AVIATION
2010
14(3): 90–94

INVESTIGATION OF EUROPEAN AIR TRANSPORT TRAFFIC BY UTILITY-BASED DECISION MODEL

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Received 13 August 2009, accepted 23 August 2010

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Abstract. Air transport was traditionally a strictly regulated industry, dominated by national flag carriers and state-owned airports. The global deregulation and liberalisation of air transport resulted in numerous changes, including the evolution of price competition, emergence of low-cost airlines, growth in load factor, airport and airspace capacity problems, etc. Later, the internal market eliminated all commercial restrictions for airlines flying within the European Union (EU). Constraints on routes, number of flights, regulated tariff policies, etc. were removed. Since the issue of the third liberalisation package, EU airlines are permitted to provide air services on any route within the EU. As a result, prices have fallen dramatically, especially on the most popular routes. The air transport sector has had the highest rate of development recently. These issues are discussed in the introduction of this paper. The main scope is to investigate air passenger transport within Europe and to present the mathematical formulation of a disaggregate airport choice model created by the authors. A complex utility function-based model has been developed and verified by the authors. The results of the model are in scope with experience in the real world.

Keywords: air passenger transport, utility, decision modelling.

1. Introduction

Air transport was traditionally a strictly regulated industry, dominated by national flag carriers and state-owned airports. The global commercial deregulation and liberalisation of air transport, which began in the USA at the end of the 1970s, resulted in numerous changes, including the evolution of price competition, emergence of low-cost airlines, growth in load factor, airport and airspace capacity problems, etc. Later the internal market eliminated all commercial restrictions for airlines flying within the European Union (EU). Constraints on routes, number of flights, regulated tariff policies, etc. was removed. Since the issue of the third liberalisation package, EU airlines have been permitted to provide air services on any route within the EU. As a result, prices have fallen dramatically, especially on the most popular routes. Over 130 scheduled airlines, a network of over 450 airports, and 60 air navigation service providers operate in Europe. The air transport sector employs more than 3.5 million people in the European Union (Oxford … 2009). Airlines and airports contribute more than 134 billion EUR to the European gross domestic product. Airports in Europe have spent 7.5 billion EUR annually on expenditures over the past 5 years. As for the future, there are plans to spend 8.1 billion EUR annually between 2006 and 2010 and 8.5 billion EUR annually between 2011 and 2015, 8 % and 13 % increases respectively. Figures published by the International Air Transport Association (IATA) on 27 March 2009 show that its 230 member airlines reported an overall decline of 10.1 % in international revenue passenger kilometres (RPKs) in February. This was intensified by the extra day last February, which means the adjusted decrease, is around 6.5 %. This is worse than the 5.6 % fall reported in January. For the second month running, only the Middle East managed to report a growth in international RPKs. However, the small RPK growth of 0.4 % was undermined by a 7.3 % increase in ASKs, resulting in an almost 5 % decline in load factor. The Far Eastern market for premium traffic was down 21.2 % in January. Although the economic recession has influenced this industry as well, air transportation is globally very important and influential, providing great benefits to society (Botond 2004).

2. Modelling airport choice behaviour

The attraction of an airport as a hub for passenger traffic is its ability to attract air transport companies to use this airport. Most airport operators are designing their strategies based on the stated preference of air transport companies. Researchers analysing the behaviour of air transport companies report no consistency between the stated and the revealed preferences of airlines concerning airport choice, however. It was therefore advised to involve in the modelling approach parameters mapping the level of usage of the port (revealed preference). See table 1.

Table 1. Yearly traffic data of airports investigated (Airport... 2007)

City	Airport	Passenger	Rank
Amsterdam	Schiphol	47,429,741	5.
Berlin	Tegel	13,357,741	30.
Brussels	Brussels International	17,838,214	23.
Budapest	Ferihegy	8,581,071	48.
Frankfurt	Frankfurt/Main	54,161,856	3.
London	Heathrow	67,056,228	1.
Madrid	Barajas International	50,823,105	4.
Munich	Franz Joseph Strauss	34,530,593	7.
Paris	Charles de Gaulle	60,851,998	2.
Stockholm	Arlanda	17,968,023	22.
Vienna	Schwechat	18,768,468	20.

Table 1 shows that the yearly traffic carried by the airports of the European cities investigated are internationally considerable. Our basic assumption in preparing the formulation of the model was that the choice of airport would follow the Logit distribution that has been shown to express best modal choice and other situations of choice in the transport field. It was also assumed that the above influencing factors could be related successfully to certain measurable parameters that can be used in an appropriate mathematical formulation.

2.1. Formula of the model

A simplified Logit model was used in order to model the airport choice situation described above. This has a standard formulation as shown in relation (1)(Bierens 2004; Bierens 1984; Veldman *et al.* 2003). In this model the dependent variable is the probability of airport choice as expressed by the ratio of passengers attracted per year to airport j divided by the total number of passengers destined to the investigated airports and originating in a given airport *i*. Therefore,

$$p_{ij} = \frac{e^{U_{ij}}}{\sum_{i=1}^{i=m}\sum_{j=1}^{j=m} e^{U_{ij}}}, \tag{1}$$

where

p_{ij} is the probability (defined as explained above) of choosing airport j while having airport i as the origin.

U_{ij} is the (total) utility function of passenger transport in choosing airport j (originating from airport i).

The utility function is defined as an additive linear function of the weighting functions and three utilities.

$$U = f(w_f, U_t, U_C, U_A), \quad (2)$$

One relates to the travel time between the origin (airport i) and the destination (airport j), another relates to the travel cost between the origin (airport i) and the destination (airport j), and yet another relates to the level of attraction (likely) to be offered by the destination airport (j). The exact formulation is shown in relations (3) and (4) below:

$$\overline{\overline{U}} = \overline{\overline{U_t}} + \overline{\overline{U_c}} + \overline{\overline{U_A}} + \overline{\overline{\varepsilon}}, \quad (3)$$

where:

U is utility matrix of destination choice from airport i to airport j;

U_t is time-utility matrix. The utility element relating to travel time from airport i (origin) to airport j (destination);

U_C is cost-utility matrix. The utility element relating to travel cost from airport i (origin) to airport j (destination);

U_A is attraction-utility matrix. The utility element relating to the *level of attraction* at the destination airport (j). After a thorough consideration of the various specific parameters that could best express this level of attraction, it was found that the best overall parameter would be *gross domestic product* and *number of inhabitants* in the destination city;

ε: error component of utility matrix.

Detailed (3) can also be expressed as (4):

$$\overline{\overline{U}} = \overline{\overline{R_t}} \cdot \overline{\overline{w_t}} + \overline{\overline{R_c}} \cdot \overline{\overline{w_c}} + \overline{\beta_{0j}} \cdot \overline{\beta_{1j}} \cdot \overline{w_a} + \overline{\overline{\varepsilon}} \quad (4)$$

where:

R_t is a matrix of *resistance* due to travel time between airports (see relation (5) below);

w_t is a parameter expressing the decision weight of travel time;

R_c is a matrix of resistance due to travel cost between airports (see relation (6) below);

w_c is a parameter expressing the decision weight of travel cost;

β'_{0j} is expresses the gross domestic product of the destination city (j);

β'_{1j} is expresses the number of inhabitants in the destination city (j);

w_a is parameter expressing the weight of attraction in the decision.

The *measure of resistance* due to travel between the airports, mentioned above, is calculated as (5) and (6):

$$R_{t_{ij}} = \frac{1}{t_{ij}}, \quad (5)$$

where t_{ij}, is the *travel time* between airports i and j

$$R_{c_{ij}} = \frac{1}{c_{ij}}, \quad (6)$$

where c_{ij}, is the *travel cost* between airports i and j.

As already mentioned, w_t, w_c, and w_a are weights of the utility function related to travel time, travel cost, and attraction.

2.2. Analysis of the travel time matrix using graph theory

Because of the specifics of air transport, travel distance and travel time to and from two cities may differ from each other. The error deriving from the difference is not significant; due to this, average travel distance and time has been used. The average length of the flight route has been used instead of the geographical distance. The travel time describes a user-centred system efficiency (Giannopoulos *et al.* 2008). In mathematics and computer science, graph theory is the study of graphs, mathematical structures used to model pair-wise relations between objects from a certain collection. A *graph* in this context refers to a collection of vertices and a collection of edges that connect pairs of vertices. In our case, we have the vertices as airports and the edges as routes between them. A graph may be undirected, meaning that there is no distinction between the two vertices associated with each edge, or its edges may be directed from one vertex to another. In the Euclidean space, the distance between two points is given by the Euclidean distance (2-norm distance). For point A (a_1, a_2,) and point B (b_1, b_2,), the distance between A and B is defined as (7):

$$d_{AB} = \sqrt{\left(\sum_{i=1}^{n} |a_i - b_i|^2\right)}, \quad (7)$$

In Cartesian geometry, the minimum distance between two points is the length of the line segment between them (8) (Szőkefalvi-Nagy 1972):

$$d_{AB} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}, \quad (8)$$

where:

x_j is the coordinates of the starting point of measurement,

y_i is the coordinates of the ending point of measurement.

This gives us the shortest straight distance between the two airports. We had to face the fact that the 2-norm Cartesian distance does not correctly describe the situation because the airplane cannot move on the shortest path. That is the reason why we have changed the Cartesian distance to *travel distance*. Travel distance describes the distance between airport *i* and *j* by the route between them. In our article, we did not take into account takeoff and landing time. The travel time can act as distance in a mathematical sense, and a symmetric travel time matrix between *m* airports can be developed (9):

$$\overline{\overline{D}} = \begin{vmatrix} 0 & d_{1j} & d_{1m} \\ d_{i1} & 0 & d_{im} \\ d_{m1} & d_{jm} & 0 \end{vmatrix} , \qquad (9)$$

where:

D is the overall distance matrix (symmetric, square matrix),
d_{ij} is the travel time between airport *i* and *j*.

This matrix is a symmetric one because $d_{ij}=d_{ji}$ and if i=j then $d_{ij}=0$. To build up a graph from the distances, we calculated the relative coordinates of the airports. We used multidimensional scaling (MDS) which is a set of related statistical techniques often used in data visualization. MDS is a special case of ordination. An MDS algorithm starts with a matrix (matrix of distances in this case) and then assigns a location for each vertex in a low-dimensional space suitable for graphing. Relation (9) describes the matrix of Euclidean distances, matrix D, based on the relative coordinates of airports (vertices) in the graph. This is how the computer calculates the place of vertices or airports compared to other vertices or airports. Since we used an MDS algorithm and the *travel time* distance between the airports instead of the Euclidean ones, we had to compare the observed *travel time* distances with the calculated data from the MDS in order to be sure that our aforementioned model was valid. Measuring the fit was therefore necessary. The most common measure used to evaluate how good (or poorly) a particular configuration reproduces the observed data (in this case the distance matrix) is the so-called stress measure. The raw stress value φ of a configuration is defined by (10):

$$\varphi = \sum_{i=1}^{m} \left[d_{ij} - f\left(\delta_{ij}\right) \right]^2 , \qquad (10)$$

where:

d_{ij} is stands for the reproduced distances;
δ_{ij} is the input data (i.e., observed distances);
$f(\delta_{ij})$ is indicates a non-metric, *monotone transformation* of the observed input data (distances).

Thus, the smaller the *stress value*, the better the fit of the reproduced distance matrix to the observed distance matrix is (in our case the value of φ_{air} was *0.22).* As an alternative way of checking, we also produced a *Shepard diagram* (Fig 1), i.e. a plot between the reproduced distances plotted on the vertical (Y) axis versus the original distances (maritime) plotted on the horizontal (X) axis (hence the generally negative slope).

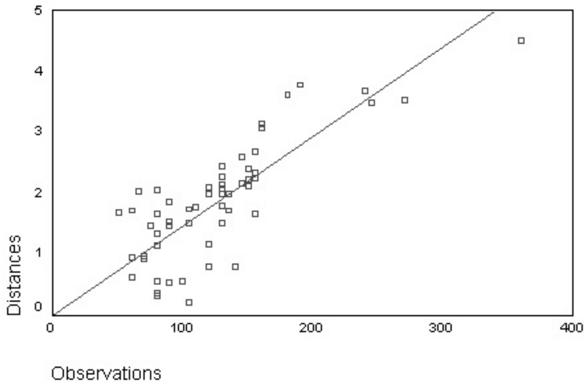

Fig 1. Shepard diagram (R^2=0.7658)
*(source: own resource, (*Szőkefalvi-Nagy 1972*))*

The correlation coefficient (R^2), sometimes also called the cross-correlation coefficient, is a quantity that gives the quality of an estimation (squares on Fig 1) compared to the ideal (linear on Fig 1). R^2 must be between 0 and 1; in our case, the higher the R^2 was, the better the transformation was. As can be seen from figure 1 the transformation of distances into a graph has a very low error[1]. So the new *relative* position of the airports under consideration as based on travel time distances and graph theory representation is different than the well known geographic one, and this is shown in figure 2:

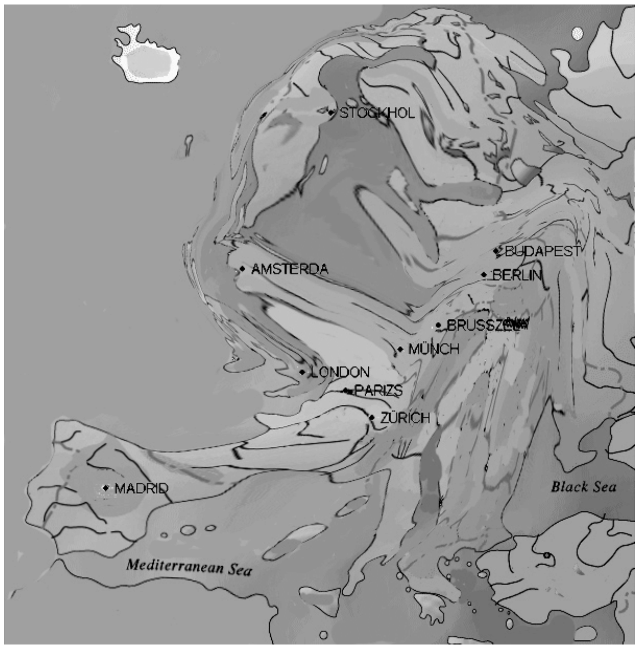

Fig 2. Map of Europe modified by travel time
(source: own research)

[1] This line represents the so called *D-hat* values, that is, the result of the monotone transformation $f(\delta_{ij})$ of the input data. If all reproduced distances fall onto the step-line, then the ordering of distances (or similarities) would be perfectly reproduced by the respective solution (dimensional model). Deviations from the step-line indicate lack of fit.

3. Conclusions

After running the model and minimizing the error by using the least squares method, a more detailed analysis was done to understand the spatial distribution of decision weights within Europe. First the spatial distribution of cost decision weight was examined (Fig 3a).

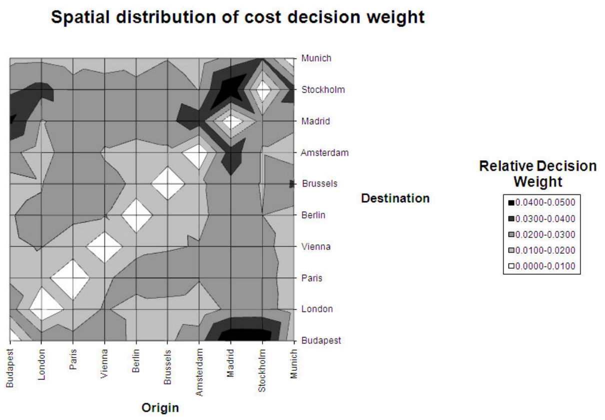

Fig 3a. Spatial distribution of cost decision weight *(source: own research)*

Here (Fig 3a) the visualisation of cost decision matrice can be seen. The matrix and the figure are asymmetric due to the asymmetric cost of air transportation (11).

$$c_{ij} \neq c_{ji} \tag{11}$$

Next the spatial distribution of time decision weight was examined (Fig 3b).

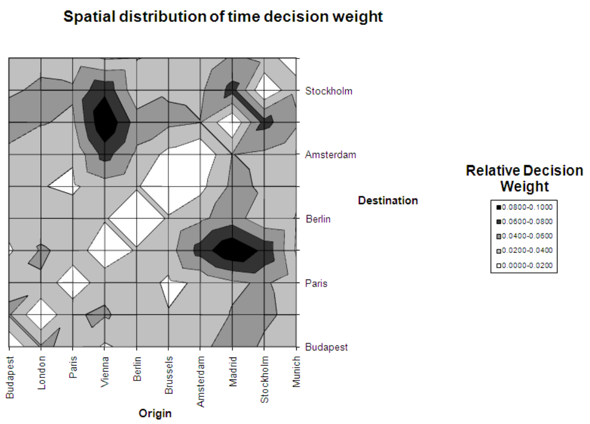

Fig 3b. Spatial distribution of time decision weight *(source: own research)*

Here (Fig 3b) the visualisation of the time decision matrix can be seen. The matrix and the figure are symmetric because of symmetric travel time due to our basic assumption (12).

$$t_{ij} = t_{ji} \tag{12}$$

The overall result demonstrated that choice of airport is influenced most strongly by level of attraction (85 %), followed by travel time (10 %) and travel cost (5 %) in the investigated intra-European passenger traffic in case of airport choice decision. This can be the basis for further development of the intra-EU air transport passenger forecast model. Intra-EU transport of passengers is likely to increase. There are a number of factors that justify this, such as the enlargement of the EU with 10 new members in 2004 and the increasing share of transport services in the GDPs of the countries in the area. In this paper, the point of investigation that a well-calibrated model for airport choice can be built and realistic results can be produced was proved.

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EUROPOS TRANSPORTO EISMO TYRIMAS, PAREMTAS SPRENDIMŲ PANAUDOJIMO MODELIU

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S a n t r a u k a

Pastaraisiais metais pastebimas itin intensyvus transporto sektoriaus vystymasis, pasireiškiantis mažinamomis kainomis, naujų pigių avialinijų atsiradimu bei įvairių komercinių apribojimų panaikinimu. Pagrindinis šio darbo tikslas yra ištirti keleivių pervežimą oro transportu Europos Sąjungos ribose ir pristatyti pasirinkto atskiro oro uosto modelio matematinę formuluotę. Modelis, paremtas kompleksinėmis panaudojimo funkcijomis, buvo patobulintas ir patikrintas pačių autorių, o gauti rezultatai atitinka realią patirtį.

Reikšminiai žodžiai: keleivių pervežimas oro transportu, panaudojimas, sprendimų modeliavimas.