through checkpoints.

2.4.1 *Extra Symbols*

Table 2: Symbol Table of Binary Decision-Tree Model

Variable	Description
L	binary decision-tree
$S(L)$	security indicator
G	number of passengers at node 1
q_k	probability that the passenger carries threat type k. k=1,2,3
$G_{k,i}$	number of passengers carrying threat k at node i
$G_{0.i}$	number of good passengers at node i

2.4.2 *Re-Assumptions*

- Threats are always revealed when passengers go through pat-downs
- A passenger carries at most one type of threat from the three types

2.4.3 *The Foundation of Model*

It's necessary to control the trade-off between security, service time and cost. Based on that idea, we can consider removing mm wave scanning once passengers are classified as good after X-ray screening. We use a binary decision-tree L to show this process intuitively.

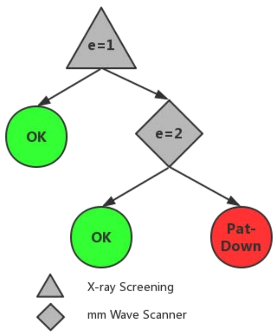
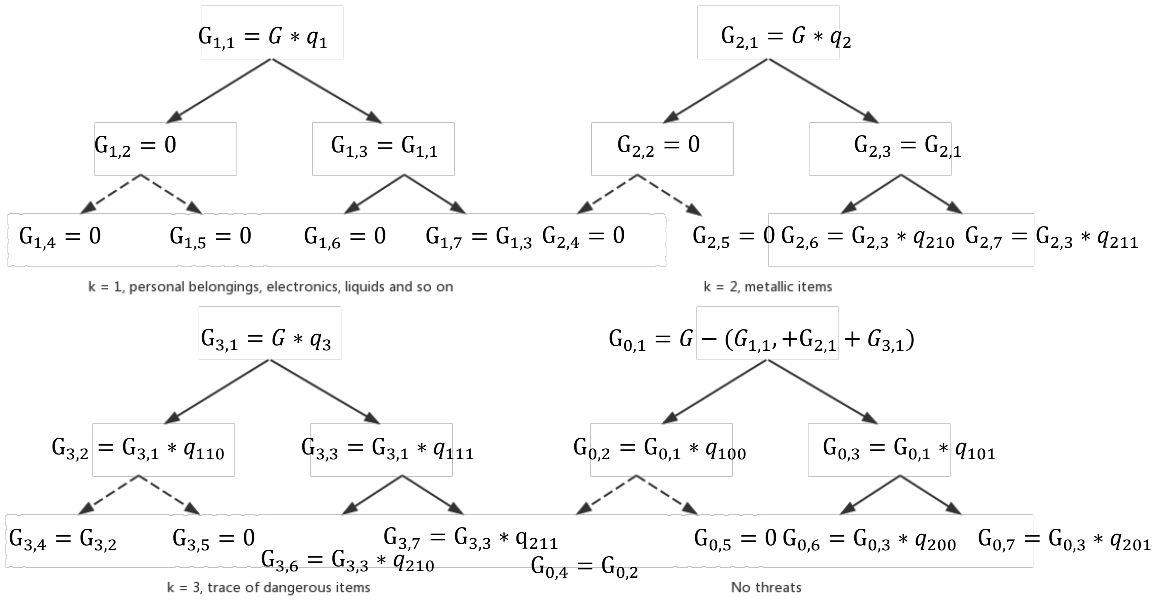


Figure 17-Binary Decision Tree

However, equipment might misjudge good passengers as bad or misjudge bad passengers as good. The following conditional probability can be obtained through historical equipment records:

e	e=1 represents X-ray scanner; e=2 represents mm wave scanner;
q_{e00}	propability that the equipment e judges a good passenger as good
q_{e01}	propability that the equipment e misjudges a good passenger as bad
q_{e10}	propability that the equipment e misjudges a bad passenger as good
q_{e11}	propability that the equipment e judges a bad passenger as bad

2.4.4 *Solution and Result*



The security indicator is in proportion to the number of passengers carrying threat and passing pat-down check, in inverse proportion to the total number of passengers carrying threat.

$$S(L) = \frac{G_{1,7} + G_{2,7} + G_{3,7}}{G_{1,1} + G_{2,1} + G_{3,1}}$$

If *S(L)* doesn't exceed a predefined expected value, we can adopt the following strategy which corresponds to the binary decision-tree shown in figure above: passengers judged as good after X-ray screening don't need to pass mm wave scanner, while those judged as bad must pass mm wave scanner and even pat-down check in zone D. Otherwise, passengers judged as good after X-ray screening must pass mm wave scanner.

III. Strengths and Weakness

3.1 Strengths

- Simpleness

The models we built are all simple enough to be studied. In Single Lane Model, we performed a piecewise function to define bottleneck of our system. In Multi Lanes Model, we introduced perplexity to explain the delay of the max of throughput. We built each model on the base of the last one, only considering one more new property for the new model.

- Practical Application

We can easily get some basic conclusion during Qualitative Analysis. We introduced a policy to balance the length of lanes as well as limit the number of lanes when there is a relatively small passenger flow.

- Simulation

Under the utilization of Q or T_a, we successfully simulated the process of queuing and service. For conclusions, we are able to evaluate the effect of the policy, such as balancing the lanes, and the variety of the system when alter Q or T_a.

- Universality

The assumptions of our model such as queuing before ID Checking, the concurrency of some checking, the perplexity of guests are valid to normal airports. That is, our model is valid to the most of situations.

- Pertinence

In Task c, we performed different ways for queueing to accommodate the requirement of varied cultures and special situations such as VIP service or allowing for “cutting”.

3.2 Weaknesses

- Strong Assumptions

Some of the assumptions of our models are unpractical and not complete. For example, we used average value to estimate t_{bag}, but the real data shows that t_{bag} are varied greatly. Secondly, we assumed the frequency of people arriving at the airport is constant and the boost of flow is not exist. That’s not practical.

- Single lane

We only assumed and analyzed single level of queue without the subsequent one. There can be serial queues in the real situation,

- Complexity

In actual Multi Lanes Model is too complexed to find a specific form of function, though it can explain perplexity better.

- Exceptional Case

There are more special conditions to be considered, such as when encountering equipment failure or the high flow of festival, the model should be more robust to explain the exceptions.

- Data scarcity

Because the data of equipment needed are not open to public and other data we collected are limited, we can't give quantitative analysis but a systematic method instead.

IV. Future Work

The security checks in zone A and zone B are serial processes. After a passenger getting ID check in zone A and entering zone B, he or she may face the choice of queue once again. It will cause another wait time and service time. The process in zone A and zone B can be regarded as double queue scheduling, thus it can be optimized by changing the sequence of passengers getting served. The correlation algorithm of double queue scheduling can be Johnson Algorithm as long as the time of every passenger's separate service at zone A and zone B can be estimated before they start to get served in zone A.

V. Conclusions

To explore the flow of passengers, we establish a simple basic model to simulate the security check at an airport and we analyze that the time of a passenger's service time is a bottleneck of the security check system. The number of service lane and the time of passengers' service time are the factors that influence the throughput ,so we propose to increase service lane and decrease service time to modify this system. Besides, the guarantee of every lane's wait time are equal can decrease the variance in wait time. What's more, different queuing principals in different countries will exert influence on the mean wait time in one queue. Finally, we obtain some measures to reduce processes in the case of reality.

The passage offers some simple models and practical methods to analyze a security check system, although data are not available and the model has a few drawbacks.

VI. References

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