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Abstract Title: Virtual Queuing at Airport Security Lanes

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VIRTUAL QUEUING AT AIRPORT SECURITY LANES

ABSTRACT

Airports continuously seek opportunities to reduce the security costs without negatively affecting passenger satisfaction. In this paper, we investigate the possibilities of virtual queuing at airport security lanes, by offering some passengers a time window during which they need to arrive to enter a priority queue. This process could result in a more uniform distribution of arriving passengers, such that the required security personnel (costs) can be decreased. While this concept has received attention in a number of settings, such as theme parks, virtual queuing at airports bears an additional level of complexity related to the flight schedules, i.e., passengers can only be transferred forward in time in a limited fashion, which we denote by the transfer time limit. We conducted a major simulation study in collaboration with a large international airport in Western Europe to determine the potential impact of virtual queuing and find that nearly one million Euro can be saved without negatively impacting the passenger waiting time.

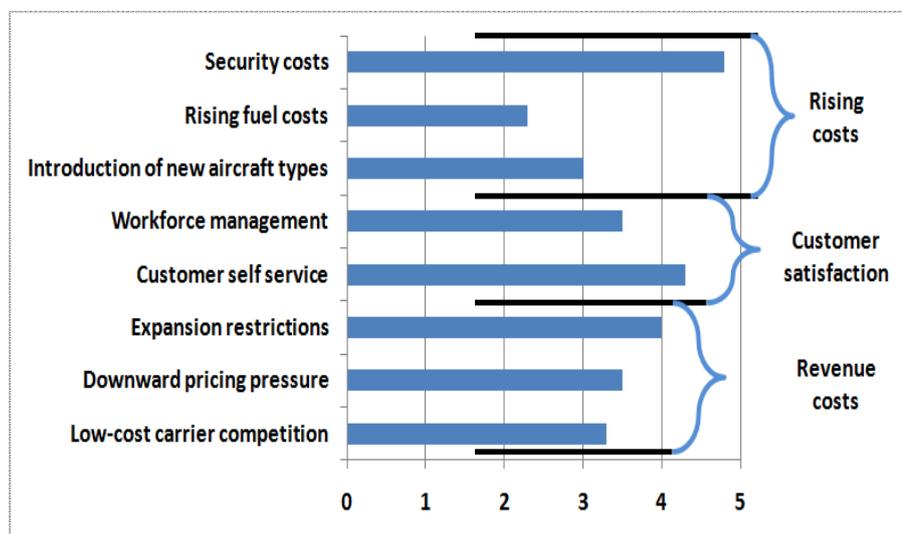
Keywords: Queuing; Simulation; Virtual Queue; Airport Security

1. INTRODUCTION

According to Airports Council International's (2009) forecast, the global passenger volumes will surpass the 5 billion mark by 2010, reaching 11 billion per year by 2027. These numbers are based on the traffic forecast from over 250 airports worldwide. After several years of strong growth, the growth pace of the global passenger traffic slowed down in 2008 and 2009 due to a number of external factors (e.g., the credit crunch and rising fuel prices). Nevertheless, the expectation is that the passenger traffic will rebound, showing an annual passenger volume growth of 4.2% over the next twenty years. However, the growth in passenger traffic volume and other trends such as increased competition and a growing demand for customer experience are leaving airports with many challenges for the future.

Airports face escalating costs, revenue growth constraints, and an increasing dissatisfied customer base. In addition, a survey among senior airport executives indicated that the common concerns of airports could be clustered into three broad categories: rising costs, customer satisfaction, and revenue constraints (refer to Figure 1).

The main concern is the increasing security costs, which is directly related to the rapid growth of the passenger traffic volume. The increased threat of terrorism is another reason, as it had resulted in the introduction of more rigorous border controls and safety procedures (Frederickson and LaPorte 2002).



Note. 1 = no impact, 5 = very high impact

Figure 1: Key concerns of airports (Vincent, 2007)

However, cutting back the security budget, for example by reducing the workforce, is risky as this could result in increased queues at security checkpoints. Queues have a negative impact on customer satisfaction (see e.g., Katz et al. 1991) and if the queues are too long, some passengers could even miss their flight. Airports can therefore not afford to make their customers wait too long. Nevertheless, airports have no other option than to accept queues to a certain extent in order to keep the security costs at a reasonable level.

In this paper we investigate a cost reduction opportunity based on the principles of virtual queuing (abbreviated to VQ) at airport security lanes. Even if capacity is able to deal with the average demand, queues usually still occur due to fluctuations in demand. Fluctuations lead to high queues when demand is at its peak and wasted resources during periods of low demand. A virtual queue can be interpreted as an invisible line of passengers waiting to enter a physical queue. In this scenario, the concept is based on the allocation of time windows (TWs) to passengers which allows them to enter a priority lane during a specific time interval. It is a process that offers the opportunity to redistribute the passenger arrivals by shifting the demand out of peak periods into idle periods.

An implementation of the VQ principles turned out to be very successful for several call centers (see e.g., Camulli 2007) and amusement parks (see e.g., Lutz 2008), which took advantage of people's flexible schedules. However, the situation at airports is more complex from a queuing perspective due to passenger time constraints related to the flight schedules (Narens 2004).

Virtual queues at airports could potentially lead to shorter queues with the same number of security agents, or similar queues with fewer security agents. Since airports' largest concern are the increasing security costs, the main objective of this paper is to identify whether the application of VQ could reduce the number of agents at airport security lanes, while not increasing the average passenger waiting time. Our results can lead to changes in the demand for capacity in terms of staff, resources, and terminal space and could contribute to an increased operational efficiency and reduction of the operating costs at airports worldwide.

The remainder of this paper is structured as follows. In section 2 we review the relevant literature in the areas of airport security, queuing, and simulation studies in general. Section 3 provides an overview of the simulation study at a large, international airport in Western Europe, including some results and analysis. We end our paper in section 4 with conclusions and recommendations.

2. LITERATURE REVIEW

In this section, we first discuss queuing theory in general, followed by recent work on virtual queuing (VQ) in call centers and amusement parks. We then briefly discuss the antecedents and implications of VQ to the passengers as well as the chosen research methodology of simulations.

2.1 Queuing theory in general

Queuing theory and simulation modeling are the two approaches most commonly used to translate customer arrivals during different time intervals into the staffing levels needed to maintain the required service standards (Ernst et al. 2004). A general queuing process depends on three main components: (a) *the input process*, (b) *the service mechanism*, and (c) *the queue discipline* (see e.g., Saaty 1957). *The input process* describes the arrival behavior of the customers at the service point. The arrival behavior is usually expressed in terms of the time intervals between the successive arrivals of the customers, denoted by interarrival times, which follow a certain distribution, or are based on real arrival data. In this paper we use a combination of both: 1) we were able to obtain real arrival data per fifteen minute interval (e.g., between 9:00AM and 9:15AM 30 passengers arrive), 2) we divide these arrivals evenly over the three five minute (e.g., between 9:00Am and 9:05AM 10 passengers arrive), and 3) we “spread out” these arrivals using the Uniform distribution over the five minute interval.¹

The service mechanism specifies the number of service points in the system that should be used, the maximum number of possible service points in the system and the service time distribution, given in terms of the time duration of the services. Usually, the service rates are assumed to be independent of the arrival process and each other, and to be identically distributed, without regard for which server provides the service. Based on the data we obtained we used a Normal distribution for the service times.

The third component is *the queue discipline*. The queue discipline describes the behavior of

¹ We also used a Normal distribution and a Triangular distribution, but found no significant differences. Since there is also no theoretical reason why passengers would arrive clustered around the third minute in each five minute interval, we simple used the Uniform distribution.

the customers who find all service points occupied. In this case a customer can act in three different ways by (1) leaving (referred to as “balking”, see e.g., Xu et al. 2007) or (2) entering the queue, but leave after a certain amount of time (“reneging”, see e.g., Blackburn 1972), and (3) waiting in the queue until a service point is free. In our case (passengers trying to get to their departing planes), we assume that (1) and (2) do not occur, and that the general principle of first-in first-out is applied, with the possible exception of the passengers in the virtual queue. This means that we leave any kind of priority queue out of this discussion (e.g., those with iris scans).

A queuing problem arises when people have to wait in a queue, especially when the waiting time is longer than their individual waiting time threshold (Chambers and Kouvelis 2006). To solve such a problem, changes have to be made in either the behavior of the arriving units, or the service facilities or both (Van Voorhis 1956). To affect these changes it is necessary to manipulate or control the factors that influence this behavior. In general, all the factors that influence the behavior of the arriving customers and the service points can be linked to the three following components (Klassen and Menor 2006): *utilization of the capacity*, defined as the percentage of the total service time that the security agents are actively providing the service, *variability of the arrival of customers* and *of the service times*, and the *level of inventory*, defined here as the number of people in the queue and the people that get served. The general relationship between these three components can be stated as follows: $Inventory = Capacity\ utilization \times Variability$.

2.2 Virtual queuing in call centers and theme parks

From a call center’s perspective a long queue (i.e., high inventory) can result in many abandoned calls, repeat attempts and customer dissatisfaction. This can either be seen as a capacity utilization problem (i.e., more staff is needed to deal with the incoming calls) taking the customer arrival pattern (i.e., the variability) as given (see e.g., Green et al. 2007), or as a variability problem. VQ systems attempt to solve the latter problem by allowing customers to receive callbacks instead of waiting in a queue. VQ does not eliminate the waiting time, but it does change its perception, since

customers are given the possibility to continue their daily activities. When offered a choice between VQ and waiting on traditional hold, customers choose VQ approximately 50 percent of the time (Merriman 2006). In addition, additional staff costs can be avoided and call centers experiencing variable peaks of traffic volume would gain more benefits.

VQ is also a common practice at amusement parks. At Disney World, for example, a limited number of customers can obtain a so-called FASTPASS, which they can use to visit certain rides during a predetermined time period without having to wait in a long queue (see e.g., Cope et al. 2008). Just like in Disney World, we merge the two queues in our simulation just prior to the dispersion of the single queue to the separate queues in front of the multiple security lanes (refer to Figure 5 in section 3.3).

Amusement parks and call centers take advantage of people's flexible schedules and reduce customer time in queues. However, airport security checkpoints have to consider the flight departure schedules. These constraints make the process more complex from a queuing perspective. While several papers have been written on airport related issues, they usually deal with airplane departures and the number of available runways (see e.g. Daniel 1995, and Ignaccolo 2003), and crew scheduling (see e.g., Azmat & Wider 2001, Barnhart et al. 2003, Barnhart and Cohn 2004, and Chu 2005). To the best of our knowledge, the only paper that deals with the potential effect of VQ on airport operations is by Narens (2004), who claims that giving airline passengers specific TWs for arriving at security checkpoints can reduce queues, enable passengers to spend almost no time waiting, and reduce total passenger waiting time at many airports. However, his research focused on the reduction of the waiting time, whereas our research's primary focus is on limiting the capacity without increasing the waiting time.

In order to achieve either benefit, three conditions have to be met. First of all, the daily arrivals at airports need to have sharp peaks that exceed security checkpoint processing capacity followed by periods of light activity when demand does not exceed processing capacity. For

example, at airports where the daily demand is consistently greater or smaller than the checkpoint processing capacity, a virtual queue is much less effective. Secondly, Narens (2004) states that not all passengers should be considered eligible. Only passengers on flights departing in the established critical TWs would be eligible, and then only if there is enough time for all the activities a passenger has to engage in after passing the security lane and prior to boarding (e.g., walking to the correct gate). Finally, the passengers' perception of virtual queuing must be positive, which we discuss next.

2.3 Passengers' perception of (virtual) queuing

From the point of view of the passengers, the waiting process is not a fully objective process, but also has subjective psychological effects. In general, waiting time has a negative effect on customer satisfaction (see e.g., Katz et al. 1991). This is aggravated by a passenger's perception that s/he didn't chose the fastest queue, which occurs up to 50% in a period when a lot of passengers arrive at the same time (Blanc 2008). Some of the other negative effects are that passengers feel like they have to wait longer when there is no occupation or activity during the waiting time, and that uncertain waits are felt longer than known, finite waits (Maister 1985). Virtual queuing can play a major role in elevating these negative effects, since passengers would know exactly how long they have to wait, and they can chose to occupy themselves by shopping or dining.

However, this all depends on whether the occupation during the wait is in the interest of the passengers who have to wait (Nie 2007). Therefore, virtual queuing should only be considered in airports that have opportunities prior to the security lanes for shopping and dining. While this rules out many major American airports at this moment (although they might want to consider offering more such opportunities if virtual queuing at airports becomes more common), most European airports are actually configured such that most of the shops and restaurants are prior to the security checks. In these airports, passengers would probably not mind entering the virtual queue, as they can actually occupy themselves better prior to the security checkpoint than after.

2.4 A simulation approach to determine the effects of VQ at airports

As mentioned in the introduction, we investigated the effect of VQ on airport security lanes by means of a simulation model. The passenger security screening operation found at modern airports fits the simple classic queuing models quite well (Gilliam 1979), as customers have no choice but to wait in the queue until they are served. Furthermore, it can deal with the peaks in arrival patterns and give insight into short-term effects and it makes it possible to test alternative operational methods (i.e., determine the impact of VQ on the waiting times).

In order to build a simulation model it is necessary to identify all the relevant parameters. Gilliam (1979) states that the parameters of a security lane operation for a queuing analysis are: the passenger service rate, the number of available security lanes, and the passenger arrival rate. The passenger service rate (i.e., how long it takes a passenger to pass through security) and the number of available security lanes are straightforward. However, verifying the passenger arrival rate is more difficult. According to Miller (2003) and Park and Ahn (2003) the following data is required in order to calculate the passenger arrival rate: flight schedules, passenger load factors (ratio between the actual number of passengers and the available seats), passenger arrival distribution and the passenger transfer rates. The latter denotes the percentage of the passengers who arrive at the airport via an arriving flight and depart on a connecting flight and thus do not have to pass through security.

However, these parameters only apply to a basic simulation of security lanes. In order to incorporate the VQ principles in a simulation model it is necessary to acknowledge several additional parameters. Narens (2004) showed that for simulating a virtual queue it is necessary to determine a VQ protocol. In other words, it is necessary to define who the eligible passengers are and how and when these passengers can arrive at the security checkpoint without waiting in the general line. We discuss these in more detail in section 3.4, after discussing the general setup of our simulation study.

3. SIMULATION STUDY

In order to identify to what extent virtual queuing (VQ) can decrease the required number of security agents without increasing the customers' average waiting time at airport security lanes, we conducted an extensive simulation study in collaboration with a large international airport in Western Europe, which we denote by WE. At the time of the study (Q4 2009), WE faced a challenge related to its security operations, just like other airports around the world. Between 2003 and 2008, the numbers of security agents at WE had increased from approximately 2,000 to 4,000, which in turn resulted in an increase of the security costs by 75% (refer to Figure 2).

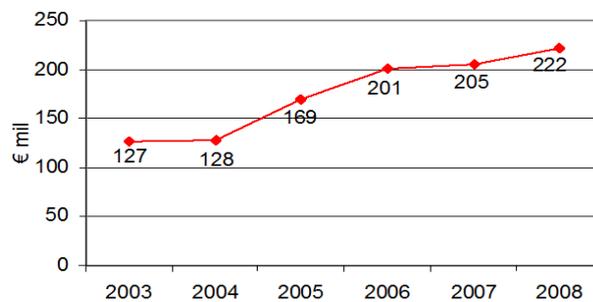


Figure 2: WE Security sector cost development 2003-2008

Research conducted by WE showed that in the future the demand for additional security capacity would continue to increase due to higher passenger volumes and the tightening of security measures. However, solving this issue by hiring more security personnel is a thing of the past. According to a spokesperson of WE: “The availability of the security workforce is gradually reaching its limits, which requires us to search for other solutions”.

3.1 Problem Description

Given the prospects for the future, it is imperative for WE to increase the operational efficiency, as this could result in a lower demand for security agents and reduce the operating costs. A possible solution can be found by introducing a new process at WE's security lanes based on the principles of VQ. Currently the passenger arrival pattern at WE's security lanes shows sharp peaks, which results in a fluctuating demand for security agents (refer to Figure 3, where the capacity of one security lane equals 52.5 passengers per 15 minutes).

The fluctuating demand for security agents (directly linked to the required number of security lanes) leads to idle capacity during the time periods between the peaks, as it is not possible to simply send security agents away for (part of) an hour. Thus, in order to reduce the demand for security agents, one solution could be to shift the arriving passengers at the security lanes out of the peak periods to idle capacity between the peak periods. The most obvious solution for this would be to alter the flight schedule. However, in practice there is little WE (or any other major airport) can do to change the flight schedule. The goal of WE to become the major international (hub) airport, requires them accommodate their largest customers (the airlines) during the peak periods.

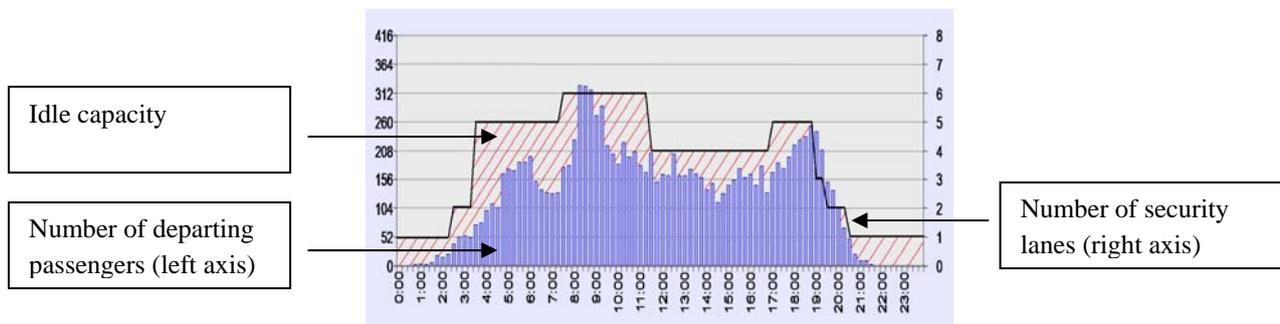
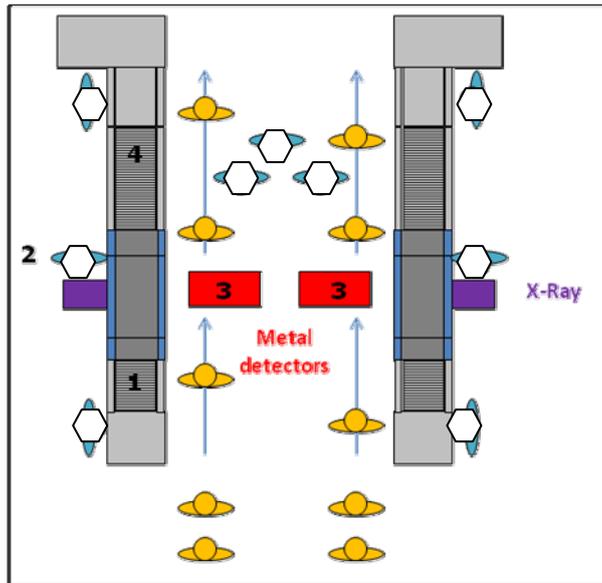


Figure 3: Passenger Arrivals (in 15 minutes intervals)

3.2 Security Lane Process

For our study, the principles of VQ were applied to the security lanes at a departure hall with a central security process and a large-scaled operation, conditions most suitable for showing the impact of VQ. It should be noted that the number of security agents is fixed at nine per two security lanes (refer to Figure 4). In case of an uneven number of security lanes (NSL), one security lane is accommodated by five security agents. This number is the result of the trade-off between the operating costs and the efficiency of the security process. More security agents would speed up the security process, but would increase the costs as well. Furthermore, the frisking process requires at least one male and one female security agent.



1. Placement of the carry-on luggage on a moving belt

2. X-Ray check of the carry-on luggage

3. Check of the passenger by a metal detector and if necessary by a security agent

4. Retrieval of the luggage

 Passenger  Security agent

Figure 4: The security lanes process (viewed from above)

3.3 Simulation Setup

The process of developing a simulation model was separated into two parts: the base case and the experimental case. First of all, we simulated WE's security lanes without a virtual queue, which was considered as the base case. The purpose of the base case was to check the reliability of the model by comparing the simulated results with the actual data (more on this in section 3.4).

Currently the passengers who arrive at the security lanes have to join a general queue, which at a certain moment is split up into multiple smaller queues for the security lanes (refer to the left panel of Figure 5).

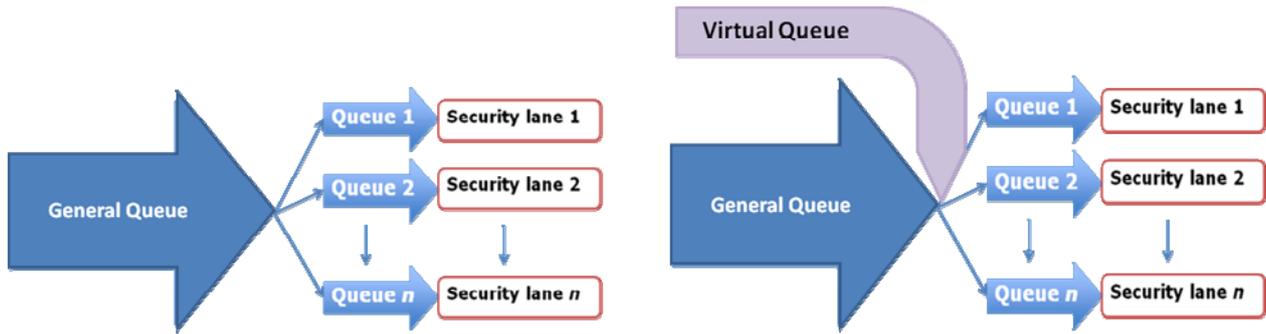


Figure 5: The current security queuing process (on the left) and the queuing process with the VQ (on the right)

The following (fixed) key parameters were used for the simulation of the base case: 1) passenger arrival rates²; 2) passenger service rate; and 3) the number of security lanes.

Secondly, we simulated the security lane process following the principles of VQ. In this scenario the queuing process for passengers was altered by adding a virtual queue for passengers with a time window (TW). However, it should be noted that the VQ process does not require a separate security lane. As displayed in the right panel of Figure 5, the virtual queue and the general queue are joined together at the point where the passengers are spread across the smaller queues for the security lanes. At this point, the passengers in the virtual queue receive priority over the passengers in the general queue to proceed to a security lane.

In this scenario the concept of VQ was based on allocating TWs to passengers. A TW could be interpreted as a time interval during which passengers are allowed to bypass the general queue. These time windows were fixed and constant during an operational day, and we ran the simulation for different values to determine the best option. The TWs could be provided in a ticket format at the check-in desks. If the passenger decides to come outside the TW, he or she would not be admitted to the priority queue.

Only those passengers who are eligible would receive a TW, which is determined by the passengers arrival time at the check-in lanes (Narens 2004), from where it is assumed that they

² These in turn depend on (i) the flight schedule, (ii) the passenger load factors, (iii) the capacity of the airplanes, (iv) the passenger arrival distribution, and (v) the passenger transfer rate.

would directly head to the security lanes if no TW is offered. A passenger thus needs to arrive at the check-in lanes just prior to or during a peak interval, where we would like to decrease the number of security lanes. This condition for eligibility is illustrated in Figure 6. The figure shows an example of the passengers arrivals at the security lanes. In this example, between 7:00 - 10:00 AM, seven security lanes are open (indicated by line A) to ensure a timely process for the arriving passengers. If the objective is to reduce the required NSL to five, the capacity would not be sufficient between 8:00 – 9:00 AM. In order to make it sufficient, the surplus of passengers needs to be transferred to idle capacity. However, not all passengers are eligible for a transfer. In this scenario, only those passengers who arrive between 8:00 – 9:00 AM at the security lanes are eligible to receive a TW.

In the simulations, we used TWs with a length of 5, 10, 15 and 20 minutes since: 1) departure times are scheduled in 5-minute intervals at WE; and 2) short TWs generated better results than long TWs.

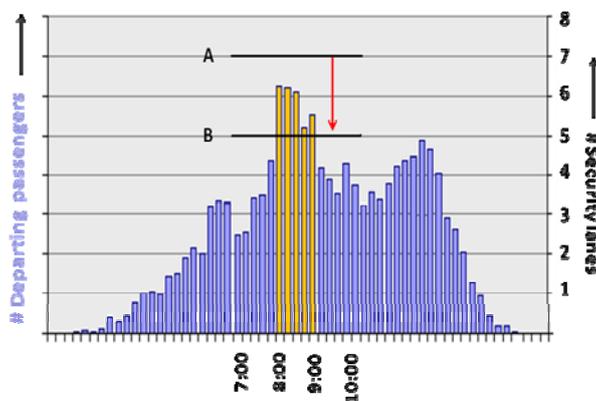


Figure 6: An illustration of the eligibility condition

Also, passengers require enough time to catch their flight, which is directly linked to the scheduled time of departure (SToD). However, we did not directly take the SToD per passenger into account for the simulation model. As an alternative, we initially tested the effect of VQ for three different levels concerning the maximum time that the passengers could be transferred to a later point in time to arrive at the security lanes. A distinction was made between a *transfer time*

limit (TTL) of 1, 1.5 and 2 hours³. In a numerical example (section 3.11) we manually checked the actual amount of time that an individual passenger could be moved forward in time.

We thus initially ran twelve simulations (four different TWs in combination with three different TTLs) to identify the configuration that yielded the best result in terms of limiting the number of security agents without increasing the customer waiting time. Finally, we performed a sensitivity analysis on the participation level of the passengers (20%, 40%, 60%, 80%, 100%) who received a TW on the best combination of TTL and TW, leading to an additional four simulations⁴, as 100% was already covered in the initial run.

3.4 Simulation Assumptions

For the development of the simulation model we had to make several assumptions. These assumptions were based on the data provided by WE and on the existing literature.

General

- No mechanical or flight delays were accounted for in the simulation.
- Balking or renegeing was not an option, as passengers have to catch their flight.
- The effect of families or groups was neglected.

Base case

- WE's departure hall contains ten security lanes.
- The passenger arrival distribution at the security lanes itself is not known. Therefore the passenger arrival distribution per airline for the check-in was used in addition to the estimated walking time from check-in to security to determine the arrival distribution at the security lanes.
- 95% of all passengers have to go through the security process within six minutes (this is a common standard, also applied by WE).

³ Note that the TTL determines the maximum amount of time that a passenger could be transferred to a later point in time, but that not all passengers who receive a TW are required to postpone their security check for that long. Actually, only a very small percentage of the TWs provided require the passengers to wait the full TTL. In our numerical study (section 3.11) we also tested for shorter TTLs.

⁴ We actually ran these sensitivity simulations on all combinations of TWs for the TTL that yielded the best results, but did not find any significantly different results worth mentioning.

- According to WE, the average service rate is equal to 3.5 passengers per minute (52.5 passengers per 15 minutes), which means that, for example, if the passengers arrival rate is 15 passengers per minute, 5 security lanes⁵ are required.

Experimental case

- We assumed that the passengers received a TW at the check-in desks⁶. Therefore, it was only possible to transfer the passengers forward in time⁷.
- We did not allow for an overlap between TWs.

Furthermore, WE maintains a reliability standard of 92% for its own simulations regarding passenger arrivals. In order to calculate this percentage, WE applies the following procedure: 1) they track the actual arrivals of passengers per 15-minute interval; 2) they identify if the actual passenger arrivals exceeds the simulated outcome with at least 52.5 passengers per 15-minute interval (in which case one additional security lane is required). If this is not the case, they assign one point, otherwise they assign zero points; and 3) they calculate the reliability percentage by dividing the total number of points by the total number of intervals.

We applied this procedure to identify the forecast reliability of our simulated passenger arrivals results for Monday, May 4th to Sunday, May 10th 2009. As indicated in Table 1, the average reliability percentage was quite high, although Monday and Sunday showed lower percentages. This could be explained by the fact that the number of flights on Monday's and Sunday's is usually significantly higher than on the remaining days due to the commuting flights. As many calculations in the model were based on monthly averages, the lower reliability percentages can be seen as a logical consequence.

⁵ In this scenario 4.3 (= 15 / 3.5) security lanes are needed. However, in such cases this number is always rounded up to the next integer.

⁶ In this situation the number of expired TW's can be reduced to a minimum, as the passengers will be already present at the airport. However, if a passenger arrives late, he will be allowed to use the TW in case he would miss his flight.

⁷ If TWs are also handed out online when customers check in a day prior to departure, it would also be possible to transfer passengers backward in time, which is not taken into account here.

Table 1: Simulation results reliability (%)

| Date | Day | Reliability |
|---------|-----------|-------------|
| 4-5-09 | Monday | 76.0% |
| 5-5-09 | Tuesday | 92.7% |
| 6-5-09 | Wednesday | 94.8% |
| 7-5-09 | Thursday | 90.6% |
| 8-5-09 | Friday | 96.9% |
| 9-5-09 | Saturday | 95.8% |
| 10-5-09 | Sunday | 67.7% |

For research related to operational activities it is a common practice at WE to use historical data that reflect the average situation at the airport. In line with this statement, WE considers the month of May, the weekday Tuesday and the weekend day Saturday to be accurate indicators for the average situation throughout the year. Thus, in order to preserve high reliability, the principles of VQ were applied for Tuesday and Saturday. As indicated in Table 1, the simulated passenger arrival pattern of both days met WE’s reliability standard of 92%. The reliability percentages were 92.7% and 95.8% for respectively Tuesday (refer to the left panel of Figure 7) and Saturday (refer to the right panel of Figure 7).

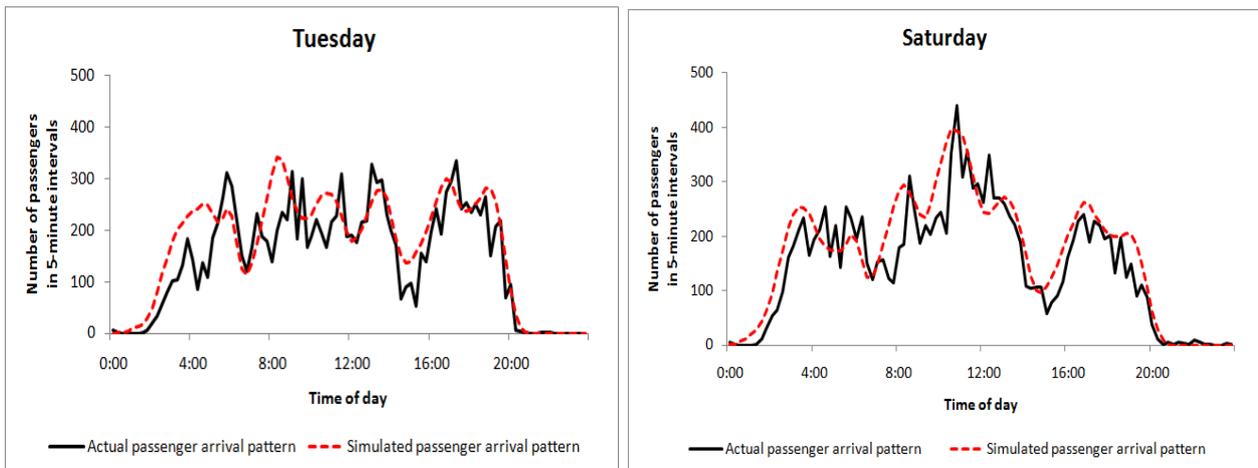


Figure 7: Actual versus simulated passenger arrivals

3.5 Initial Results

Due to variation in the passenger arrival pattern, the required NSL differ throughout the day. Therefore, in order to generate more accurate results, we divided the operational day into five time intervals, illustrated in Figure 8. This made it possible to separate the peaks and to identify the maximum required NSL per interval (indicated by the red line).

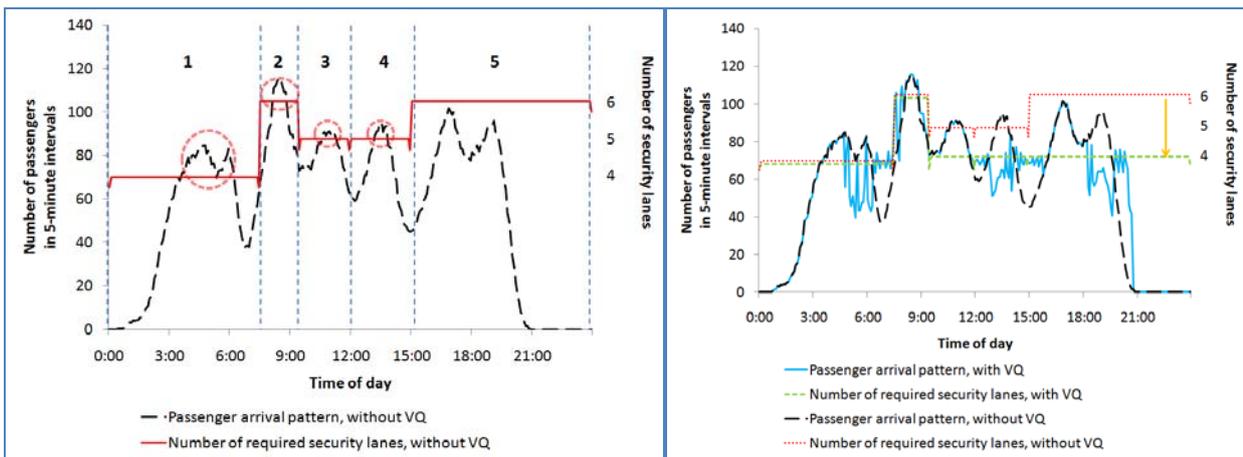


Figure 8: The base case without VQ (on the left) and an example of the experimental case with VQ (on the right) for a Tuesday

For the calculation of the maximum required NSL, the capacity rates and the 95% upper bound waiting time standard were taken into account. Because of the 95% upper bound waiting time standard in the simulation model, the capacity exceeds the (average) demand in each of the time interval. First, the maximum NSL per interval was identified for the arrival rate of all the passengers in the base case, which is the scenario without VQ. Secondly, the effect of VQ on minimizing the required NSL per interval was explored for the experimental case (i.e., the 12 combinations of TTLs and TWs). Finally, we calculated the reduction in the maximum NSL by comparing these results with the base case values. The right panel of Figure 8 illustrates this process for a TTL of 1.5 hours and a TW of 10 minutes. A reduction in the NSL is visible between the base case (red line) and the experimental case (green line) between 9AM and midnight.

The left panel of Figure 9 shows the relationship between the TTL and the average reduction in the NSL throughout an operational day (for a TW of 10 minutes). As expected, a high TTL had a positive effect on the reduction of the average required NSL, as a higher number of eligible passengers could be shifted. However, a TTL of two hours might not be realistic, since some passengers would then miss their flight. Since the TTL of 1.5 hours performs (almost) as well as the 2 hour TTL, this seems to be the best choice at this time.

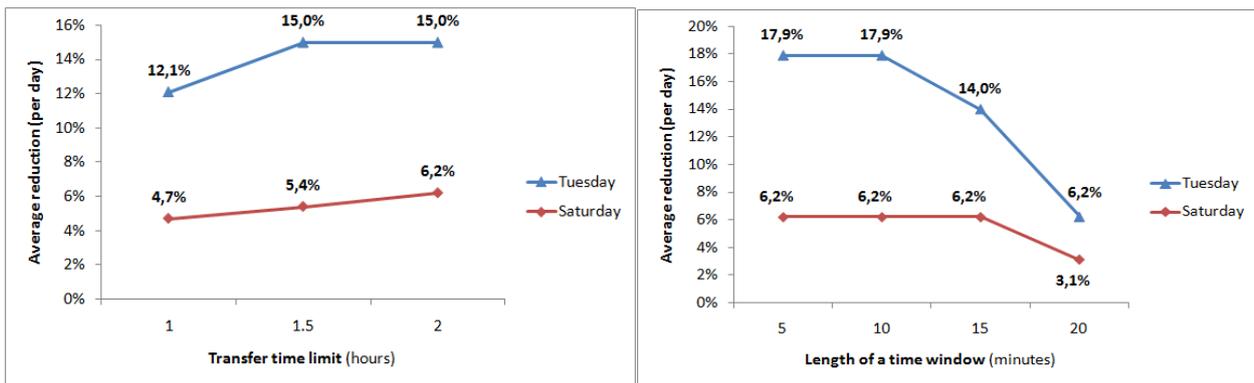


Figure 9: The relationship between the different TTLs (on the left) and TWs (on the right) and the reduction in security lanes. The average of the different TWs and TTLs respectively are shown.

The right panel of Figure 9 shows that longer TWs generate a lower reduction percentage (here the TTL was fixed at 1.5 hours). Although the difference is minimal in the beginning, the reductions decline rapidly as the TWs are longer. For short TWs, the simulation can transfer passengers with a relative high accuracy to idle capacity (see Figure 10). However, a five minute TW could potentially lead to many passengers that in reality would not show up in the specified time. Since the 10 minute TW performs as well as the 5 minute TW, without this drawback, this seems to be the best choice at this point.

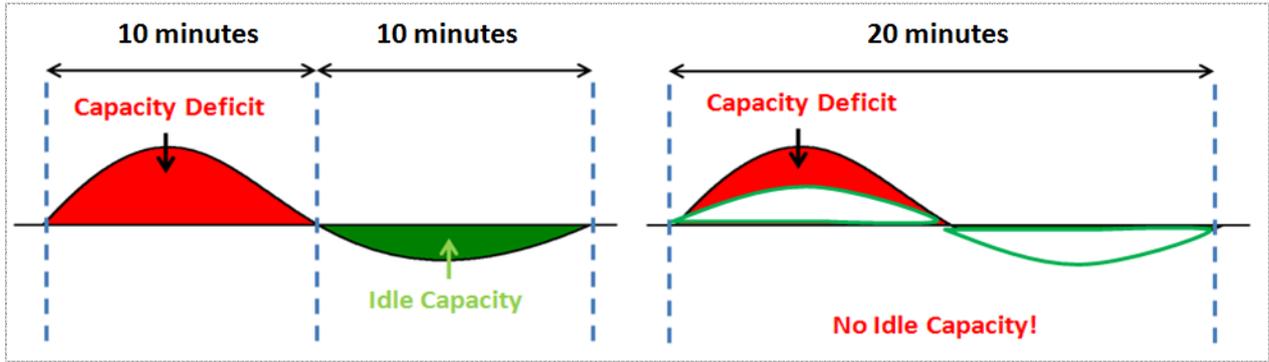


Figure 10: Decreasing accuracy as time windows increase

Finally, the reduction difference between Tuesday and Saturday was caused by a difference in the passenger arrival pattern. The application of VQ generated a higher reduction on Tuesday due to the presence of more sharp peaks, followed by idle capacity. We can thus conclude at this point that the presence of sharp peaks in passenger arrivals is a prerequisite for implementing VQ at airport security lanes.

3.6 Capacity Deficit Reduction

Although the results discussed in the previous section provide some guidelines for the best combination of TTL and TW, there are still too many identical values to clarify more concrete differences between TTLs and TWs. We therefore define a new term “capacity deficit”, which is determined by the number of passengers who have to wait for service in a certain time interval (i.e., those passengers who cannot immediately pass through security). In this section we determine the reduction in capacity deficit that can be reached by implementing different TTLs and TWs.

As illustrated in Figure 11, higher TTLs and shorter TWs lead to higher capacity deficit reductions, which is in line with the previous results. Also as before, the differences between a TW of 5 and 10 minutes is relatively small, whereas the 15 and 20 minute TWs perform a lot worse. The difference between the 1 and 1.5 hour TTL (e.g., 191 for the TW of 10 minutes on Tuesday) is also larger than the difference between the 1.5 and the 2 hour TTL (87). Thus, while from a pure simulations perspective the combination of a 2 hour TTL and a 5 minute TW reaches the best

results, these results once again seem to point in the direction of a 1.5 hour TTL and a 10 minute TW as the most appropriate choice to balance simulation results and realism.

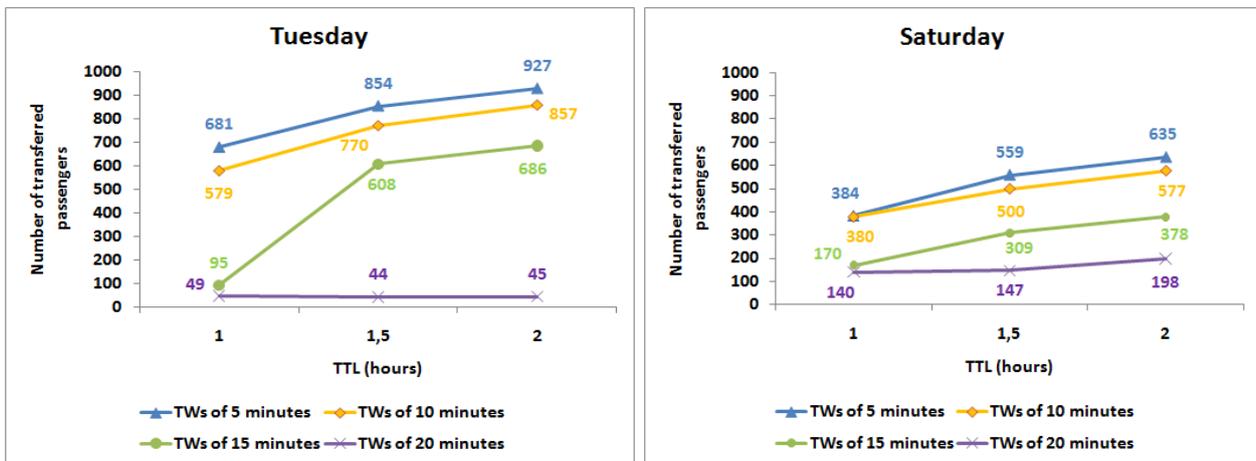


Figure 11: Capacity deficit reduction as a function of different levels of TTLs and TWs

As before, there is a large difference between the number of transferred passengers on Tuesday and Saturday. On Tuesday the capacity deficit reduction was in most cases significantly larger, which resulted in a higher reduction of the required NSL. However, as the capacity deficit reduction was higher, the number of passengers that needed to be transferred was higher as well. Thus, to realize the potential reduction more passengers need to collaborate, which can be a challenge. We investigate the impact of passenger participation rates in 3.10.

3.7 Reduction of Security Agents and Costs

The reduction percentages discussed previously do not directly translate to the number of security agents and the costs. As mentioned in the previous paragraph, the number of security agents is fixed at nine per two security lanes (or five per single lane), and each lane can comfortably handle 52.5 passengers per 15-minute interval.

The maximum possible reduction for the required man hours as well as the daily costs are 17.5% and 6.4% for Tuesday and Saturday respectively (refer to Table 2). Both percentages can actually be reached in almost all simulated scenarios, except from a few scenarios that contained the longer TWs of 15 or 20 minutes. This seems to indicate that the differences found previously between the different TTLs and TWs are not significant enough to result in complete security lane

reductions (e.g., a requirement of 3.2 security lanes, or 3.8 security lanes would both result in 4 whole security lanes). Therefore, at this point it seems that a short TTL in combination with a long TW would perform best (i.e., the reduction on man hours and daily costs are the same as the other combinations, while this is the easiest from the passengers' perspective). However, with that combination, the average waiting times for Tuesdays and Saturdays might increase, which is what we investigate in the next section.

Table 2: Effect of VQ on reduction in man hours and daily costs

| | Tuesday | Saturday |
|--|----------|----------|
| Max. reduction in man hours (per day) | 82 hours | 27 hours |
| Max. reduction of the daily cost (€) | €2,445 | €810 |

Since WE considers the passenger arrival pattern on Tuesday as the average situation for Sunday (considered as a week day instead of a weekend day) till Friday, the yearly cost savings for the security agents alone could reach approximately €800,000.⁸

3.8 The Effect On The Waiting Time Using Simulated Arrival Data

As mentioned above, we determined the reduction in the required level of the NSL taking into account the waiting time standard. Thus, none of the applied scenarios for the experimental case surpassed the 95% upper bound waiting time of six minutes. Actually, as illustrated in Figure 12, the effect of VQ on Saturday's average waiting time was rather positive, while on Tuesday they increased somewhat, mostly due to a lower average waiting time in the base case. On Tuesday we also see that the combination of a short (1-hour) TTL and a long (15 minute) TW, as suggested in the previous paragraph, performs worse than the 1.5-hour TTL and 10 minute TW combination. For example: on Tuesday, the latter results in an increase of the average waiting time by 0.1 minutes, while the former to an increase of 0.4 minutes. Please note that we only show the results for those combinations that can generate the cost savings as presented in Table 2 (e.g., the combination of a

⁸ For this calculation 52 weeks of 7 days were taken into account.

1-hour TTL and a 20-minute TW is unable to reduce the number security lanes by 17.5% and 6.4% for Tuesday and Saturday and is therefore not shown here).

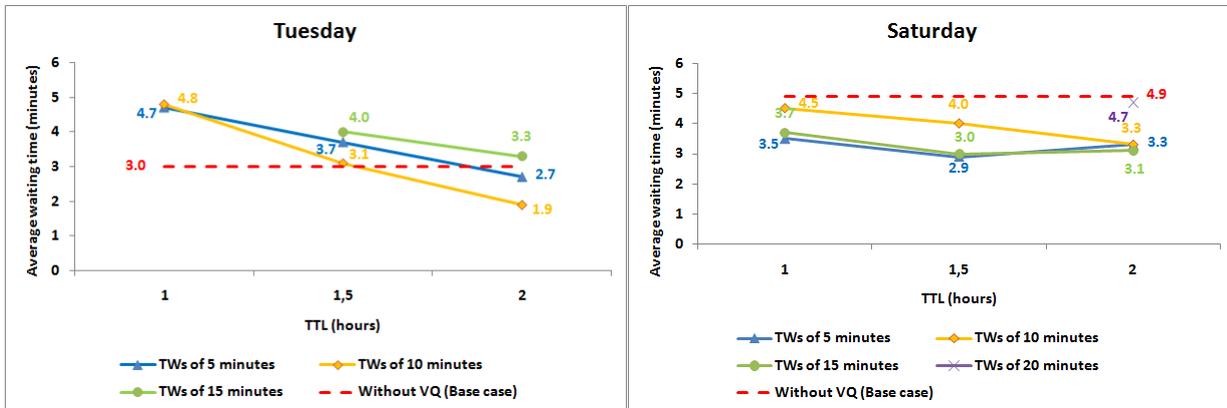


Figure 12: Effect of VQ on the waiting time (simulated data)

Interestingly, we did not find a linear effect in the TWs. For example, on Tuesday, the 5 minute TWs outperform the 15 minute TWs, but the 10 minute TWs outperform those for the 1.5 and 2 hour TTLs. This effect is a result of the non-overlapping TWs. For example, with 5 minute TWs it is possible that certain TWs are completely filled up with eligible passengers, while others remain empty. Using 10 minute TWs instead could lead to smoother results, while the 15 minute TWs are too long to realize the smoother results.

In summary: on Tuesday (the day with more frequent peaks, but overall more steady passenger arrivals as compared to Saturday, refer back to Figure 7) the 10 minute TWs perform the best, while on Saturday the 15 minute TWs perform almost as good as the 5 minute TWs, and better than the 10 minute TWs.

3.9 The Effect on the Waiting Time Using Actual Arrival Data

The reduction of the required NSL was based on a forecasted passengers arrival rate. As this forecast is not 100% accurate, the question remains whether or not the results would be acceptable when the forecast of the required NSL would be applied to the actual arrival data of the days which were used for the simulation. Thus, the average waiting time and the 95% upper bound waiting time were identified in this scenario as well.

As illustrated in Figure 13, the values of the average waiting times on Tuesday and Saturday are shown. Saturday's were significantly lower for the actual data than for the forecasted data. This can be explained by the high accuracy percentage (i.e., 95.8%). A high reliability percentage of the forecasted data implies that in most cases the forecasted passenger arrival rate met or surpassed the actual passenger arrival rate. Thus, in reality fewer passengers arrive at the security lanes than forecasted, which results in a reduction of the actual average waiting times. Tuesday shows a somewhat different story, which can be explained by the lower accuracy percentage (i.e. 92.7%) compared to Saturday.

On the other hand, the 95% upper bound waiting times remained on acceptable levels, except for one combination (i.e., TTL = 1.5 hours and TWs = 20 minutes on Saturday), which showed a 95% upper bound waiting time level of 6.2 minutes. Using the actual arrival data, we now also found that the 10 minute TWs outperformed the other TWs in almost all combinations.

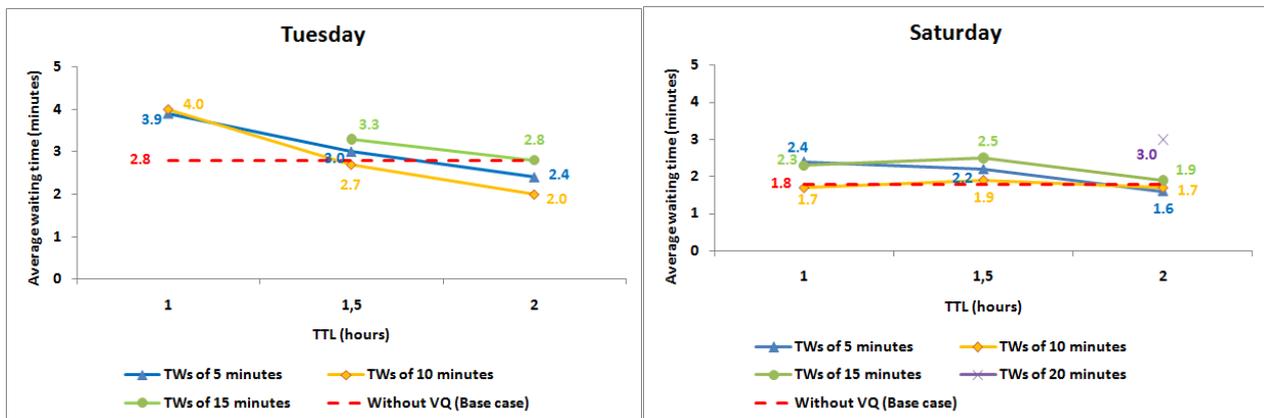


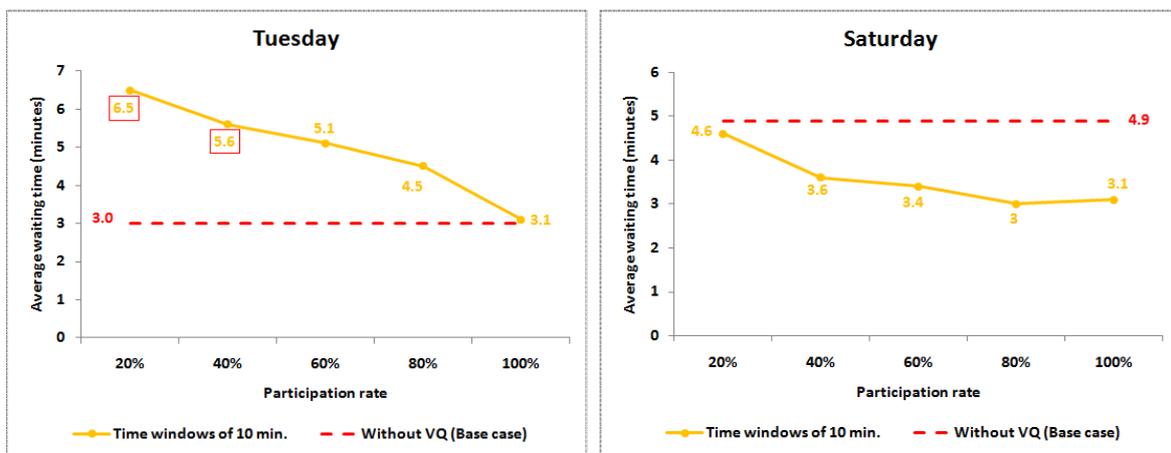
Figure 13: Effect of VQ on the waiting time (actual data)

Thus, while all the combinations shown in Figure 13 could realize the same cost savings, some could lead to longer average waiting times for the passengers. We therefore conclude that a 1.5-hour TTL in combination with a 10 minute TW provides the best combination in terms of (simulated) cost benefits and ease of implementation.

We now turn to the issue of passenger participation. We use the combination of a 1.5-hour TTL and a 10 minute TW to perform a sensitivity analysis on the passenger participation rate, followed by a manual analysis taking into account the passengers' SToDs.

3.10 Sensitivity of the Participation Rate

So far, the identified average waiting time is based on the assumption that all passengers would arrive in the provided TW. However, in reality external factors could influence the participation rate. Therefore, we conducted a sensitivity analysis in order to identify how a declining participation rate would influence the average waiting time and the 95% upper bound waiting time. In Figure 14, this effect is indicated for a TTL of 1.5 hours and TW of 10 minutes as discussed above⁹. It is clear that lower participation rates lead to longer average waiting times. Also, for Tuesdays, it could lead to a non-conformance with the 95% waiting time standard, when the participation rate falls below 60%¹⁰.



Note = In violation of the 95% waiting time standard.

Figure 14: Participation rate sensitivity

⁹ We actually performed this sensitivity analysis for all the combinations with TTLs of 1.5 hours and TWs of 5, 10, 15, and 20 minutes. The results were similar in nature as shown in Figure 14, with these differences: longer TWs (15 and 20 minutes) lead to more violations, whereas the shorter TW of 5 minutes leads to fewer violations.

¹⁰ We also checked a 50% participation rate, and this was not in violation of the 95% waiting time standard (if barely).

3.11 Manual Analysis Taking Into Account the Actual Flight Schedules

As mentioned above, the simulation model did not select eligible passengers based on their SToD. Instead, the effect of VQ was tested for three different levels of the TTL (i.e., 1, 1.5 and 2 hours), and we determined that the 1.5-hour TTL provided the best results in combination with 10-minute TWs. Nevertheless, in order to identify whether the results would be better or worse in case the SToD would be included, we also conducted a manual analysis. Thus, we calculated the capacity deficit reduction manually taking into account the passengers' SToD. For this calculation a passenger was only considered eligible if s/he was able to arrive at the security lanes 30 minutes or more before the SToD in order to catch his or her flight.

Capacity deficit reduction

Currently, the NSL on Tuesday and Saturday are given in Table 3 for the five different time intervals. To achieve the reduction in costs as discussed in section 3.7, these NSL need to be reduced in certain time intervals, as shown in the third column. However, this would lead to the capacity deficits, measured in the number of passengers who cannot immediately go through the security checkpoint upon arrival, in the last column. The higher capacity deficit, the longer passengers need to wait, which is why we would like to reduce this number (i.e., provide TWs to shift these passengers to non-peak moments) as much as possible.

We then calculated the capacity deficit reduction manually by applying the following method: 1) we identified the number of passengers that needed to be shifted from the peak to the idle capacity (i.e., the capacity deficit as shown in Table 3); 2) we identified the cluster of time intervals after the peak which together have a sufficient cumulative idle capacity; 3) we calculated the number of passengers that can be shifted until the final time interval of the cluster identified in step 2; 4) we divided the number of passengers that can be shifted by the capacity deficit. This value equals the capacity deficit reduction, measured in a percentage of the capacity deficit. The

results of these calculations are provided in Table 4 for both the simulated scenario, using a 1.5-hour TTL and the manual calculations (i.e., no specific TTL), using 10 minute TWs in both cases.

Table 3: The capacity deficit (in passengers) per 15 minute interval

| | Tuesday | | |
|----------------------|-------------|-------------|------------------|
| Time interval | NSL (no VQ) | Desired NSL | Capacity deficit |
| <i>00:00 – 07:30</i> | 4 | 4 | 249 |
| <i>07:30 – 09:30</i> | 6 | 6 | 60 |
| <i>09:30 – 12:00</i> | 5 | 4 | 329 |
| <i>12:00 – 15:00</i> | 5 | 4 | 268 |
| <i>15:00 – 24:00</i> | 6 | 4 | 738 |
| | Saturday | | |
| Time interval | NSL (no VQ) | Desired NSL | Capacity deficit |
| <i>00:00 – 07:30</i> | 4 | 4 | 166 |
| <i>07:30 – 09:30</i> | 4 | 4 | 389 |
| <i>09:30 – 12:00</i> | 6 | 6 | 353 |
| <i>12:00 – 15:00</i> | 6 | 4 | 323 |
| <i>15:00 – 24:00</i> | 4 | 4 | 198 |

These results indicate that the number of shifted passengers could be significantly higher if the SToD would be taken into account in almost all the time intervals. There are only three time intervals where the 100% capacity deficit reduction cannot be obtained (see e.g., 9:30 – 12:00 on Tuesday) because there is only very little idle capacity around those peaks. However, for the other seven time intervals, the benefits of applying the principles of VQ is a lot higher than assumed previously. However, in this scenario no limit for the TTL was set. Thus, the maximal transfer time could rise to a significant length. For example, on Saturday between 09:30 – 12:00, some

passengers needed to be shifted three hours ahead in time in order to obtain a 100% capacity deficit reduction. However, this is a very extreme example and in general the maximal transfer time remains (well) below 1.5 hours.

Table 4: Capacity deficit reduction (in passengers) per 15 minute interval

| Tuesday | | | | |
|----------------------|------------------|--------------------------|----------------------------|-----------|
| Time interval | Capacity deficit | Max. transfer time (min) | Number of TWs provided (%) | |
| | | | 1.5-hour TTL | Manually |
| <i>00:00 – 07:30</i> | 249 | 65 | 148 (59) | 249 (100) |
| <i>07:30 – 09:30</i> | 60 | 30 | 28 (47) | 60 (100) |
| <i>09:30 – 12:00</i> | 329 | 55 | 72 (22) | 72 (22) |
| <i>12:00 – 15:00</i> | 268 | 80 | 203 (76) | 268 (100) |
| <i>15:00 – 24:00</i> | 738 | 85 | 319 (43) | 738 (100) |
| | | Total TWs | 770 | 1389 |
| Saturday | | | | |
| Time interval | Capacity deficit | Max. transfer time (min) | Number of TWs provided (%) | |
| | | | 1.5-hour TTL | Manually |
| <i>00:00 – 07:30</i> | 166 | 85 | 87 (52) | 166 (100) |
| <i>07:30 – 09:30</i> | 389 | 30 | 60 (15) | 70 (18) |
| <i>09:30 – 12:00</i> | 353 | 180 | 55 (16) | 353 (100) |
| <i>12:00 – 15:00</i> | 323 | 70 | 265 (82) | 323 (100) |
| <i>15:00 – 24:00</i> | 198 | 95 | 33 (17) | 68 (35) |
| | | Total TWs | 500 | 980 |

Required participation rate

In order to generate the results that are indicated in Table 4, a certain percentage of eligible passengers should be willing to participate. In order to identify the extent of this potential challenge, we determined the required participation rate per interval in Table 5.

Table 5: The required (average) participation rate of eligible passengers per interval considering TTLs of 1.5 hours TWs of 10 minutes using manual calculations

| Time interval | Required participation rate (in %) | |
|----------------------|------------------------------------|------------------|
| | Tuesday | Saturday |
| <i>00:00 – 07:30</i> | 52 | 8 |
| <i>07:30 – 09:30</i> | 23 | <i>1</i> |
| <i>09:30 – 12:00</i> | <i>5</i> | 33 |
| <i>12:00 – 15:00</i> | 8 | 22 |
| <i>15:00 – 24:00</i> | 8 | <i>51</i> |

As indicated, with exception from a few time intervals, the participation rate required to achieve the cost reduction, is in general quite low. Furthermore, we have highlighted the time intervals when we could not obtain a 100% capacity deficit reduction (due to the lack of idle capacity around those peaks, refer back to Table 4). These are potentially the most risky time intervals since the capacity deficit reduction could fall even further if the required participation rate is not achieved (i.e., it would be less impactful if for example only 50% of the passengers participated between midnight and 7:30 on Tuesday, as the capacity deficit reduction would then still be close to 100%). In two of these we see very low required participation rates of 1% and 5% respectively indicating that while many passengers could be shifted, there really is limited idle capacity. Only the Saturday evening time interval is actually a potential risk, as there is both a lack of idle capacity and of those passengers that can be shifted, 51% need to cooperate.

Also, in reality it is not unlikely that some passengers would refuse to wait for 1.5 hours or even longer. Therefore, we also calculated the capacity deficit reduction for shorter TTLs (15, 30, 45, and 60 minutes) in addition to the no limit case above. Figure 15 shows how the capacity deficit reduction would change for the selected TTLs. On Saturday the capacity deficit reduction declined rapidly as the TTLs became shorter. On Tuesday this effect was less severe, but still considerable compared to the capacity deficit reduction of the “no limit” scenario.

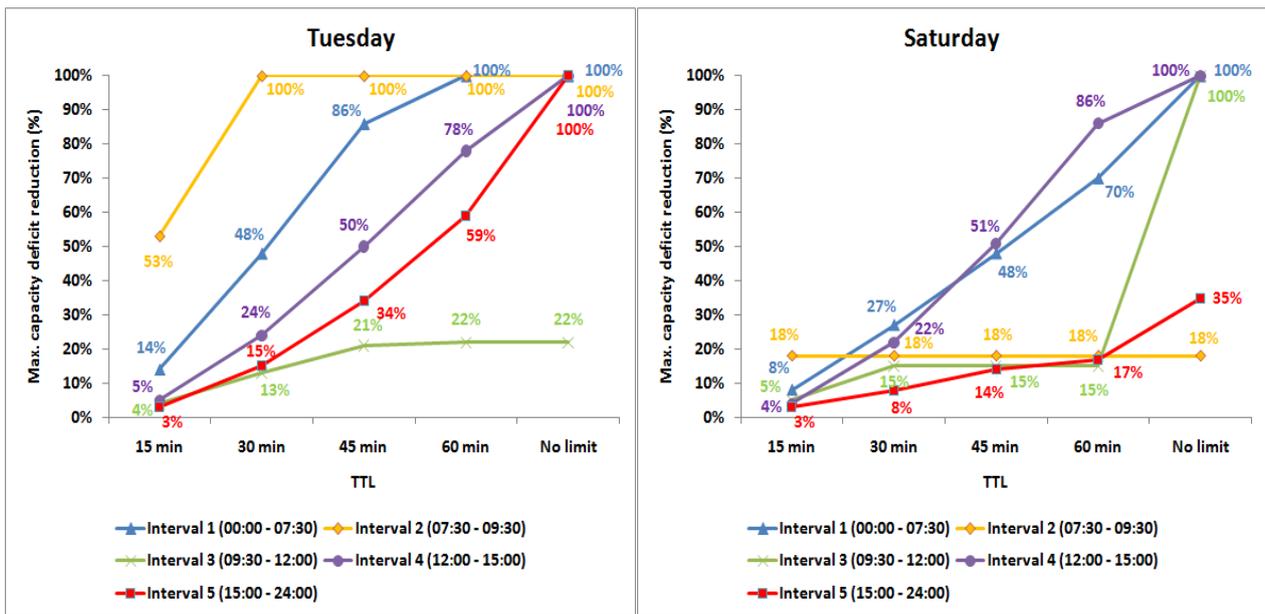


Figure 15: Maximal capacity deficit reduction for different TTLs

4. CONCLUSIONS & RECOMMENDATIONS

When the number of security lanes is decreased, the average passenger waiting time in general increases. However, our research showed that by applying the principles of virtual queuing (VQ) this effect could be limited to acceptable levels. In many occasions the average waiting time could even be reduced. However, the success of VQ depends on the reliability of the forecast model, the passenger arrival pattern, and the number of eligible participating passengers and the length of the time windows (TWs).

Our research showed that the effect of VQ was more beneficial when the passenger arrival pattern showed sharp peaks that exceeded the capacity (capacity deficit) followed by periods of idle capacity, which is in line with Narens (2004). However, this effect was interlinked with the number

of eligible passengers. In order to preserve the benefits of VQ, a sufficient number of eligible (and participating) passengers should be present to prevent a dramatic increase in the average waiting time, as a reduction in the NSL would increase the capacity deficits. Furthermore, the TWs should be kept as short as possible to maximize the transfer accuracy rate, as this results in a higher utilization of the idle capacity and thus a larger reduction of the capacity deficit.

It should be noted that our simulation model did not consider the scheduled time of departure (SToD) per passenger. As an alternative, the effect of VQ was examined for 12 different scenarios by combining different values of the TTLs (i.e., 1, 1.5, and 2 hours) and TWs (i.e., 5, 10, 15, and 20 minutes). Thus, the optimal effect of VQ was identified for all the scenarios by taking into account the 95% upper bound waiting time standard of 6 minutes.

The essence of our research was to identify to what extent the NSL could be limited without increasing the average waiting time. Based on these criteria, the best results were gained by applying TWs of 5 and 10 minutes in combination with TTLs of 1.5 and 2 hours. Other combinations showed significantly lower potential benefits, especially TWs of 20 minutes.

We also conducted a manually calculation taking into account the SToD per passenger. These calculations showed that a higher reduction of the capacity deficit could be achieved than was assumed for the simulation. However, in this scenario no limit was taken for the TTL. Thus, this situation could in theory lead to extreme transfer times. However, in general the maximal transfer time remained below the 1.5 hours.

As it is not unlikely that the passengers would refuse to wait 1.5 hours or longer to go through security, the effect of lower TTLs on the capacity reduction was identified. The results were quite severe, as the reduction percentage in general decreased very rapidly for TTL values below the 1 hour. Nevertheless, the low percentage of the required participation rate of the eligible passengers still allows WE to achieve the potential benefits.

4.1 The Proposed Combination of TWs and the TLL

Based on our results we believe that TWs of 10 minutes in combination with a TTL of 1.5 hours would be the best fit. We expect that TWs of 5 minutes would not offer the passengers with sufficient time to arrive at the security lanes and thus could have a negative effect on the customer satisfaction and the participation rate. In addition, although TWs of 5 minutes could result in slightly higher capacity deficit reductions and lower average waiting times, the reduction in the number of security agents remains the same in comparison with 10-minute TW scenarios.

Furthermore, it is not realistic to assume that passengers would be willing to wait several hours before going through the security lanes, even in airports with plenty of opportunities to occupy themselves prior to the security checkpoint. Our results showed that in order to maximize the benefits of VQ a minimal TTL of 1.5 hours should be applied. Lower levels for TTLs would restrict the beneficial effect of VQ, especially for TTLs below 1 hour. However, it is important to realize that a TTL of 1.5 hours implies a maximum level. Thus, not all passengers are required to wait for 1.5 hours. This percentage is lower as the arrival pattern shows sharp peaks that exceed the capacity followed by periods of idle capacity.

Additionally it is necessary to identify whether there is enough support potential across the involved parties to apply the principles of VQ. Thus, research should be conducted with respect to the following issues 1) Actual participation rate among the passengers; 2) impact on customer satisfaction; 3) airlines' willingness to cooperate; and 4) incentives to persuade the passengers to accept a TW.

In general a shorter waiting time at the security lanes during the peak hours can be seen as the main benefit of VQ for the passengers. However, it is unlikely that this incentive would be enough to convince the passengers to wait for approximately an hour to go through the security lanes. Therefore, additional incentives should be used to convince the passengers. For example, rebates or vouchers.

For our study it was assumed that the TWs were provided at the check-in desks. We suggest covering this process by providing the passengers a TW in a ticket format. On this ticket a time interval will be displayed in which a passenger is allowed to arrive at the security lanes. This ticket should also be used to gain access to the virtual queue at the automatic entrance gate. If the passenger shows up outside the TW, he or she will not be admitted to the virtual queue.

4.2 Further Fields of Research

We have identified three areas for additional research:, 1) distributing time windows prior to airport arrival, 2) segmenting customers, and 3) virtual queuing at other companies.

Distribution of TWs before arrival at the airport

In our research we assumed that the TWs were distributed among the passengers at the check-in desks. Thus, the passengers should be physically present at the airport in order to receive a TW. As mentioned in the previous chapters, this could lead to situations of high TTLs. However, it is doubtful whether the participation rate would be sufficient in such scenarios. Therefore, it could be interesting to conduct additional research to find out whether it could be effective to provide the passengers with TWs before their arrival at the airport, for example while checking in online.

It would also be interesting to identify what the effect are of including the possibility of shifting passengers to a TW earlier in time. In other words, passengers who arrive during peak hours should be encouraged to arrive earlier in order to prevent long waiting times at the security lanes. Because the shifting of passengers to idle capacity is then done in two directions in time, there is more idle capacity available.

By applying this process, the passengers who are provided with a TW do not have to wait in a long queue at the security lanes, which could lead to a higher participation rate. However, since the TWs are not provided at the airport, the likelihood of passengers arriving at the security lanes within the provided time interval could decrease. Thus, it would be reasonable to apply longer TWs. However, as concluded from our research, higher TWs could lead to lower benefits. Furthermore,

the possibility of passengers that would not accept a TW caused by the fear of missing their flight could apply in this scenario. Another drawback is that it is harder to identify the right passenger (i.e., those arriving during an arrival peak), since they haven't arrived at the airport yet.

Different lengths of TWs for segmented customers

A second field of further research is the possibility of segmentation of the customers with respect to the length of the TWs. In this scenario customers with a less predictable arrival behavior, such as families, would receive a longer TW to increase the chances of a timely arrival at the security lanes. The reverse is applicable for customers that show a more predictable arrival behavior, such as business travelers. This could lead to more potential participants.

Virtual queuing at other companies

Customers that participate in a virtual queue are provided with the opportunity to spend their time in their own way instead of waiting in a queue. Since unoccupied waiting time feels longer than occupied waiting time (Maister 1985), it is recommended to create some possibilities for activity. But this only has a possible positive effect if the activity is to the interest of the people who have to wait (Nie 2000). For example, if an airport lacks any kind of leisure in the area before passing the security it is not likely that many passengers would be willing to participate. At amusement parks on the other hand, customers have many possibilities to enjoy their time, while waiting in a virtual queue. It could therefore be interesting to investigate at which companies other than airports, call centers or theme parks VQ can be implemented.

4.3 Conclusion

The application of VQ is an unfamiliar practice among airports. Thus, little is known about the potential benefits that the principles of VQ can have on airport operations. Many amusement parks and call centers already managed to grasp the opportunity, by taking advantage of their customers' flexible schedule. However, the presence of numerous restrictions and constraints that airports have

to deal with, made the majority believe that the setting were not suitable for a successful implementation of the VQ concept.

Nevertheless, our research proved otherwise. A case study, performed at one of Europe's leading airports, showed that the application of VQ could provide significant benefits with respect to reduction of the average waiting times and operating costs. However, it has become clear that not everyone can benefit from applying the principle of VQ. Our research showed that there are a few important conditions that have to be met in addition to ample shopping and dining opportunities prior to the security checkpoint. These are: a reliable forecasting model, a sufficient number of participating passengers, short time windows and a passenger arrival pattern that shows steep peaks followed by idle capacity. In a time frame where security costs are considered as the largest concern of the management at airports, VQ could provide a great opportunity.

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