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A Network Flow Approach for Optimizing the Passenger Throughput at an Airport Security Checkpoint

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Abstract. This paper is intended to solve the checkpoint throughput optimization for an International Airport. We establish a network flow structure to analyze the bottleneck of the security system.After identifying the number of each person's identity, the number of screening lanes,and the ratio of regular lanes to Precheck,we simulate the fluctuations of passenger flow,reduce the variance of waiting time and improve the passenger throughput process.

1. Introduction

With the increment amount of passengers, the congestion happens more and more frequently at the airport, as it gradually is the main cause of dis-satisfactions from passengers. The long wait queues and high variance in waiting time have become the common concern of airports worldwide.

Since Gilliam(1979) uses queuing theory in X-ray screening for airport passengers[1],Operational research (OR) plays a good role in aviation safety.Some researchers have studied checkpoint optimization in recent years.Wilson,et.al solve the safety challenges by using of space discrete event simulation with physical space, passenger behavior and movements combined with traditional queuing model method [2]. Other researches as Modeling the screening of passengers and baggage in a aviation security system[3],queuing model applications[4,8], the waiting time traffic volume deduced by modeling[5],the hazard-based duration model to explore the factors that affect airport security transit times[6] ,the operation of the passenger security control system and expert system[7],different optimization strategies for the minimization of flight and passenger delays[9] ,the cost of providing security in airports, especially in facilitating passenger throughput[10-11].Besides,a simulation framework is developed[12] .

The conflict between efficiency of the checkpoints and strong safeguards has always been a sticky issue.The aim of the paper is to create models which analyse the passenger flow processes at the airport terminal.A sequential arrangement consisting of four submodels has been put forward for the check-in and security check system. We identify the bottleneck of throughput of passengers for the security check after differentiating the routine with Pre-Check passengers when they pass through the checkpoint.Our work is more comprehensive building as to some researches before.

2. Models Setting

In this section, we build a network flow approach for both routine and Pre-check passengers going through checkpoints.The method can be divided into such models:

(1) Decision Model: Routine or Pre-check passengers have the chance to decide which queue to wait for receiving screening when passing over the identity checkpoint,. At the same time, TSA(Transportation Security Agency) at the checkpoint can give their entry according to congestion condition of the screening process.

(2) Screening model: This model studies the procession when passenger proceeding through millimeter wave and their belongings receiving X-ray check at the same time.

(3) Terminal Model: The model analyse the process for passengers collecting their belongings.
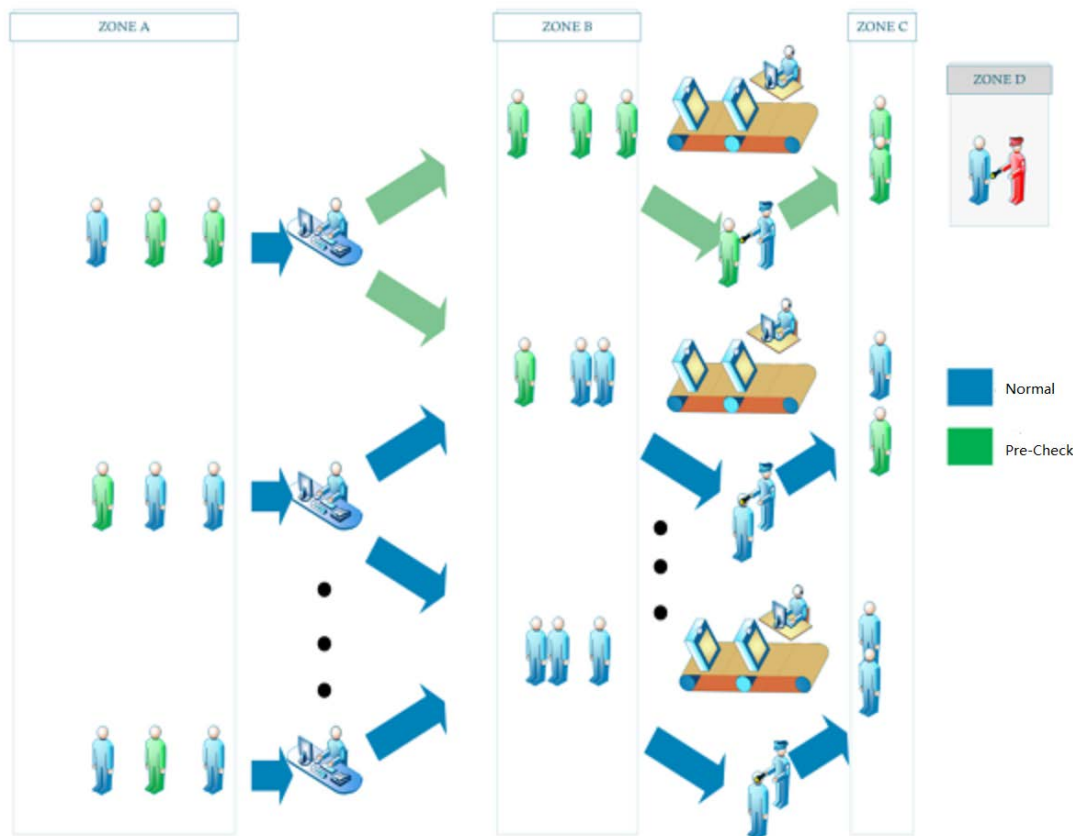
Figure 1. An illustration of the TSA Screening Process.

2.1. Decision Model

Let $N_P(t)$ be the total of Pre-Check passengers and $N_R(t)$ NR (t) be the total of routine passengers, $P_{Pi}(t)$ and $P_{Ri}(t)$ which stand for the probability of Pre-Check and routine passengers who choose to wait in the queue before checkpoint a_i.

Then, the sum of passengers who wait in the queue of a_i can be shown in the following equation:

$$A_i^+(t) = P_{Pi}(t) \bullet N_P(t) + P_{Ri}(t) \bullet N_R(t) \tag{1}$$

In order to reduce the congestion wait time for passages in the queue from zone A to B, the optimum waiting time can be expressed as follow:

$$T_{W1} = \begin{cases} \lambda_{ai} & B_j < B_{\min} \\ (B_j - B_{\min}) \bullet k_1 & B_{\min} \le B_j \le B_{\max} \\ (B_{\max} - B_{\min}) \bullet k_1 & B_j > B_{\max} \end{cases} \tag{2}$$

where T_{W1} stands for the wait time at identity checkpoint a_i ; λ_{ai} is the maximum amount of passengers throughput ; B_j is the length of the queue waiting before the screening checkpoint; B_{max} and B_{min} are the maximum and minimum length of the queue waiting before the screening checkpoint respectively;and K_1 a supposed parameter.

Therefore, let T_{all} be the total time for one passenger passing identity checkpoint , T_A be the routine process of inspecting one passenger's identity and boarding documents. We use :

$$T_{all} = T_A + T_{W1}$$

Thus we draw a conclusion that the sum of passengers who leave a_i can be shown in the equation:

$$A^-_i(t) = \begin{cases} \lambda_{ai} & B_j < B_{min} \\ \lambda_{ai} - q \bullet (B_j - B_{min}) & B_{min} \leq B_j \leq B_{max} \\ 0 & B_j > B_{max} \end{cases} \tag{3}$$

where q is a supposed parameter.

We then sum up the total passengers amount at a_i in the end of time t:

$$A_i\ (t) = A_i(t-1) + A_i^+(t) - A_i^-(t) \tag{4}$$

We set the Constraint Condition in order to ensure the stability of the security system and to restrict the input and output of Zone B.

$$\lim_{t \to \infty} \frac{1}{l} \sum_{t=k}^{k+1} (A_i^+(t) - A_i^-(t)) \leq 0$$

2.2. Screening Model

We suppose the time millimeter wave and X-ray take are subject to Negative Exponential Distribution, which are represented as T_P and T_S , we get:

$$E[T_P] = \lambda_{BP} = \lambda_{pw} + \lambda_{cl} \bullet x_k \tag{5}$$

$$E[T_s] = \lambda_{BS}$$

where λ_{BP} , λ_{pw} , λ_{cl} and λ_{BS} stand for distribution of millimeter wave time, waiting time, additional screening time and x-ray time; and x_k is assigned to 1 when a passenger is required an additional check to Zone D,otherwise,equals.

As our data shows approximately 45% passengers enroll in the Pre-Check program. We suppose that 10% Pre-Check passengers don't choose the special passway.(In the case that these special passways may be more congested than the routine ones.) The process can be illustrated in Figure 2.
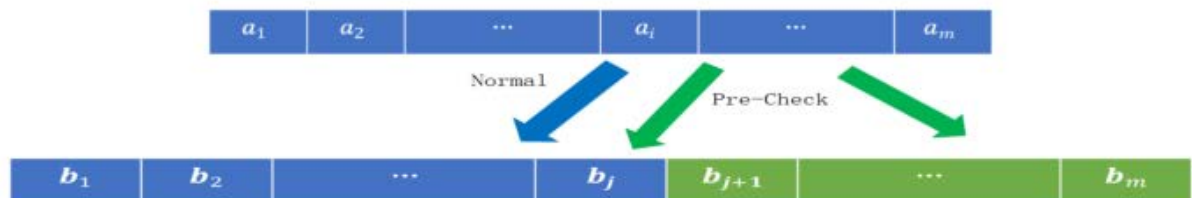
Figure 2. Distribution of passages flow between queues with identity checkpoints

Consequently, the sum of passengers who wait in the queue of screening checkpoint b_j from identity checkpoint a_i can be shown in the following equation(we take the actual values into the Eq.(6),otherwise they can be changed depending on different situations.It is same in Eq.(10)):

$$E_{ij}(t) = \begin{cases} 55\% \, A_i^-(t) + 45\% \bullet 10\% \bullet A_i^-(t) \\ 45\% \bullet 90\% \bullet A_i^-(t) \end{cases} \tag{6}$$

The total number of passengers waiting in the queue of screening checkpoint b_j can be expressed as:

$$B_j^+(t) = \sum_{i=1}^{m} E_{ij}(t)$$

Let T be the maximum of T_P and T_S, then the maximum passenger throughput is:

$$E(T) = \frac{1}{\lambda_{BP}} + \frac{1}{\lambda_{BS}} - \frac{1}{\lambda_{BP} + \lambda_{BS}} \tag{7}$$

If the passenger throughput of Zone B is limited by the congestion condition of Zone C, the total time it costs for one passenger passing screening checkpoint b_j can be shown as:

$$T_{Bll} = T_B + T_{W2}$$

where T_{Bll} stands for the total time; T_B is total of routine millimeter wave screening time and X-ray screening time; and T_{W2} is the waiting time.

Similarly, the optimum waiting time before screening can be expressed as:

$$T_{W2}(t) = \begin{cases} 0 & C_j < C_{\min} \\ (C_j - C_{\min}) \bullet k_2 & C_{\min} \le C_j \le C_{\max} \\ (C_{\max} - C_{\min}) \bullet k_2 & C_j > C_{\max} \end{cases} \tag{8}$$

where $T_{W2}(t)$ stands for the wait time at screening checkpoint b_j; C_j is the length of the queue waiting to get scanned belongs; $C_{\max}$ and $C_{\min}$ is the maximum and minimum of C_j respectively;and K_2 is a supposed parameter.

Consequently, we draw a conclusion that the sum of passengers who leave b_j can be shown in this equation:

$$B_j^- = \begin{cases} \lambda_{BP} & C_j < C_{\min} \\ \lambda_{BP} - s \bullet (C_j - C_{\min}) & C_{\min} \le C_j \le C_{\max} \\ 0 & C_j > C_{\max} \end{cases} \tag{9}$$

where s is a supposed parameter.

Sum up the total passengers at b_j in the end of at time t,we get:

$$B_j(t) = B_j(t-1) + B_j^+(t) - B_j^-(t)$$

And the constraint condition is :

$$\lim_{t \to \infty} \frac{1}{l} \sum_{t=k}^{k+1} (B_i^+(t) - B_i^-(t)) \le 0$$

2.3. Terminal Model

Obviously, the number of passengers who wait for collecting their belongings is the same as the number of people who leave the process of screening. Thus, we get

$$C_j(t) = C_j(t-1) + C_j^+(t) - C_j^-(t)$$

where $C_j(t)$ and $C_j(t\text{-}1)$ are the total number of passengers at Zone C at time t and $t-1$ respectively; $C_j^+(t)$ stands for the number of passengers who wait for collecting their belongings at time t; and $C_j^-(t)$ stands for the number of passengers who leave the whole checking process at time t.

In the case that Pre-Check passengers are not bound to remove shoes, belts, or light jackets and they also do not need to remove their computers from their bags, we suppose that they can save 25% time compared with routine passengers in collecting belongings. Therefore, the total number of passengers who leave the whole checking process can be expressed as:

$$C^-{}_i(t) = \begin{cases} C_j(t-1) \bullet [55\% \bullet \int_t^{t+1} f(t)dt + 45\% \bullet 10\% \bullet \int_t^{t+1} g(t)dt] & j \le r \\ C_j(t-1) \bullet 45\% \bullet 90\% \bullet \int_t^{t+1} g(t)dt & j > r \end{cases} \quad (10)$$

Where $f(t)$ and $g(t)$ are the probability density for a routine passenger and a Pre-Check passenger to collect their belongings respectively. With the condition, $\lambda_g = \dfrac{1}{0.7}\lambda_f$ based on our calculation from the data in the airport terminals.

3. Results
We realize above models programmatically and get the experimental result. Then we process the data to see the cause of congestion.

After analyzing over process through the checkpoint, we find out there are several factors determining the performance of the throughput of passengers at the bottleneck of the process.They are the number of windows for identity check(m) ,the number of lanes for screening(n) and the ratio of routine-check lanes number to Pre-Check lanes number(r). In figure 3, we give the result of dealing with these three factors for the passages flow.
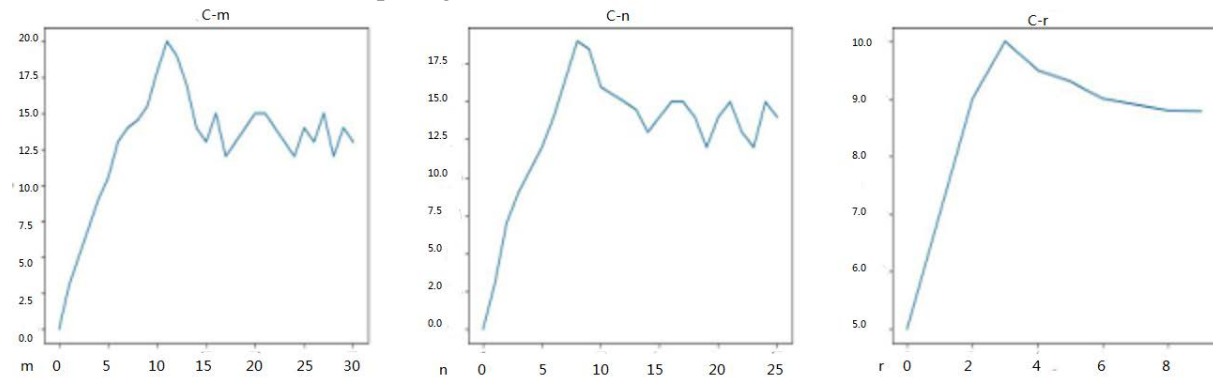
Figure 3. The variations of three factors.

As Figure 3 shows, the throughput of passengers boosts as m increases at first. It leads to the crowd in the Zone with the influx of passengers.Since the lanes of screening keep unchanged, the throughput decreases as more windows in Zone A are opened.

Similarly, the throughput of passengers boosts as n increases at first, which is limited by the queues in Zone c. The throughout of passengers decreases when the windows number in Zone B is over the critical value.

The value r can also restrain passengers throughput. The throughput increases as there are more routine-check lanes than Pre-Check ones at first. Nevertheless, as approximately 45% of passengers enroll in Pre-Check program, high ratio of r will definitely lead to congestion in Pre-Check lanes and causes the throughout decreases when the ratio is over the critical value.

4. Conclusion

The paper simplifies the inspection process and other conditions during the research process of the security checking. Based on the idea of network flow, we abstract the passenger flow to network flow and the security system of a three-layer network consisting of arriving airport, Zone A, Zone B,and Zone C. Positive network flows as well as feedback flows transfer between layers. The possible transference of network flows between layers is used to simulate the fluctuation of passenger flow in airport checking system.

We use the number of identity checkpoint, the number of screening lanes, and the ratio of common lanes to Pre-Check lanes as our parameters. Besides, we also assign the number of outflow from Zone C as the throughput of passengers. It is found that the connections between parameters and throughput: when one parameter changes, the total throughput will increase to the top and then goes downward slowly.At last,the bottlenecks are well suitable for passages flow.

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