ASSESSING AIRPORT PASSENGER SCREENING PROCESSING SYSTEMS

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ABSTRACT

This paper presents a decision supporting tool for the most suitable airport passenger screening system under different circumstances by investigating parameters such as passenger disutility and their value of time. It assesses different possible airport passenger screening types such as: centralized security system or 'sterile concourse'; semi centralized security system and gate by gate security system or 'sterile gate'. A queuing theory analytical model is used to assess different passenger processing systems. The main decision parameter, number of servers (check in positions or security lanes) along with less dynamic parameters such as average processing times could be used to estimate the average or maximum wait times passengers will experience. A typical high season day for passenger demand at Calgary International Airport is used for the data input. Increases in passenger demand are also considered in the sensitivity analysis of the model. The results show that, with a desired minimum gate occupancy level enough for the screening of passengers, having a gate by gate system may not necessarily be a loss for the airport. If the objective is to maximize social benefit (including both the airport authority and the users) such a system may even be on a more socially optimum at some level.

Keywords: passenger screening systems, stochastic queuing theory, deterministic queuing theory

INTRODUCTION

Although the rapid changes in passenger and baggage screening at airports during the last decade helped to minimize the risk of threats and consequently increased passenger comfort and security, massive delay and long queues at passenger screening check points have become inevitable. Using the existing literature on airport security including the processing times, operations and technology, this paper investigates and assesses three different possible airport security processing schemes: 1) centralized security system or 'sterile concourse' 2) semi centralized security system and 3) gate by gate security system or 'sterile gate'. The first system, the most commonly used, has a single security check: all passengers must go through this 'node' to enter the terminal and then proceed to their boarding gates. Most airports in the world including Calgary International Airport have this type of security system. The second system either has several stations to enter the main terminal and thus should have a security screening at each station or have multiple separated terminals of boarding gate that also require multiple stations for security screening. London Heathrow International Airport is an example of such system. The third and the least common system, has one screening station located at each boarding gate to screen passengers as they enter the restricted waiting area. Queuing theory analysis is used to estimate average and maximum queue lengths and wait times for each category.

BACKGROUND

Like with other service oriented processes at airports – such as check in and baggage handling – there are different approaches to model security screening. The most conventional approach is queuing theory. Queuing analysis could always raise the problem of trade off; managing the long queues and wait times on the system on one hand and providing the costly high service capacity to minimize the wait times on the other hand. Decision maker should always consider the appropriate balance between the service cost and amount of waiting. There are many studies on literature using stochastic queuing theory to model the security process (Regattieri, et al. 2010, Gilliam 1979, Olapiriyakul and Das 2007). These studies vary from 1979 until present which had different processes modeled, with a completely different processing service rate due to ever changing regulations for security process especially after 9/11.

Gillam (1979) considered the passenger security screening is a simple classical queuing model that fits as a practical problem well since (1) these service facilities for security should always be available; (2) the service procedures should not change and be unvarying; and (3) there is no practical alternative to accept this service for the airline passengers. The third reason stated by Gillam is due to the fact that passengers have no other choice than waiting in the line to be screened and enter the terminal where in reality in many queuing systems people may change their activity. When several flights in brief interval are scheduled to depart (e.g. for a value of less than 30 minutes) the passenger flow through an airport tends to become continues and the arrival rate at the security screening tend to be a random variable. This behavior of arrival could fit as exponential distribution since inter-arrival times are independently and identically distributed. Gillam uses M/M/m queuing model; meaning exponential stochastic arrival behavior and service time, and m as the number of servers for the security screening.

Van Dijk (2002) illustrates there are very few applications of queuing theory to problems in daily life. It can be too detailed and mathematically complex for direct practical applications. These very complicated queuing models are also based on significant set of constraints that often limit their application in real-world examples. It is also suggested by Regattieri et al. (2010) to use the only basic queuing model followed by an intensive analysis of the results rather than basing the decisions according to the results obtained from a complex queuing model.

Although Regattieri et al. reveal a good insight on using queuing theory and model validation of arrival and service distribution; the model only includes a one-level security without considering the need for a secondary screening of passengers or bags. This may result a single entity with long service time to impact the total wait time in the system. Such cases may have been uncommon in the past but this is not the case for current situation.

Olapiriyakul and Das (2007) consider a two-stage inspection system in which the service rate of the first inspection can be controlled. It uses speed and accuracy operating characteristic curves for the relationship between the inspection service rate and accuracy. They have also used a queuing model to derive the optimal design for the passenger security inspection operation at a given arrival rate.

In a paced inspection process in which a time limit has been imposed, the inspector must either clear or reject the entity in the given time interval (Drury 1978). This could be applied for modeling the first stage security inspection process. So in the security inspection, the rejection or alarm rate could be used as a measure of accuracy. In Olapiriyakul and Das (2007) a linear SAOC curve is used as follows:

$$\alpha_{\mu 1} = (\mu - \mu^{Min})\{(\beta^{Max} - \beta^{Min})/(\mu^{Max} - \mu^{Min})\} \qquad (1)$$

Where
μ is the service rate
β : the rejection rate
μ_{max}: maximum inspection rate
μ_{mn}: the slowest inspection rate; the rate at which the inspection accuracy could possibly be 100% and no entities are rejected(note that the real number of bad entities is as low as 001%
Similarly β_{max} and β_{min} (maximum and minimum inspection rejection rate corresponds to μ_{max} and μ_{mn}

The function $\alpha_{\mu 1}$ describes the SAOC curve for the inspection process, such that the entity rejection rate at service rate μ_1. By using a two stage security processing with proper service rate at the first stage according to SAOC curves, the total cost of inspection and wait time in the system could be significantly minimized. Olapiriyakul and Das however, do not consider two independent processes of passenger inspection, Walk Through Metal Detector (WTMD), and the baggage inspection X-ray. It is only using a single inspection for both to model the queuing system and hence a unique service rate and arrival rate for both process which is not the case in reality.

Leone and Das (2010) have investigated the issue of the two independent processes for security. On arrival, passengers split into two sub-entities of bags or other carry-on items and passenger body. These two entities must rejoin prior to exit. There is a 1:M ratio between passengers and carry-on items with M≥0. Figure 1 presents the security process as described above. The detailed description of this passenger security flow diagram will be provided in the Mathematical Model section of the paper.

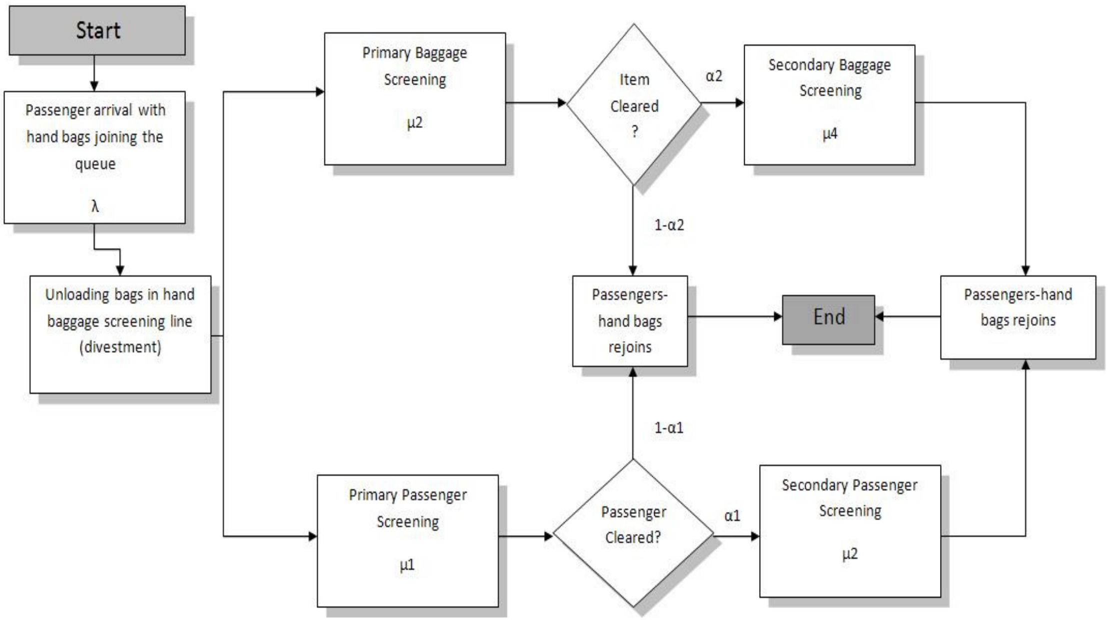

Figure 1 : passenger flow chart in a security system.

Five major equipment for the security process includes:

- X-ray for carry-on bags
- Walk-through metal detector (WTMD)
- A search area for passengers who set off the WTMD
- Explosives Trace Detection (ETD) for checking bags
- Whole Body Image (WBI)

A study performed by Martin et al. (2007) examined the relationship between server behavior and queue length on airport security queuing system. No increase in service time of the X-ray screeners was observed except laptop computers. The impact of screening speed-up was also explored by examining the speed-accuracy trade-off. It was shown that for laptop passengers there is a significant decrease in detection probability and on the probability of correct rejection.

Leone and Das (2010) suggest operating characteristic curve on expressing the relationship between a system decision for a given system input. It investigates the percentage of carry-on items cleared or not cleared based on the defined function of maximum inspection time on large hub airports. It was shown that a high portion of the overall inspection time represented a small number of complicated and time consuming screen. Thus if these items proceed to a secondary inspection, there will be an improvement of the primary inspection process although it requires more resources for implementing the inspection. The collected results showed 80% of all items had the inspection time of 9 seconds or less that only take up 65% of total time spent on the screening. Also the data revealed that the last 10% of carry-on items take up about 20% of total inspection time.

Deterministic queuing theory was also used for modeling passenger services in the airport. De Barros and Tomber (2010) estimated cumulative arrival and departure profile to a discrete process for sequences of a time interval; as the result the queue at the end of time interval I is

$$Q_i = A_i - D_i \qquad (2)$$

Where A_i and D_i are cumulative number of arriving for the service and number of passengers passed the server (here security station) and start their next activity in the airport.

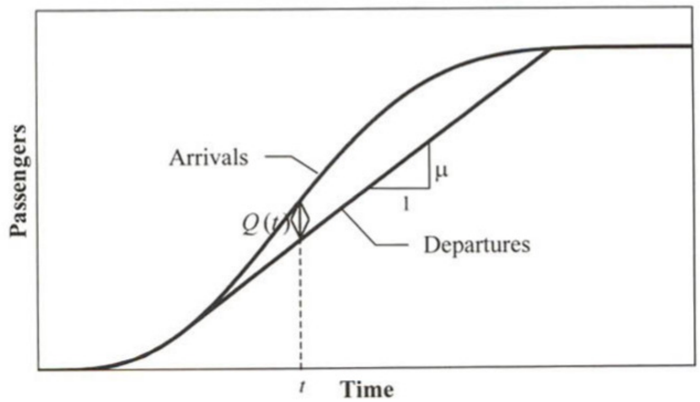

Figure 2 – Deterministic queuing analysis (De Barros and Tomber, 2010)

For both security and check in stations, the main decision parameter, number of servers (check in positions or security lanes) along with less flexible parameters for changing such as average processing times could estimate the average or maximum wait times passengers will experience. For deterministic models the assumption of passengers arriving at the processing areas at a constant rate during the entire peak period is required. This assumption made use of all available processing capacity and therefore can make a stable passenger flow at the security checking. It should be noted that this estimated value (e.g. recurred number of positions or servers to maintain a set level of service) is always lower than the real value required. So this estimated value is only a start point to do sensitivity analysis for different conditions, monitoring the expected wait times, and area required to accommodate the queue length.

Using a bell shape distribution of passenger rather than a fix arrival rate during the peak period can better reflect real world passenger arrivals and thus the resulting wait times and queue length are more realistic. However, the estimated results are still lower than the real value as the distribution is still deterministic and does not consider the stochastic behavior of the entities and services.

Finally the third approach and the most common in recent year for modeling a security system is using simulation (Pendergraft et al., 2004). Since airport system involves many uncertain and random factors, setting up a mathematic model cannot accurately reflect the real problems. This results in simulation method to deal with these random and uncertain problems.

Wilson et al. (2006) present Security Checkpoint Optimizer (SCO), a 2-D spatially aware discrete event simulation tool designed to address physical space concerns, passenger behavior, and passenger movement incorporated with the traditional queuing model methodology to solve today's transportation security challenges.

MATHEMATICAL MODEL

This paper analyses the passenger security screening process in two methods: 1) using stochastic queuing theory 2) analytical deterministic model. Each method has its advantage and disadvantages as discussed in the previous section.

The passenger flow for the security system is similar to Leone and Das (2010) also presented in figure 1 with one minor difference. There is an additional process of divestment (de Barros and Tomber, 2010) prior to X-ray and WTMD where passengers would unpack laptop computers, take off their jackets, belts or shoes in some cases and also remove metal objects from their pockets on divestment tables provided before the X-ray and WTMD devices. As the main focus on this paper is to compare the different security systems and since this service is identical for all of the three systems analyzed, it is assumed that the divestment process is not a bottleneck for this process. Passengers have enough divestment tables and space required for this activity thus the actual queue length is for the X-ray and WTMD processes. Similar to figure 1, passengers after divestment activity will go through the WTMD while their hand baggage and their other items are being screened on the X-ray machine. With probability of α_1 passengers are rejected from WTMD process and therefore are guided for the secondary hand wand manual inspection. Similarly, α_2 of items from X-ray machine are rejected and go to the secondary manual and EDT hand baggage inspection. Finally passenger and their hand bag are rejoined at the roller beds and collection tables and seats, to put clothing back on and re-pack bags. The security process then is finished at this point and the passenger can precede to his/her next activity.

Stochastic Queuing Theory

General M/M/m queuing model was assumed for all the stations and each of the five activity (Divestment, hand bag X-ray, passenger WTMD, manual passenger inspection and manual hand bag inspection). m is the number of servers for each activity that may vary according to the layout configuration. In this model there is no limit on queue length capacity. The arrival distribution is an exponential distribution with the rate of λ. Each server has an exponential distribution for their service time with the rate of μ. If the number of entities in the system (n) is lower than number of servers(m) the rate of entities leaving the system is nμ; otherwise, if number of entities are grater or equal to number of servers, the rate of departing from the system will be mμ. The mathematical modeling for this system is described (equations 3 to 8) as follows based on queuing theory principles for M/M/m model:

$$\pi_0 = \frac{1}{\sum_{n=0}^{m-1} (\lambda / \mu)^n * \frac{1}{n!} + \frac{(\lambda / \mu)^m}{m!} * \frac{1}{(1-\rho)}} \qquad (3)$$

$$\rho = \frac{\lambda}{m*\mu} \quad (4)$$

$$L_q = \frac{\pi_0}{m!} * (\frac{\lambda}{\mu})^m * \frac{\rho}{(1-\rho)^2} \quad (5)$$

$$W_q = \frac{L_q}{\lambda} \quad (6)$$

$$W = W_q + \frac{1}{\mu} \quad (7)$$

$$L = \lambda * W = \frac{\pi_0}{m!} * (\lambda/\mu)^m * \frac{\rho}{(1-\rho)^2} + \frac{\lambda}{\mu} \quad (8)$$

Where ρ is the server utilization
L: Average number of entities in the system
W: Average wait time(both in queue and during service) per entity
L_q : Average queue length
W_q: Average wait time per entity in the queue
Π_0 : Probability of the system being empty(no entity in the system)

Since there are 5 activities for the analyzed security system, a network of queue stations should be analyzed for this problem. There are different networks of queue and solving many of them are not possible with analytical methods. However, using Jackson's queuing network makes this simpler under these conditions (Jakson 2004):

- The arrival pattern to the network should follow a Poisson distribution
- The service rate at each station should be an exponential distribution and the rate should be independent from the service rate on other stations
- The queue capacity at all stations should be unlimited.

If all the stations have no feedback (return to the same station with a probability) we can assume each station 'independent' thus simply doing the analysis similar to a single queuing system. Thus for analyzing this problem, the conditions mentioned above are assumed.

Deterministic Approach

The same passenger flow for the queuing analysis is used for analytical deterministic approach. Similar to [9] the cumulative sum of the flight loads scheduled to depart for each interval j is calculated. After considering check-in process effect on passenger arrival, which is an independent factor for comparing these three security systems, the cumulative number of passenger at each of the security stations are calculated from equation 9:

$$A_i = A_{i-1} + \sum_{i=1}^{i+m} S_j \, P_{j,i-1} \quad (9)$$

Then cumulative number of departures from each security process is calculated as follow:

$$D_i = \min(A_i, D_{i-1} + \mu\tau) \quad (10)$$

Then A_i – D_i determines the queue at the end of interval i. The maximum wait time experienced by the last passenger is calculated by dividing the Q_i by the processing rate μ. (de Barros and Tomber, 2010). The same procedure can be performed for all the processes within a single security system (X-ray, WTMD, manual passenger and hand bag secondary inspection).

RESULTS

For result analysis Calgary International Airport flight schedule data were used. A typical 'High Season' day during the month of July (Friday July 17th, 2010) was chosen. A passenger load factor of 90% was chosen due to the high demand expected on high season peak. The data then combined with passenger profile data provided by de Barros and Tomber (2010) representing distribution arrival of passengers to the airports before their scheduled flight departure. A time interval of 5 minute was used. Figure 4 represent cumulative the arrival pattern to the airport according to the flight schedule and passenger profile.

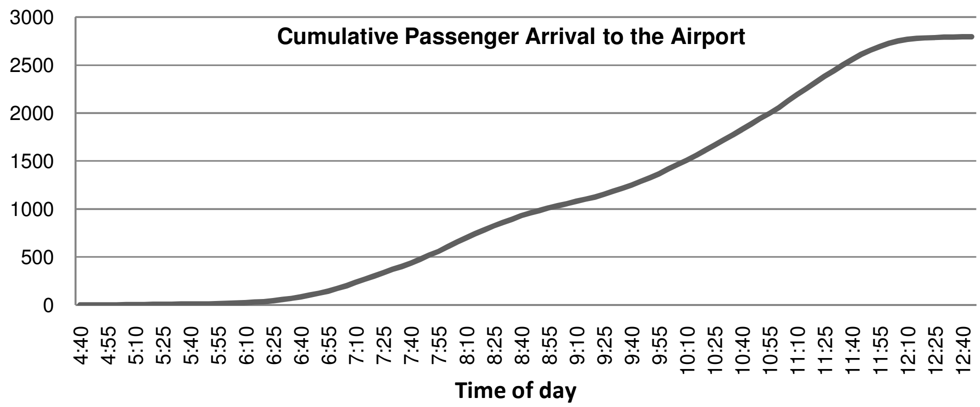

Figure 3: Expected cumulative passenger arrival to Calgary International Airport based on flight schedules and passenger profile

Table 1 illustrates input parameters for the model are used. The average processing time values are taken based on Olapiriyakul and Das (2007), and Leone and Das (2010).

Table 1: Assumed input values for all screening systems

Item	Average Processing Time
μ first check - passenger (pass/hour)	150
μ first check – X-ray (item/hour)	150
μ second check – passenger manual (pass/hour)	18
μ second check – baggage manual (item/hour)	26
Average number of item(hand baggage,…) per passenger	2
Rejection rate for passenger	10%
Rejection rate for baggage	10%

Table 2: Number of equipments considered for all screening systems

Station	Number of items used
Total Number of X-ray	8
Total number of WTMD	8
Total number of manual passenger inspection server	4
Total number of manual passenger inspection server	4

For the first set of analysis the same numbers of equipments (shown on table 2) are considered to assess the wait time and queue on each of the systems:

Centralized Security System

The following table represents the results for centralized security system using deterministic approach with the parameters stated in table 1 and 2.

Table 3: Centralized Security System – Deterministic approach

Maximum Total Queue on the system	44.0
Average Total queue	3.7
Maximum Wait time	2.3min
Average Wait time	0.2 min

The obtained values are based on deterministic approach and thus especially wait times may be lower than the real value because of calculation of wait time based on each time interval. For example for a arrival of Y during time step I, and service rate of Y per interval, the wait time for service will be zero provided there is no queue left from previous intervals. The same argument could be made over the accurate queue length estimation. The reason for this underestimation is apparent from due to its deterministic behavior. In this approach it is assumed that the arrival rate during each time interval is exactly uniform distributed, thus there will be no queue forming.

Stochastic Queuing theory can address this issue by taking the stochastic behavior of both passenger arrival and the service rate for them. The result of using the queuing theory approach with the same input are presented on the table 4. Note that the average demand being used is the total number of passenger arrival for the morning (from 4.30 until 12:30) shift at the airport divided by the length of the morning shift. (λ=350)

Table 4: Centralized Security System – Stochastic approach (λ=350)

Average number of passenger in the system (L)	14.76
Average Time for an passenger in the system per minute (W)	1.59
Average Total Queue Length on the system (L_q)	2.18
Average wait time in queue per minute (W_q)	0.22

The disadvantage of this approach is that the average arrival rate considered may not represent the correct distribution of arrivals (70% of passengers during 3.5 hours and the rest 30% during 4.5 hours from 5 AM until 1 PM). By substituting the new Average passenger arrival (λ= 500) result would significantly change. (See table 5)

Table 5: Centralized Security System – Stochastic approach (λ=500)

Average number of passenger in the system (L)	43.51
Average Time for an passenger in the system per minute (W)	5.02
Average Total Queue Length on the system (L_q)	26.77
Average wait time in queue per minute (W_q)	1.67

Another problem with stochastic queuing theory is that the analysis when the arrival rate exceeds the service rate, the calculation will be very complicated because there is no stable condition under such situation. There are some complex queuing models that can include a time frame and calculate the wait times and queue length for a specific period which is not described in the paper. Note that the capacity for this system is when arrival passenger rate is 520 per hour when the system experience an infinity queue length and wait time.

Semi Centralized Security System

The same inputs are used for calculating the wait times and queues for a semi centralized security system. Suppose instead of one central security station where all the passenger have to pass from a single node, there are several stations that do the security screening process. In this paper a semi centralized system with 4 nodes all having an equal number of 2 X-Ray and WTMD devices(8 in total) and one server for each secondary passenger and baggage inspection(total of 4 for each activity). Variations in the distribution of passenger using each station are considered. Table 6 shows an example of this variation:

Table 6 Passenger share for using each station

Proportion of passenger using station i	
1	0.15
2	0.15
3	0.3
4	0.4

Using Queuing theory analysis for arrival rate λ=350 will give the following results:

Table 7: Semi Centralized Security System – Stochastic approach

Security Station	1	2	3	4
Total L_q	16.04	0.50	5.65	16.04
Total W_q	0.36	0.36	1.88	4.08
Average Wait time per passenger			2.30	

By using the upper case λ=500 for the arrival the queuing model on node 4, will cause the over capacity situation and thus the analysis are impossible. This problem, however, shows the need for more X-ray machines in station 4. This would be effective only if there is no changes to the share distribution; thus if demand share is relatively static, equipment allocation other than equally would have been used.

Comparing the results on table 4 and 7 also shows overall increase in wait times experienced on in the semi centralized security system. Similarly, comparing the results for the analytical approach shows that the average wait times and maximum queue will be higher in the semi centralized security system due to the fact that a high portion of the passenger are using a lower proportion of the service and experience longer queues and wait times.

Table 8: Semi centralized security system – Deterministic approach

	1	2	3	4	Total
Max Queue	0	0	18.94	34.81333	-
Max wait time	0	0	3.28	6.04	-
Average Queue	0	0	2.46	6.94	9.40
Average Wait time	0	0	0.42	1.19	0.60

Gate by gate Security System

The same logic for semi centralized security system can be used and argued that due to un-evenly share of gate uses some passengers will experience a higher service rate, shorter queue and wait times and others (which are the higher portion of the passengers) experience a long wait time with a very low level of service. Besides, the stochastic queuing analysis for such model for short period of occupancy of one gate for one flight departure will not be useful. Thus, such a system requires a different approach of what have been used on previous sections to model.

The arrival distribution in such case would not follow the passenger profile pattern used in the previous systems. Thus, an assumption on distribution of passenger arrival to the gate is being used. Note that on the worst condition, all the passengers have arrived at the beginning of operation of the security at the gate. Table 9 represents the wait times and queues under such condition for different values of flight size for a single gate.

Table 9: Gate by gate security system

flight size(passenger)	80	140	255
Maximum wait time(min)	19	19	43
Average Wait time(min)	6.5	11	13.6
Maximum Queue	52.83	52.83	121.83
Average Queue	23.33	39.31	37.82

Assuming the July 17th flight departure data in the morning for Calgary International Airport, with 8 gates to be used for departures, the lower case limit of 50 minutes gate occupancy time were required to schedule all the planned flights during time 7:50 until 12:40.

SENSITIVITY ANALYSIS

Passenger demand

For this analysis the passenger demand are increased with different values and the effect on the wait time and queues are presented on table 10. Note that, the same number of equipment and service rate and same share of passenger arrival for semi centralized security system are being used. Besides, for gate by gate security, an equal number of passenger for each gate are assumed with the number gates equal to number of X-ray and WTMD equipment (8 in this example).

Table 10: Sensitivity analysis – changes in demand factor

Increase Demand Factor		Centralized	Gate by gate(for each gate)	Semi centralized
3	Maximum Queue	361.43	43.35	161.78
	Average Queue	110.53	12.79	55.93*
	Maximum Wait time	18.81	15.7	28.12
	Average wait time	5.74	4.79	6.31
2	Maximum Queue	202.73	23.51	98.29
	Average Queue	49.87	5.551	54.04*
	Maximum Wait time	10.54	8.8	17.08
	Average wait time	2.59	2.16	3.21
1.5	Maximum Queue	123.38	13.79	66.55
	Average Queue	22.65	2.45	18.39*
	Maximum Wait time	6.41	5.35	11.56
	Average wait time	1.17	0.973	1.79

* average wait time for the worst security node

As apparent from the table, with increase in passenger arrival, the queue length and wait times for gate by gate and semi centralized decreases relative to the centralized system. It is noticeable that for semi centralized security system, the maximum queue and maximum wait times are much lower compare to the centralized system because the passenger are spreading on the different security nodes. However, on weighted average of wait time based on different share of the arrivals, passengers experience a higher wait time although the difference is not very high.

For gate by gate side, the unrealistic assumption of equal passenger size for each flight and also the assumption of having enough gate occupancy time for doing the processing causing the results a lot more in favor of the gate by gate security system.

Distribution of share on semi centralized system

It was mention earlier that with a more even distribution of the share on the nodes in semi centralized security system, the queue and wait time results will be lower. Tables 11 and 12 represent the results for the uniform passenger distribution on the 4 stations both in deterministic and stochastic approach:

Table 11: Sensitivity analysis - distribution of share - deterministic

	Semi centralized	Base centralized system
Max Queue	11.01	44.03
Max wait time(min)	1.9	2.27
Average Queue	0.92	3.66
Average Wait time(min)	0.15	0.189

Table 12: Sensitivity analysis – distribution of share - stochastic

	Semi centralized	Base centralized system
Total average number of passenger in the system	33.74	43.51
Average time each passenger spends in the system(min)	8.88	3.04
Total Average queue length	29.58	26.77
Total average wait time in the system(min)	7.52	1.67

Using the two approaches (deterministic and stochastic queuing theory) may lead to different conclusion. These different interpretations are not because the models are wrong rather because of the different definitions in the average wait time in their analysis. The deterministic model shows decrease in average wait time per passenger on the security and opposite of that, queuing theory analysis shows that although there is significant improvement in queue and wait times with a uniform distribution of the share, the centralized system is still more efficient in reducing the average wait time. However, it would be expected that, according to what found in deterministic model, the maximum wait time for passengers are lower in a uniformly distributed semi centralized security system.

CONCLUSIONS AND DISCUSSIONS

It can be argued that the disutility of passengers waiting on the security line just beside the gate is at a much lower value than the other 2 systems. Besides normally in most airports, passengers are required to arrive between 0.5 to 1 hour earlier to the departure at the gate. Thus, the wait time passengers experience at the gate and the wait time for the security check can be merged and provide a much lower passenger disutility due to their significant time saving in the security line. They may experience a longer time standing for security for some cases (which may not be the case for a very congested airport) but in total their wait time is at a much lower value.

Below shows a simple approach for determining the number of additional security equipment for gate by gate system. If that number is less or equal to the minimum number of gates which can properly operate based on gate occupancy times, it is economical to operate in such fashion. Assumptions used in this simple decision making analysis includes:

- The time spent by passengers waiting for the security check at each gate are the same as their expected time at the gate in centralized security system.

- The benefit associated with the time savings are considered in perpetuity with social discount rate of 10%.
- The variable costs such as staffing are not included. The difference of the variable costs with the two systems may not be very significant with appropriate resource allocation strategies.

The following parameters were used in this cost-benefit analysis shown in Table 13:

Table 13: Parameter definitions and example values for cost benefit analysis.

Parameters	Definition	value
I	total cost and investment on security equipment for each additional set of security screening	$1,500,000
M	number of centralized security equipments being used in centralized security system for a specific level of service	8
D	passenger demand per hour on AM or PM peak	1500 passenger per hour
W_q	Average wait time per passenger at security queue	5.74 min
VoT	Value of time per person per hour	20 $/hour
H	peak duration (AM or PM)	5
N	Number of gates	

Equation 11 should be met to switch to gate by gate system:

$$-(N-M)*\ I\ +2*365*\left(D*\ W_q*H*VoT\right)*10\ \geq 0 \qquad (11)$$

Thus:

$$N\ \leq M+\ \frac{2*365*\left(D*W_q*H*VoT\right)*10}{I} \qquad (12)$$

Note that in equations 11 and 12, the number 2 represents the number of peaks per day (morning and evening), 365 as number of days per year to calculate the benefit each year and 10 is the factor multiplied by the benefit each year to calculate for perpetuity.
As an example, the case of high demand level discussed in the sensitivity analysis section is used to calculate N. Using these values in the equation 12: N ≤ 13.77.

Thus, if the airport can accommodate enough gate occupancy time to fit in all the passengers at the gate security, with the purchase of 5(5=13-8) more security equipment, the airport can maximize the social welfare of the airport authority and the passengers.

As it was shown on the paper, especially by increase in passenger arrival rate, the possibility of a having security system moving toward a gate by gate system become higher. There are several factors other than the cost and the value of the time saved by passengers that could cause such a shift. The most important one is availability of space in the airport for operating on any of the systems. An example of such constraint is Schiphol Airport in Amsterdam after it was required to provide security system even for transfer passengers. The design of the airport does not provide a suitable passenger flow with a centralized security system. Thus the alternative will be among semi centralized or gate by gate security screening. The idea of this paper is to show that with desired minimum gate occupancy level enough for doing the screening process for passenger; having a gate by gate system may not necessarily be a loss for the airport because of having more fixed security equipment and staff for each of the gate. If the objective being set is to maximize social benefit (including both the airport authority and the users) such a system may even be on a more socially optimum at some level.

REFERENCES

de Barros, A. G., and D. D. Tomber (2010). Quantitative analysis of passenger and baggage security screening at airports. Journal of Advanced Transportation, Vol. 41, No. 2, pp. 171-193.

Drury, C.G. (1978). Integrating human factors in statistical quality control. Human Factors 205, 561–570.

Gilliam, R. (1979). An application of queuing theory to airport passenger security screening. Interfaces 9(4) 117–123.

Jakson J. R. (2004) Jobshop-Like Queuing Systems. Journal of Management Science Vol. 50, No. 12, pp. 1796-1802

Leone, K and S. Das (2010). Operating Characteristics of Passenger Screening Processes and the Development of a Paced Inspection System. Proceedings of 51st Transportation Research Annual Forum, Arlington, Virginia.

Marin, C. V., C.G. Drury, R. Batta and L. Lin (2007). Server adaptation in an airport security system queue. OR Insight, 20(4), 22-31.

Modarres Yazdi, M. (1990), Queuing Theory. The University Press, Sharif University of Technology, Tehran, Iran.

Olapiriyakul, S. And S. Das (2007). Design and analysis of a two-stage security screening and inspection system. Journal of Air Transport Management 13. 67–74.

Pendergraft, D. R., C. V. Robertson, and S. Shrader (2004). Simulation of an airport passenger security system. Proceedings of the Winter Simulation Conference, 1:878.

Pendergraft, D. R., C. V. Robertson, an S. Shrader (2000). Simulation modelling and analysis of a new international terminal. Proceedings of the Winter Simulation Conference, 2:1168–1172.

Regattieri, R., R. Gamberini, F. Lolli and R. Manzini (2010). Designing production and service systems using queuing theory: principles and application to an airport passenger security screening system. International Journal of Services and Operations Management. Vol. 6, No. 2.

van Dijk, N. (2002). To pool or not to pool? The benefits of combining queuing and simulation. In Proceedings of the Winter Simulation Conference.

Wilson, D., E. K. Rose, and A. A. So. (2006). Security checkpoint optimizer (SCO): An application for simulating the operations of airport security checkpoints. In Proceedings of the 2006 Winter Simulation Conference.