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ARTICLE INFO	Marc Ch. Gelhausen (2010). A nested logit-model based on Kohonen’s Self-Organizing Maps for airport and access mode choice in Germany. *Innovative Marketing* , *6*(2)
RELEASED ON	Wednesday, 09 June 2010
JOURNAL	"Innovative Marketing "
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

Innovative Marketing, Volume 6, Issue 2, 2010

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A nested logit-model based on Kohonen's Self-Organizing Maps for airport and access mode choice in Germany

Abstract

The subject of this paper is to present an integrated airport and access mode choice model based on a nested logit approach. The theoretical framework is extended to build a model which can handle any number of airports and combinations of airports and access modes, by defining distinct airport categories. These airport categories are composed from the perspective of air travellers, i.e. from a demand-oriented point of view, according to flight plan characteristics. Thereby it is possible to better evaluate future infrastructure scenarios, i.e. actual new airports and new airport/access mode combinations beyond "variations on a theme". Thus, we come much closer to seeing different airports as being different products which belong to particular market segments. Having said this, airport categories represent product categories like for example, small cars, medium-sized cars or sports cars in the automobile market. Kohonen's Self-Organizing Maps are employed to cluster airports into categories. The paper concludes with a model application of an airport and access mode choice case in the Cologne region, Germany, to demonstrate both the strength of the chosen approach and how airport and access mode characteristics affect the choice of an air traveller in a complex way. The methodology presented in this paper is general in nature and thus can be applied to other (transportation) markets as well. The model is of particular interest for airport managers and mobility providers in order to help them make strategic management decisions, as well as policy makers to help them assess the effects of different policies.

Keywords: airport and access mode choice, discrete choice model, Kohonen's Self-Organizing Maps, nested logit model.

Introduction

Modelling the airport choice of air passengers has been a subject of interest for air transport scientists and airport managers for quite some time. Various airport and access mode choice models based on discrete choice analysis have been developed in recent years; however, a number of papers have focused exclusively on the airport choice aspect of the problem (for example, Kanafani et al., 1975; Skinner, 1976; Harvey, 1987; Ashford and Bencheman, 1987; Ozoka and Ashford, 1988; Innes and Doucet, 1990; Thompson and Caves, 1993; Furuichi and Koppelman, 1994; Windle and Dresner, 1995; Bondzio, 1996; Moreno and Muller, 2003; Basar and Bhat, 2004; Hess and Polak, 2005). These models were mainly developed to be applied to a specific set up of airports; the airports of the San Francisco Bay Area have been of particular study interest. On the other hand, some models have focused on the combined choice of airport and access mode to account for interrelationships in the choice process; again they were mainly developed with certain airports in mind (for example, Veldhuis et al., 1999; Holzschneider, 2000; Pels et al., 2003; Hess, 2004).

Our hypothesis with regard to modelling airport and access mode choice in a combined fashion is that these choice processes are closely interrelated. Air travellers typically have a strong preference for the nearest airport as the German Air Traveller Survey 2003 (about 210,000 air travellers interviewed) reveals (Wilken et al., 2005, 2007). In Germany, 67 per cent of air travellers choose on average the nearest airport. However, access travel time not only depends on distance covered, but also on the accessibility of fast access modes, such as, for instance, high speed intercity trains. Access time and access costs play a major role in airport choice, which in turn depends on access mode choice. The availability of different modes of access is again airport specific.

This paper presents a combined airport and access mode choice model based on a nested logit approach and Kohonen's Self-Organizing Maps (Gelhausen, 2007a). The empirical evidence from the survey mentioned above serves as the main data source for model estimation. As a means to achieve a more general applicability of the model, airports have been clustered into so-called "airport categories" using Kohonen's Self-Organizing Maps. Airports are categorized from a demand-oriented point of view, to form clusters of homogeneous airports in terms of their general picture of flight schedules. Thus, we emphasize the view that airports possess different characteristics which are decision-relevant to air travellers (see, for example, Lancaster (1966) for a more general discussion relating to consumption theory activity analysis). In this model, airports are solely a means to get from an origin to a destination by plane; therefore, in this paper, analysis is restricted to flight schedules only. "Secondary" factors such as shopping opportunities at the airport, are excluded from the analysis.

Overall, we come much closer to seeing different airports as different products which belong to certain market segments. Having said this, airport categories represent product categories, like, for example, small cars, medium-sized cars or sports cars in the automobile market. Thus, the model is not restricted to specific airports or a certain number of airport and access mode combinations ("variations on a theme"), but allows us to evaluate airport plans like the future Berlin-Brandenburg International Airport (BBI) in the southeast of Berlin, or the introduction of new access modes, such as direct high speed intercity train access to already existing airports, as was the case between Cologne and Frankfurt airport in 2002. Section 1 lays down the theoretical foundations for building alternative categories in a discrete choice framework which is applied to airports in Section 2. We speak subsequently about alternative categories instead of product categories as the former is more general. The concepts outlined in this paper are not only applicable to product choice alone, but also to situations of mutually exclusive choice between certain alternatives. In this paper, we look at airport and access mode choice.

The model is of particular interest for airport managers as well as mobility providers since it shows the dependence between the market share of an airport and access mode combination and its quality regarding their attributes, such as travel time, travel cost and weekly flight frequency to a given destination. Thus, on the level of the individual firm, the model serves as a tool to support strategic management decisions: the model has been applied, for example, to the Deutsche Bahn AG (Berster et al., 2006) to optimize their feeder trains to airports, and to large-scale airport studies (Berster et al., 2008) to support strategic management decisions. The model configuration for Deutsche Bahn AG comprises more than 20 airports Germany-wide, each airport having potentially seven access modes. Thus, the model has more than 140 alternatives and is, to our knowledge, one of the largest airport and access mode choice models. Furthermore, the model is also of interest for policy makers to assess the impact of different policies.

1. Discrete choice theory and alternative categories

The fundamental hypothesis of discrete choice models is the assumption of individual utility maximization. Alternatives are evaluated by means of a utility function, and the one with the highest utility is supposed to be chosen. From an external point of view, the utility of an alternative for a specific individual is a random variable, so that the utility U_i of alternative i is described as a function composed of a deterministic component V_i and a random component ε_i (Maier and Weiss, 1990, p. 100):

$$U_i = V_i + \varepsilon_i. \qquad (1)$$

The random component of the utility function is introduced for various reasons, such as a lack of observability of the relevant attributes of alternatives, or their incomplete measurability (Maier and Weiss, 1990, pp. 98f.).

From an external point of view, only evidence in terms of the probability of an alternative being the one with the highest utility can be given, because of the random component in the utility function. Specific discrete choice model concepts differ in terms of their assumptions concerning the random component. The most prominent member of this class of models is the logit-model, with independently and identically distributed random components; the choice probability of an alternative i is computed as (Train, 2003, p. 40):

$$P\left(a_i = a_{opt}\right) = \frac{e^{\mu V_i}}{\sum_j e^{\mu V_j}}. \qquad (2)$$

As a consequence of the independently and identically distributed random components of the utility functions, the ratio of two choice probabilities is solely dependent on the utility of those two alternatives (Ben-Akiva and Lerman, 1985, p. 108):

$$\frac{P\left(a_i = a_{opt}\right)}{P\left(a_j = a_{opt}\right)} = \frac{\dfrac{e^{\mu V_i}}{\sum_k e^{\mu V_k}}}{\dfrac{e^{\mu V_j}}{\sum_k e^{\mu V_k}}} = \frac{e^{\mu V_i}}{e^{\mu V_j}} \qquad (3)$$

This property of the logit-model is called "Independence from Irrelevant Alternatives" (IIA) and may be regarded as both a weakness and a strength of the model. Due to the distribution assumptions of the random component of the utility function, it is not possible to model correlations among alternatives owing to unobserved factors. A major advantage of the IIA-property is the possibility of estimating the model parameters, excluding alternative-specific variables, on a subset of the alternatives (McFadden, 1974, p. 113; McFadden, 1978, p. 87ff.; Ortuzar and Willumsen, 2001, p. 227f.; Train, 2003, p. 52f.), and the possibility of evaluating new alternatives without the need to re-estimate alternative-unspecific model parameters (Domencich and McFadden, 1975, p. 69f.).

The nested logit-model relaxes the IIA-restriction to some extent, without losing the closed-form expression of the choice probabilities. For this purpose, the random component ε_i in (1) is split up into a part ε_i^a, which varies over all alternatives i, and a part ε_k^c, which is identical for all alternatives of a nest k (Maier and Weiss, 1990, p. 154f.):

$$U_i = V_i + \varepsilon_i^a + \varepsilon_k^c. \qquad (4)$$

Thereby, it is possible to model correlations due to unobserved factors among subsets of the alternatives by partitioning the choice set into clusters with highly correlated alternatives (Hensher and Greene, 2002, p. 3). Formula (5) represents an example of a covariance matrix for four alternatives partitioned into two clusters with the first two belonging to cluster one and the last two assigned to cluster two (Gelhausen, 2007a, p. 34; Maier and Weiss, 1990, p. 154f.).

$$\Omega = \begin{bmatrix} \sigma_{11}^2(\mu_1^c) & \sigma_{12}^2(\varepsilon_1^c) & 0 & 0 \\ \sigma_{21}^2(\varepsilon_1^c) & \sigma_{22}^2(\mu_1^c) & 0 & 0 \\ 0 & 0 & \sigma_{33}^2(\mu_2^c) & \sigma_{34}^2(\varepsilon_2^c) \\ 0 & 0 & \sigma_{43}^2(\varepsilon_2^c) & \sigma_{44}^2(\mu_2^c) \end{bmatrix}. \qquad (5)$$

Each cluster k is characterized by an individual scale parameter μ^c_k and an identical non-negative covariance for all alternatives i within a cluster k. Alternatives of different clusters are assumed not to be correlated.

For modelling reasons, the choice probabilities $P(a_i = a_{opt})$ are decomposed into an unconditional choice probability $P(c_k = c_{opt})$ that cluster k is chosen, and a conditional choice probability $P(a_i = a_{opt} \mid a_i \in c_k)$, that alternative i from cluster k is chosen (Maier and Weiss, 1990, p. 156):

$$P(a_i = a_{opt}) = P(a_i = a_{opt} \mid a_i \in c_k) * P(c_k = c_{opt}). \qquad (6)$$

The conditional choice probabilities are equal to the logit-model with the choice set being restricted to the alternatives of the appropriate nest. The choice probability of a nest k is determined by its maximum utility V_k^c (Maier and Weiss, 1990, p. 157):

$$V_k^c = \frac{1}{\mu} \ln \sum_{i \in k} e^{\mu V_i}. \qquad (7)$$

The choice probability of an alternative i in nest k can be written as (Maier and Weiss, 1990, p. 158):

$$P(a_i = a_{opt}) = \frac{e^{\mu V_i}}{\sum_{j \in k} e^{\mu V_j}} * \frac{e^{\mu_k^c V_k^c}}{\sum_l e^{\mu_l^c V_l^c}}. \qquad (8)$$

The hierarchical structure of (8) does not imply a sequential decision process. An extension to more than two levels is possible (Ben-Akiva and Lerman, 1985, p. 291ff.).

In the nested logit-model, the IIA-property only holds for two alternatives of the same cluster:

$$\frac{P(a_1 = a_{opt} \mid a_1 \in c_1) * P(c_1 = c_{opt})}{P(a_2 = a_{opt} \mid a_2 \in c_1) * P(c_1 = c_{opt})} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}} = \frac{e^{\mu V_1}}{e^{\mu V_2}} \qquad (9)$$

However, the ratio of the choice probabilities for two alternatives of different clusters depends on the characteristics of all alternatives of those two clusters:

$$\frac{P(a_1 = a_{opt} \mid a_1 \in c_1) * P(c_1 = c_{opt})}{P(a_2 = a_{opt} \mid a_2 \in c_2) * P(c_2 = c_{opt})} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_2} e^{\mu V_j}} * \dfrac{e^{\mu_2^c V_2^c}}{\sum_l e^{\mu_l^c V_l^c}}} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_2} e^{\mu V_j}}} * \frac{e^{\mu_1^c V_1^c}}{e^{\mu_2^c V_2^c}}. \tag{10}$$

Therefore, the nested logit-model lacks the IIA-property for some pairs of alternatives. Therefore, model estimation on a subset of the choice set is not possible.

However, if it is feasible to form categories of at least approximately similar clusters, and to assign an identical covariance matrix to all clusters of the same category, then it is possible to estimate alternative-unspecific model-parameters on a subset of alternatives, equal to the logit-model. Thereto, each category of clusters must be represented by at least one member in this subset, to enable the estimation of all cluster-specific scale parameters. Formula (11) shows a covariance matrix of six clusters belonging to three different categories, with two equal clusters per category. Every cluster is again composed of a number of alternatives and a covariance matrix as in (5). Figure 1 explains the relationship between a category and a cluster.

$$\Omega = \begin{bmatrix} A & 0 & 0 & 0 & 0 & 0 \\ 0 & B & 0 & 0 & 0 & 0 \\ 0 & 0 & B & 0 & 0 & 0 \\ 0 & 0 & 0 & C & 0 & 0 \\ 0 & 0 & 0 & 0 & A & 0 \\ 0 & 0 & 0 & 0 & 0 & C \end{bmatrix} \tag{11}$$

The letters A, B and C represent the covariance structure of a cluster; the same letters indicate an equal covariance structure for different clusters. Figure 1 illustrates the assignment of clusters to categories.

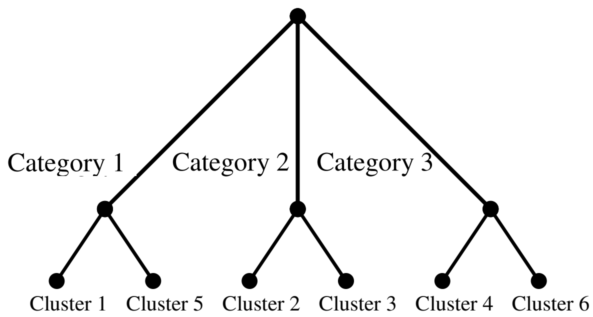


Fig. 1. Dependence between clusters and categories

If identical alternative-specific model-parameters, in particular alternative-specific constants, can be assumed reasonably well for different clusters of the same category, the estimation of the whole set of model-parameters is feasible on a subset of all alternatives as described above.

The main advantage of this approach lies not only in the reduction of computational costs for very large choice sets, as many econometric software packages limit the maximum number of clusters and alternatives for nested logit estimations, but especially in a better way of developing a more generally applicable choice model beyond the alternatives included in the data set that is used for model estimation, for example in the context of scenario analysis.

2. Airport categories

Clusters of the same category are characterized by an identical covariance matrix and alternative-specific parameters, especially alternative-specific constants. As correlations among alternatives and alternative-specific constants represent unobserved factors, a categorization of clusters corresponds to an aggregation in terms of the similarity of those unobserved factors. Airport and access mode choice is a two-dimensional choice problem. Therefore, a categorization in respect of both dimensions is necessary. However, as the access mode choice is sufficiently general in nature, only airports need to be categorized.

Airports have been categorized from a demand-oriented point of view, whereby a description of flight services at an airport in terms of frequencies and destinations, serves as a quality criterion. Flight services of an airport are thus measured on the basis of the number of flights per destination type and flight type and the number of different destinations, segmented by type of destination. Three types of destination are defined:

- domestic,
- European,
- intercontinental.

Flight types are divided into:

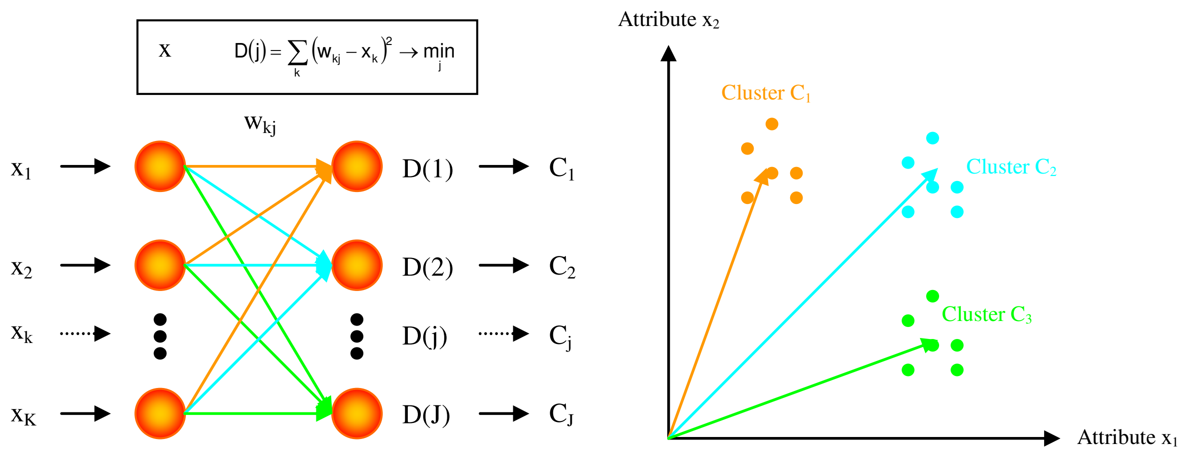
- low cost,
- charter,
- full service.

Table 1 summarizes the relevant attributes retained for categorizing airports.

Table 1. Attributes of airport categories

Attribute (abbreviation)	Definition
Number of domestic low cost flights (LCBRD)	Flights per week
Number of domestic charter flights (CCBRD)	Flights per week
Number of domestic full service flights (FSBRD)	Flights per week
Number of European low cost flights (LCEUR)	Flights per week
Number of European charter flights (CCEUR)	Flights per week
Number of European full service flights (FSEUR)	Flights per week
Number of international low cost flights (LCINT)	Flights per week
Number of international charter flights (CCINT)	Flights per week
Number of international full service flights (FSINT)	Flights per week
Number of domestic destinations (NUMBRD)	Number of destinations
Number of European destinations (NUMEUR)	Number of destinations
Number of international destinations (NUMINT)	Number of destinations

Clusters are identified by means of Kohonen's Self-Organizing Maps (Kohonen, 2001, p. 109ff.). Figure 2 is a schematic illustration of a Self-Organizing Map. Neurons are defined as simple computational units connected by weighted edges. Computations in a neuron are performed according to a simple transfer function. Input neurons correspond to clustering attributes and output neurons represent the clusters. The transfer function of the input neurons is the identical function f(x) = x. The output neurons have a "winner-takes-all" transfer function. The neuron with the smallest distance between the input vector and its synaptic weight vector wins the competition, and is activated. In the learning process of a Self-Organizing Map, the synaptic weight vector of the output neurons approaches the corresponding cluster centroid as the right hand side of Figure 2 illustrates.



Key

D(j): Euclidean distance between a specific airport and airport category j

x_k: Attribute k of an airport (for example number of intercontinental destinations)

w_{kj}: Weight of airport attribute k for airport category j

Fig. 2. Kohonen's Self-Organizing Map

Table 2 shows the parameters for optimal cluster identification. The Self-Organizing Map is fairly stable with regard to parameter variations, thus indicating distinct airport categories.

Table 2. Parameters of a Self-Organizing Map for airport categorization

Parameter	Value
Topology of output neurons	Linear
Measure of distance	Euclidean
Neighborhood function	Linear: 2 – 0.002*iteration
Learning rate	0.01
Number of iterations	10000
Data normalization	yes, [-1;1]
Number of input neurons	12
Number of output neurons	3

Three airport categories have been identified in Germany. The output neurons are arranged in a linear grid, and the distance between an input vector and the synaptic weight vector of the corresponding output neuron is measured in a Euclidean fashion. A linear neighborhood function is used. The neighborhood contains all output neurons at the beginning of the learning process and shrinks to zero within 1,000 iterations. The number of learning iterations is 10,000 and the learning rate is chosen to be rather small, with 0.01. Each element of the input vector is normalized to the interval [-1; 1].

Table 3 shows the synaptic weights for the trained Self-Organizing Map. The color of the columns equals the color of the synaptic weights in Figure 2. The artificial neural network software NeuroDimension Version 4.33 (NeuroDimension, 2004) was employed for estimation of the synaptic weights of the Self-Organizing Map.

Table 3. Cluster centroids of airport categories

Attribute	Airport		
	Category 1	Category 2	Category 3
LCBRD	0.054281	0.026181	-0.073566
CCBRD	0.63343	-0.23698	-0.902359
FSBRD	0.820399	-0.16164	-0.810737
LCEUR	-0.814996	-0.248973	-0.717447
CCEUR	0.673964	0.145995	-0.811895
FSEUR	0.767974	-0.596754	-0.967617
LCINT	-0.999997	-0.507511	-0.862715
CCINT	0.459986	-0.679604	-0.986041
FSINT	0.128171	-0.975403	-0.999997
NUMBRD	0.810002	0.570222	-0.409338
NUMEUR	0.791409	-0.012681	-0.737397
NUMINT	0.314031	-0.817745	-0.991489

Table 4 shows the result of assigning those airports that were contained in the German Air Traveller Survey 2003, to identified categories. 18 international and four selected regional airports were included in the survey. Although the service characteristics of the three Berlin airports vary substantially, they were viewed as one single airport; it is for this reason that they have not been included in the sample for model estimation, and were not considered in the airport categorization. However, it is possible to apply the model to the airports of Berlin as well.

An airport is not permanently linked to its current category. If the characteristics change sufficiently over time, then it falls into a different category. It is even theoretically possible that new airport categories may emerge in the future.

Table 4. Assigning airports to categories

Category	Airport (IATA code)
AP1	Frankfurt a. M. (FRA)
AP1	Munich (MUC)
AP2	Dusseldorf (DUS)
AP2	Hamburg (HAM)
AP2	Cologne/Bonn (CGN)
AP2	Stuttgart (STR)
AP3	Bremen (BRE)
AP3	Dortmund (DTM)
AP3	Dresden (DRS)
AP3	Erfurt (ERF)
AP3	Frankfurt Hann (HHN)
AP3	Friedrichshafen (FDH)
AP3	Hanover (HAJ)
AP3	Karlsruhe/Baden (FKB)
AP3	Leipzig/Halle (LEJ)
AP3	Lubeck (LBC)
AP3	Munster/Osnabruck (FMO)
AP3	Neiderrhein (NRN)
AP3	Nuremberg (NUE)
AP3	Paderborn/Lippstadt (PAD)
AP3	Saarbrucken (SCN)

Table 5 and Table 6 illustrate some properties of the three identified airport categories in terms of relative and absolute values, to help the interpretation of the estimation results presented in Table 3. The three, respectively two highest values concerning the flight frequency and the number of different destinations, are highlighted in color.

Table 5. Structure of flights per airport category (in per cent)

	LCBRD	CCBRD	FSBRD	LCEUR	CCEUR	FSEUR	LCINT	CCINT	FSINT	NUMBRD	NUMEUR	NUMINT
AP1	3.18	0.43	20.39	0.87	5.83	55.81	0.00	1.24	12.25	8.31	60.27	31.42
AP2	8.97	0.58	28.27	11.65	11.76	37.24	0.02	0.71	0.79	16.23	74.62	9.16
AP3	1.29	0.86	39.22	32.57	15.57	10.05	0.02	0.42	0.00	19.94	78.90	1.16

Table 6. Structure of flights per airport category (in absolute values)

	LCBRD	CCBRD	FSBRD	LCEUR	CCEUR	FSEUR	LCINT	CCINT	FSINT	NUMBRD	NUMEUR	NUMINT
AP1	106	16	756	32	225	2138	0	49	517	19	144	83
AP2	104	7	348	129	153	487	0	11	11	17	80	12
AP3	3	1	80	47	25	39	0	0	0	6	22	1

Airports in the first category represent hub airports. They mainly offer full service flights and are principally focussed on European and intercontinental destinations. The number of domestic destinations is low in relation to European and intercontinental destinations. However, they are served with a higher frequency. Hub airports offer the highest number of flights and destinations. Airports in the second category mainly serve domestic and European destinations with full service flights. The share of European low cost and charter flights is approximately equal, however, it is smaller than the share of full service flights. The structure of flights and destinations of airports in the third category is similar to those in the second category, but their focus is more on full service flights to domestic and a few European destinations served by low cost and charter carriers. These airports are the smallest in terms of the number of flights and destinations.

Table 7 shows the standard deviation of each attribute for each airport category. Airports of the first category exhibit the greatest heterogeneity, while airports of the third category show the smallest diversity.

Table 7. Standard deviation of attributes by airport category

	LCBRD	CCBRD	LBRD	LCEUR	CCEUR	LEUR	LCINT	CCINT	LINT	NUMBRD	NUMEUR	NUMINT
AP1	96.00	3.50	75.00	8.50	37.50	279.00	0.00	18.00	396.00	1.00	16.50	43.00
AP2	77.00	0.00	32.00	164.50	66.50	162.00	0.50	2.00	1.50	2.50	5.50	1.00
AP3	0.00	0.00	68.00	9.00	21.00	29.50	0.00	0.00	0.00	2.50	10.50	0.00

3. Model estimation and results

The main data source for model estimation is the German Air Traveller Survey conducted in 2003 (Wilken et al., 2005, 2007). About 210,000 air travellers were interviewed at 18 international airports and four regional airports. In order to better simulate the choice behavior of passengers, they have been grouped into rather homogeneous groups with respect to the purpose and length of the journey. Seven different market segments were defined:

- Journeys to domestic destinations, subdivided into private and business trip purposes.
- Journeys to European destinations for business trip purposes.
- Journeys to European destinations for private short stays for up to four days.
- Journeys to European destinations for holiday reasons for five days or longer.
- Journeys to intercontinental destinations, subdivided into private and business trip purposes.

Table 8. Airports and available access modes

	Car	Kiss and ride	Rental car	Taxi	Bus	Urban railway	Train
Berlin	x	x	x	x	x	x	
Bremen	x	x	x	x		x	
Dortmund	x	x	x	x	x		
Dresden	x	x	x	x	x	x	
Dusseldorf	x	x	x	x	x	x	x
Erfurt	x	x	x	x	x		
Frankfurt a. M.	x	x	x	x	x	x	x
Frankfurt Hann	x	x	x	x	x		
Friedrichshafen	x	x	x	x	x	x	
Hamburg	x	x	x	x	x		
Hanover	x	x	x	x	x	x	
Karlsruhe-Baden	x	x	x	x	x		
Cologne/Bonn	x	x	x	x	x		
Leipzig/Halle	x	x	x	x	x		x
Lubeck	x	x	x	x	x		
Munich	x	x	x	x	x	x	
Munster/Osnabruck	x	x	x	x	x		

Table 8 (cont.). Airports and available access modes

	Car	Kiss and ride	Rental car	Taxi	Bus	Urban railway	Train
Niederrhein	x	x	x	x	x		
Nuremberg	x	x	x	x	x	x	
Paderborn/Lippstadt	x	x	x	x	x		
Saarbrucken	x	x	x	x	x		
Stuttgart	x	x	x	x	x	x	

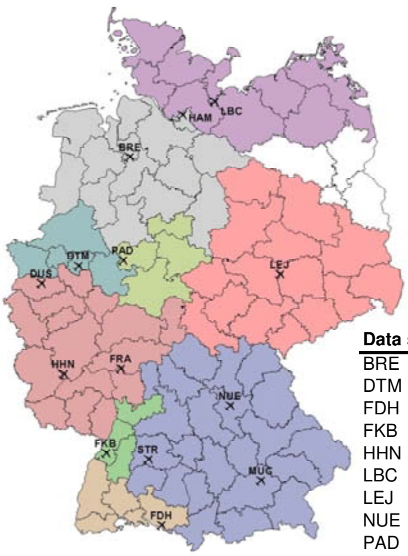
Table 8 illustrates the actual availability of access modes to the airports covered by the German Air Traveller Survey 2003, as indicated by a cross in the appropriate field. The access mode "car" includes parking at the airport for the duration of the journey. For "kiss and ride", the number of trips is doubled compared to all other access modes, as the car is parked at the trip origin again. The "taxi" alternative includes taxis and private bus services operating on demand only. The access mode "bus" contains scheduled public-transit buses. "Urban railway" and "train" are distinguished in terms of the tariff paid. If the tariff of the Deutsche Bahn applies, it is a train; otherwise it is an urban railway.

Access time and access costs are defined for the double trip length between the origin of the journey and the departure airport, so that there is no need for an arbitrary allocation of any parking fees at the airport to either the outbound or the return trip. Access frequency is defined as the daily frequency. Its inverse multiplied by 0.5 equals the average waiting time in the case of a uniformly distributed arrival time. Population density is chosen as a measure for estimating the access time to public transport. The evaluation of the access quality from the access mode terminal to the airport terminal is measured in a binary fashion due to a lack of information on the chosen parking site and air terminal. The fare level of a direct flight connection to a specific destination, is estimated in relation to the degree of airline competition on that link, based on the hypothesis that a higher degree of competition indicates a lower fare level. For many stop-over flights, a maximum of competition is reached because, typically, there are a great number of possible flights between any origin and destination. The time advantage of a direct flight connection is measured via its existence, and its quality is assessed by means of its weekly flight frequency. To consider different price levels, low cost- and charter-flights are taken into consideration separately. Due to a lack of information, exact air fares are not considered. Table 9 summarizes the explanatory variables and their definitions.

Table 9. Definition of explanatory variables

Variable (Abbreviation)	Definition
Access cost (COST)	Cost in € per person incl. parking fees, double trip lenght
Access time (TIME)	Time in minutes, double trip lenght
Waiting time (Wait)	Inverse of the daily frequency
Inverse of the population destiny (INVPD)	Inverse of residents per km^2
Competition on a direct flight connection (COMP)	Inverse of the number of a alliances and independent airlines on that particular O-D link
Quality of terminal access (AAS)	binary (good/bad)
Existence of a direct flight connection (DIRECT)	binary (good/bad)
Frequency of a direct flight connection (DFREQ)	Number flights per week
Existence of a low cost connection (LC)	binary (yes/no)
Frequency of a low cost connection (LCFREQ)	Number low cost flights per week
Existence of a charter flight connection (CC)	binary (yes/no)
Frequency of a charter flight connection (CCFREQ)	Number charter flights per week

The entire data set for model estimation is partitioned into several disjointed data subsets. The prime objective of creating data subsets is to make model estimation manageable, and to develop a model that is applicable to new situations such as new airports. Each data subset contains only a subset of the full set of airport and access mode alternatives of just one airport of each category and its access modes. Each data subset includes observations of individuals who have chosen one of the alternatives of the reduced alternative set. By a suitable definition of data subsets, it is possible to estimate a model with the full set of seven access modes for all three airport categories. For this purpose, the airports of Frankfurt a. M., Düsseldorf and Leipzig/Halle are included, as these were the only airports of their category with access by train in the reference year, 2003. The individual data subsets are merged into a single new estimation data set, thereby reducing the number of alternatives from 122 to 21. The estimation data set remains statistically representative by weighting each observation. Figure 3 shows the geographical definition of the data subsets. The nearest airport of each category is assigned to each data set, which is marked in different colors. Every subset is named according to its third category airport.



Data subset	Airport (IATA code)
BRE	FRA, HAM, BRE
DTM	FRA, DUS, DTM
FDH	MUC, STR, FDH
FKB	FRA, STR, FKB
HHN	FRA, DUS, HHN
LBC	FRA, HAM, LBC
LEJ	FRA, HAM, LEJ
NUE	MUC, STR, NUE
PAD	FRA, DUS, PAD

Fig. 3. Data subsets and assigned airports

After airports and access modes have been selected for a specific application case, they are assigned to categories with the appropriate model parameters. As a result of the grouping of clusters, the model is applicable to airports and airport/access mode combinations, other than those of the estimation data set. Figure 4 summarizes the general process of model estimation and its application.

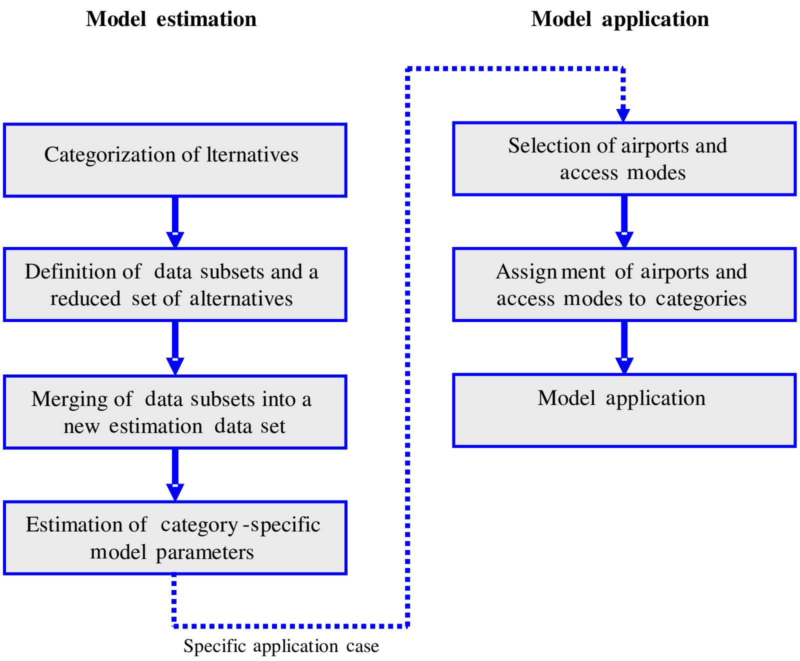


Fig. 4. Estimation and application process of airport and access mode choice model

Table 10 shows the reduced alternative sets as used for model estimation, based on the aforementioned airport categories. Each alternative is composed of both an airport category and one of the potentially seven access modes to the airport.

Table 10. Reduced alternative set

Alternative	Abbreviation
AP 1/Car	AP1CAR
AP 1/Kiss and ride	AP1KAR
AP 1/Rental car	AP1RC
AP 1/Taxi	AP1TAXI
AP 1/Bus	AP1BUS
AP 1/Urban reilway	AP1UR
AP 1/Train	AP1TR
AP 2/Car	AP2CAR
AP 2/Kiss and ride	AP2KAR
AP 2/Rental car	AP2RC
AP 2/Taxi	AP2TAXI
AP 1/Bus	AP2BUS
AP 2/Urban reilway	AP2UR
AP 2/Train	AP2TR
AP 3/Car	AP3CAR
AP 3/Kiss and ride	AP3KAR
AP 3/Rental car	AP3RC
AP 3/Taxi	AP3TAXI
AP 3/Bus	AP3BUS
AP 3/Urban railway	AP3UR
AP 3/Train	AP3TR

Figure 5 illustrates the nesting structure of airport categories and access modes for model estimation. Each nest consists of one airport category at the top, and potentially seven access modes below, subdivided into private (PR) and public (PU) transport. However, for model application, the nesting structure is scaled up to the actual problem size, but each airport and access mode obtained its parameters from its category.

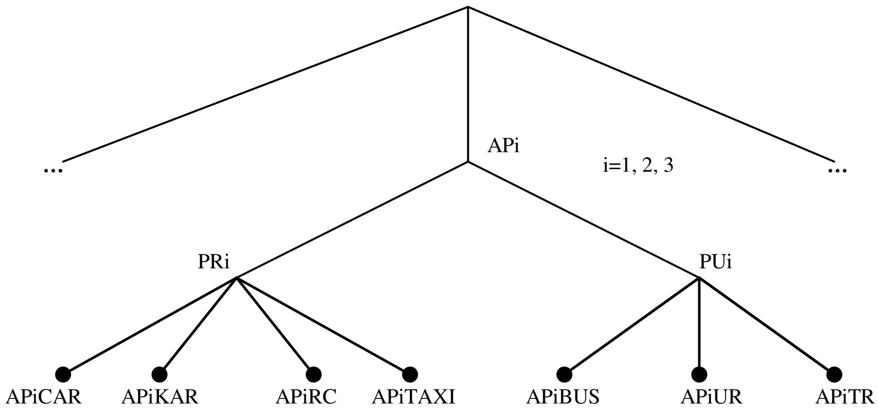


Fig. 5. Nesting structure

The deterministic part of the utility function is of a linear form:

$$V_i = alt_i + \sum_k b_k * x_{k,i} \quad (12)$$

with alt_i: alternative-specific constant of alternative, i, b_k: Coefficient of attribute, k, $x_{k,i}$: value of attribute k for alternative i.

Alternative specific constants are denominated according to the abbreviation of their alternative. One alternative-specific constant has to be arbitrarily chosen, the value of which is set to zero. In this study the constant of the alternative AP 3/Train has been selected to be set to zero. Scale parameters are normalized on the lowest level of the nesting structure to a value of one to enable their identification (Hensher and Greene, 2002, p. 3f.). Model parameters are estimated using the maximum-likelihood estimation method, and the BFGS-algorithm is applied for numerical optimization (see, for example, Greene, 2003, p. 938ff.). The covariance matrix of the estimated parameters is computed by means of the BHHH-estimator (see, for example, Train, 2003, p. 196ff.). The significance of model parameters is evaluated by the t-ratio and p-value. The goodness-of-fit is assessed by means of the pseudo-R^2. The benchmark is a model without any variables (R2null) and a market share model (R2const). The econometric software NLOGIT Version 3.0 is employed for model estimation and evaluation (Econometric Software, 2002a, 2002b, 2002c and 2002d). Tables 11-17 show the estimated model parameters, t-ratios and p-values for the seven market segments as defined above. Alternative-specific constants and scale parameters are separated by a dashed line. Depending on the market segment, not only the values of the variable coefficients vary (relative to each other), but also the set of decision-relevant variables differ. For example, flight frequency (DFREQ) is not significant in the market segments relating to intercontinental travel (INT P and INT B). Therefore, the attribute processing strategy (Rose et al., 2005, p. 400ff.) of air travellers depends on market segments such as trip origin, trip destination and trip duration. There has been much discussion about the values of scale parameters of different levels in the nested logit model tree, and whether they have to decline if we move up the tree structure to model utility maximization behavior (e.g., Börsch-Supan, 1990; Daly, 1987; Hensher and Greene, 2002 (and the references therein); Koppelman and Wen, 1998). Here, the values of the scale parameters mostly do not decline (however, this is not unusual for empirical studies, examples are: McFadden, Talvitie and Associates, 1977; Coslett, 1978; Small and Brownstone, 1982; Hensher, 1984; Börsch-Supan, 1985), yet they are statistically different from a value of one (in this case, the model equals a multinomial logit model) at a significance level of at least 5%, with the exception of some scale parameters of the domestic business travel model (Gelhausen, 2007a, p. 160ff.). Thus, we conclude, the underlying problem structure might not exactly fit the nested logit structure, as stochastic correlations seem to be more complex, and a different tree definition did not resolve the problem. However, the model is significantly different from a simpler multinomial logit approach, and does perform better. Therefore, one possibility is to employ less restrictive and more complex models (e.g., Louviere et al., 2000, p. 189ff.; Gelhausen, 2007a, p. 162ff.). But the appeal of the nested logit model is its ability to accommodate some degree of interdependence between alternatives of the choices set, compared to the simpler multinomial logit model while, at the same time, being relatively easy to estimate and implement for large-scale applications due to its closed-form structure. We have tested the estimated model extensively in large-scale applications, and found the model to perform sensibly. Consequently, from our point of view the model is a good approximation (Gelhausen, 2007a, p. 168).

Table 11. Domestic private travel (BRD P)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0263035	7.47E-05	-352.091	2.89E-15
TIME	-0.0081889	3.65E-05	-224.172	2.89E-15
WAIT	-28.8061	0.0521136	-552.755	2.89E-15
INVPD	-187.86	2.74598	-68.4127	2.89E-15
COMP	-0.158635	0.0204772	-7.74689	9.33E-15
AAS	0.920627	0.0109263	84.2575	2.89E-15
DIRECT	2.29637	0.0252162	91.0672	2.89E-15
DFREQ	0.00682913	0.00016972	40.2374	2.89E-15
AP1CAR	-0.89308	0.0299652	-29.8039	2.89E-15
AP1KAR	-0.935515	0.0312753	-29.9123	2.89E-15
AP1RC	-4.1011	0.0360866	-113.646	2.89E-15
AP1TAXI	-1.66527	0.0317124	-52.5116	2.89E-15
AP1BUS	-0.0749869	0.0448874	-1.67055	0.0948097
AP1UR	0.671661	0.0431181	15.5772	2.89E-15
AP1TR	-0.289548	0.0422378	-6.85519	7.12E-12
AP2CAR	-1.42599	0.0497169	-28.6823	2.89E-15
AP2KAR	-0.969869	0.0508523	-19.0723	2.89E-15
AP2RC	-4.31713	0.0554302	-77.884	2.89E-15
AP2TAXI	-1.66024	0.0511273	-32.4727	2.89E-15
AP2BUS	-2.0108	0.0755529	-26.6145	2.89E-15
AP2UR	-0.561955	0.0722517	-7.77775	7.33E-15
AP2TR	-0.628393	0.0717579	-8.75712	2.89E-15
AP3CAR	-2.32656	0.0266369	-87.3434	2.89E-15
AP3KAR	-2.28413	0.0265816	-85.9291	2.89E-15
AP3RC	-4.56071	0.0611955	-74.527	2.89E-15
AP3TAXI	-3.28287	0.0273826	-119.889	2.89E-15
AP3BUS	-5.74305	0.150649	-38.1219	2.89E-15
AP3UR	-2.56922	0.0464991	-55.2532	2.89E-15
PR1	1.07092	0.0100494	106.566	2.89E-15
PU1	0.745385	0.00715937	104.113	2.89E-15
PR2	0.492518	0.00595683	82.6813	2.89E-15
PU2	0.390636	0.00358923	108.835	2.89E-15
PR3	0.817955	0.0174313	46.9245	2.89E-15
PU3	0.428619	0.0104805	40.8967	2.89E-15
AP1	1.81029	0.0161987	111.755	2.89E-15

Table 11 (cont.). Domestic private travel (BRD P)

Variable	Coefficient	Standard deviation	t-ratio	p-value
AP2	2.10174	0.0240208	87.4967	2.89E-15
AP3	2.35248	0.0467621	50.3075	2.89E-15
			R2(null)	57.41%
			R2(const)	43.82%

Table 12. Domestic business travel (BRD B)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0204609	1.08E-05	-1900.36	2.89E-15
TIME	-0.0152572	2.79E-05	-546.331	2.89E-15
WAIT	-18.935	0.0524438	-361.053	2.89E-15
INVPD	-21.8829	1.08584	-20.1529	2.89E-15
AAS	1.12781	0.00482371	233.805	2.89E-15
DIRECT	3.64119	0.0137238	265.318	2.89E-15
DFREQ	0.00601159	8.99E-05	66.8909	2.89E-15
AP1CAR	0.821324	0.0249217	32.9562	2.89E-15
AP1KAR	-0.205879	0.0254374	-8.09355	2.89E-15
AP1RC	-1.86138	0.0256406	-72.5952	2.89E-15
AP1TAXI	-0.3315	0.0251872	-13.1615	2.89E-15
AP1BUS	-1.47598	0.0298635	-49.4241	2.89E-15
AP1UR	-0.361618	0.0277497	-13.0315	2.89E-15
AP1TR	-1.53084	0.0277493	-55.1667	2.89E-15
AP2CAR	0.448667	0.0240099	18.6868	2.89E-15
AP2KAR	-1.03968	0.0243685	-42.6648	2.89E-15
AP2RC	-1.5527	0.024637	-63.023	2.89E-15
AP2TAXI	-0.475198	0.0243418	-19.5219	2.89E-15
AP2BUS	-1.74549	0.0306954	-56.8649	2.89E-15
AP2UR	-0.554791	0.0284689	-19.4876	2.89E-15
AP2TR	-0.771201	0.0283786	-27.1755	2.89E-15
AP3CAR	-0.625039	0.0221069	-28.2735	2.89E-15
AP3KAR	-1.73868	0.0222633	-78.0963	2.89E-15
AP3RC	-2.23438	0.025964	-86.0567	2.89E-15
AP3TAXI	-1.82039	0.0224969	-80.9173	2.89E-15
AP3BUS	-3.74058	0.0331825	-112.728	2.89E-15
AP3UR	-2.3761	0.0182418	-130.256	2.89E-15
PR1	1.02375	0.00561628	182.283	2.89E-15
PU1	0.978059	0.00470008	208.094	2.89E-15
PR2	1.00829	0.0054788	184.035	2.89E-15
PU2	0.992109	0.00421163	235.564	2.89E-15
PR3	1.00988	0.011452	88.1839	2.89E-15
PU3	0.999286	0.00799378	125.008	2.89E-15
AP1	1.01119	0.00545905	185.231	2.89E-15
AP2	1.00887	0.00552003	182.766	2.89E-15
AP3	1.01164	0.011702	86.45	2.89E-15
			R2(null)	54.10%
			R2(const)	40.47%

Table 13. Intercontinental private travel (INT P)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0138527	2.31E-05	-600.751	2.89E-15
TIME	-0.00541014	1.71E-05	-316.804	2.89E-15
WAIT	-18.7546	7.06E-05	-265589	2.89E-15
INVPD	-25.6109	1.1622	-22.0365	2.89E-15
AAS	0.840462	0.00491188	171.108	2.89E-15

Table 13 (cont.). Intercontinental private travel (INT P)

Variable	Coefficient	Standard deviation	t-ratio	p-value
DIRECT	1.85847	0.00516084	360.109	2.89E-15
AP1CAR	-1.67803	0.0043471	-386.012	2.89E-15
AP1KAR	-0.675255	0.00641839	-105.206	2.89E-15
AP1RC	-4.52249	0.0104444	-433.006	2.89E-15
AP1TAXI	-2.24118	0.00699765	-320.276	2.89E-15
AP1BUS	-2.76277	0.0150412	-183.68	2.89E-15
AP1UR	-0.567135	0.00827126	-68.5669	2.89E-15
AP1TR	-0.628369	0.00965685	-65.0698	2.89E-15
AP2CAR	-2.55593	0.00563923	-453.241	2.89E-15
AP2KAR	-0.781095	0.0063191	-123.609	2.89E-15
AP2RC	-5.48899	0.0179425	-305.921	2.89E-15
AP2TAXI	-1.9829	0.00663292	-298.949	2.89E-15
AP2BUS	-1.93506	0.0254801	-75.9441	2.89E-15
AP2UR	-1.75212	0.0212681	-82.3822	2.89E-15
AP2TR	-48.5491	8.61E+10	-5.64E-10	1
AP3CAR	-2.09268	0.00426141	-491.077	2.89E-15
AP3KAR	-0.470189	0.00543666	-86.485	2.89E-15
AP3RC	-3.52639	0.00769235	-458.428	2.89E-15
AP3TAXI	-1.13561	0.00554722	-204.716	2.89E-15
AP3BUS	-1.95589	0.00957575	-204.254	2.89E-15
AP3UR	-0.418627	0.00539374	-77.6136	2.89E-15
PR1	1.13266	0.00734164	154.278	2.89E-15
PU1	0.983045	0.00675649	145.496	2.89E-15
PR2	1.06067	0.0131951	80.3838	2.89E-15
PU2	0.927296	0.0110789	83.6991	2.89E-15
PR3	0.813943	0.00281214	289.44	2.89E-15
PU3	0.137029	0.00165706	82.6942	2.89E-15
AP1	1.10489	0.00678013	162.959	2.89E-15
AP2	1.19742	0.0144386	82.9317	2.89E-15
AP3	1.23031	0.00474654	259.201	2.89E-15
			R2(null)	48.89%
			R2(const)	32.86%

Table 14. Intercontinental business travel (INT B)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.00936472	1.59E-05	-589.728	2.89E-15
TIME	-0.00535887	3.15E-05	-170.349	2.89E-15
WAIT	-35.7591	0.0277649	-1287.92	2.89E-15
INVPD	-32.2589	2.8701	-11.2397	2.89E-15
AAS	0.382595	0.012889	29.6838	2.89E-15
DIRECT	0.439344	0.00441956	99.4091	2.89E-15
AP1CAR	-0.059388	0.0754859	-0.786742	0.431433
AP1KAR	1.17409	0.0772982	15.1891	2.89E-15
AP1RC	-0.823745	0.0767846	-10.728	2.89E-15
AP1TAXI	1.05928	0.076873	13.7796	2.89E-15
AP1BUS	2.01162	0.233108	8.62957	2.89E-15
AP1UR	2.67192	0.232672	11.4836	2.89E-15
AP1TR	1.3506	0.232603	5.80647	6.38E-09
AP2CAR	-1.04963	0.102518	-10.2385	2.89E-15
AP2KAR	0.0612584	0.103547	0.591601	0.554118
AP2RC	-2.32606	0.103863	-22.3954	2.89E-15
AP2TAXI	-0.229266	0.103265	-2.22016	0.0264076
AP2BUS	-1.54098	0.174892	-8.81106	2.89E-15
AP2UR	-0.460972	0.169567	-2.71853	0.00655733

Table 14 (cont.). Intercontinental business travel (INT B)

Variable	Coefficient	Standard deviation	t-ratio	p-value
AP2TR	-0.625187	0.1686	-3.70811	0.00020881
AP3CAR	-2.00291	0.098986	-20.2342	2.89E-15
AP3KAR	-1.11849	0.0987287	-11.329	2.89E-15
AP3RC	-3.06497	0.10039	-30.5306	2.89E-15
AP3TAXI	-1.18451	0.0991565	-11.9459	2.89E-15
AP3BUS	-3.09884	0.0707277	-43.8137	2.89E-15
AP3UR	-1.9117	0.0408988	-46.7422	2.89E-15
PR1	1.03073	0.00684748	150.526	2.89E-15
PU1	0.32899	0.00387138	84.9801	2.89E-15
PR2	1.3532	0.0265898	50.8917	2.89E-15
PU2	0.832438	0.0120304	69.1943	2.89E-15
PR3	0.91783	0.0320818	28.6091	2.89E-15
PU3	0.718249	0.0410799	17.4842	2.89E-15
AP1	2.10553	0.0154688	136.115	2.89E-15
AP2	1.16102	0.0217542	53.3699	2.89E-15
AP3	1.73837	0.0551256	31.5348	2.89E-15
			R2(null)	47.46%
			R2(const)	28.30%

Table 15. European private short stay travel (EUR S)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0199987	6.35E-05	-315.076	2.89E-15
TIME	-0.0061063	3.08E-05	-197.958	2.89E-15
WAIT	-8.33078	0.101522	-82.0589	2.89E-15
INVPD	-215.876	3.45959	-62.3992	2.89E-15
COMP	-1.22176	0.0143873	-84.9193	2.89E-15
AAS	0.20336	0.0105667	19.2453	2.89E-15
DIRECT	3.63327	0.0204966	177.262	2.89E-15
DFREQ	0.0104684	0.00020263	51.6641	2.89E-15
LC	0.0863075	0.0103855	8.31037	2.89E-15
LCFREQ	0.0631856	0.00061005	103.575	2.89E-15
AP1CAR	-0.498688	0.0666011	-7.48768	7.02E-14
AP1KAR	0.318789	0.0674283	4.72781	2.27E-06
AP1RC	-3.33871	0.0706322	-47.269	2.89E-15
AP1TAXI	-0.435522	0.06765	-6.43788	1.21E-10
AP1BUS	0.210693	0.0906689	2.32377	0.020138
AP1UR	1.50982	0.0897749	16.8179	2.89E-15
AP1TR	0.122875	0.0904775	1.35807	0.174442
AP2CAR	-0.303182	0.0680182	-4.45737	8.30E-06
AP2KAR	0.278229	0.0686423	4.05333	5.05E-05
AP2RC	-3.171	0.0716133	-44.2795	2.89E-15
AP2TAXI	-0.0993231	0.0688372	-1.44287	0.149057
AP2BUS	0.65932	0.0990006	6.65975	2.74E-11
AP2UR	1.27978	0.0981204	13.043	2.89E-15
AP2TR	0.98543	0.0983198	10.0227	2.89E-15
AP3CAR	0.40639	0.0634284	6.40707	1.48E-10
AP3KAR	0.538874	0.0643244	8.37744	2.89E-15
AP3RC	-3.70737	0.0712379	-52.0421	2.89E-15
AP3TAXI	-0.131292	0.0646538	-2.0307	0.0422853
AP3BUS	0.528475	0.127801	4.13513	3.55E-05
AP3UR	0.71755	0.126304	5.68113	1.34E-08
PR1	0.764486	0.0087763	87.1079	2.89E-15
PU1	0.593257	0.00626677	94.6671	2.89E-15
PR2	0.767123	0.00715629	107.196	2.89E-15

Table 15. European private short stay travel (EUR S)

Variable	Coefficient	Standard deviation	t-ratio	p-value
PU2	0.543582	0.00583578	93.1464	2.89E-15
PR3	0.821821	0.00996985	82.4306	2.89E-15
PU3	0.395656	0.00806925	49.0325	2.89E-15
AP1	1.80601	0.0199672	90.4489	2.89E-15
AP2	1.76862	0.0162451	108.871	2.89E-15
AP3	1.74828	0.0226854	77.0664	2.89E-15
			R2(null)	52.40%
			R2(const)	41.94%

Table 16. European holiday travel (EUR H)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0173617	2.08E-05	-835.813	2.89E-15
TIME	-0.00857067	1.13E-05	-759.386	2.89E-15
WAIT	-4.40982	0.0215587	-204.549	2.89E-15
INVPD	-235.641	1.1008	-214.064	2.89E-15
COMP	-1.13258	0.00417551	-271.244	2.89E-15
AAS	0.46823	0.00313156	149.52	2.89E-15
DIRECT	3.31697	0.00579373	572.511	2.89E-15
DFREQ	0.0153856	7.51E-05	204.84	2.89E-15
LC	0.563633	0.00232754	242.158	2.89E-15
AP1CAR	-0.783801	0.0163485	-47.9432	2.89E-15
AP1KAR	1.19964	0.0166094	72.2267	2.89E-15
AP1RC	-3.24672	0.0176445	-184.008	2.89E-15
AP1TAXI	-0.153202	0.0166854	-9.1818	2.89E-15
AP1BUS	0.46742	0.0277141	16.8658	2.89E-15
AP1UR	1.96562	0.0272271	72.1935	2.89E-15
AP1TR	0.850638	0.027015	31.4876	2.89E-15
AP2CAR	-1.02568	0.0149567	-68.5768	2.89E-15
AP2KAR	0.903728	0.0152148	59.398	2.89E-15
AP2RC	-3.10541	0.0159476	-194.726	2.89E-15
AP2TAXI	-0.187646	0.0152637	-12.2936	2.89E-15
AP2BUS	-1.32489	0.0236498	-56.0211	2.89E-15
AP2UR	-0.154352	0.0227366	-6.7887	1.13E-11
AP2TR	-0.359231	0.0226828	-15.8371	2.89E-15
AP3CAR	-0.377357	0.0132672	-28.4428	2.89E-15
AP3KAR	0.315622	0.0135114	23.3597	2.89E-15
AP3RC	-4.37193	0.0182017	-240.194	2.89E-15
AP3TAXI	-0.628438	0.013613	-46.1644	2.89E-15
AP3BUS	-1.77275	0.0123277	-143.803	2.89E-15
AP3UR	-1.44559	0.00937011	-154.277	2.89E-15
PR1	0.61189	0.00189196	323.417	2.89E-15
PU1	0.3847	0.00150032	256.412	2.89E-15
PR2	0.570138	0.0018957	300.753	2.89E-15
PU2	0.437515	0.0014318	305.569	2.89E-15
PR3	0.610065	0.00342601	178.069	2.89E-15
PU3	0.551239	0.00290076	190.033	2.89E-15
AP1	1.65075	0.0049926	330.639	2.89E-15
AP2	1.92646	0.00606395	317.691	2.89E-15
AP3	1.99236	0.0108685	183.315	2.89E-15
			R2(null)	52.29%
			R2(const)	38.22%

Table 17. European business travel (EUR B)

Variable	Coefficient	Standard deviation	t-ratio	p-value
COST	-0.0216885	2.66E-05	-816.759	2.89E-15
TIME	-0.00795957	1.99E-05	-399.792	2.89E-15
WAIT	-9.94709	0.0352918	-281.853	2.89E-15
COMP	-0.182127	0.00715126	-25.4678	2.89E-15
AAS	0.504623	0.00472046	106.901	2.89E-15
DIRECT	1.43564	0.00850917	168.717	2.89E-15
DFREQ	0.0177437	0.00010425	170.208	2.89E-15
LC	0.275153	0.00504501	54.5396	2.89E-15
LCFREQ	0.0761092	0.00037252	204.307	2.89E-15
AP1CAR	0.72216	0.0296247	24.3769	2.89E-15
AP1KAR	0.233292	0.0300636	7.75995	8.44E-15
AP1RC	-0.661771	0.0301596	-21.9423	2.89E-15
AP1TAXI	0.750386	0.030056	24.9663	2.89E-15
AP1BUS	-0.436805	0.0640814	-6.8164	9.33E-12
AP1UR	1.33854	0.063386	21.1173	2.89E-15
AP1TR	-0.0557889	0.0635451	-0.877942	0.379975
AP2CAR	0.393121	0.0291205	13.4998	2.89E-15
AP2KAR	-0.260475	0.0294758	-8.83691	2.89E-15
AP2RC	-0.671533	0.0296515	-22.6475	2.89E-15
AP2TAXI	0.415442	0.029515	14.0756	2.89E-15
AP2BUS	-1.76693	0.0359288	-49.1786	2.89E-15
AP2UR	-0.855622	0.0343798	-24.8873	2.89E-15
AP2TR	-0.848627	0.0343025	-24.7395	2.89E-15
AP3CAR	-0.300282	0.0223921	-13.4102	2.89E-15
AP3KAR	-0.698722	0.0227567	-30.7041	2.89E-15
AP3RC	-1.05248	0.0239982	-43.8567	2.89E-15
AP3TAXI	-0.609462	0.0226451	-26.9137	2.89E-15
AP3BUS	-2.26991	0.0401428	-56.5459	2.89E-15
AP3UR	-1.49274	0.0246333	-60.5983	2.89E-15
PR1	0.808397	0.00380609	212.396	2.89E-15
PU1	0.386155	0.00263013	146.82	2.89E-15
PR2	0.783306	0.00371673	210.751	2.89E-15
PU2	0.708662	0.00269609	262.848	2.89E-15
PR3	0.937914	0.0123815	75.7514	2.89E-15
PU3	0.805435	0.0108905	73.9574	2.89E-15
AP1	1.61072	0.00814231	197.821	2.89E-15
AP2	1.67197	0.0073826	226.474	2.89E-15
AP3	1.77295	0.0232875	76.1333	2.89E-15
			R2(null)	48.58%
			R2(const)	35.96%

4. Case study: Airport choice in the Cologne region

To illustrate the way the presented model works, a case study of air passengers from the Cologne region, travelling for private reasons and choosing between departure airports and airport access modes, has been chosen. However, the main focus of this paper lies in the methodology and general model approach. Therefore, the case study represents only an excerpt from a larger case study, and a full discussion would go beyond the scope of this paper. For more details on the case study, the reader is pointed to Gelhausen (2007b), Gelhausen et al. (2008) and Gelhausen et al. (2009). The region of Cologne is served by the two airports of Düsseldorf and Cologne in close geographical proximity, and the more remote airport of Frankfurt a. M. as the next hub airport with a large supply of intercontinental flights. A high speed intercity connection (ICE) between Cologne main station and Frankfurt a. M. airport has reduced travel time between the main station and the airport to about one hour, whereas travel time was around one and a half hour before the intercity express (IC) was replaced by the ICE in 2002. These three airports meet almost the whole air transport demand of the

Cologne region in terms of domestic and European air travel, and a good deal of intercontinental air travel. The residual demand is served by some smaller airports such as Dortmund and Weeze.

The airport and access mode choice on the part of private air travellers is analyzed for a selected domestic, European and intercontinental destination. Berlin in Germany represents the domestic, Barcelona in Spain the European and Dallas in the USA the selected intercontinental destination. Scenario data such as transport supply facts have been taken from schedules and other surveys and apply for 2005. Figure 6 depicts the geographical situation of the case study.

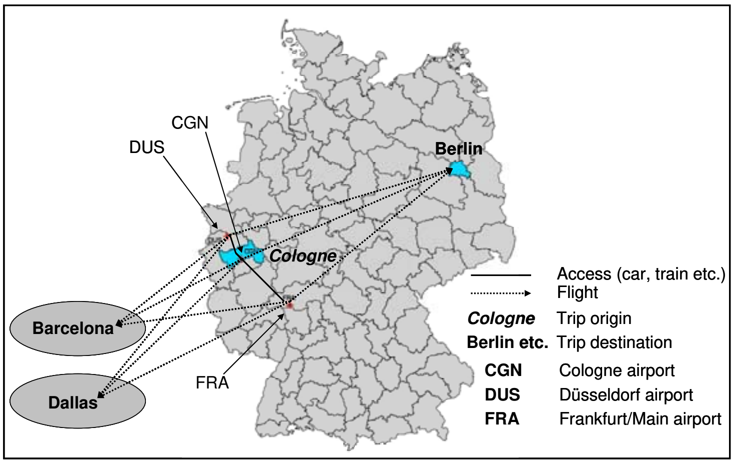


Fig. 6. Illustration of the case study (Gelhausen et al., 2008, p. 360)

Table 18 displays airport and access mode choice of air passengers travelling to the chosen domestic, European and intercontinental destinations mentioned in the base scenario. The matrix elements shown are modal shares (per cent) by departure airport, destination and trip purpose. The base scenario is characterized by flight plans for 2005, and airport and access mode availability as displayed in Table 8, including the aforementioned high speed intercity connection between Cologne main station and Frankfurt a. M. airport. Frankfurt a. M. is the only airport offering a non-stop flight to Dallas in the USA in this scenario.

Table 18. Airport and access mode choice in the base scenario with a high speed intercity connection between Cologne and Frankfurt a. M. airport

Trip origin: Cologne region												
Department airport ⟶	Frankfurt a. M.				Dusseldorf				Cologne			
Trip destination ⟶	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas
Access mode ↓	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P
Car	0.02%	0.08%	0.09%	4.71%	0.90%	14.77%	2.90%	0.94%	10.00%	3.25%	2.38%	2.65%
Kiss and ride	0.01%	0.07%	0.25%	9.95%	2.54%	23.04%	23.52%	9.02%	37.81%	8.80%	27.06%	19.78%
Rental car	0.00%	0.00%	0.01%	0.34%	0.02%	0.33%	0.32%	0.05%	0.15%	0.09%	0.23%	0.09%
Taxi	0.00%	0.01%	0.04%	0.79%	0.57%	11.83%	8.82%	2.49%	16.58%	5.99%	10.49%	6.22%
Bus	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%	1.93%	1.52%	2.26%
Urban railway	0.00%	0.00%	0.00%	0.00%	1.66%	14.89%	7.27%	1.62%	22.06%	5.74%	7.12%	2.79%
Train	0.04%	0.11%	0.47%	16.28%	0.65%	7.10%	4.20%	0.00%	3.28%	1.95%	3.34%	0.00%
Airport	0.07%	0.27%	0.85%	32.07%	6.34%	71.95%	47.02%	14.12%	93.59%	27.76%	52.13%	33.78%

Nearly 94 per cent of the air travellers travelling for private reasons to Berlin (abbreviated BRD P in Table 18) chose Cologne airport as the departure airport because it offers both the shortest access time and the highest frequency of direct flights to Berlin. Access time measured in single trip length is about 20 minutes (by car) and the weekly frequency of direct flights to Berlin is 132. Most air travellers choose "kiss and ride" or a taxi in order to arrive at the airport, as these access modes are much cheaper than parking the car at the airport for the duration of the trip due to the short distance to the airport. Due to the increased access time of about 50 minutes (by car) from Cologne, and only having 94 direct flights a week, Düsseldorf airport attracts a much smaller portion of the demand (6 per cent). "Kiss and ride" and the urban railway are the preferred access modes to the airport, because there is no need to pay parking fees and the distance to the airport is still short. As a result of the much longer access time of around 85 minutes via ICE or about 130 minutes by car from Cologne to

Frankfurt a. M., this airport's share of passengers is negligible. The frequency of 106 direct flights per week to Berlin is not that much better than from Düsseldorf, and is even lower than from Cologne airport. Consequently, Frankfurt a. M. airport cannot offset the longer access time and higher access costs.

The picture is similar for air passengers travelling for short stays (EUR S) or holidays (EUR H) to Barcelona, Spain, with the airports of Cologne and Düsseldorf switching position. This is due to the much better frequency of 28 direct flights per week compared to Cologne airport with only seven direct flights to Barcelona per week. As a result, the longer access time is more than balanced by the higher direct flight frequency to the desired destination. On top of this, Düsseldorf airport offers twice as many low cost flights per week to Barcelona as does Cologne airport. Frankfurt a. M. airport offers the greatest number of direct flights to Barcelona, but because of the absence of any low cost flights, once more its share is only marginal.

However, for intercontinental flights to Dallas, USA, Frankfurt a. M. airport is the first choice, as it is the only airport with a direct flight connection. About 32 per cent of air passengers flying for private reasons from the Cologne region choose Frankfurt a. M. as the preferred airport for departing to Dallas, closely followed by the airport of Cologne with a market share of about 30 per cent. This example shows the trade-off between the value of a direct flight connection and a shorter access time. Düsseldorf airport is only chosen by approximately 14 per cent of air travellers, as it has neither a direct flight connection to Dallas nor better access time than Cologne airport. It is therefore caught between two stools. However, there are other reasons why some passengers choose Düsseldorf airport for the Dallas link.

Table 19 displays the model results (modal shares) for a scenario with a normal train (IC) instead of a high speed intercity connection between Cologne main station and Frankfurt a. M. airport as was the case prior to 2002. Access costs decrease from 35 € to 27 €, but access time increases by about half an hour.

Table 19. Airport and access mode choice in the scenario without a high speed intercity connection between Cologne and Frankfurt a. M. airport

Trip origin: Cologne region												
Department airport ⟶	Frankfurt a. M.				Dusseldorf				Cologne			
Trip destination ⟶	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas
Access mode ↓	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P
Car	0.01%	0.07%	0.06%	4.98%	0.90%	14.77%	2.91%	1.00%	10.00%	3.25%	2.38%	2.84%
Kiss and ride	0.01%	0.07%	0.17%	10.52%	2.54%	23.05%	23.59%	9.67%	37.82%	8.81%	27.14%	21.21%
Rental car	0.00%	0.00%	0.01%	0.36%	0.02%	0.33%	0.32%	0.06%	0.15%	0.09%	0.23%	0.09%
Taxi	0.00%	0.00%	0.02%	0.83%	0.57%	11.83%	8.85%	2.67%	16.58%	6.00%	10.53%	6.67%
Bus	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%	1.93%	1.52%	2.43%
Urban railway	0.00%	0.00%	0.00%	0.00%	1.66%	14.90%	7.29%	1.74%	22.06%	5.74%	7.14%	2.99%
Train	0.02%	0.08%	0.28%	10.47%	0.65%	7.10%	4.22%	0.00%	3.28%	1.95%	3.35%	0.00%
Airport	0.04%	0.23%	0.54%	27.16%	6.34%	71.99%	47.17%	15.14%	93.61%	27.77%	52.29%	36.23%

Because of the small market share of Frankfurt a. M. airport in terms of domestic and European travel to Berlin and Barcelona, respectively, major changes only occur in intercontinental travel to Dallas. The market share of Frankfurt a. M. airport falls from 32 per cent to 27 per cent, while the share of Düsseldorf and Cologne airports rise between about one and two and a half points, respectively.

Table 20. Airport and access mode choice in the scenario with a non-stop flight from Düsseldorf airport to Dallas

Trip origin: Cologne region												
Department airport ⟶	Frankfurt a. M.				Dusseldorf				Cologne			
Trip destination ⟶	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas	Berlin	Barcelona		Dallas
Access mode ↓	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P	BRD P	EUR S	EUR H	INT P
Car	0.02%	0.08%	0.09%	2.17%	0.90%	14.77%	2.90%	4.11%	10.00%	3.25%	2.38%	2.65%
Kiss and ride	0.01%	0.07%	0.25%	4.60%	2.54%	23.04%	23.52%	39.53%	37.81%	8.80%	27.06%	9.13%
Rental car	0.00%	0.00%	0.01%	0.16%	0.02%	0.33%	0.32%	0.23%	0.15%	0.09%	0.23%	0.04%
Taxi	0.00%	0.01%	0.04%	0.36%	0.57%	11.83%	8.82%	10.93%	16.58%	5.99%	10.49%	2.87%
Bus	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%	1.93%	1.52%	1.04%
Urban railway	0.00%	0.00%	0.00%	0.00%	1.66%	14.89%	7.27%	5.54%	22.06%	5.74%	7.12%	1.29%
Train	0.04%	0.11%	0.47%	7.52%	0.65%	7.10%	4.20%	0.00%	3.28%	1.95%	3.34%	0.00%
Airport	0.07%	0.27%	0.85%	14.81%	6.34%	71.95%	47.02%	60.34%	93.59%	27.76%	52.13%	15.60%

Table 20 displays the effects of a direct intercontinental flight connection from Düsseldorf airport to Dallas on the choice behavior of air passengers travelling for non-business reasons. As one might expect, Düsseldorf is now first choice, with a market share of about 60 per cent as it is much closer to Cologne than Frankfurt a. M. airport. The market shares of Cologne and Frankfurt a. M. airport are approximately halved. With about 15 per cent, the market share of Frankfurt a. M. airport is relatively high compared to Cologne and Düsseldorf airports due to its hub function and therefore being a category one airport.

Summary and conclusions

The purpose of this paper is to present a novel approach to discrete choice modelling to estimate an airport and access mode choice model based on a nested logit model. The model is applicable to airport and access mode combinations of any type and number; therefore, an evaluation of new airport/access mode combinations or airports beyond "variations on a theme" is possible.

A main feature of this approach is the clustering of airports from a demand-oriented point of view by means of artificial neural networks, so-called Kohonen's Self-Organizing Maps. Three airport categories have been identified in Germany with regard to the general picture of their flight plans: hub airports, medium-sized airports serving mostly domestic and European destinations by full service flights, and small regional airports focussing mainly on domestic full service flights to category one airports and offering European low cost and charter flights. Thus, we come much closer to looking at different airports as essentially being different products which belong to certain market segments. Hence, airport categories represent product categories. However, airports are not permanently linked to their current category. If the characteristics of an airport change sufficiently over time, then it falls into a different category. Theoretically, even new airport categories may emerge in the future. The view taken in this paper on modelling airport and access mode choice expands the scope of analysis significantly.

To better simulate travel behavior in the model, seven market segments representing homogeneous traveller groups are distinguished according to destination type and trip purpose. The destination type is divided into domestic, European and intercontinental destination and the trip purpose into private und business trips, with private trips to European destinations further subdivided into short stay and holiday purpose, depending on the trip duration.

Decision-relevant attributes determining airport and access mode choice by air travellers can be divided roughly into access mode-specific attributes such as access time and access cost on the one hand, and airport-specific attributes like weekly flight frequency to a given destination on the other. However, this classification is not as clear-cut as it may seem. These attributes determine airport and access mode choice in a complex way, which can be analyzed by different trade-offs between attributes with different dimensions such as access time versus the existence of a direct flight connection, or access time versus access cost.

To demonstrate the model's ability of simulating air travellers' combined choices, case studies of the airport and access mode choice of air travellers from the Cologne region with private trip intentions have been carried out for two different scenarios. First, the impact of the high speed intercity connection between Cologne main station and Frankfurt a. M. airport has been analyzed; subsequently, the effects of a better supply of intercontinental direct flights at Düsseldorf airport have been evaluated by means of the example of Dallas in the USA.

As a result of the model application, air travellers tend to choose the nearest airport. However, they are willing to travel to airports further away if they can get a direct flight connection to their destination in this way. This is notably true for air passengers travelling for private purposes to European and intercontinental destinations. The size of the catchment area of an airport depends both on the supply of direct flight connections and on the availability of attractive access modes such as high speed trains. The supply of low cost flights plays a major role in European air travel, both for private and business purposes. The attractiveness of an airport has two aspects: a "land"-side and an "air"-side. Although the latter seems to be more important to air travellers in some cases, the impact of access quality should not be underestimated, as this case study has demonstrated.

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