QUANTIFYING CAPACITY LOSSES OF THE PHYSICAL SEPARATION OF DOMESTIC AND INTERNATIONAL PASSENGERS USING DISCRETE EVENT SIMULATION

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ABSTRACT

Today's airport terminals suffer from various usage restrictions such as the physical separation of domestic and international passenger flows. New technologies like biometrics may enable the abolition of this physical constraint and hence increase the terminal capacity. This paper uses a discrete event simulation environment to quantify the capacity effect of an abolition of the physical separation of international and domestic passenger flows in airport terminals for the European case. Therefore, a simulation model in AnyLogic is applied. The simulation model uses varying shares of domestic an international passengers as an input and models different scenarios. The different scenarios in the simulation allow comparing different terminal layouts and the particular usage restrictions behind.

Keywords: Airport Capacity; Terminal Simulation; Discrete Event Simulation; Future Terminal Concepts; Level of Service

1. INTRODUCTION

The aviation sector is facing a continuing growth (IATA 2017). Consequently, airports, as a main player in the aviation sector, have to deal with increasing traffic and passenger volumes in their terminals. Often limited in their options for infrastructure expansion, they are frequently facing capacity issues. A clear fact in terms of efficiency and capacity management is a flexible use of the existing infrastructure. Therefore, restrictions and constraints in terminal operations may cause capacity issues.

Today's airports have to deal with various restrictions. A paragon of inefficient airport terminal operations is the physical separation of domestic and international passengers. For the European case, the present Schengen Border Code prescribes airport operators to "physically separate (…) passengers on internal flights from passengers (…) on other flights." (Lilico et al. 2016). As a result, terminal gate areas at airports can be used solely for either Schengen or Non-Schengen flights. This constraint affects daily airport operations, causing capacity losses, and is costly for passengers and airport operators.

This study aims to quantify the capacity losses caused by the restriction of the aforementioned physical separation of passengers in airport terminals. Therefore, we will compare restricted terminal scenario to an unrestricted terminal scenario with the help of computer simulation. The unrestricted terminal scenarios in this study are based on the terminal concept called Uniform Terminal Area (UTA), which will be explained more detailed in a subsequent section.

In a prior work, we could already prove capacity effects for the abolition of the physical separation. While we used aggregated flight schedule data for 50 European airports as an input for our simulation in that prior work, this paper will deploy a clustered airport class approach. We will take into account the different volatilities of the individual flight schedules of the 50 airports.

Hypothesis: Airports with a greater volatility in their flight schedules in terms of domestic and international flights are facing greater capacity losses in a restricted gate scenario.

To test this hypothesis, a simulation model using Discrete Event Simulation (DES) is applied. In this paper, we will derive three airport categories depending on their volatility in their individual flight schedules. With this airport category approach, we can compare our restricted terminal model with the unrestricted UTA scenario and test our stated hypothesis.

Subsequent to a brief summary of the system idea of a UTA in section 2, the methodology of this paper will be explained in four consecutive steps. In section 4 we introduce our simulation model using DES in AnyLogic. The sections 5 and 6 will pave the way for our simulation in AnyLogic, as we generate the right input data. Therefore, we consider historic flight schedule data and determine the volatility in the flight schedule of individual airports. At the end of section 6, we derived three airport categories and generated the arrival rate schedules for our simulations. In section 7 we present the results of the DES in AnyLogic. Ascertained throughput values for different scenarios combined with queuing times will allow us to quantify the capacity losses in the restricted scenario. Conclusions will be drawn in section 8. A short discussion of the results concludes the paper.

2. SYSTEM IDEA OF UTA

The system idea of the Uniform Terminal Area was introduced in detail in a previous publication . This section gives a brief summary of the idea of a shared and uniform terminal area.

Current terminal processes at an international airport can be described by the following simplified scenario (Mensen 2013). Subsequent to check-in and baggage claim, all departing passengers have to undergo a security inspection when entering the terminal airside. Depending on the passenger's destination, a passport control is mandatory. Domestic and international passenger flows (or used as a synonym in this paper: Schengen and Non-Schengen) are physically divided after this passport control. Consequently, passengers traveling to Non-Schengen countries will always use different and physically separated terminal areas than Schengen passengers. At the

end of the process chain, all passengers will leave the terminal airside when boarding the plane. Figure 1 shows a generic terminal layout of an airport with the present restrictions and processes described before. For the terminal airside the light blue rectangle represents the domestic gate area while the dark blue rectangle represents the international gate area. Both areas are separated physically, for instance by a wall. This physical separation will represent the restricted scenario in the subsequent capacity analysis.

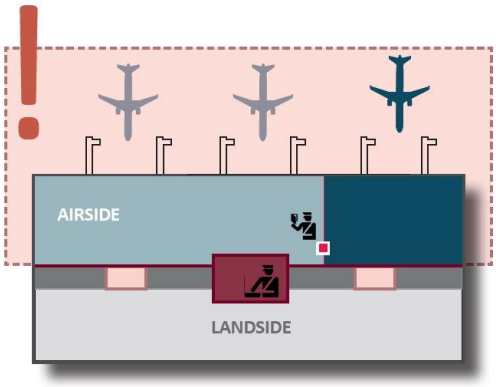


Figure 1: Generic Terminal Layout with a physical separation of domestic and international passengers

The processes within a UTA will be similar to current procedures in a passenger terminal, just without a physical separation of passenger flows (see Figure 2). To ensure the reliable unbundling of departing passengers, three biometric checkpoints are established. Starting with a biometric enrollment (facial recognition) for all passengers at security control, a mandatory passport control for passengers flying to Non-Schengen countries will follow. To prevent unauthorized emigrations and to ensure the reliable unbundling of passengers, a third biometric checkpoint is needed at the boarding gate. The last checkpoint at the boarding gate will ensure the reliable unbundling of passengers travelling inside the Schengen area and passengers travelling outside. For a detailed determination of the three biometric checkpoints we refer to (Schulze Schwienhorst, 2019b). The UTA layout will represent the UTA scenario in the subsequent capacity analysis.

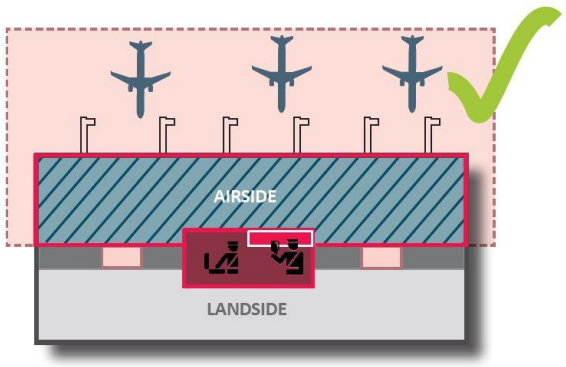


Figure 2: System Idea of a Uniform Terminal Area (UTA)

The previously presented processes in a UTA are guided by present terminal operations to make them more comprehensible. The rigid setup of the single processes is not limited to the introduced one. Checkpoint two, for instance, could work with single kiosks spread around the terminal airside or even without a physical checkpoint in the future (Dutton, 2017). The European Entry and Exit System (EES) initiative, going into effect in 2020, is introducing self-service border-crossing facilities, for example, and paving the way for trendsetting and modern border-crossing processes (European Commission, 2016). Therefore, technological and regulatory changes will facilitate the idea of a UTA in the near future.

3. METHODOLOGY

In a previously published paper, we could already prove significant capacity effects for the abolition of the physical separation. While we used aggregated flight schedule data for 50 European airports as an input for our DES in that prior work, this paper will deploy a clustered airport class approach. Therefore, we will analyze OAG (Official Airline Guide) flight plan data from 2016 and derive varying hourly shares for domestic and international flights for each day of the week. Based on the Mean Average Deviation (MAD) for the hourly shares of the individual 50 airports, we will cluster the airports in three groups. Consequently, the domestic and international shares will be more homogenous within the three groups and conclusions from the discrete

event simulation will be more specific and related to the particular airport category.

In order to describe a comprehensible procedure, we will subdivide the methodology in four consecutive steps. In a **first step**, historic flight schedule data from 2016 are analyzed. The flight schedule data we use come from the OAG and include information about all commercial flights conducted worldwide for one week in July 2016. Having a focus on the European Case and thus on flights from the Schengen area[1], we are examining the weekly flight schedules of all airports in the Schengen Area with a minimum volume of 5 million passengers per year and a maximum volume of 30 million annual passengers. In total, these 50 airports were handling more than 28,000 commercial flights (departing flights only) in the chosen week in July 2016. For every day of the week, from 5 am to 11 pm, the varying share of flights to either Schengen or Non-Schengen destinations are derived. Additionally, we calculate a weekly average of the ratio of flights to Schengen and Non-Schengen destinations.

Within the **second step**, we will use the results of the flight schedule analysis of step one to determine the volatility of the flight schedules of the individual 50 airports. Keeping in mind the hypothesis of the paper's introduction, the individual airports will be clustered depending on the volatility of their flight schedules in terms of Schengen and Non-Schengen flights. Therefore, we will use the Mean Absolute Deviation (MAD). The MAD can be used as a robust measure of the volatility for historic data (Ederington and Guan, 2006). In contrast to the Standard Deviation (SD) the MAD only takes the absolute deviation into account. Considering the absolute deviation instead of a squared deviation lowers the influence of especially extreme outliers.

Calculating the MAD for every of the 50 airports allows us to cluster the 50 airports in three categories. Airport category I contains the third of the considered airports with the lowest volatility in their Schengen and Non-Schengen ratio. On the other side, airport category III contains the third of the considered airports with the highest volatility in their flight schedules. The result of this second step is a classification of our airports in terms of volatility in their flight schedules. This classification allows us a more specific consideration of our hypothesis on one hand and represents a more homogenous basis for our following simulation scenarios.

Step three of this study is combining the results of step one and two and thus to generate the input parameters for the DES. The ascertained airport categories of step two enable us to derive tailored passenger arrival profiles for domestic and international flights for every airport category. Therefore, we have to conflate the rolling hourly shares (10-minute-steps) of domestic and international flights for the airports of the particular airport category. These shares are transformed into arrival rate schedules, the input parameter of our DES.

In order to transform the hourly shares into arrival rate schedules, we do need to know about the passenger volume. As the aim of this paper is to quantify the capacity of different terminal layouts, we are interested in the throughput and corresponding queuing times. Hence, we will run our DES with various passenger volumes. In this study, we started with a constant passenger volume of 100 PAX/h for all of the three airport categories. We increased the passenger volume in steps of 100 PAX/h up to a maximum passenger volume of 2300 PAX/h.

The result of step three are 69 arrival rate schedules as an input for our DES. Consequently, for every airport category we calculated 23 arrival rate schedules with varying passenger volumes. The underlying rolling hourly shares thereby stay constant within the airport category, while the passenger volume increases for the 23 arrival rate schedules.

The **fourth step** of this study is to determine the capacity of two different scenarios. Scenario 1, named the restricted

[1] Germany, Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Iceland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and Switzerland have all acceded to the Schengen Agreement and are thus Schengen states. Citizens of Schengen countries can cross the internal borders of all member states without passport checks. The Schengen visa entitles the holder to visits of up to 90 days every 6 months in the entire Schengen area. (Federal Foreign Office Germany. Link: https://www.auswaertiges-amt.de/en/einreiseundaufenthalt/-/231202

scenario, corresponds the current airport terminal configuration where gate restrictions in terms of a separation of domestic and international passengers are present. Scenario two, named the UTA scenario, corresponds the UTA configuration where no gate restrictions in terms of a separation of domestic and international passengers are present. To determine the capacity of the two scenarios we use DES. The tool we use therefore is AnyLogic Professional (version 8.3.3). Our DES uses the arrival rate schedules derived in step three of this study as an input. Based on the process-modelling library in AnyLogic, our simulation can calculate individual queuing times for the different scenarios. By applying the Level of Service (LoS) concept (Zografos et al., 2013) we can compare the different terminal configurations for different airport categories.

Using varying passenger volumes as well as specific arrival rates for three airport clusters as an input, the results of the comprehensive simulations in AnyLogic allow us to draw nuanced conclusions and to quantify the capacity effect of the physical separation of domestic an international passengers in most of today's airport terminals.

4. SIMULATION MODEL

For an advanced analysis of the capacity effect of the physical separation of passenger flows, we use DES. The simulation runs were conducted with AnyLogic Professional (version 8.3.3) using the Process Modeling Library. The fundamental structure of the simulation model is shown in Figure 3. The simulation model contains both, the restricted scenario (gate restrictions are present) and the UTA scenario. Therefore, it is considering three types of passengers (Schengen, Non Schengen and UTA passengers).

While Schengen and Non Schengen passengers in the restricted scenario enter the simulation via the S_source and NS_source, UTA passengers in the UTA scenario use the UTA_source. Both scenarios have different resources in their gate and boarding service stations (delay blocks).

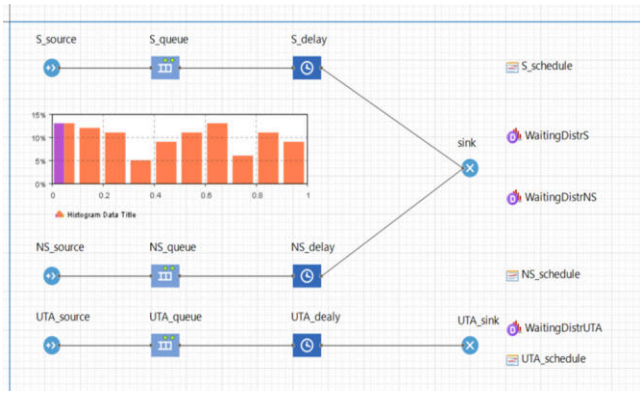


Figure 3: Simulation Model in AnyLogic

All passengers enter the simulation following a predefined schedule. The individual schedules we are using will be derived in section 6 and base on the flight schedule analysis. Our DES uses varying arrival rates in terms of passenger volumes (PAX/h) as well as varying Schengen and Non-Schengen shares as an input.

5. HISTORIC FLIGHT SCHEDULE ANALYSIS

To obtain a sensible basis for the DES we are analyzing historic flight schedule data from 2016 (first step of the methodology). The underlying database for the evaluation in this section is an OAG database, containing all global flights (commercial, regular flights) for one week in July 2016. The primary database includes but is not limited to the following information: flight number, departing airport, arriving airport, local departure time, local arrival time and days of operation.

As this paper is using the Schengen Area to quantify the capacity impact of the physical separation of domestic and international passenger flows in airport terminals, this evaluation is about departing flights from airports inside the Schengen Area. Consequently, we adjusted the database by flights departing from airports within the named Schengen Area.

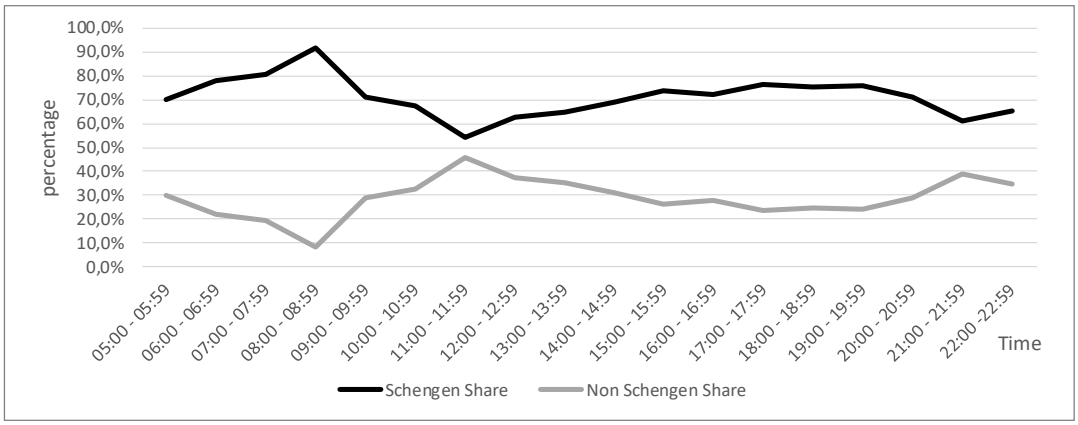


Figure 4: Exemplary plot of the Schengen/ Non Schengen Share for a group of airports (Friday, July 2016 | airport category II)

In order to prevent a blending of too many airport categories in our study, global hubs (Malighetti et al., 2009) and small airports were excluded from the evaluation of the OAG flight schedule data. Therefore, only airports with a minimum volume of 5 million passengers per year and a maximum volume of 30 million annual passengers were considered. The operating hours were limited to a period from 5 am to 11 pm to preclude the prevalent night flight bans at European airports.

Based on the filtered database, we derived varying shares for departing Schengen and Non-Schengen flights for every day of the week and for all of the 50 airports. Additionally, we calculated a weekly average of the ratio of flights to Schengen and Non-Schengen destinations.

Figure 4 shows an exemplary plot of the diurnal variation of the Schengen and Non Schengen share for a group of airports (example set is later on defined as airport category II) on a Friday in July 2016. One can see a strong domination of Schengen flights in the morning hours. With a peak of 91.8 percent of Schengen flights from 08:00 to 08:59 the Non Schengen share is increasing around midday. The greatest Non-Schengen share stated with 45.6 percent in the period from 11:00 – 11:59.

On a weekly average, the Schengen and Non Schengen flight share equals a 30.6 percent of Non-Schengen flights and 69.4 percent of Schengen flights ratio. The average hourly shares show a minimum share of 8.2 and a maximum share of 45.6 percent in Non-Schengen flights. For Schengen flights, the minimum hourly share corresponds to 54.4 percent while the maximum corresponds to 91.8 percent.

In summary, it can be stated for the first step that the study consists of flight schedule data for 7 days and 50 airports and is taking into account departing flights from 19 different countries. The result of this first step is a total view of the Schengen and Non Schengen shares for every individual airport and for each day of the week.

Within the second step, we use these processed data to determine the volatility of the flight schedules of the individual airports. Therefore, we apply the MAD as a measure of volatility. Equation 1 shows the calculation of the MAD and demonstrates the dependency on the weekly ratio of Schengen and Non Schengen flights (equals m(X)). This weekly ratio corresponds to the quantity of flights to Schengen or Non-Schengen destinations proportional to the total amount of flights at the specific airport. As the Schengen and Non Schengen shares are interdependent, the MAD of the Schengen Share equals the MAD of the Non Schengen Share.

Equation 1: Mean Average Deviation

$$MAD = \frac{1}{n}\sum_{i=1}^{n} |x_i - m(X)|$$

Calculating the MAD for the individual 50 airports allows us to cluster the airports in three categories. Therefore, we had to sequence the

airports depending on their MAD. Following this, we split the airports into three equal groups.

Table 1 depicts the list of airports belonging to airport category I. This airport category is the one with the lowest volatility in the individual flight schedules. We could observe that the airport of Oslo (Norway) has the lowest MAD value with 9.1 percentage points. The greatest volatility within airport category I shows the airport of Nice (France) with a MAD value of 19.0 percentage points.

Table 1: Airport Category I: Mean Absolute Deviation of international passenger shares

Airport City	*IATA Code*	*PAX/a in 2016*	*MAD [%]*
Oslo	*OSL*	*25.787.691*	*9.1*
Bergen	*BGO*	*5.949.060*	*10.8*
Palermo	*PMO*	*5.325.559*	*11.0*
Porto	*OPO*	*9.378.082*	*14.1*
Hamburg	*HAM*	*16.224.154*	*14.4*
Stockholm	*ARN*	*24.682.466*	*15.1*
Catania	*CTA*	*7.914.117*	*15.7*
Brussels	*BRU*	*21.818.418*	*16.2*
Cologne	*CGN*	*11.910.138*	*16.6*
Copenhagen	*CPH*	*29.043.287*	*16.6*
Mallorca	*PMI*	*26.253.882*	*17.0*
Helsinki	*HEL*	*17.184.681*	*17.4*
Milan	*BGY*	*11.159.631*	*17.8*
Vienna	*VIE*	*23.352.016*	*18.4*
Dusseldorf	*DUS*	*23.521.919*	*18.8*
Geneva	*GVA*	*16.532.690*	*18.9*
Nice	*NCE*	*12.427.427*	*19.0*

Concurrent to the details of airport category I, Table 2 depicts the list of airports belonging to airport category II. The airports of this category have a medium volatility in their flight schedules. We could observe that the airport of Zurich (Switzerland) has the lowest MAD value of airport category II with 19.1 percentage points. The greatest volatility within airport category II shows the airport of Heraklion (Greece) with a MAD value of 24.4 percentage points.

Table 2: Airport Category II: Mean Absolute Deviation of international passenger shares

Airport City	*IATA Code*	*PAX/a in 2016*	*MAD [%]*
Zurich	*ZRH*	*27.666.428*	*19,10%*
Lisbon	*LIS*	*22.449.289*	*19,30%*
Milan	*LIN*	*9.682.264*	*19,60%*
Toulouse	*TLS*	*8.081.179*	*20,60%*
Venice	*VCE*	*9.553.250*	*21,10%*
Ibiza	*IBZ*	*7.416.368*	*21,20%*
Stuttgart	*STR*	*10.626.430*	*21,40%*
Athens	*ATH*	*20.017.530*	*21,40%*
Milan	*MXP*	*19.420.690*	*21,70%*
Valencia	*VLC*	*5.799.104*	*23,00%*
Berlin	*SXF*	*11.652.922*	*23,60%*
Basel	*BSL*	*7.314.269*	*23,70%*
Malaga	*AGP*	*16.672.776*	*23,70%*
Lyon	*LYS*	*9.553.250*	*23,90%*
Bologna	*BLQ*	*7.680.992*	*24,20%*
Heraklion	*HER*	*6.742.746*	*24,40%*

For airport category III, Table 3 depicts the list of airports belonging to that category. The airports of this category have the highest volatility in their flight schedules. We could observe that the airport of Brussels Charleroi (Belgium) has the lowest MAD value of airport category III with 24.5 percentage points. The greatest volatility within all of the 50 airports shows the airport of Reykjavik (Island) with a MAD value of 36.6 percentage points.

Table 3: Airport Category III: Mean Absolute Deviation of international passenger shares

Airport City	*IATA Code*	*PAX/a in 2016*	*MAD [%]*
Brussels	*CRL*	***7.303.720***	*24,50%*
Alicante	*ALC*	***12.344.945***	*24,50%*
Budapest	*BUD*	***11.441.999***	*24,90%*
Prague	*PRG*	***13.074.517***	*25,10%*
Marseille	*MRS*	***8.475.809***	*25,20%*
Naples	*NAP*	***6.775.988***	*25,20%*
Berlin	*TXL*	***21.253.959***	*25,40%*
Faro	*FAO*	***7.630.909***	*26,50%*
Bordeaux	*BOD*	***5.779.569***	*26,60%*
Thessaloniki	*SKG*	***5.687.325***	*27,10%*
Hannover	*HAJ*	***5.408.814***	*29,60%*
Gothenburg	*GOT*	***6.369.396***	*31,10%*
Rome	*CIA*	***5.395.699***	*31,40%*
Warsaw	*WAW*	***12.795.356***	*32,70%*
Malta	*MLA*	***5.080.071***	*34,60%*
Riga	*RIX*	***5.400.243***	*36,10%*
Reykjavik	*KEF*	***6.821.358***	*36,60%*

The result of this second step is a classification of our airports in terms of volatility in their flight schedules. This classification allows us a more specific consideration of our hypothesis on one hand and represents a more homogenous basis for our DES we already showed in section 4.

6. INPUT PREPARATION

Within this section, we are going to combine the results of the flight schedule analysis and the airport categorization in order to generate the input parameters for the DES. The ascertained airport categories enable us to derive tailored passenger arrival profiles for domestic and international flights for every airport category. As a result of the airport schedule analysis, diurnal variations of the Schengen and Non Schengen shares for every of the 50 airports and for every day of the week are available. Based on these results, we compile rolling hourly shares with a frequency of 10-minute-steps. We compile the rolling hourly shares for domestic and international flights for all airports of the particular airport category. We transform theses shares into arrival rate schedules, subsequently.

Table 4 indicates the primary step on the way to our arrival rate schedules. The table exemplary shows for the airport category II how data about the hourly shares are available. The sample period starts at 5 am with a Schengen share of 75.8 % and a Non Schengen share of 24.2 %. One can see that the share values update in 10-minute-steps. Around midmorning, the Non Schengen share has increased up to 38.1 % while the Schengen share corresponds 61.9 %.

Table 4: Rolling Hourly Shares of Schengen and Non-Schengen flights for Airport Category II (weekly average)

Time [hh:mm]	*S-Share [%]*	*NS-Share [%]*
05:00 – 05:59	*75.8*	*24.2*
05:10 – 06:09	*83.3*	*16.7*
05:20 – 06:19	*86.5*	*13.5*
05:30 – 06:29	*88.3*	*11.7*
05:40 – 06:39	*87.8*	*12.2*
05:50 – 06:49	*82.2*	*17.8*
...	...	...
11:00 – 11:59	*61.9*	*38.1*
11:10 – 12:09	*63.2*	*36.8*
11:20 – 12:19	*67.6*	*32.4*
11:30 – 12:29	*65.3*	*34.7*
11:40 – 12:39	*64.0*	*36.0*
11:50 – 12:49	*65.1*	*34.9*
...	...	...
20:00 – 20:59	*72.1*	*27.9*
20:10 – 21:09	*72.2*	*27.8*
20:20 – 21:19	*72.3*	*27.7*
20:30 – 21:29	*69.9*	*30.1*
20:40 – 21:39	*66.8*	*33.2*
20:50 – 21:49	*61.1*	*38.9*
...	...	...

In order to transform the hourly shares into arrival rate schedules, we do need to know

about the passenger volume. As the aim of this paper is to quantify the capacity of different terminal layouts, we are interested in the throughput and corresponding queuing times. Hence, we will run our DES with various passenger volumes. In this study, we start with a constant passenger volume of 100 PAX/h for all of the three airport categories. We increase the passenger volume in steps of 100 PAX/h up to a maximum passenger volume of 2300 PAX/h. The underlying rolling hourly shares thereby stay constant within the airport category, while the passenger volume increases for the 23 arrival rate schedules of the individual three airport categories.

An example for a completed arrival rate schedule can be seen in Table 5. The table shows the individual arrival rates for the airport category I with a passenger volume of 1,600 PAX/h. The schedule contains arrival rates for the S_source, the NS_source and the UTA_source. The arrival rate schedule starts with a period from 0 to 600 seconds (which equals the first 10 minutes of the simulation) and updates in 10-minute-steps. The last arrival rate is given for a period ending at 64,800 seconds. The 64,800 seconds equal 18 hours which is the total time of the period of the analysis.

Table 5: Example of the AnyLogic Input – Rate-Schedule for Airport Category I with a Passenger Volume of 1,600 PAX/h

AL_Time [s]	*s_rate [PAX/s]*	*ns_rate [PAX/s]*	*UTA [PAX/s]*
0 – 600	*0.360*	*0.084*	*0.444*
600 – 1,200	*0.351*	*0.094*	*0.444*
1,200 – 1,800	*0.355*	*0.090*	*0.444*
1,800 – 2,400	*0.340*	*0.104*	*0.444*
2,400 – 3,000	*0.348*	*0.097*	*0.444*
3,000 – 3,600	*0.355*	*0.089*	*0.444*
3,600 – 4,200	*0.362*	*0.083*	*0.444*
…	*…*	*…*	*…*
… – 64,800	*0.339*	*0.106*	*0.444*

The result of this section's 'input preparation' are 69 arrival rate schedules as an input for our DES. Consequently, for every airport category we calculated 23 arrival rate schedules with varying passenger volumes. The arrival rate schedules serve as the input parameter in our DES.

7. RESULTS

A main objective of this paper is to testing the stressed hypothesis. The hypothesis implies that for airports with a greater volatility in the flight schedule, the application of UTA has a stronger capacity effect than for airports with a lower volatility in the flight schedule. Therefore, we had to determine the capacity for the restricted and the UTA scenario for our three airport categories separately.

In the subsequent figure and the subsequent tables, we will present the results of the 69 simulation runs in AnyLogic. For the restricted scenario, we have separate outcomes for every airport category and every passenger volume. The UTA scenario in contrast has the same outcome for every airport category at a given passenger volume. Hence, our results have four output columns (UTA, Cat 1, Cat 2 and Cat 3).

Figure 5 shows the summarized results for the 69 simulation runs in terms of the average queuing time per passenger. One can see for low passenger volumes that both scenarios, the restricted (for three different airport categories) and the UTA scenario show no relevant queuing times. At about a passenger volume of 1,500 passengers per hour, the queuing times increase for the restricted scenario. Within the restricted scenario, the queuing times for airport category III are the first that increase. Followed by the queuing times for airport category II and finally the queuing times for airport category I. The queuing times for the UTA scenario stay steady on a low level (<10 s) until a passenger volume of around 2,000 per hour. As the technical capacity of the terminal is designed for 2,000 passengers per hour, the results reveal reliable. Small waiting times occur even if the demand rate is lower than the service rate (Jacquillat and Odoni, 2017).

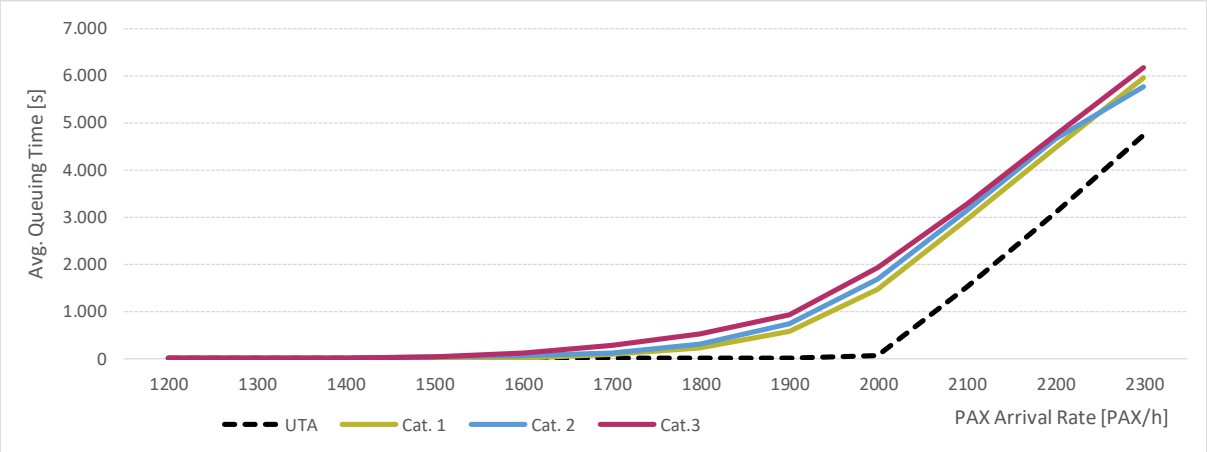


Figure 5: Average Queuing Time per PAX

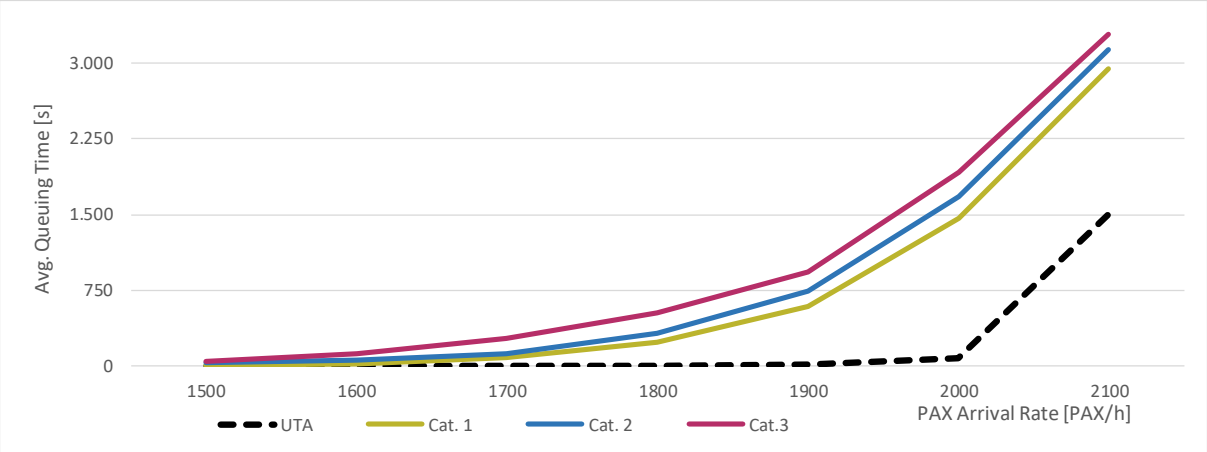


Figure 6: Average Queuing Time per PAX (enlarged)

For a detailed view on the most interesting part of the mean queuing times, Figure 6 shows an enlarged extract of the results for passenger volumes from 1,500 to 2,100 per hour. For every point in time, the queuing times for passengers in the restricted scenario are greater than the queuing times for passengers in the UTA scenario.

To use the results of the DES for a comparison of the two scenarios, we now apply the Level of Service concept. With the help of capping the mean queuing times, we can determine the performance of the different scenarios. As we do not intend to decide on a specific mean queuing time, we determine the performance for three different thresholds.

The throughput values for the different scenarios and different airport categories in Table 6 reveal that the throughput for UTA is above 2,000 passengers per hour for each of the three thresholds of the mean queuing time. For the 10 min threshold for instance, the UTA scenario has a throughput of about 2,036 passengers per hour. The restricted scenario on the other hand has a throughput of about 1819 passengers per hour for airport category III and a throughput of about 1901 passengers per hour for airport category I.

Table 6: Throughput of the individual airport categories for three service levels (mean queuing times)

Mean Queuing Time	*UTA [PAX/h]*	*Cat. I [PAX/h]*	*Cat. II [PAX/h]*	*Cat. III [PAX/h]*
5 min	*2015.79*	*1819.57*	*1790.05*	*1712.13*
10 min	*2036.63*	*1901.45*	*1866.86*	*1818.80*
15 min	*2057.46*	*1935.74*	*1917.10*	*1897.38*

8. CONCLUSIONS

The results presented in the previous section indicate that the UTA terminal design achieves a better performance than the terminal design in the restricted scenario. This counts for both the mean queuing times and the ascertained throughput.

To better quantify the capacity effects of the different scenarios we converted our results of the DES as shown in Table 7. Setting the throughput of the UTA scenario to 100 %, we can put the three different airport categories of the restricted scenario in relation.

A first conclusion of the results shown in Table 7 is that the airport category has an impact on the performance.

Table 7: Capacity of the individual airport categories compared to the UTA capacity (=100 %) for three service levels (mean queuing times)

Mean Queuing Time	*UTA [%]*	*Cat. 1 [%]*	*Cat. 2 [%]*	*Cat. 3 [%]*
5 min	*100.0*	*90.3*	*88.8*	*84.9*
10 min	*100.0*	*93.4*	*91.7*	*89.3*
15 min	*100.0*	*94.1*	*93.2*	*92.2*

Taking the difference between the performance of the UTA scenario and the performance of the restricted scenario basically defines the capacity losses. Looking at the 5 min (mean queuing time) threshold for airport category II for instance, one can see a capacity loss of the restricted scenario of 11.2 per cent compared to the UTA scenario. To put it another way, the benefit of abolishing the physical separation of domestic and international passengers could increase the capacity by 11.2 per cent for the input parameter of airport category II and a determined threshold of 5 min for the mean queuing times.

Table 8: Capacity losses of the individual airport categories compared to the UTA capacity (=100 %)

Mean Queuing Time	*Cat. 1 [%]*	*Cat. 2 [%]*	*Cat. 3 [%]*
5 min	*- 9.7*	*- 11.2*	*- 15.1*
10 min	*- 6.6*	*- 8.3*	*- 10.7*
15 min	*- 5.9*	*- 6.8*	*- 7.8*

The summarized data in Table 8 indicate that there are two main conclusion to draw. First, the volatility of the flight schedule of the airport category has an impact on the performance. Airport category I has the lowest volatility and at the same time the lowest capacity losses compared to the UTA scenario. Airport category III, with the highest volatility in the flight schedule has the highest capacity losses compared to the UTA scenario. This holds true for all of the three thresholds for the mean queuing time.

The second conclusion to draw is related to the Level of Service criteria. In the present analysis, we used the mean queuing time as the prevalent criteria. We could observe greater capacity losses for the restricted scenario for stricter thresholds of the mean queuing times. The capacity losses for the 5 min threshold are greater compared to the 10 min threshold for all airport categories. The same applies to the 10 min to 15 min threshold comparison. In other words - if the LoS criteria is set strict, the greater the capacity losses can be anticipated.

9. DISCUSSION

The aim of this paper was to quantify capacity losses caused by the physical separation of domestic and international passengers for the European case. The focus of this paper was the impact of the volatility of an airport's flight schedule on the observed capacity losses. With the objective of answering the research question and testing the stated hypothesis, we used DES to compare our restricted and UTA scenario for three different airport categories.

Our results of the DES allow two main conclusions. The first conclusion is that there is a capacity effect caused by the physical separation of domestic and international passengers. Our analysis showed, depending on the airport category and LoS threshold, a capacity loss for the restricted scenario of 5.9 to 15.1 per cent compared to the UTA scenario. The introduction of UTA therefore would probably generate positive effects in terms of airport terminal capacity.

The second conclusion is that the airport category and with that the volatility of the flight schedule has an impact on the performance. The

lower the volatility in the flight schedule, the lower are the capacity losses in the restricted scenario. Hence, the stated hypothesis can be accepted. Beyond the volatility, we could also observe an impact of the defined LoS criteria. The stricter (meaning shorter) the LoS criteria is set, the greater the expected capacity losses can be anticipated.

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