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Security Check Model Based on Queuing Theory

Mengyao Yang
North China Electric Power University, Beijing, 102206
alanncepu@foxmail.com

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Abstract. Nowadays, airlines are committed to minimize inconvenience in security while maximize security for passengers. In this paper we develop a convenient security engineering model to identify bottleneck in security, proposing proposals to improve to great extent from perspective of optimization of checkpoint equipment and procedures and management of security officer under the premise of ensuring safety criterions. We build a security check model considering the checkpoint equipment and procedures from 4 aspects, passenger queuing mode, and the management of security lane, security procedure design and real-time monitoring system. It's found that guiding passengers to queue in S-shaped based on the M/M/C theory, controlling the proportion of lane of regular and Pre-Check according to demand, establishing multi-level security system and monitoring the checkpoint situation, providing regular maintenance can reduce queuing time and variance of bottlenecks greatly while ensure to maximize security. Finally, propose reasonable suggestions to improve the passenger throughput and reduce the variance in waiting time based on the model established.

Introduction

Airport security which is significantly essential to both people and country has been one of the world's concerns. Airports have security checkpoints, where passengers and their baggage are screened for explosive and other dangerous items. All these are to prevent passengers from hijacking or destroying aircraft. Simultaneously, airlines also aiming to provide pleasant and convenient flight for passengers by minimizing the time they spend waiting in line at security checkpoints or waiting for their flight. Therefore, there's a need to find a balance between desires to maximize security while minimize inconvenience to passengers. The security check model's description is as follows.

Modeling and Solution

The Optimization Model of Security Checkpoint Equipment and Procedures. Recently, the rapid development of the air transport industry brings the airport both more revenue and great challenges. The whole process of passengers entering and exiting includes arrival, check-in, security, waiting and departure, etc. Especially the relatively complex security checkpoint is a common point of passenger retention. The airport infrastructure plays an essential role in improving passenger satisfaction and service quality. So we formulate a model to improve the passenger throughput of airport security points from four aspects: passenger queuing, dynamic management security lane, multi-level security system and real-time monitoring system, aiming at building a safe and convenient project for passengers.

It should be noted that, we consider the security check as a unified whole to simplify the problem analysis, the influence of different procedure is ignored.

Passenger Queuing Model

1) Modeling Establishment

M/M/1 queuing model

Parallel queue corresponds to M /M / 1 model which is also called single queue single server model. According to Little formula:

$$L_s(t)=\frac{\lambda(t)}{\mu(t)-\lambda(t)}\quad W_s(t)=\frac{1}{\mu(t)-\lambda(t)} \tag{1}$$

$$L_q(t)=\frac{\rho(t)*\lambda(t)}{\mu(t)-\lambda(t)}\quad W_q(t)=\frac{\rho(t)}{\mu(t)-\lambda(t)} \tag{2}$$

$$\rho(t)=\frac{\lambda(t)}{\mu(t)} \tag{3}$$

M/M/C queuing model

M/M/C queuing model is also called single queue multi-server model, corresponding to the S-shaped queue. Passengers queue in front of C security checkpoints, so the arrival rate of the queue is the sum of C security checkpoints. So does the service rate. Parameters here become:

$$P_0(t)=\left[\sum_{k=0}^{c-1}\frac{1}{k!}\left(\frac{\lambda(t)}{\mu(t)}\right)^k+\frac{1}{c!}*\frac{1}{1-\rho(t)}\left(\frac{\lambda(t)}{\mu(t)}\right)^c\right]^{-1} \tag{4}$$

$$L_q(t)=\frac{(c(t)\rho(t))^c\rho(t)}{c!(1-\rho(t))^2}P_0(t)\quad L_s(t)=L_q(t)+\frac{\lambda(t)}{\mu(t)} \tag{5}$$

$$W_q(t)=\frac{L_q(t)}{\lambda(t)}\quad W_s(t)=\frac{L_s(t)}{\lambda(t)}\quad \rho(t)=\frac{\lambda(t)}{C*\mu(t)} \tag{6}$$

$\lambda(t)$——the rate of arrival in (t,t+1] time, which is short for t time period. $\mu(t)$——the rate of service in t time period. $\rho(t)$——service intensity in t time period. $L_s(t)$——the number of passengers in queue, including passengers in queue and are screened. $W_s(t)$——the checkpoint congestion time of passenger, including queuing time and being screened time. $W_q(t)$——queuing time of passenger.

In the security check process nowadays passengers can choose any security lane, due to lack of organization, causing the decrease of the efficiency of the queue. However, if we guide passengers to queue in S-shaped, as the figure shows below, which is superior compared with parallel queue. When the first passenger of a queue can not pass the security checkpoint for some reason, the follower can choose another security checkpoint to complete security tasks without waiting, thereby not only reduce waiting times, but also enhancing the efficiency of security screening and fluency.

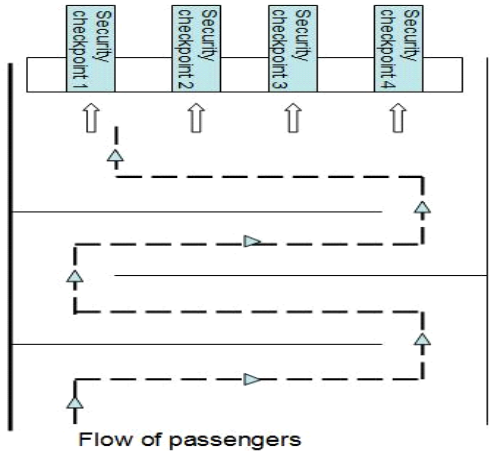

Figure 1.

The M / M / C model has the characteristics that efficiency increase reduce as the value of C increases, so too large queue lateral displacement will bring inconvenience to the passengers too, so in the actual situation taking it into comprehensive consideration is necessary.

Model Verification. Illustrate the superiority of the S-shaped queue through comparative calculation analysis, taking the security check service data of a certain international airport on April 13, 2006. According to the historical data, parameters of a security lane at all times of the day are as follows:

Table 1

Time	The rate of service	The rate of arrival	Waiting times in queue before	Time	The rate of service	The rate of arrival	Waiting times in queue before
6	4.18	4.03	6.58	12	3.72	3.55	5.61
7	5.21	5.10	8.90	14	4.26	3.97	3.17
8	3.79	3.62	5.51	15	4.63	4.52	8.61
9	3.78	3.58	4.82	16	4.24	4.05	5.03
10	3.71	3.45	3.58	17	4.21	3.97	3.87
11	4.12	3.90	4.30	18	4.29	4.03	3.66

Take five security checkpoints as a S-shaped region, that is, C = 5, then we can obtain the comparison of waiting time between before and after optimization according to the algorithm of M / M / C model. The specific data is as the table below.

Table 2

Time	The rate of service	The rate of arrival	Waiting times in queue after	/	Time	The rate of service	The rate of arrival	Waiting times in queue after	/
6	4.18	4.03	1.31	5.37	12	3.72	3.55	3.26	5.61
7	5.21	5.1	2.61	8.9	14	4.26	3.97	2.56	3.17
8	3.79	3.62	3.21	5.51	15	4.63	4.52	2.9	8.61
9	3.78	3.58	3.1	4.82	16	4.24	4.05	2.87	5.03
10	3.71	3.45	2.91	3.58	17	4.21	3.97	2.73	3.87
11	4.12	3.9	2.84	4.3	18	4.29	4.03	2.63	3.66
variance			0.21631044	3.1859	variance			0.21631044	3.1859

As the table shows, the passenger throughput all improves in different degrees and the waiting times variance also reduces, which illustrate the superiority and convenience of S-shaped queue.

2.2.2 Dynamic Management of Security Lane. The variation difference of passenger flow in a day is as the figure shows according to the historical statistic data of a certain international airport. We can see that there is no doubt that fixed number of security lanes will lead to a resource waste when there's a small flow of passenger.

So we can dynamically control the number of open security lanes according to the actual arrival and service rate of passenger of the security checkpoints to obtain the optimal number of open security lane to enhance resource utilization and reduce waiting times variance caused by different passenger flows at different times in a day.

To analyze the influence of the number of open security lanes on waiting times variance, the passenger queue is assumed to correspond to M / M / C model, then the whole security procedure is the sum of n M / M / C queuing system.

Under the circumstances that the total arrival rate of passenger is fixed:

$$\lambda(t) = \frac{\lambda'(t)}{n(t)} \tag{7}$$

$\lambda'(t)$——total passenger arrival rate of airlines.
n(t)——number of parallel M / M / C systems.

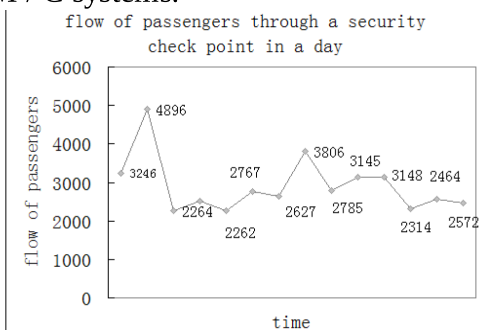

Figure 2

Based on M/M/C queuing model, obtainλ(t) using the certain waiting time Wq(t) and service rate of passenger μ(t), then get n(t) according to the algorithm, finally the number of security lanes is derived. Dynamic and scientific management of security lane in the peak hours and off-peak hours is helpful to reduce waiting times variance and operating cost, improve equipment utilization under the premise of maximizing the safety and convenience of passengers.

The following table shows the waiting times variance when the number of security lanes in S-shaped area is different.

Table 3

	Waiting times in queue (c=5)	Waiting times in queue before	Waiting times in queue (c=7)	Waiting times in queue (c=5)	Waiting times in queue before	Waiting times in queue (c=7)
	1.31	5.37	0.87	2.69	6.31	0.84
	2.61	8.9	1.22	2.56	3.17	0.39
	3.21	5.51	0.71	2.9	8.61	1.17
	3.1	4.82	0.62	2.87	5.03	0.65
	2.91	3.58	0.44	2.73	3.87	0.49
	2.84	4.3	0.55	2.73	3.87	0.49
	3.26	5.61	0.73	2.63	3.66	0.46
variance	0.21631044	3.185870879	0.069364835	0.21631044	3.185870879	0.069364835

In addition, the background information shows that approximately 45% of the passengers enroll in a program called Pre-Check which has a few modifications designed to expedite screening for trusted travelers. There is often one Pre-Check lane open for every three regular lanes, which indicates that fewer Pre-Check lanes carry close to half of the passenger flow. Based on the theory of dynamic control security lane, make the Pre-Check lane independent from the regular lane, establish the criterion of the service rate and waiting times of passenger for Pre-Check lane, so as to get the appropriate open number of the Pre-Check lane.

We draw a conclusion that the main reason resulting passenger congestion is the time of opening baggage and organizing personal items around the X-ray security machine is pretty long through the bottleneck identification model. When the security system alarm and alarm source is not easy to find, the passengers need to check repeatedly, resulting in follower passengers' congestion. In view of this situation, establish multi-level security system model, that is, to increase the reserve area for passengers to prepare for security and organize their baggage, and set recheck lane for those who fail to pass the first check to ensure the convenience and for follower passengers and the fluency of the whole security check.

The distribution algorithm of regular lane and recheck lane is as follows:

$$\frac{C_1}{C_2} = \frac{N\overline{t_1}}{N\overline{t_2}} \tag{8}$$

C_1, C_2——the number of regular and recheck lanes.
N_1, N_2——the number of passengers passing regular security lane and recheck lane.

Multi-level Security System Model .Multi-level security system model is shown in the figure above, the recheck area not only carries the passenger flow that fail to pass the security checkpoint first time, but also plays the role of fast-track security process to provide convenience for those late arrivals. Besides, make security zone on the opposite side of annular check-in area, through which can shorten the distance between check-in and security, save the walking time and improve fluency.

Real-time Monitoring System. To maximize security, establish real-time monitoring system to monitor the operating condition of security equipment. Provide regular maintenance for security equipment to ensure that all aspects of equipment meet standards and lower failure frequency. In case of failure, take modular maintenance, improve maintenance efficiency. Through those measures, guarantee the safety and convenience to the greatest extent. Minimize inconvenience to passenger, establish information management system and encourage passengers to release information on the platform which can show the current passenger flow and waiting time situation in security checkpoint, provide the greatest degree of convenience for passengers.

Conclusion

We develop the convenient security engineering model to improve the bottlenecks. There is a conclusion that guiding passenger to queue in S-shaped can reduce waiting time. Besides, opening more security lanes in the peak time will help reduce the variance. Multi-level security system and real-time monitoring system and regular maintenance for equipment and the monitoring security real-time situation is effective.

Here comes some policy and procedural recommendations based on the model and discussion.

1. Establish multi-level security system, when the security alarm, passengers will be transferred to the recheck area, which won't affect the security efficiency of follower passenger.
2. Encourage passengers to queue in S-shaped to reduce the waiting time.
3. According to the characteristics of passenger flow, manage the number of security lanes dynamically.

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