A MODEL OF AIRPORT CAPACITY EXPANSION DELAYS

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ABSTRACT
Air traffic has grown substantially in the past by about 4%-5% per year and according to forecasts of institutions like ICAO or manufacturers like Airbus or Boeing, demand for air traffic is expected to grow in the future by about the same pace. That means that global air traffic doubles every 15 years if airport capacity is sufficient to handle the increased demand for flights. However, as we have seen in the past, air traffic is heavily concentrated on a rather small number of large airports: About 4% of the airports worldwide with scheduled traffic, i.e. 100 airports, handle more than 50% or 28 m aircraft movements. Hub traffic is essential for the global air traffic network to achieve a high degree of connectivity between any two origin – destination pairs efficiently. However, at the same time, it is becoming more and more difficult to expand hub airports like e.g. London Heathrow or Frankfurt to account for the increased demand for flights. In many cases the runway system is the critical bottleneck in long term airport capacity, thus enhancing airport capacity means adding new runways and possibly a lengthy plan approval process.

Therefore, the purpose of this paper is to present an econometric model of runway expansion delays at airports that are operating near or at their capacity limit. A runway expansion delay means that runway capacity is insufficient to meet the actual demand and results in modification of demand, e.g. a temporal or regional demand shift or a demand loss. The model is based on the idea, that the main driver of runway expansion delays is the opposition from the population surrounding the airport caused by the noise emissions. The degree of opposition depends on various factors like e.g. welfare level, number of aircraft movements and location of the airport with respect to the urban agglomeration. Depending on those factors, the degree of opposition at an airport may range from marginal opposition to such a degree of opposition that building a new runway is virtually impossible. The model is based on discrete choice and Markov chain models and calculates the expected time span of delayed runway expansion at a congested airport. In a case study we compare a scenario of unconstrained 3.5% per annum growth of aircraft movements at the largest 100 airports worldwide with a scenario in which capacity constraints and delayed runway expansions are included.

KEYWORDS: Airport Capacity Constraints, Runway Expansions, Model of Airport Capacity Expansion Delays, Discrete Choice Model, Markov Chains

CLASSIFICATION: Aviation Infrastructure, Air Transport Demand, Environmental Issues in Air Transport Industry

1. INTRODUCTION

Global air traffic has grown substantially in the past and the pace of growth was only interrupted by oil and financial crises, terrorism and wars. Since 1992, the number of aircraft movements has increased by nearly 103% and reached a volume of about 30 million aircraft departures in 2011 (ICAO, 2005 & 2012). This means an annual average growth per year of 3.6% (compounded annual growth rate, CAGR). The number of air passengers and revenue passenger kilometers (RPK) has grown even stronger: The number of air passengers increased by 139% (CAGR: 4.6%) and RPK grew by 162% (CAGR: 4.9%) since 1992 (ICAO, 2005 & 2012).

The long term forecasts of aircraft manufacturers like Airbus and Boeing as well as ICAO (International Civil Aviation Organization) differ only marginally and basically see a continuation of the past growth for the future: According to Boeing’s Current Market Outlook, RPK is forecast to grow by a CAGR of 5.0% between 2011 and 2031 (Boeing, 2012). Airbus (2012) forecasts a CAGR of RPK of 4.7% for the time period from 2012 to 2031. ICAO distinguishes between three scenarios for the RPK growth between 2010 and 2030. In a low growth scenario, ICAO foresees a CAGR of 3.7%, the most likely scenario comprises a CAGR of 4.7% and in a high growth scenario ICAO forecasts a CAGR of 5.2% (Teyssier, 2010). Finally, Eurocontrol (2008) forecasts a CAGR of the number of flights at European airports of between 2.2% and 3.5% for the period 2008 to 2030.

If we compare the past development with the results of the aforementioned forecasts, we find a high degree of compliance. This essentially means that on a global scale the past growth of air traffic development is expected to continue in the future. However, we have to take note of the fact that all these forecasts are to different degrees only demand forecasts, i.e. that there is the implicit hypothesis of more or less sufficient airport capacity to serve the forecast demand.

The purpose of this paper is to present an econometric model to forecast runway expansion delays. The focus of the model is on runway capacity, because in the long run this is the most critical bottleneck in airport expansion plans and typically requires lengthy plan approval procedures in many countries. It is not rare that runway expansion plans at large airports, e.g. Frankfurt, take up to 10 years or even more until they are completed. We briefly outline the global airport capacity utilisation situation to motivate the research presented. After describing the model in detail we construct a “simple” 20 years forecast by applying a rather conservative 3.5% CAGR to airport traffic values of the year 2012 and identify possible capacity gaps at airports. However, this approach is not a true forecast in itself, because it lacks differentiation of growth rates between regions of the world and redistribution of traffic that exceeds airport capacity. The approach serves to identify possible gaps in runway capacity with regard to the underlying growth scenario.

2. CURRENT AIRPORT CAPACITY SITUATION WORLDWIDE

In this section we give a brief overview of the airport capacity situation worldwide to motivate the development of a model to forecast runway expansion delays. For a more detailed presentation of the global airport capacity situation the reader is referred to e.g. Gelhausen et al. (2013), Reichmuth et al. (2011) and Wilken et al. (2011).

Figure 1 displays the cumulative distribution of aircraft movements at airports worldwide. There is a high concentration of air traffic on a rather small number of airports as indicated by a high value of the Gini-coefficient of 0.8: The largest 100 airports (4.1%) already handle 51% or 28 m aircraft movements and the largest 1000 airports (41%) handle 95% (52 m) of all aircraft movements at 2438 airports in 2008.

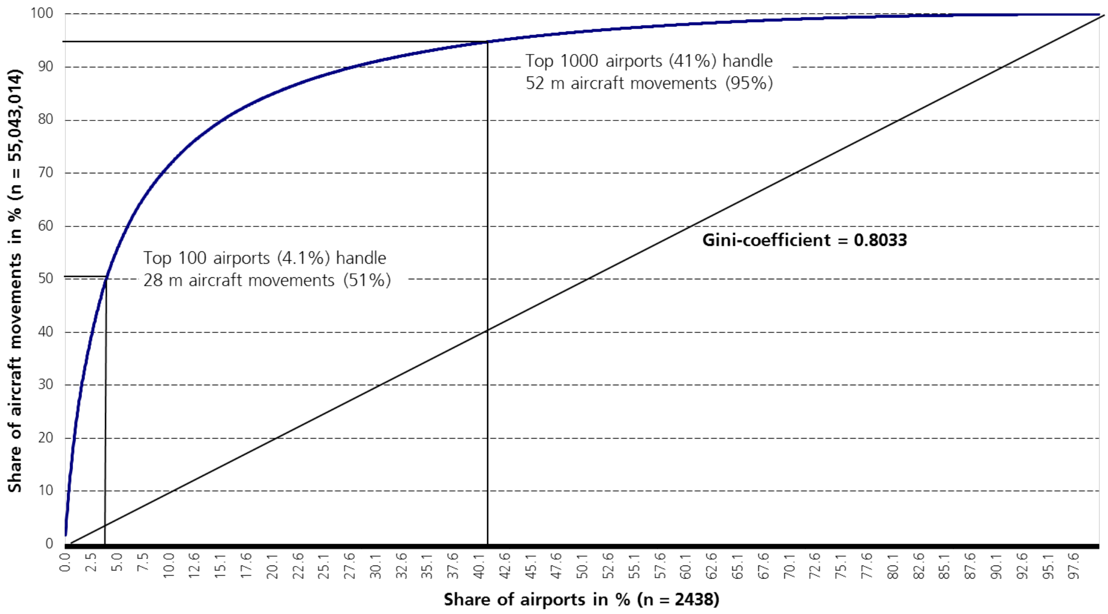

Figure 1: Cumulative distribution of airport traffic in the year 2008 (Gelhausen et al., 2013; data from OAG, 2008)

Figure 2 shows the traffic development in Europe and at two congested European hubs, Frankfurt and London Heathrow, between the years 2000 and 2010. Here, the year 2000 serves as a reference basis (2000 = 100). Because Frankfurt and London Heathrow are near or at their capacity limits, they have only partially participated in the general market growth since 2000, as free slots are only available at unattractive times such as night times or weekends. Since the year 2000, the number of departures increased on average by 20% at European airports. However, the number of aircraft movements only increased by 11% at Frankfurt and 3% at London Heathrow and remains virtually constant since 2006. The number of aircraft movements only dropped in 2009 because of the global financial crisis, but recovered quickly thereafter. Furthermore, the number of flight movements dropped less at Frankfurt and London Heathrow than in Europe overall, emphasising the tight capacity situation. A fourth runway was opened late in October 2011 at Frankfurt, so that the airport can participate again in the general market growth since then. However, the gain in runway capacity is released stepwise over time. In this paper, Frankfurt (with three runways) and London Heathrow therefore serve as examples for airports that are operating near or at their capacity limits.

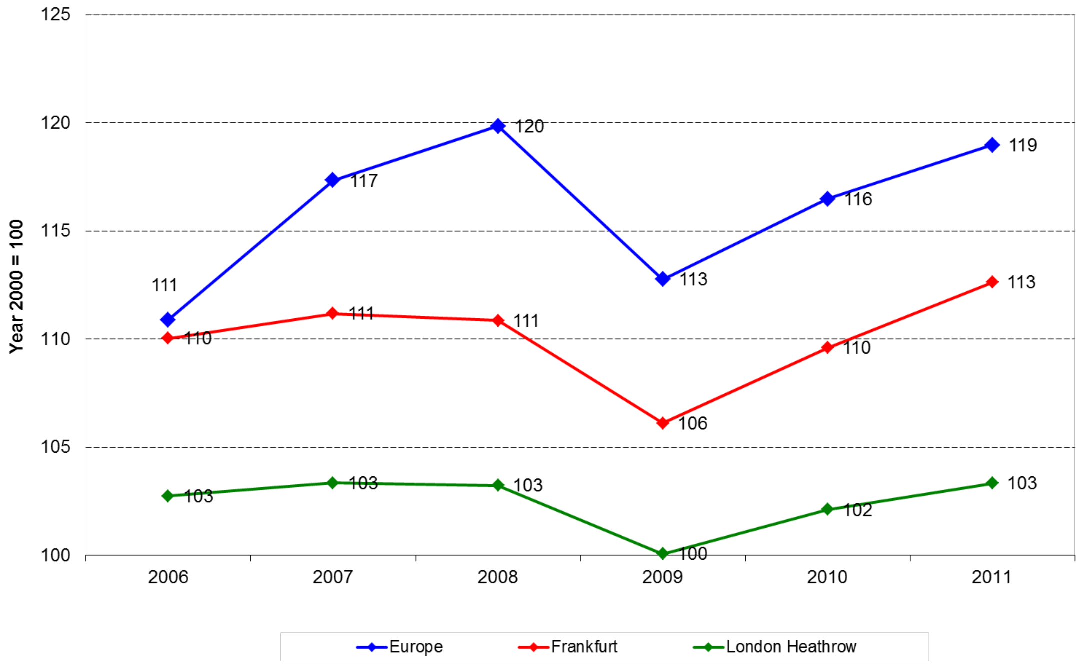

Figure 2: Air traffic development in Europe and at London Heathrow and Frankfurt airport 2006-2010 (OAG, 2000-2012)

Figure 3 shows the capacity utilisation index values (CUIs) for the top 1000 airports worldwide as well as the portion of the total global flight movements they serve (left y-axis). The CUI is an indicator of airport capacity utilisation and is defined as the ratio of mean hourly flight volume to 5% peak hour flight volume (Reichmuth et al., 2011). The majority of the airports (> 900) range in the lower left section of Figure 3, i.e. they show a low CUI and they only serve a small share of the total global flight movements. Another cluster of airports is located in the upper right section of Figure 3. Airports of this cluster show a high CUI value and they serve a notably larger share of the total global flight volume. Almost all of these airports are hubs, which are important for the global air traffic network because of the large number of origin-destination connections they create. However, it is difficult to define a theoretically exact discrimination value for the CUI to separate congested airports from such which have ample capacity reserves. Congestion is a rather sneaky process which gradually increases with traffic volumes. However, from empirical observations we suggest that values in a range of about 0.65 to 0.70 serve as an indicator of significant congestion problems. This is also supported by the examples of Frankfurt and London Heathrow in Figure 2. In this range of CUI values, we find airports such as London Heathrow (CUI = 0.85), Frankfurt (CUI = 0.74), Paris Charles de Gaulle (CUI = 0.70), Munich (CUI = 0.66), Vienna (CUI = 0.66) and Amsterdam Schiphol (CUI = 0.64). The solid line of Figure 3 represents the cumulative distribution of CUI values with regard to the share of the total global flight volume (right y-axis). For example, airports with a CUI value of 0.65 or less cover 55% of the total global flight volume and airports with a CUI value of 0.65 or higher cover 40% of the total global flight movements. Thus, the dots between CUI values 0.65 and 0.85 represent the airports that account for 40% of the global air traffic. As a result, Figure 3 shows that global air traffic is concentrated on a rather small number of large airports with a high degree of capacity utilisation and therefore only small capacity reserves (if at all), which is also revealed by the Gini-coefficient related to the CUI that is 0.49.

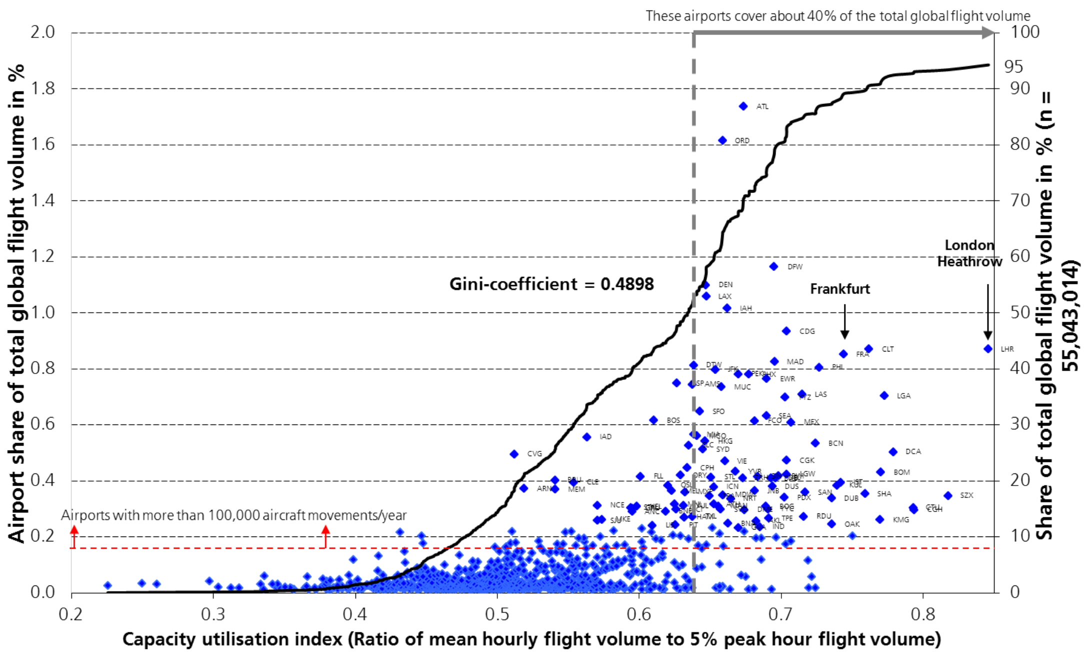

Figure 3: CUI with regard to airports' share of the total global flight movements (Reichmuth et al., 2011)

3. THE MODEL

If there is a current or future capacity gap at an airport, we need to analyse whether adding new runways is possible in time with regard to the demand development, and, if realisation is not in time, how long this process may be delayed. This analysis is conducted airport by airport and runway by runway. The econometric model employed is based on the idea that there is a particular degree of opposition to airport expansion from the population surrounding the airport. The degree of opposition depends on factors like noise annoyance, welfare level, economic opportunities, participation level and intermodal substitution. The degree of opposition may range from almost no opposition to such a degree of opposition that airport expansion is virtually impossible. The model determines the probability of realisation on the basis of discrete choice theory.

The approach used is a probabilistic one based on logit models (McFadden, 1974) and Markov chains (Markov, 2006). The key idea of the model is to estimate and transform the degree of opposition into an expected time delay of realising a new runway. The pros and cons of airport expansion have to be assessed and this depends on preferences that are different in various parts of the world, therefore the model comprises segments like North America and Europe. The model has been calibrated on a sample of 591 airports world-wide.

There are two distinct states at an airport in the Markov chain (Figure 4):

- Capacity constrained state
- Capacity unconstrained state

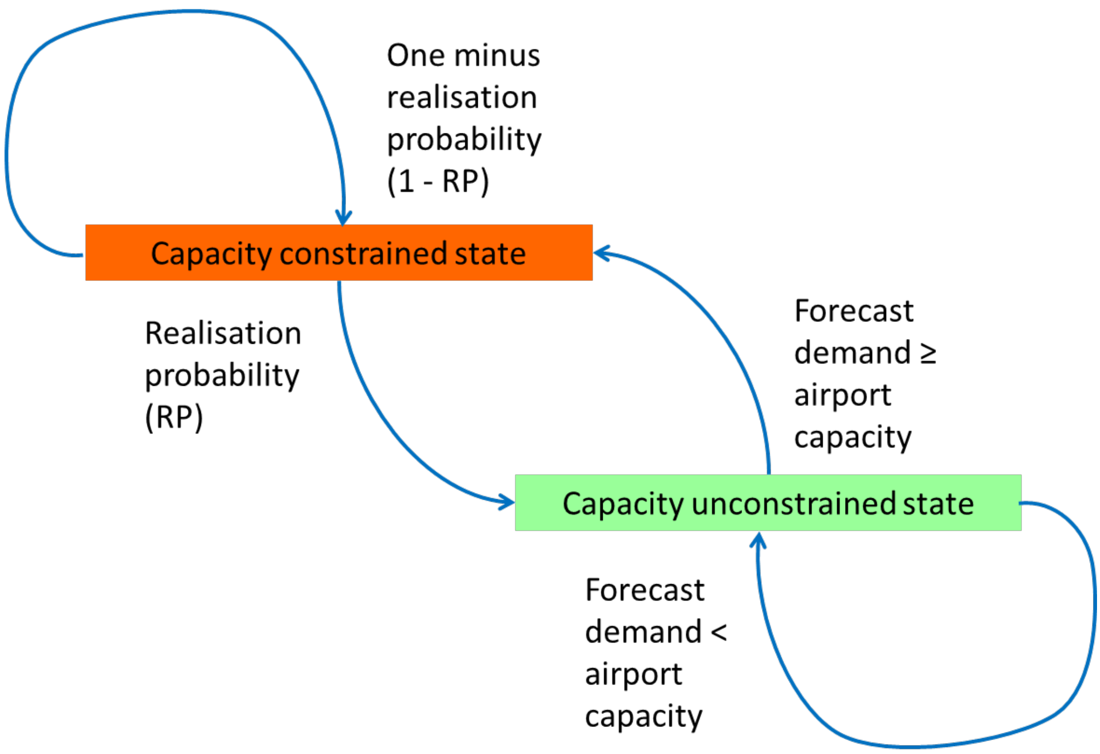

Figure 4: Markov chain of runway expansion

If an airport enters state one ("capacity constrained state") the binary logit-model (Figure 5) computes a so-called realisation probability (RP) of runway expansion at a capacity constrained airport, until state two ("capacity unconstrained state") is reached again. Thus, RP corresponds to a transition probability from a "capacity constrained state" to a "capacity unconstrained state" without any delay in the Markov chain. As a result, the expected delay of runway capacity expansion is the inverse of the transition probability minus one, because if RP is one, i.e. 100%, then there is no delay (Bhattacharyya and Johnson, 1977). The subtraction of one from the inverse of the transition probability is just a matter of definition, so that there is no delay if an airport becomes constrained during year t and becomes unconstrained in year (t+1). Entering state one is triggered by the underlying demand forecast and the current capacity of an airport.

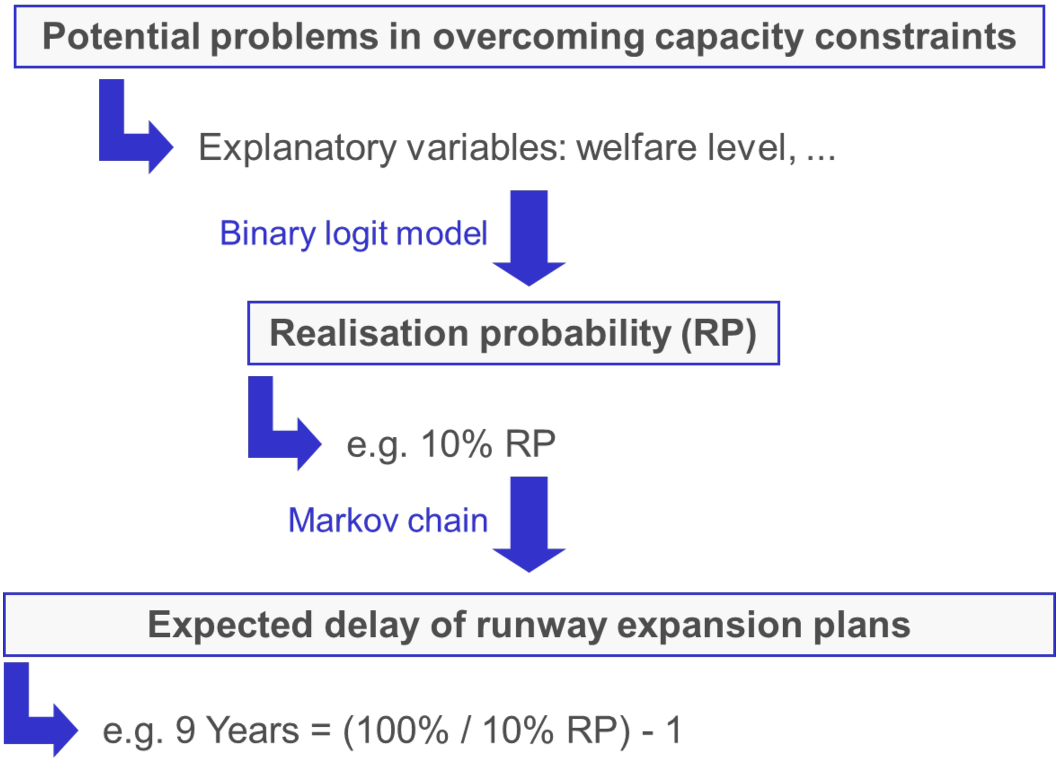

Figure 5: Realisation probability computed by a binary logit model

We have estimated the model on a cross-sectional data set to avoid problems of the availability of long time series data for some explanatory variables. For example, global high-resolution time series data of the population living in the airport neighbourhood for the past decades is basically unavailable. To illustrate the estimation approach and the relationship between RP and expected delay of runway capacity expansion we have built a very simple example. This example consists of 3 identical airports. These airports operate always exactly at their capacity limit even if their capacity has been recently enhanced. Let us assume that RP is 1/3 and as a result average delay is two periods. Figure 6 displays two possible random permutations. The symbol ”x” means that no enlargement has taken place and the symbol “o” means that the runway capacity has been enhanced in that period. Every row contains two ”x” and one “o” as a result of RP being 1/3. The two permutations have been “manually” created by shifting “o” one position to the right each period (Permutation 1) and two positions to the right (Permutation 2), respectively. After three periods one cycle has been finished and starts again (grey rows indicate cycle 2). Figure 6 shows, that every airport has an expected delay of runway capacity expansion of two periods. The same holds true for a combination of Permutation 1 and Permutation 2. However, in this case we have a delay of three periods for Airport 1, only one period for Airport 2 and two periods for Airport 3 in cycle

2. Nevertheless, expected delay is still 2 periods and this holds true for any combinations of permutations as long as RP is 1/3. Variance of the expected delay increases if the permutations are more non-systematic, but expected delay is still two periods if RP is fixed at 1/3. Needless to say that in our model RP is not fixed to a certain value but related to explanatory variables as listed in Table 1. As a result, unexplained variance is reduced considerably.

Period	Airport 1	Airport 2	Airport 3
1	x	x	o
2	o	x	x
3	x	o	x
4	x	x	o
5	o	x	x
...	x	o	x

Random Permutation 1

Period	Airport 1	Airport 2	Airport 3
1	x	x	o
2	x	o	x
3	o	x	x
4	x	x	o
5	x	o	x
...	o	x	x

Random Permutation 2

Figure 6: A simple example illustrating model estimation from cross-sectional data

From an empirical point of view, we have subdivided the model by different regions, so that the regions themselves are not too heterogeneous with regard to problems in overcoming capacity constraints. However, we had to balance the desire to make a larger number of more homogeneous regions against the fact that this results in statistically less significant results, because in some regions, significant capacity constraints and past airport expansions are rather rare events, especially in Region 3, (called "Others"). As a (from our point of view, good) compromise, we have chosen to subdivide the model into three regions:

- Region 1 (R1): Europe
- Region 2 (R2): North/Central America, Australia, New Zealand, Oceania, Japan, South Korea, Taiwan & Singapore
- Region 3 (R3): Others

The statistical results we have obtained from model estimation suggest that this subdivision is acceptable. The variables are in most cases instrumental, because a number of factors, such as noise annoyance, are difficult to measure directly on a global scale. Even welfare level, which is typically measured by GDP per capita or similar variables, is hard to capture in this model. E.g., in Europe, the range of GDP per capita is much wider than the welfare-related problems in overcoming capacity constraints. Furthermore, as this is a global modelling approach, the weakest link in the "data chain" is the bottleneck, i.e. data sources and level of detail need to be consistent across the countries modelled.

Realisation probability RP_{ij} of a runway expansion project i in region j is modelled by means of a binary logit model (e.g. Ben-Akiva and Lerman, 1985):

(1) $$RP_{ij} = \frac{1}{1 + e^{V_{ij}}}$$

(2) $$V_{ij} = \sum_{k} \beta_{kj} * x_{kij}$$

V_{ij} is a function that describes the level of opposition against runway project i in region j. It is the equivalent to the negative utility function in typical discrete choice models, because a higher value of opposition means a lower level of utility for the population around the airport. Hence, x_{kij} is the value of attribute k for runway expansion project i in region j and β_{kj} is the coefficient for attribute k and region j. Table 1 shows the coefficient estimation results by region (R1, R2 & R3). We have sampled 591 airports worldwide for model estimation. These sample airports were drawn according to their size and location to obtain representative results and avoid bias. For this purpose, the world has been subdivided into approximately 80 regions. The models differ by their explanatory variables to account for regional differences and the variables are highly significant (significant at the <= 1% level). Overall model fit, described by the pseudo-R^2, is high and is between 52% for R3 and 61% for R2. This roughly corresponds to an R^2 of linear regression of about 95% and higher (Domencich and McFadden, 1975).

Model	Variable	Coefficient		Pseudo R-squared	# of obs.
R1	AP1	-5.24534	***	57.84%	259
	AP2	-1.67711	***		
	POP10KM	1.5472E-06	***		
	ATM	3.6565E-06	***		
	BROAD	3.7298E-06	***		
R2	AP1	-6.63962	***	61.25%	97
	POP10KM	1.0389E-06	***		
	ATM	3.4042E-06	***		
	GGDP	-105.829	***		
	BROAD	0.00010021	***		
	TOUR	-0.340495	***		
	RAILKM	24.1668	***		
R3	AP1	-8.93214	***	51.67%	235
	AP2	-6.53189	***		
	POP10KM	8.909E-08	***		
	ATM	2.4019E-06	***		
	BROAD	4.942E-05	***		
	PART	5.38518	***		
*** Significant at the <=1% level				∑	591

Table 1: Results of parameter estimation

AP1, *AP2*, *POP10KM* and *ATM* are variables to describe the factor *noise annoyance*. *AP1* and *AP2* are binary variables that take values of 1 if the number of aircraft movements is below 100,000 per year and between 100,000 and 200,000, respectively (OAG, 2007-2012). *POP10KM* describes the number of people living within 10 km of the airport (Bright et al., 2008). *ATM* is the number of aircraft movements at an airport (OAG, 2007-2012). *BROAD* is a variable to describe the factor *welfare level*. *BROAD* is the number of broadband subscribers per 100 people (The World Bank, 2007). *GGDP* and *TOUR* are variables to describe the factor *economic opportunities*. *GGDP* represents the GDP per capita, purchase power parity (constant 2005 international $) growth rate (The World Bank, 2007). *TOUR* describes the receipts from international tourism as percentage from total exports (The World Bank, 2007). *RAILKM2* is a variable to describe the factor *intermodal substitution*. *RAILKM2* is the number of railway kilometers per square kilometer of the country (The World Bank, 2007). *PART* is a variable to describe the factor *level of participation*. *PART* is a binary variable and takes a value of 1 if the type of government conforms to democratic principles and a value of 0 if not.

Table 2 lists the standard errors of the forecast realisation probability for the R1, R2 and R3 models. However, to transform the values of Table 2 into more conceivable numbers we have constructed 80% confidence intervals according to expected airport expansion delay. We have chosen a rather low value of 80% (compared to typical 90% or 95% confidence intervals) to account for the naturally high complexity and thus uncertainty that is typical for the task of forecasting airport expansion delays in the long term. If we take a 90% or 95% confidence interval, upper and lower bounds of expansion delays become rather fuzzy.

Model	Standard error of forecast	80% confidence intervall (+/-)
R1	0.205401	0.016413
R2	0.264273	0.034614
R3	0.133262	0.011179

Table 2: Standard errors of forecast and 80% confidence intervals

Figure 7 shows the relationship between realisation probability and expected runway expansion delay as well as the 80% confidence intervals. The black solid line represents the relationship between realisation probability and expected runway expansion delay for all three models. The dotted lines with markers display the upper and lower bounds of the 80% confidence intervals according to the R1, R2 and R3 models. Taking the expected delay for the base scenario, the 80% confidence intervals form the lower and upper bounds and allow for optimistic and pessimistic scenarios to assess the degree of uncertainty in the base case. From Figure 7, we see that a rather precise forecast of airport expansion delay is possible until 10 to 15 years of delay. However, if the delay is beyond 15 years, the forecast loses precision considerably: Expansion delays may be a few years shorter in an optimistic scenario or much higher in a pessimistic scenario. If expected expansion delays are beyond 15 years, airport expansion is virtually impossible in a pessimistic scenario.

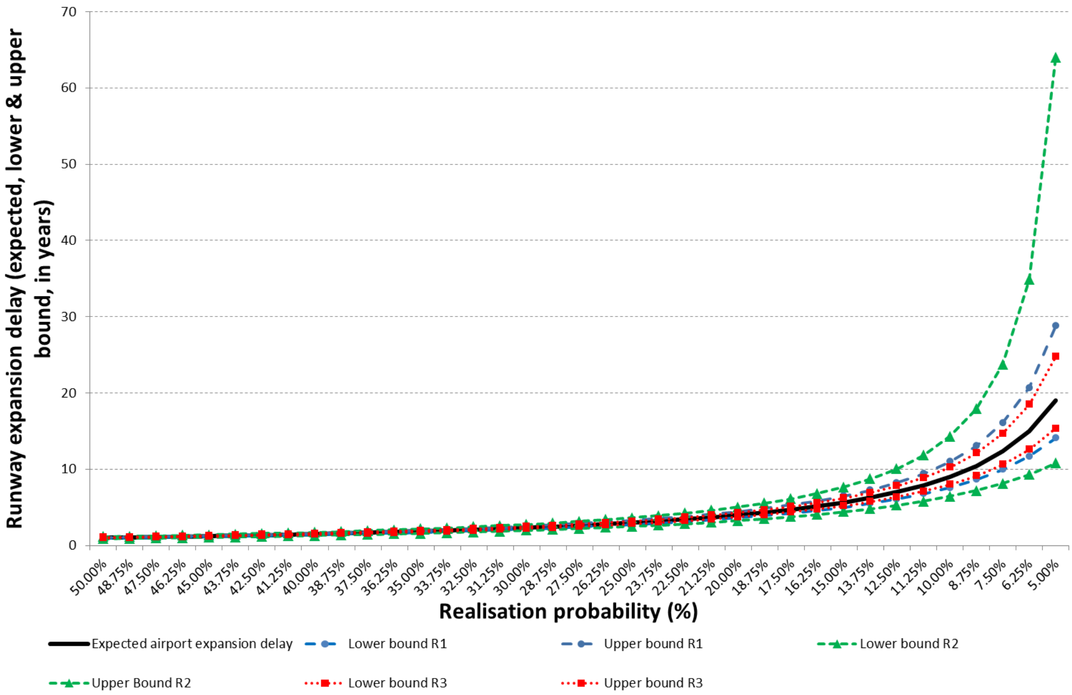

Figure 7: Realisation probability, runway expansion delay and 80% confidence interval

However, in a particular case study with a forecast horizon of 10 to 20 years and a very uneven distribution of airport sizes, i.e. a few numbers of very large airports and a large number of rather small airports, differences between a most-likely scenario and a pessimistic scenario are not necessarily as large as Figure 7 may suggest. For small airports, the difference in runway expansion delay between a pessimistic and a most-likely scenario is too small to shift a large number of runway expansions beyond the forecast horizon. For very large airports, the runway expansion delay is already in the most-likely scenario for many of these airports on such a high level, that runway expansions take place after the forecast horizon anyway. Therefore, the increase in runway expansion delay if we move to a pessimistic scenario does not necessarily shift a large number of extra runway expansion plans beyond the forecast horizon. This is a direct consequence of the high degree of concentration of air traffic on a rather small number of large airports (Figure 1).

4. THE IMPACT OF AIRPORT CAPACITY CONSTRAINTS FOR FUTURE GROWTH

To assess the impact of potential airport capacity constraints for future growth of air traffic, we apply a 3.5% CAGR to the 2012 traffic volumes for each of the largest 1000 airports worldwide (OAG, 2012). This value is slightly lower than CAGR of the past 20 years (3.6%; ICAO, 2005 & 2012). A 3.5% CAGR over a time span of 20 years means a growth factor of 1.99, i.e. virtually a doubling of traffic volumes. The largest 1000 airports handle about 95% of the global aircraft movements (see Figure 1) and this sample is large enough to comprise any airport that may suffer from serious capacity constraints for the next 20 years. Annual service volume of a particular runway system is calculated according to Gelhausen (2012), Gelhausen et al. (2013) and Wilken et al. (2011). Runways are added one by one at an airport; however, this assumption seems not to be too restrictive. If there is no opposition and thus no delay in airport expansion, adding runways one by one is basically identical to adding more than one runway at a time. However, if there is significant opposition to airport expansion, examples such as Frankfurt or Munich airports show that adding more than one runway at a time is rather unlikely.

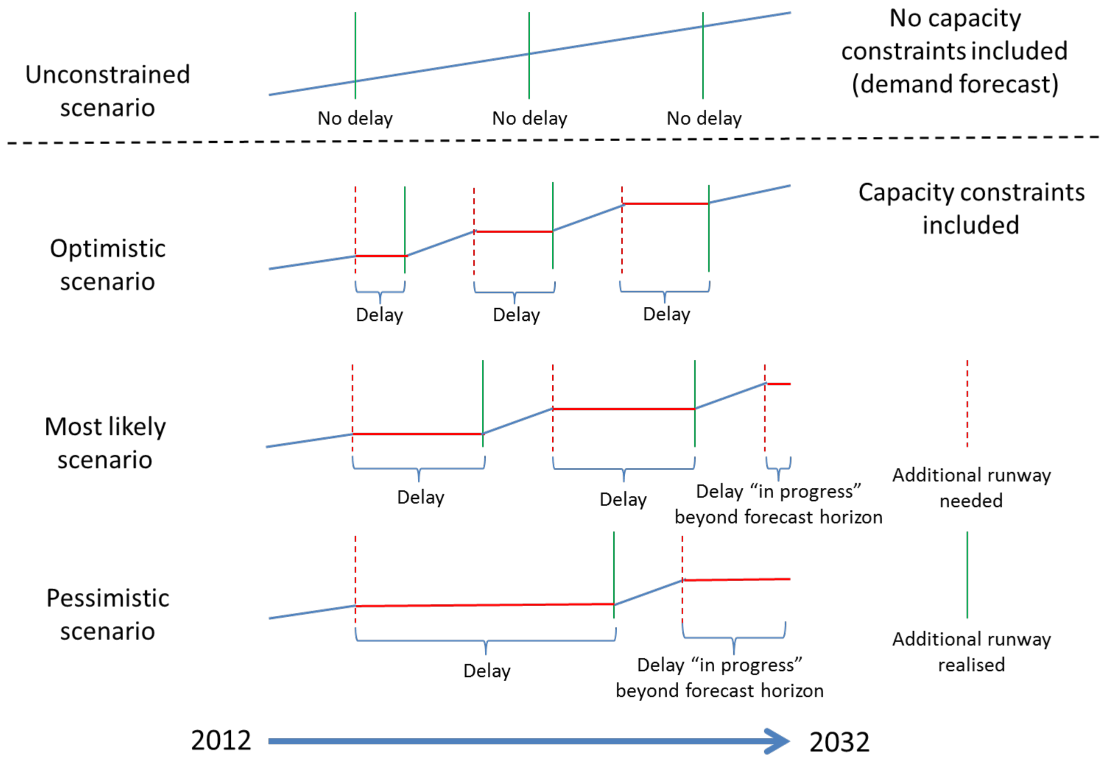

Figure 8: General structure of scenarios with relation to expansion delay characteristics

Figure 8 displays the general structure of the three scenarios with regard to the expansion delay characteristics. The unconstrained scenario is characterised by a situation of a CAGR of 3.5% of aircraft movements at all airports and no capacity constraints, so that there is always enough capacity to serve demand. The most likely scenario is defined by the parameter estimates of the model as described by Table 1, i.e. this scenario comprises the mean of the forecast delay (black solid line in Figure 7) and is therefore the most likely scenario. The optimistic and the pessimistic scenarios are defined by the upper and lower bounds, respectively, as displayed by Table 2 and Figure 7. That is, the forecast runway expansion delay at an airport lies between the optimistic and pessimistic scenario with a probability of 80%. Delays tend to be shortest in an optimistic scenario and longest in a pessimistic scenario. Furthermore, we assume that the piling up of demand during the phase of a runway expansion delay leads to a temporary increased growth rate when the delay has been dissolved. This assumption seems to be not too far from reality. If we look at Frankfurt in Figure 2, the projected annual growth rate between 20th October 2011 (opening of the new runway) until the end of the year 2011 is about 9%, whereas aircraft movements at all European airports grew by only 2% to 3% during 2011. The growth rate at Frankfurt after the opening of the fourth runway equates to a factor of 3 to almost 5 of the general market growth. Thus, to keep things robust and to accomplish a higher degree of comparability with unconstrained demand forecasts, we assume that the piling of demand is released instantly and completely if a delayed runway expansion is realised. However, this means that we conceptually move a step towards an unconstrained demand forecast, because there is no growth lost as long as necessary (multiple) capacity expansions are finished until the forecast horizon. Nevertheless, after a number of runway expansions, further enhancements are practically impossible because of the very high opposition. Overall, the model tends to underestimate the true effect of enhancement delays on traffic growth, if the piling of demand is not released instantly and completely if a delayed runway expansion is realised. Basically, it is possible to allow for more sophisticated growth scenarios, but in this case study they are omitted for reasons of confirmability.

Scenario	# of new runways	Capacity gap	CAGR (20 years)	# of delayed runway expansions	Mean / Standard deviation of delay (in years)
Unconstrained	107	0.00%	3.50%	-	-
Optimistic	76	2.09%	3.39%	76	10.9 / 21.0
Most likely	70	2.77%	3.36%	95	11.2 / 24.2
Pessimistic	65	3.23%	3.33%	85	16.3 / 30.0

Table 3: Model results of the three runway capacity constraints scenarios

Table 3 shows the results of model application to the demand forecast. To fulfil the demand forecast, 107 new runways at specific airports are needed until 2032. The unconstrained demand forecast serves as a benchmark against which the three scenarios with airport capacity constraints are compared. The capacity gap is defined as the percentage of flights of the unconstrained scenario that cannot be accommodated in a scenario with capacity constraints. In the most likely scenario, 70 of those 107 runways needed are realised until 2032. This means that there is a capacity gap of 2.77% of aircraft movements compared to the demand forecast. As a result, the CAGR corrected for capacity constraints is reduced from 3.50% to 3.36%. Altogether, there are 95 delayed runway expansions until 2032: 70 are realised until 2032 and 25 are still in progress (marked as “delay ‘in progress’ until forecast horizon” in Figure 8). Adding a new runway is on average delayed by 11.2 years with a standard deviation of 24.2 years. The high value of the standard deviation illustrates the uneven distribution of delays: there are 21 runway expansions that are delayed by 10 years or even more but about 60 runway expansions are delayed by 5 years or less.

In an optimistic scenario six more runways are realised until 2032. The number of delayed runway expansions is (by mere chance) the same as the number of realised runway expansions (= 76); however, those two entities are still not identical. There are some runway expansions, e.g. especially at small Chinese airports, that are actually not delayed and therefore not listed under the number of delayed runway expansions. Runway expansions that are still in progress beyond 2032 account for a capacity gap of 2.09%. CAGR corrected for capacity constraints is 3.39%.

In a pessimistic scenario only 65 new runways are finished until 2032. The number of delayed runway expansions decreases to 85, because the rather long delays tend to dampen the number of runway expansions that are realised or started but still in progress until the forecast horizon 2032. As discussed earlier in this paper, runways are added consecutively on the timeline at an airport. Average delay is 16.3 years with a standard deviation of 30.0 years. This leads to an overall capacity gap of 3.23% of aircraft movements compared to the unconstrained demand forecast and CAGR corrected for capacity constraints is 3.33%.

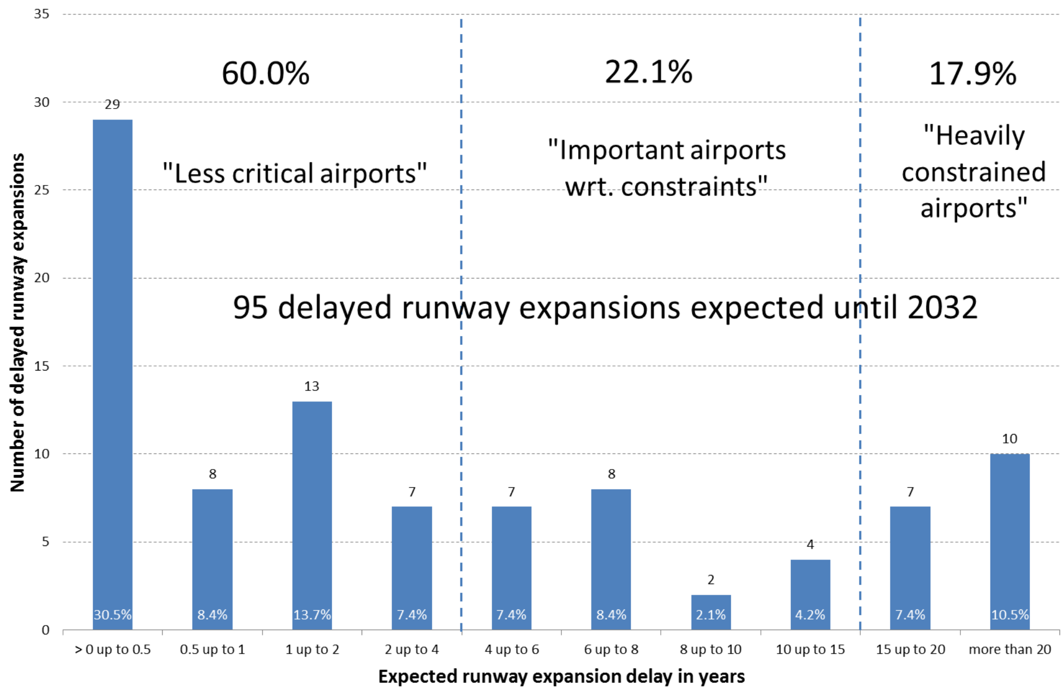

Figure 9: Distribution of delayed runway expansions (most-likely scenario) until 2032 (CAGR 3.5%)

Figure 9 displays the distribution of delayed runway expansions for the most-likely scenario in more detail. 60% of delayed runway expansions belong to the category ”Less critical airports” and capacity enhancements are delayed by up to four years. 29 out of 57 delays do not last more than half a year, i.e. these delays are virtually nonexistent. Most of these marginal delays take place at small airports, e.g. airports with a single runway that are upgraded to a two-runway system. On the other hand, 17.9% of delayed runway expansions belong to the category “Heavily constrained airports” that comprises delays of 15 years and more. 10 out of 17 delays are expected to last more than 20 years, i.e. major runway enhancements are virtually impossible. These are typically very large hubs like e.g. London Heathrow, Chicago O’Hare, Frankfurt or Paris Charles de Gaulle. Because of their high number of flights, they efficiently interconnect a large number of origin-destination pairs and therefore play an important role in the global flight network (e.g. Velduis, 2013). However, these airports are also those that are prone to long-lasting capacity constraints.

5. SUMMARY AND CONCLUSIONS

In this paper we have presented an econometric model that allows for forecasting the delay of runway expansions for airports worldwide, if demand exceeds capacity. The key idea of the model is that delayed runway expansions are a result of opposition due to negative effects of such plans on the airport neighbourhood. Factors of the model are noise annoyance, level of welfare, economic opportunities, intermodal substitution and level of participation. These factors are in turn modelled by instrumental variables such as the number of aircraft movements, the number of people living around an airport or the ratio of broadband subscribers. Because of the naturally high complexity and uncertainty that is typical for the task of forecasting capacity enhancement delays in the long term, we have included forecast confidence intervals to allow for different scenarios.

In the second part of the paper we have applied the model to a “simple” 20 years forecast that is characterised be an annual growth (CAGR) of aircraft movements of 3.5% at every airport worldwide. The aim of this approach is not to build a truly realistic forecast for every single airport, but to identify major runway capacity gaps that might affect any significant long term growth. Here, we have taken the unconstrained demand growth as a benchmark, against which three scenarios are compared. Therefore we have defined an optimistic, a pessimistic and a most likely scenario. These scenarios differ in their delay structure, i.e. delays tend to be longer in a pessimistic scenario than in an optimistic scenario. The most-likely scenario is characterised by most-likely values of the delays and thus positioned in between the pessimistic and optimistic scenarios. To fulfil the unconstrained demand growth, 107 new runways at particular airports are needed until the forecast horizon of 2032. However, depending on the scenario, only 65 to 76 of those runways are realised until 2032 and the great majority of these enhancements are more or less delayed. Furthermore, 31 to 42 runway expansions are delayed beyond the forecast horizon or are virtually impossible to realise. As a result, there is a capacity gap of 2.09% to 3.23% of aircraft movements that reduce CAGR to values between 3.39% and 3.33%.

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