Probability Distribution of Time for Passengers Arriving at Security Area in Terminal

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***Abstract*—The long queue time in the process of security inspection not only affects passengers' boarding experience, but also has great influences on the efficiency of airport operation. It is a considerable challenge to solve this problem, because the time of passengers arriving at security areas is unknown. In order to reduce the queue time before security inspection, the airport managers generally decide to open or close some security counters according to the number of passengers standing in the security areas. However, this method cannot satisfy the requirements enough, and there will be some passengers waiting in the queue for a long time during the peak period. On the other side, it will waste security resources in the trough time. This paper studies the behaviors of passengers departing from check-in counters to the security areas in terminal based on a global optimal iterative method to generate the walking time from check-in counters to the security areas, waiting time in the security queue and the service time in security process. Furthermore, the distribution of time for passengers arriving at security areas is presented. It is possible to make an arrangement of opening security counters dynamically in advance. The research work in this paper can improve the utilization efficiency of airport security resources and is of great importance to improve the efficiency of airport operation and passengers' experience.**

Keywords—security inspection queue, passengers prediction, probabilistic distribution, civil aviation security, civil aviation efficiency

I. INTRODUCTION

Security inspection is one of the most important processes for passengers to depart from the airport on their journey[1]. The long queue time in the process of security inspection not only affects the passengers' travelling experience, but also has great influences on the efficiency of airport operation and service[2]–[4]. At present, the number of opening security counters in terminal relies on airport managers' manual adjustment commonly. In order to decrease the queue time of security inspection, the airport managers generally adjust the number of opening security counters, according to the quantity of passengers arriving at the security areas, although there are some other methods to improve the efficiency of the security process[5], [6]. This method can alleviate the situation of long queuing time in the process of security inspection to some extent. However, some problems still exist, such as insufficient utilization of security counters resources in the low-trough period and the long waiting time for passengers in the peak period.

In order to solve the problem above, we can adjust the quantity of opening security counters dynamically to achieve the best match between the actual quantity of passengers arriving at security areas and the quantity of passengers crossing the opening security counters every minute using simulated method and historical data analysis technology[2], [3].It is feasible to open or close some security counters beforehand to maintain the utilization efficiency of security resources to be at a high level. Hitherto, airport video data and structural passengers data are widely used in data mining for this issue. With the development of artificial intelligence, video data analysis technology has remarkable ability on calculating the number of passengers in the queues, which is beneficial for the arrangement of opening security counters. But video data analysis technology cannot give out the elaborative regulation of time for passengers arriving at security areas, which means that it is difficult to fill the gap between the requests and the opening resource in advance. Based on structural passenger data, the mathematics method can mine the behaviors of departing passengers in the terminal. The model has strong robustness under the circumstances that the plan of flight is changing in terms of both flight time and quantity.

Using the airport dataset of check-in and security inspection, this paper studies the time distribution of passengers arriving at security areas based on a global optimal iteration method. The walking time from check-in counters to the security areas, waiting time in the queue of waiting security and the service time in the identification process are generated with the proposed method. The distribution of time for passengers arriving at the security inspection areas also is analyzed. The research work in this paper can provide supports for the dynamic adjustment of the quantity of security counters and improve the utilization efficiency of airports' security inspection resources and the passengers' travel experience.

II. MATERIALS

A. Data Description

A super-large hub airport in southern China has been taken as an example, the check-in data and security data of passengers departing from the airport are used in this paper to simulate the walking time from check-in counters to the security areas, waiting time in the queues of security inspection and service time of security.

The passengers' check-in data in the terminal on November 1, 2017 is used, including passenger ID, check-in time, flight departure time and so on. The passengers' security data in a specific area of the terminal on November

1, 2017 is used, including passenger ID, security check time, flight departure time, security inspection counters, etc.

B. Data Processing

The input parameters of the model include passengers' check-in time, security time, security counter ID and departure time. Therefore, the first step in data process is to merge the two data sets into a unified data set, according to the common attribute fields of the two data sets. The generated new passengers' data set is referenced with the indexes of security data set.

A small minority of passengers' check-in time is missing in the merged data set, as shown in Fig. 1. For different security counters, the percentage of available data ranges from 90.7% to 99.3%, and the average percentage of that is 92.5%. It is impossible to remove these passengers from whole data set directly, because all passengers in the merged data set including these passengers missing check-in time have participated in the queuing process of security inspection. Therefore, this group of passengers needs to be taken into account in the model. The default check-in time is set at zero on the same day for passengers who lack check-in time, and zero is used to fill in their check-in time. The unit of all the time has been converted to minute in the model for the convenience of simulation.

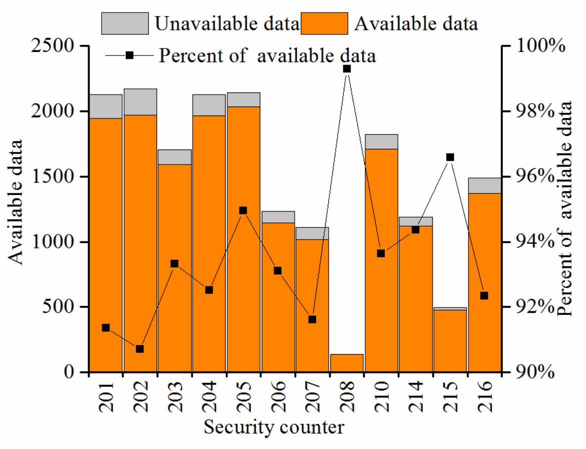

Fig. 1. Statistics of available dataset in each security counter.

III. Methods

Passengers need to experience some processes from check-in to security inspection including waiting for the luggage for checking, walking from check-in to security areas, selecting the queue of security inspection to jump in, waiting in security inspection queue[9]. The time of passengers arriving at the security service desk can be expressed as (1).

$$t_{Security} = t_{Checkin} + \Delta t_{bagscheck} + \Delta t_{walk} + \Delta t_{selectqueue} + \Delta t_{waite} \quad (1)$$

where $t_{security}$ is the time of passenger arriving at security service desk, $t_{checkin}$ is the time of passengers' check-in, $\Delta t_{bagscheck}$ is the time of passengers spending on luggage checking, Δt_{walk} is the time of passengers spending on walking from check-in to security areas, $\Delta t_{selectqueue}$ is the time of passengers spending on selecting the security counters, Δt_{waite} is the time of passengers spending on waiting in the security queue. Irrespective of $\Delta t_{bagscheck}$ and $\Delta t_{selectqueue}$, Equation (1) can be simplified to (2)

$$t_{Security} = t_{Checkin} + \Delta t_{walk} + \Delta t_{waite} \quad (2)$$

In order to obtain the time that passengers jump in the security inspection queue, it is necessary to calculate the time for passengers spending on walking from completing check-in to jump in the queue. In this paper, the passengers' initial minimum time spending on walking from check-in to security areas is searching with a boundary function firstly, then a forward simulation method is adopted to simulate the process of passengers walking and queuing before security inspection and finally simulate the time for passengers arriving at security inspection. By comparing the simulated time of security inspection with the actual security time, the differences of that has been fed back to the passengers' walking time if the differences are beyond the setting threshold. Passengers re-queue for security inspection and iterate repeatedly until the iterative condition is satisfied. The specific steps are shown as following:

1) Determine the minimum time boundary function between check-in and security inspection using passengers' check-in time, security time and departure time of flight, and then calculate all passengers' initial minimum walking time between check-in and security inspection using the boundary function.

2) Find out the seed passengers without queuing, according to use the minimum time boundary function from check-in to security areas and the time interval of security time.

3) Calculate the time of passengers entering the security areas by adding the passengers' check-in time with passengers' minimum walking time. All passengers are divided into different queues with the security counters. It is assumed that the order for passengers jumping in and out the security queue remains unchanged. Therefore, the order for passengers jumping into the queues is adjusted according to the order of passengers jumping out of the security inspection in each counter.

4) Calculate each passenger's service time with security time series in each queue, and estimate individual waiting time in the queue and the time for passengers arriving at the security desk.

5) Compare the difference of time between the simulated passengers' security time and the ground-truth security time. When the different time is beyond the threshold, it will be fed back to the passenger's walking time, and step 2) is taken.

6) With multiple loop iterations, the global optimal solution of the walking time and queuing time for all passengers is obtained.

A. Function of Passengers' Minimum Walking Time

The behaviors of departing passengers in the terminal are mainly driven by flight time[4]. The time for passengers spending on walking from the check-in areas to security areas includes their actual walking time and other wasted time. The walking time is not only related to the distance between the check-in counter and security area, but also passengers' walking speed. Distance is constant for a specific airport. So the main factor affecting the gross walking time is the passengers' speed. The subjective factors affecting the speed include individual personal characteristics, such as gender, age, etc.[11]. Objective factors include flight departure time, the quantity of bags, etc.[12]. As shown in Fig. 2, the difference of time for passengers between security inspection and check-in varies with the difference of time between passenger check-in time and flight departure time.

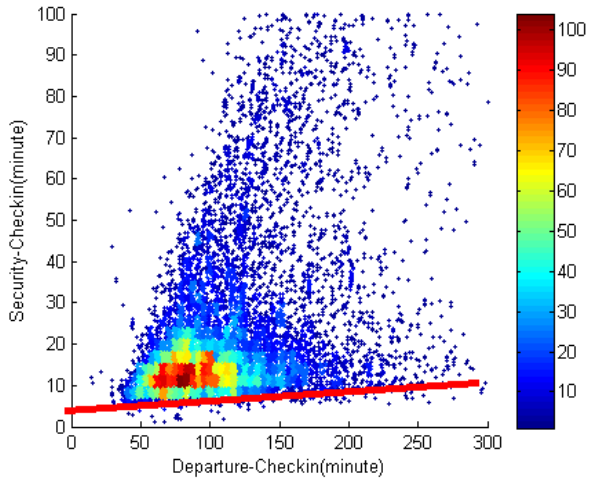

Fig. 2. Difference of time between passengers'security time and check-in time varies with the difference of time between passengers' check-in time and departure time

There is an obvious boundary at the bottom of the image. As the difference of time between check-in time and departure time of flight increases, the minimum difference of time between check-in time and security time increases linearly. This indicates that passengers are driven by the flight time dominantly as the departure time of flight is approaching. The sense of time urgency enhanced. Passengers walk faster than normal speed. Obviously, the boundary function is the minimum walking time for passengers theoretically. Assuming the walking time for passengers is mainly driven by the difference of time between check-in time and departure time of flight. The boundary function varies linearly at a fixed time interval. The passengers' minimum walking time from check-in to security areas can be expressed by a linear function as (3).

$$f(t) = a \cdot t + b \quad (3)$$

where a and b are constant values, t denotes the difference of time between check-in time and departure time of flight.

For these points under the line of boundary function, the difference of time between check-in time and security time is less than the minimum walking time calculated by function. Therefore, it is considered that these passengers go across the security counters directly without queuing, which are also set as a seed point. The initial minimum walking time is equal to the difference of time between the actual check-in time and security time. For these points above the line of boundary function, it is sometimes difficult to distinguish these passengers without queuing for the security service from whole passengers directly. Because some passengers whose difference of time between check-in time and security time beyond the function values may not queue, if they had spent some time on other parts during these periods. Therefore, the minimum walking time boundary function $f(t)$ can be given in (4).

$$f(t) = \begin{cases} 30a + b & , t \in [0,30) \\ at + b & , t \in [30,150] \\ 150a + b & , t \in (150, +\infty] \end{cases} \quad (4)$$

B. Security Queue

Passengers just have to select a specific counter from all opening security counters before starting the security inspection, when they arrived at the security areas. Once passengers enter the security queue. it is assumed that they will not change queue to other different security queue and the order of the sequence will not change in queue. Based on the previous premise, first-in-first-out, it is notable for passengers to jump in and out of the queue in each counter with a same order. So we can adjust the sequence of passengers going in the queue, according to the passengers out of the queue with the series of security time. It should be noted that to confirm a corrected order of the queue is very important to the model.

For these passengers whose check-in time existed, we should adjust the order of them with the time series of seed passengers arriving at security areas. Starting from a seed passenger, if the sum of passenger's check-in time and walking time is smaller than the sum of front passenger's check-in time and walking time, it is considered that the front passenger walking too long. So the front passenger's walking time should be decreased. Meanwhile, starting from a seed passenger, if the sum of passenger's check-in time and walking time is larger than the sum of next passenger's check-in time and walking time, the next passenger's walking time should be increased. The detailed strategy of adjustment is shown as (5).

For these passengers whose check-in time not existed, we may adjust the order of them with the time series of passengers existing check-in time by using a linear relation varies with the distance.

For the purpose to search out more seed passengers, we choose these passengers that the gap of security time between two travelers is beyond 1 minute. These situations including emergent inserting into the queue and the changing sequences in line are not considered.

According to the principle of clarified above, the service time of passengers in the security queue can be equal to the difference of time between two near passengers. The service time, particularly, is set at 0.25 minutes for passengers without queuing. The service time for passengers is shown as (6).

If passengers' simulated walking time are equal to the difference of time between the actual check-in time and the security time, the initial walking time of these passengers are set as the time difference between the actual check-in time and the security time, and these passengers are marked as new seed points.

$$\Delta t_{walk,i-1} = \begin{cases} \Delta t_{walk,i-1} - (t_{Checkin,i-1} + \Delta t_{walk,i-1} - t^{s}_{Checkin,i} - \Delta t^{s}_{walk,i}) - \varepsilon & , if\ (t^{s}_{Checkin,i} + \Delta t^{s}_{walk,i}) < (t_{Checkin,i-1} + \Delta t_{walk,i-1}) \\ \Delta t_{walk,i-1} + (t^{s}_{Checkin,i} + \Delta t^{s}_{walk,i} - t_{Checkin,i+1} - \Delta t_{walk,i+1}) + \varepsilon & , if\ (t^{s}_{Checkin,i} + \Delta t^{s}_{walk,i}) > (t_{Checkin,i+1} + \Delta t_{walk,i+1}) \end{cases} \quad (5)$$

$$t_{service,i} = \begin{cases} 0.25, & i = 1 \cup mark_i = 1 \cup t_{security,i} - t_{security,i-1} > 1 \\ t_{security,i} - t_{security,i-1}, & i > 1 \cap mark_i = 0 \cap t_{security,i} - t_{security,i-1} \le 1 \end{cases} \quad (6)$$

The passenger's waiting time can be calculated with the sum of the service time of all passengers standing in front of the passenger at the time *t*. The individual waiting time can be expressed as (7).

$$\Delta t_{waite,i} = \sum_{n=1}^{K} t_{Service,n} \quad (7)$$

C. Global Optimal Iteration

Passenger's security time can be represented by the model simulation as (8).

$$t^{s}_{Security,i} = t_{Checkin,i} + \Delta t_{walk,i} + \Delta t_{waite,i} \quad (8)$$

In order to quantify the overall performance of the simulated results, the average bias for passengers arriving at the security counters can be expressed as (9).

$$\delta = \frac{\sum_{n=1}^{K} (t^{e}_{Security,n} - t^{0}_{Security,n})}{k} \quad (9)$$

Where δ is the average bias for passengers arriving at each counter, *k* is the number of passengers in each counter. The minimum time interval of the model is determined by the value of δ. In this paper, the smallest time interval of simulation is 1 minute. Therefore, when the average bias is below 1 minute or the number of iterations is beyond 100, the iteration will be stopped. Otherwise, half of the difference of time between the simulated values and the ground-truth values of the passengers' security time are fed back to the passengers' walking time. For passenger *i*, the adjusted walking time can be given in (10).

$$\Delta t^{(j+1)}_{walk,i} = t^{s}_{Security,i} - t^{(0)}_{Security,i} \quad (10)$$

IV. RESULT & DISCUSSION

A. Results of Passengers Arriving at Security Areas

After the global optimal iteration completed, the walking time, waiting time in queues and service time in security inspection for all passengers are obtained. The results that the time for passengers arriving at security areas are shown in Fig. 3. It is of difficulty to generalize a unique formula to fit the distribution of time directly. However, it may be possible to divide the curve into two or three segments as shown in (11).

$$P(t) = \begin{cases} 9.58611e^{-7} t^{2.37272} & , t \in [0,70] \\ -3.56973e^{-5+\frac{t}{18.89407}} + 0.01788 & , t \in (70,120] \end{cases} \quad (11)$$

The difference of time between the simulated security time and passengers' ground-truth security time is shown in Fig. 4.The average deviation in each counter varies between -0.01and 0.01 minute. The standard deviation for most of the counters is below 0.1 minutes, and the absolute bias for 95 percent of passengers is below 0.5 minute. The results simulated by the method proposed in this paper agree well with the ground-truth values.

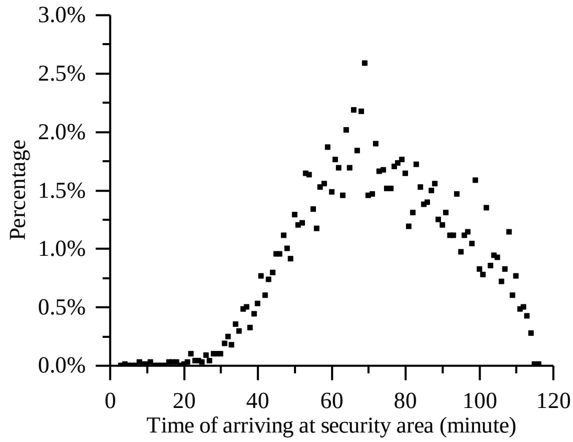

Fig. 3. Statistic of time for passengers arriving at security

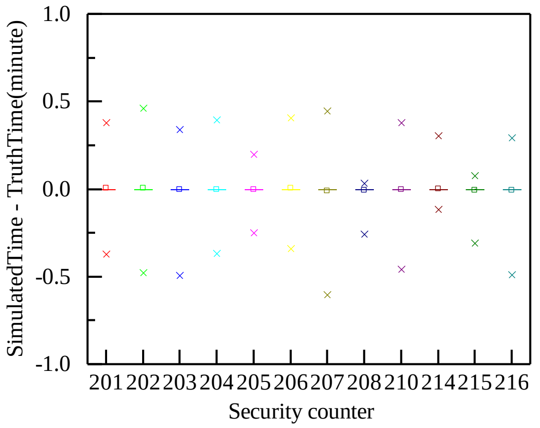

Fig. 4. Statistic of errors between simulated security time and truth values

B. Evaluation and Fitting of the Distributions of Walking Time, Waiting Time and Service Time

Passengers whose check-in time is below 120 minutes before departure time are chosen, and the histogram of the frequency of passengers' walking time is presented in Fig. 5. The results show that passengers' walking time from check-in to security areas varies at the range between 5 to 30 minutes mainly, and the whole distribution of the time shows an obvious heavy-tailed distribution character. A fitting curve of the results is shown in Fig. 5 using a solid red line with Lognormal function (12). The Lognormal curve can better represent the distribution of passengers' walking time. The Residual Sum of Squares and R^2 is 0.011 and 0.818, respectively.

The histogram of frequency of passengers' waiting time is shown in Fig. 6. The results demonstrate that the passengers' waiting time in security queues range between 0 to 10 minutes, and the entire distribution presents an obvious inverse function character. The red solid line in Fig. 6 is a fitting curve with Bradley function (13). The Bradley curve can better represent the distribution of passengers' walking time. The Residual Sum of Squares and R^2 is 0.002 and 0.913, respectively.

The histogram of frequency of passengers' security service time is shown in Fig. 7. The results show that the passengers' service time mainly ranges between 12 and 36 seconds, and the entire histogram presents Gauss distribution. The red solid line in Fig. 7 is a fitting curve with Gauss function (14). The Gauss curve can better represent the distribution of passengers' security service time. The Residual Sum of Squares and R^2 is 0.009 and 0.807, respectively.

$$P(t=T_{walk}) = 0.00338 + 1.96965\frac{e^{\frac{-(\ln\frac{t}{7.33741})^2}{414.05372}}}{\sqrt{2\pi t}} \quad (12)$$

$$P(t=T_{wait}) = -0.05126\ln(0.26553\ln t) \quad (13)$$

$$P(t=T_{service}) = 0.0168 + 1.78715\frac{e^{-2(\frac{(t-0.34201)}{0.18107})^2}}{\sqrt{\frac{\pi}{2}}} \quad (14)$$

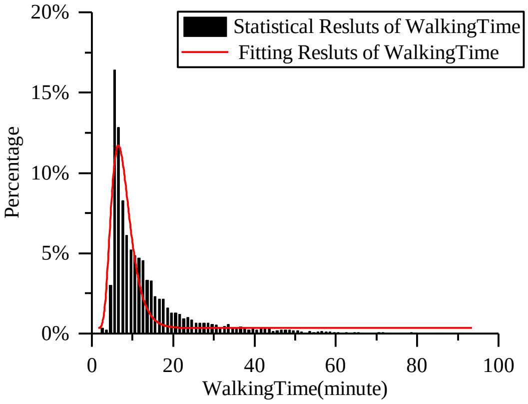

Fig. 5. Histogram of passengers' walking time of from check-in to security areas

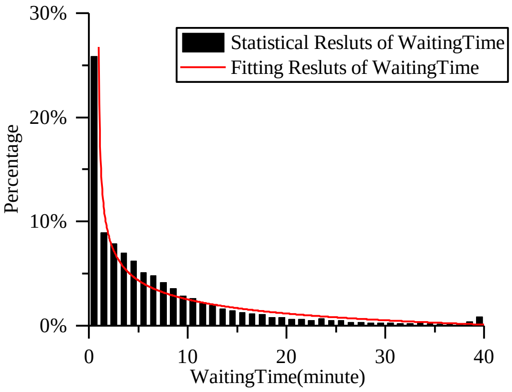

Fig. 6. Histogram of passengers'waiting time for the security service

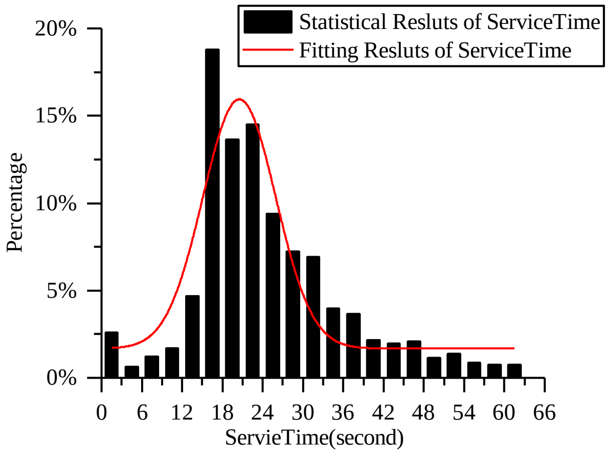

Fig. 7. Histogram of passengers' service time in security

C. Analysis of Walking Time Varies with Time

Taking into account of passengers' walking time varying with the departure time of flight, the scatter plot of passengers' walking time is shown in Fig. 8. These passengers whose check-in time is below 120 minutes before the flight departing are analyzed. Majority of passengers' walking time is within 20 minutes. Passengers spend a shorter time on walking from check-in to security areas when the departure time of fights approaches, and the range of walking time is decreased. There are some further more efforts are still needed us to dedicate in on this issue.

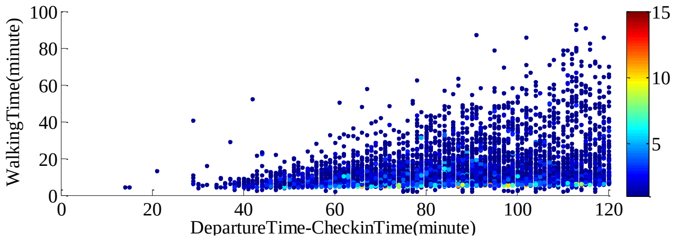

Fig. 8. Scatterplot of walking time varies with the time difference between departure time and check-in time

V. CONCLUSION

Long queuing time not only affects passengers' boarding experience, but also has significant effects on the efficiency and security of the airport operation. A forward simulation based on global optimal iterative method has been proposed in this paper to obtain the probabilistic distribution of time for passengers arriving at security inspection areas. By the way, walking time from check-in to security areas, waiting time in queue for security service and service time in the security process are simulated. The probabilistic distributions of mentioned above are also evaluated. The results suggest that the global optimal iterative method has made an excellent performance on this issue. The research work in this paper can not only provide effective supports for the control and prediction of passengers flow, but also have potential in matching the gap between the quantity of passengers arriving at security areas and the security opening resources.

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