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Practical airport demand forecasting with capacity constraint: methodology and application

E. P. Kroes
Den Haag and VU University of Amsterdam, The Netherlands

Abstract
Airports require demand forecasts for operational, tactical and strategic purposes. This chapter provides a description of a practical, operational methodology that has been developed to provide such demand forecasts, for horizons ranging from short term (next year) to long term (20 years ahead or more); and for regional airports as well as major international airports. The model system consists of three elements: a demand model, a supply model and an iterative procedure to take account of capacity constraints. The demand model uses three main components: a detailed data base describing existing passenger flows between air zones worldwide, a growth model describing expected relative increases in passenger flows and a discrete choice based competition model allocating passenger flows to different airports, airlines, air routes and alternative modes of transport. The supply model is essentially a three-dimensional cross-table of aircraft movements, distinguishing movements by size, technology class and time-of-day of departure. Starting from a detailed data base of existing aircraft movements, a simple aging method combined with incremental log-linear modelling provides estimates of future aircraft movements. A shadow-price mechanism is used to adjust demand and supply levels to fit within the limits of available runway and environmental capacity, if necessary. We have also described two applications of the methodology to Amsterdam Airport, one addressing long-term airport capacity issues and the other exploring the expected impact of an air flight tax for the Netherlands.

Keywords: air demand forecasting; airport competition; airport capacity constraint; time-series models; random utility models.
1 Introduction

A few decades ago air transport analysts have been using trend extrapolation (a simple form of time-series analysis) to obtain estimates of demand in the near future. Since then more advanced methods of time-series analysis have been applied, using causal factors such as economic development, as the key drivers of growth. The implicit assumption was still that the market shares of the airports under consideration would remain constant, even in the longer term. Such an assumption might be justified in a largely regulated environment.

However, in more recent years new dynamics and constraints have entered the system. Liberalization has led to more competition between airlines and airports. This dramatically increased competition between airports, airlines and alliances on the one hand, and led to serious airport capacity issues on the other, which made extrapolations of historic demand no longer adequate. Airport demand forecasts now need to take account of the many competitive elements and the physical and environmental constraints in addition to standard growth scenarios.

As a consequence discrete choice models have found there way to explain how choices of (potential) air passengers, reacting to a multitude of competing offers, affect airport traffic flows. Chapter 4 has given an overview of the various demand forecasting methods, while Chapter 5 has given an extensive description of the most advanced methods of airport choice modelling.

In this chapter, we have a somewhat more practical focus: here we describe how we use a combination of the different available methods to arrive at estimates of expected future passenger volumes for airports, whether regional or main airport. In order to do that we represent decisions by potential air passengers (the demand side: passenger numbers) and airlines (the supply side: aircraft movements) and their interaction, subject to external capacity constraints (physical, environmental); in other words an equilibrium model approach.

In this paper, we provide a brief description of the AEOLUS model and its main components. Then we report two applications of the model for Amsterdam airport: first to assess capacity issues and a range of policy measures for the planning horizons 2020 and 2040, and second to estimate the short and medium term impact of alternative flight tax measures in the Netherlands.

2 Approach

The formal objective of the air demand forecasting model described here was to develop a practical, operational tool capable of providing air demand forecasts at airport level, for planning and policy evaluation purposes. In addition to this fairly general objective a large number of requirements were specified, including the following (in random order):

- the model had to be strategic in nature and suitable for quick policy evaluation;
- the model had to be reasonably quick in terms of computing time and pragmatic in application;
the methodology had to be intuitive and transparent in its operation;

- the model had to take into account the competition between airports and airlines (including low-cost airlines and alliances) in North-West Europe;

- it had to take into account the landside accessibility of the airports under consideration;

- the model had to include competition with surface transport modes including high-speed rail where relevant;

- it had to take into account the effects of both airport capacity and noise constraints;

- the method should be suitable for assessing the implications of a range of policy measures (such as levies for specific market segments);

- the methodology should be capable of assessing the welfare effects of the capacity constraints and policy measures.

The combination of the objective and the many requirements has lead to a fairly simple modelling approach; it would have been impossible to include for instance state-of-the-art demand modelling techniques as described in Chapter 4 in the system, as the run-times would have become excessive. On the other hand the model system is unusually comprehensive, in that it includes also explicit supply-side modelling, and pragmatic, in that it uses whatever data is available and generates the missing detail where necessary.

The model considers worldwide traffic flows to, from and through the airports under consideration. The architecture of the simulation system consists of two modules: a module to forecast traveller choices (e.g. which airports to depart from? Which air route?) and a module to forecast airline choices (which mix of aircraft to use?). The traveller choice module requires current passenger counts and level-of-service data for calculating travellers’ preferences for the available alternatives in the current base year (in this example 2003). The airline choice module computes numbers of yearly flights per type of aircraft and per period of the day, also for the base year (in this example 2003; see Figure 1).

The observed numbers of passengers in the base year are extrapolated towards the forecast year (for instance 2020, in the example) using origin-destination (OD) specific growth factors that depend on expected economic and price developments between each OD pair. This is essentially a simple time-series model.

The distribution over departure airports, air routes etc. is calculated again in the travellers’ choice module, this time using the level-of-service anticipated for the forecast year. And the airline choice module is also calculated for the forecast year. The traveller choice module is connected to the airline choice module by an iterative loop, to meet any capacity constraints that may arise in the forecast year.
3 Demand forecasts

The demand forecasting method within the AEOLUS model contains three elements:

1. An observed base year passenger flow data base.
2. A growth factor model.
3. A traveller choice module.

The logic is as follows:

1. Starting point is the existing observed base year pattern of passenger flows: the numbers of passengers travelling from each origin to each destination through all airports and modes. No attempt is made to model this base year situation, to explain the frequency of air travel or the OD pattern (distribution). By working this way the model is by definition consistent with the base year statistics, and the complex interactions that exist within the base year demand profile are retained without explicitly trying to capture them.

2. Growth factors are then used to extrapolate the base year OD pattern to new year \( t \) volumes. This is done by using demand elasticities for key drivers of air travel volume, such as GDP. The elasticities are applied using OD specific developments in the drivers, and separately for different journey purposes. By combining 1 and 2 a new modified OD matrix is obtained for the target year.

3. The traveller choice module reproduces the decisions of the air passengers, and in particular how those affect the market shares of different airports under consideration. The module is applied both for the base year and for the forecast horizon, to obtain a factor that indicates the increase or decrease in market share. This module simulates the expected change in competitive
position of the airports under consideration, as a function of changes in the air network (destinations, frequencies, alliances, hub-structure), air fares and also surface accessibility.

All three elements are used in combination to obtain the ultimate demand forecasts:

\[ V_{ijp}^t = V_{ijp}^b \times \text{Fac}_{ijp}^t \left( \frac{P_{ijp}^a}{P_{ijp}^{ba}} \right), \]

where: \( V_{ijp}^t \) = volume of air passengers in year \( t \);
\( i = \) origin zone;
\( j = \) destination zone;
\( p = \) purpose;
\( V_{ijp}^b \) = volume of air passengers in base year \( b \);
\( \text{Fac}_{ijp}^t \) = growth factor of passenger volume from year \( b \) to year \( t \);
\( P_{ijp}^a \) = proportion of air passengers using airport \( a \) in year \( t \);
\( P_{ijp}^{ba} \) = proportion of air passengers using airport \( a \) in base year \( b \).

Each of these elements is described in some more detail in the subsequent sections.

### 3.1 Traveller choice module

The traveller choice module simulates the number of long-distance trips that travellers make between all airports worldwide, which are represented in origin and destination zones. And in particular, it calculates how these trips are distributed over the wide range of available choice alternatives.

The total number of zones worldwide is typically some 100, with the geographic coverage of the origin and destination zones being relatively small within the catchment area of airport(s) under investigation. The zones become larger for destinations within the same continent when distances to the airport increase, and the zones are very large for intercontinental trips.

For trips with an origin (or destination) within the catchment area of the airport(s) under consideration, the model forecasts the market shares for each of the possible departure (or arrival) airports in this region (see Figure 2 for an example of the airports in the catchment area of Amsterdam airport) and the market shares of the modes used to access (or egress from) the airport. For trips with an origin (or destination) inside the catchment area of the airport and with a destination (or origin) somewhere else on the same continent, the model forecasts the distribution over the available main modes as well: car, train (high-speed) and aircraft. This specific structure reflects air passenger choices among competing departure and hub airports in north-west Europe in a straightforward way.
Figure 2: Assumed catchment area of Amsterdam airport.

The market shares of the available combinations of travel alternatives are determined by simulating traveller choices at up to three levels (see Figure 3):

![Diagram of traveller choices]

Figure 3: Traveller choices.
1. The choice between main modes of transport from O to D: car, train (high-speed) or aircraft.
2. The choice between available air routes, specified by departure airport, airline or alliance, direct flight or indirect flight via a hub.
3. The choice between access modes to the airport: normally car or train.

Not all choices are modelled for each OD combination, see Table 1.

Table 1: Choices that are modelled for each origin–destination combination.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Catchment area</th>
<th>Rest of Europe</th>
<th>Rest of world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>(Out of scope)</td>
<td>Main mode choice; Route choice; Access mode choice</td>
<td>Route choice; Access mode choice</td>
</tr>
<tr>
<td>Rest of Europe</td>
<td>Main mode choice; Route choice; Egress mode choice</td>
<td>Route choice</td>
<td>Route choice</td>
</tr>
<tr>
<td>Rest of world</td>
<td>Route choice; Egress mode choice</td>
<td>Route choice</td>
<td>Route choice</td>
</tr>
</tbody>
</table>

The AEOLUS model uses random utility models, in this case standard nested logit [1], to simulate the traveller choices. Travel times, waiting and transfer times, travel costs, and service frequencies are the main determinants of choice included in the utility functions. The coefficients have been inferred from a number of previous studies, and a large number of alternative-specific constants are calibrated from base year air passenger statistics for airports in the catchment area.

### 3.1.1 Access mode choice

Two alternatives are typically included here: car and train (if available, or coach). Generalized costs for the car mode are determined by fuel cost, parking cost and travel time. Travel times are converted into generalized cost by means of multiplication by a value-of-time depending on the travel purpose (business or non-business). Generalized costs for the train mode are determined by the train fare and generalized train travel time. Travel fares and times are taken from an input file with surface access level-of-service information for all departure airports in the area under consideration.

The same model is used to model the egress mode in case the destination of the trip is within the catchment area (backward journey).

### 3.1.2 Route choice

The choice alternatives are defined by airline (e.g. Skyteam, Star Alliance, OneWorld, low-cost airlines, other airlines), by hub (direct flight, or one of the
64 international hubs considered) and by access/egress airport (only if origin or destination is within the catchment area). The utility of each alternative is determined by the logarithm of the number of flights per week, by a generalized cost term (determined by an assumed ticket fare and flight time (with an extra penalty for an indirect flight)) and by an accessibility term for the airport (only in catchment area). This accessibility term is the logsum of the access mode choice model. Air level of service information including destinations served, flight frequencies, fares, flight times, interconnections, etc. are taken from an input file. This has been prepared using Official Airline Guide (OAG) [2] flight data and a fares model.

### 3.1.3 Main mode choice

There are three choice alternatives here: car, train (high-speed) and aircraft. The utilities for the first two modes are determined by travel cost (fuel or train fare) and generalized travel time; the utility of the air alternative is determined by the logsum of the route choice model. Level of service for car and (high-speed) rail is obtained from international surface transport network data.

### 3.1.4 Air Freight model

In addition to the passenger demand model, a small air freight demand model can also be used. In this model both the volume of air freight and its distribution among alternative airlines and full freighters and belly-freight can be simulated.

### 3.2 Observed base year OD matrix

Another key component of the demand model system is the observed base year pattern of air trips. This is derived from a combination of different sources:

- passenger surveys on airports (e.g. the ‘continuous survey’ carried out at Amsterdam airport);
- detailed passenger statistics (annual volumes by destination) published by airports;
- other international sources of information on surface transport.

In the ideal case complete and accurate information for all OD flows should be available, for all airports, airlines/alliances, air routes, surface transport modes, etc. In practice this is often not available, or only in the form of aggregate information. Our pragmatic solution for this has been that we have used detailed passenger survey data for a single airport in combination with the traveller choice model described above, to estimate the missing OD information for the other airports.

In short the procedure works as follows. The unobserved volume for an airport \( k \) is calculated by multiplying the observed volume \( l \) by the ratio between the simulated market share of alternative \( k \) and \( l \):

\[
V_{\text{unobserved}}(k) = (\text{Market share}(k) / \text{Market share}(l))V_{\text{observed}}(l).
\]

If the simulated market shares for airport \( l \) are not too close to 0 this generally gives credible results. This method is described in some more detail in [3].
In practice, obtaining a reasonable accurate ‘observed’ base year OD matrix is often a substantial activity, which requires a major effort. And the result will inevitably be subject to some error. But when one makes sure that all available information is taken into account, that at least a fairly accurate source of OD information for one important airport is included, and that the marginal distributions for all airports are checked against the published statistics (and corrected where necessary), this forms a reasonable starting point for the modelling procedure.

3.3 Growth factor model

The growth factor model provides factors which are applied to the observed base year passenger volumes to obtain the future year OD matrix. The specification is simple:

\[ \text{Fac}^\prime_{ij} = \left( \text{Driver}^\prime_{dij} / \text{Driver}^b_{dij} \right) \text{Elast}_{ij}, \]

where:
- \( \text{Elast}_{ij} \) = Demand elasticity for Driver d, OD pair \( i-j \) and purpose \( p \);
- \( \text{Driver}^\prime_{dij} \) = Driver of demand growth d, OD pair \( i-j \) and purpose \( p \).

This procedure is applied on a year-by-year basis, for as many years as are necessary. We use the following drivers of growth:

- population size for purpose leisure;
- GDP for purpose leisure;
- trade volume for purpose business;
- price for purposes leisure and business.

For OD relations, we take the average of the drivers’ values for origin and destination zone.

Because the values of driver growth are often different for different OD pairs (e.g. expected future GDP growth for Asian zones is much higher than for European zones) the structure of the OD matrix is modified by the application of this growth-factor procedure.

4 Supply forecasts

Often a substantial growth of air traffic is predicted. The resulting numbers of aircraft movements in the coming 10 to 20 years often exceed the current runway capacity. Furthermore, the amount of noise generated by aircraft may exceed existing legal boundaries. And the same may hold for other environmental emissions. To take these effects into account, we developed an airline choice module that simulates the deployment of a mix of different aircraft to transport the passenger volume as predicted by the traveller module. This module distinguishes three dimensions:

1. the size of the aircraft (nine classes);
2. the technological status of the aircraft (five classes);
3. the time-period of departure/arrival (four periods per day).
This results in 180 possible combinations. We have used observed base year distributions, and foreseeable trends to predict the future distribution of aircraft over these 180 combinations. One such foreseeable trend is the future renewal of the aircraft fleet, based upon a simple aging model. From this distribution, we infer the implicit preference utility values for each of the combinations (the table is seen as a log-linear model, where each cell has an associated utility which can be inferred from its share). When for instance airport charges are introduced, these utilities are modified (costs per seat are computed and converted into utility values, and added to the base utility using an assumed cost coefficient). This type of application is similar to the well-known incremental logit-modelling approach, described for instance in [1]. After modification of the utilities new shares can be computed, and new distributions over the possible combinations can be determined (Figure 4). This enables us to simulate how autonomous developments (through aging of the fleet), capacity constraints (through shadow cost) or policies (through actual cost increases) modify the distributions of aircraft used.

An estimate of the total number of aircraft movements (per year and per period of the day) and the total environmental burden (i.e. the amount of noise generated by the departing and arriving aircraft) can be calculated using this airline choice model.

![Figure 4: Structure of the airline choices module.](image)

### 4.1 Forecasting demand and supply

For the base year the passenger choice and the airline choice module are run once to calculate a base scenario. The output values for the number of passengers, the number of flights and the volume of noise produced are calibrated using correction factors to match the observed values in the base year. Typically only small corrections are necessary.

For the forecast year we specify:
• the expected changes in air level-of-service (increase of flight frequencies, change in air fares, flight times typically remain constant);
• the expected changes in level-of-service of the land modes (fuel cost, train fares, travel times);
• the expected change in value-of-time (due to real increase of incomes);
• the expected changes in the airlines’ preferences for the deployment of aircrafts of certain sizes (due to the availability of larger aircraft);
• the expected changes in the airlines’ preferences for the deployment of aircrafts of certain technology (due to the availability of newer and more quite aircraft). For this we use a simple fleet aging and replacement model.

The number of travellers in the forecast year travelling between an origin and a destination zone are determined by applying a growth factor to the number of travellers in the base year. For non-business travellers this growth factor depends on population growth in the origin zone, real GDP per capita growth in the origin zone and the price growth in both origin and destination zones. For business travellers, this growth factor depends on trade growth between the origin and destination zone and price growth. Price elasticities are within the ranges indicated by Brons et al. [4].

The passenger choice module is then run again to determine the market shares of the available alternatives in the forecast year. Consecutively, the airline choice module is run again to calculate the number of aircraft movements and the amount of generated noise in the forecast year.

5 Capacity constraint

If demand in the forecast year exceeds supply, during any of the time periods considered, a capacity constraint procedure is necessary in order to establish a consistent equilibrium solution. In the model system this works as follows. If the total number of aircraft movements exceeds either the physical (runway) capacity or the legal environmental noise limit, an iterative procedure is started (Figure 5). In each iteration the passenger airfares are increased by a shadow cost, so that demand is reduced and airlines that fly with larger aircraft and/or from airports with less severe capacity constraints become relatively more attractive. In parallel, charges for the airlines stimulate the use of larger and more modern (i.e. less noisy) aircraft. This iterative procedure is repeated until the demand (passengers converted into aircraft movements) can be accommodated within the capacity limits.

The user of the AEOLUS model can choose between two options for the way the shadow costs are allocated: slot allocation based upon slot trading, or a system based on grandfathering rights. The first option allocates a charge to each aircraft movement, independent of the airline. Since these costs are partly transferred to the passengers by increased air fares, the final distribution of slots will favour those airlines (and those passengers) that have the highest willingness to pay for such a slot. This simulates a free slot trading system where airlines may win and loose slots.
Figure 5: Iterative procedure.

The second option keeps the number of flights per airline in the base year fixed. This means that slots that have been allocated to an airline in the past, can not be transferred to another airline (this is called the system of grandfathering rights). Any remaining slots that have not been allocated in the base year are distributed over the airlines proportional to their demand for additional slots. However, a small number of slots are given to the smaller airlines to simulate the current policy to stimulate new entrants in the market.

In case of slot trading, the shadow cost is (partly) dependent on the amount of noise that an aircraft generates in case the noise limitations are exceeded. This stimulates the choice for newer types of aircraft. In case of a slot allocation system with grandfathering rights there is no dependency of the scarcity charges on noise production, and hence no incentive to use newer and less noisy aircraft.

The model also takes the runway capacity limits on competing main airports into account to prevent unrealistic predicted growth on these airports as a result of the limited capacity on the main airport(s) under consideration.

6 Case study 1: Amsterdam airport capacity planning

The AEOLUS model has originally been developed and applied for the Dutch Ministry of Transport, Public Works and Water Management, under supervision of aviation experts from airports, airlines and the national economic research centre. The case study reported here investigated what possible capacity problems might arise for Amsterdam airport (Schiphol) for the years 2020 and 2040, under four different macro-economic and technological scenario assumptions. The welfare effects were evaluated, and a series of 14 different policy measures was investigated to mitigate the adverse societal effects.

The results of this study were used as an input for the scenario policy assessment that the Ministry of Transport, Public Works and Water management together with other ministries completed on the future of Amsterdam Schiphol
airport. This assessment was a key input to the new Dutch government policy decision concerning the future of the airport.

The scenario assessment is based on macro-economic scenarios for the Netherlands that were developed by the Netherlands bureau for economic policy analysis [5]. The implications of these four scenarios for air travel through Amsterdam airport are summarized in Figure 6.

![Figure 6: Four futures for air travel in 2020.](image)

The two dimensions in Figure 6 represent possible orientations of economic development for Europe and the Netherlands:

- Emphasis on private responsibilities or on public responsibilities?
- Emphasis on international cooperation or national sovereignty?

Figure 7 shows the predicted numbers of flights in 2020 for all four scenarios for each of the three assumptions:

- no runway or noise restrictions, which represents the unconstrained potential demand for air travel on Amsterdam airport;
- the current policy scenario, with existing runway and noise restrictions, and with a slot allocation system based on grandfathering rights;
- an alternative capacity constrained scenario, with a new slot allocation system based on slot trading.

For the two high economic growth scenarios (Global Economy and Transatlantic Markets) the potential demand in 2020 exceeds the existing capacity constraints, in particular the noise limits. The slot trading system is clearly more efficient in that it is able to accommodate more flights within the existing noise capacity constraints. This is mainly due to the fact that this system has noise-generation dependent scarcity charges that stimulate the use of new and more quite aircraft.
Other charging schemes and policies that have been simulated are reported in [6].

7 Case study 2: The impact of air flight tax in the Netherlands

In 2007 Dutch Government decided to levy a tax on air flights to and from all airports in the Netherlands. The objective was to generate 350 million Euro per year. But the exact implementation was still under discussion: it was not yet specified which travellers would pay and which would be exempt from this tax. The Dutch Ministry of Finance commissioned a study to investigate the expected effects, and to decide about the preferred specification of the tax. The AEOLUS model was used for this. In this section, we discuss five of these alternative implementations.

Sixteen alternative versions of the ticket tax have been studied. These versions differed in the amount of tax that each of the segments (departing passengers, transferring passengers, freight) had to pay. In all versions, the total amount of tax collected per year was 350 million Euro. In the remaining of this section, we discuss five of these versions. Since this chapter concentrates on passenger choices, we have only selected versions with no tax on freight (Table 2). The names of the versions correspond to the names in the original report [7].

The AEOLUS model simulates the effects of the ticket tax in 2011 by increasing the fare of air travel starting from the year of introduction of the tax, 2008. Four macro-economic scenarios were simulated, the same as the ones mentioned in the previous section.

Figure 7: Model forecast of the number of flights per year in 2020 for the four scenarios for three cases (no capacity constraints, slot allocation based on grandfathering rights and slot allocation based on free trading).
Table 2: Effects of ticket tax (introduced in 2008) for the year 2011.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Tax per departure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European destinations</td>
<td>€ 23.00</td>
<td>€ 16.67</td>
<td>€ 12.50</td>
<td>€ 13.75</td>
<td>€ 9.50</td>
</tr>
<tr>
<td>Intercont. destinations</td>
<td>€ 23.00</td>
<td>€ 37.50</td>
<td>€ 47.50</td>
<td>€ 13.75</td>
<td>€ 21.38</td>
</tr>
<tr>
<td><strong>Tax per transfer</strong></td>
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<td></td>
</tr>
<tr>
<td>Europe–Europe</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>€ 13.75</td>
<td>€ 9.50</td>
</tr>
<tr>
<td>Europe–ICA</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>€ 13.75</td>
<td>€ 15.44</td>
</tr>
<tr>
<td>ICA–ICA</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>€ 13.75</td>
<td>€ 21.38</td>
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<tr>
<td><strong>Amsterdam</strong></td>
<td></td>
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</tr>
<tr>
<td>Total passengers</td>
<td>–10 to –12%</td>
<td>–8 to –11%</td>
<td>–8 to –10%</td>
<td>–19 to –22%</td>
<td>–26%</td>
</tr>
<tr>
<td></td>
<td>–13 to –12%</td>
<td>–11 to</td>
<td>–10 to</td>
<td>about –10%</td>
<td>about –9%</td>
</tr>
<tr>
<td>Dep. total</td>
<td>–14%</td>
<td>–12%</td>
<td>–11%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Dep. Europe</td>
<td>–15 to –12%</td>
<td>about –12%</td>
<td>–9 to –10%</td>
<td>–11 to</td>
<td>about –9%</td>
</tr>
<tr>
<td></td>
<td>–16%</td>
<td>–12%</td>
<td>–12%</td>
<td></td>
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<tr>
<td>Dep. interc.</td>
<td>–8 to –9%</td>
<td>–11 to</td>
<td>–14 to</td>
<td>–6 to –9%</td>
<td>–14%</td>
</tr>
<tr>
<td>Transferring</td>
<td>–5 to –8%</td>
<td>–5 to –7%</td>
<td>–4 to –8%</td>
<td>–37 to –39%</td>
<td>–44%</td>
</tr>
<tr>
<td>Total flights</td>
<td>–9 to –12%</td>
<td>–8 to –9%</td>
<td>–8 to –9%</td>
<td>–20%</td>
<td>–23%</td>
</tr>
<tr>
<td>Regional airports</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dep. passengers</td>
<td>–18 to –20%</td>
<td>–14 to</td>
<td>–11 to</td>
<td>–13 to –15%</td>
<td>–12%</td>
</tr>
<tr>
<td>Emissions (Amsterdam)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Noise (dBA)</td>
<td>about –0.3</td>
<td>–0.2 to –0.3</td>
<td>–0.2 to</td>
<td>–0.7 to –0.9</td>
<td>–0.3</td>
</tr>
<tr>
<td>Particles</td>
<td>–5 to –10%</td>
<td>–5 to –9%</td>
<td>–3 to –9%</td>
<td>–14 to –17 to</td>
<td>–19%</td>
</tr>
</tbody>
</table>

For the discussion of the effects of the ticket tax, we distinguish between departing and transferring passengers. Note that a transfer passenger has to pay the tax twice per journey, since he makes a transfer both during the outward trip and the return trip. Arriving passengers do not pay a tax. However, since most passengers buy a round-trip ticket, we assume that half of the tax applies to the outward journey and half of it applies to the return journey. Therefore, the effects on arriving passengers are in the model identical to the effects on departing passengers.
Version 1: Tax on departing passengers only

In this version, each passenger departing from a Dutch airport (except transfer passengers) has to pay a tax of €23. As a result, less travellers will use a Dutch airport as their departure airport. The number of departing passengers at Schiphol airport decreases by 10–12% in 2011 (depending on the macro-economic scenario, see Table 2). As a result, the number of flights will be reduced. This affects transfer passengers since they have fewer options to travel via Amsterdam. This results in a decrease of transfer passengers of 5–8%.

For European destinations the relative increase in air fare is larger than for intercontinental destinations. Hence, the decrease of the number of travellers that depart from Amsterdam to a European destination is larger than for an intercontinental destination (15–16% vs. 8–9%). Since the regional airports offer mainly European destinations, and they lack the segment of transfer passengers that do not have to pay a tax, regional airports are stronger affected than Amsterdam airport (decrease of total number of passengers of 18–20% for regional airports vs. a decrease of 10–12% for Amsterdam).

Version 1E: Differentiation between European and intercontinental destinations

In this version of the ticket tax departing passengers with a European destination have to pay a tax of €16.67, while passengers with an intercontinental destination have to pay a tax of €37.50. As a result, the decrease of the European market at Amsterdam is similar to the decrease of the intercontinental market (about 12%).

Version 1E-B: Further differentiation between European and intercontinental destinations

In this version of the ticket tax departing passengers with a European destination have to pay a tax of €12.50, while passengers with an intercontinental destination have to pay a tax of €47.50. As a result, the decrease of the European market at Amsterdam is less than the decrease of the intercontinental market (9–10% vs. 14–18%). Regional airports are less affected than in versions 1 and 1E: the decrease of the total number of passengers for regional airports is about the same as for Amsterdam airport (11–13% for regional airports vs.8–10% for Amsterdam).

Version 2: Tax on departing and transferring passengers

Transfer passengers pay the same amount of tax (per transfer) as departing passengers. In order to raise 350 million Euro per year, the tax level is set at €13.75. This results in a very strong decrease in the number of transfer passengers (37–39%). This is due to the fact that these passengers have to pay the tax twice per round journey, since they will make a transfer both during the outward and the return trip. Furthermore, these passengers have a large number
of good alternatives, because most of them can also choose to make a transfer at London Heathrow, Frankfurt or Paris Charles de Gaulle without paying extra tax or having to make a detour.

**Version 2E: Differentiation between European and intercontinental destinations**

This version is similar as version 2, but the amount of tax depends on the destination (tax for intercontinental destinations is about 2.25 times as high as for Europeans destinations). This has an even larger effect on transferring passengers (that are predominantly passengers with an intercontinental origin or destination). The decrease of the total number of passengers at Amsterdam airport is 20–26%, while the decrease at regional airports is limited to 9–12%.

**Effects of ticket tax on departing passengers**

In all versions presented, the number of passengers departing from Dutch airports will decrease. Instead, they will:

- depart from a foreign airport, where they do not have to pay the ticket tax;
- travel using another mode (either train or car). This is only an alternative for travel within Europe;
- decide not to travel at all.

Figure 8 displays the number of passengers (absolute number of passengers, as determined after averaging over the four macro-economic scenarios), who change their travel behaviour for each version of the ticket tax (departure and arriving together). The total number of passengers that no longer depart from/arrive at a Dutch airport (either Amsterdam, or at one of the regional airports) is equal to the number of passengers that either shift their departure/arrival to a foreign airport (about 45%), or shift to a different mode (about 10%) or no longer travel (about 45%).

![Figure 8](image-url)

Figure 8: Effect of ticket tax on passengers departing/arriving at Dutch airports (2011).
Effects of ticket tax on transfer passengers

Travellers that stop transferring at Amsterdam airport as a result of the introduction of the ticket tax will instead:

- transfer at another airport;
- shift to a direct flight;
- decide not to travel at all.

Figure 9 displays the effect on the number of transfer passengers at Amsterdam, Frankfurt and Paris Charles de Gaulle. In versions 1, 1E and 1E-B, the number of transfer passengers at Frankfurt and Charles de Gaulle reduces as well. These are travellers that would have departed from a Dutch airport and would have transferred at FRA or CDG if there would not have been a ticket tax. In versions 2 and 2E, the number of transfer passengers at Frankfurt and Charles de Gaulle increases. These are travellers that have diverted their route due to the ticket tax at Amsterdam airport.

![Chart showing the effect of ticket tax on passengers transferring at Amsterdam airport (2011).](image)

**Final implementation**

In order to mitigate the effects of the ticket tax on the airlines and airports (particularly on the regional airports), the Dutch government decided to implement a version that is very similar to version 1E-B. It was decided that the tax would be € 11.25 for all destinations within 2500 kilometres, including all EU member countries) and € 45 for other destinations. An exception is made for countries with destinations on both sides of the 2500 kilometres border. The low tax of € 11.25 also applies for other destinations in those countries, provided that they are not further away than 3500 kilometres.

This tax was implemented in the Netherlands on 1 July 2008, and its effects were quickly noticeable. The number of passengers departing from foreign airports increased substantially according to travel agencies. One of these agencies (D-reizen) reported an increase of 350% for their customers [8]. Amsterdam airport announced that their passenger growth would stagnate [9].
KLM expected to lose half a million to a million passengers in 2008 [10]. These effects were reinforced by the impact of the economic crisis that followed in 2008. Early 2009 the Dutch government decided to abandon the tax from 1 July 2009 onwards.

8 Conclusion

In this chapter, we have described a practical demand forecasting model that has been developed for strategic planning purposes. The model has been applied in several studies in the Netherlands, two of which have been described. But, the concept is generic and can easily be applied to simulate demand at airports elsewhere; for instance in other countries, both for main and regional airports. As an example, the model has been successfully implemented in 2007 for forecasting air passenger demand in France, in particular for the various airports in the Paris region.

Having discussed some of the main features and capabilities of the AEOLUS model system, it is also useful at this point to discuss some of its limitations.

1. First we would like to emphasize that the AEOLUS model presented here is a simple, pragmatic forecasting model that uses fairly straightforward methods. It is far from the state-of-the-art methodologies that are described for instance by [11]. That is related to its key objective, and to the requirements of transparency and intuitivity of operation.

2. Another limitation is the fact that the coefficients of several of the models have not been formally calibrated, but were ‘imported’ from other similar studies. To our defence, we can say that we have, of course, extensively tested the response characteristics of the model, and the resulting demand elasticities. Also our model has been audited by the Netherlands Bureau for Economic Policy Analysis, with favourable outcome. But empirically calibrated coefficients would still add further credibility.

3. Then the supply model, which is a very simple, again highly pragmatic heuristic that has no solid foundation in economic theory. Particularly the way in which the observed multidimensional distribution of aircrafts is modified in response to cost increases would benefit from further work, both in terms of methodology and use of marginal cost functions.

4. The equilibrium procedure: we use a heuristic iterative procedure that adjusts (shadow) costs and passes these on to demand (generalized cost of air passengers) and supply (marginal cost for airlines) until demand and supply are more or less in equilibrium. This problem could be re-specified as a multidimensional optimization problem that could be solved by means of dedicated solvers. In fact we have now implemented a new version of AEOLUS using the General Algebraic Modelling System (GAMS) [12] package.

A final issue that we want to raise is the fact that this type of model is quite demanding in terms of availability of data. Firstly, it requires extensive passenger survey information (including detail about trip origin, destination,
journey purpose, air route and socio-economic information) for at least one important airport under consideration, and ideally more. But also it needs detailed airside level of service information, which can be derived from the OAG database [2] and airport statistics. And landside level of service, which can be derived from surface transport networks for road and rail. In return, however, it also provides a mass of information, thus enabling a detailed assessment of future developments and possible impacts of policy measures.

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References

