PASSENGERS' AIRPORT CHOICE

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1. INTRODUCTION

Modelling airport choice of passengers has been a subject of interest for air transport scientists and airport managers already for a while. Wilken, Berster and Gelhausen have reported of a market segment specific model approach to airport choice in Germany in a paper entitled "Airport Choice in Germany - New Empirical Evidence of the German Air Traveller Survey 2003" presented at the Air Transport Research Society World Conference 2005 in Rio de Janeiro, Brazil [15]. In continuation of the analysis of airport choice, based on the evidence coming from the data of the survey mentioned, this paper deals with a model of combined airport and access mode choice in Germany by market segment.

The question arises why to model airport and access mode choice simultaneously. The underlying hypothesis is that airport and access mode choice are closely interrelated. Air travellers typically have a strong preference to choose the nearest airport as the aforementioned survey reveals. In Germany, 67% of the air travellers choose on average the nearest airport, however, 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, to reduce travel time [15]. Access time and access cost play a major role in airport choice, which in turn depend on access mode choice. The availability of access modes is again airport specific. Because of the strong dependence of airport and access mode choice on each other a combined model approach seems more sensible than two separate models. The combined approach allows including the aforementioned interrelations.

This paper presents a combined airport and access mode choice model based on a nested logit approach, first presented at the Air Transport Research Society World Conference 2006 in Nagoya, Japan [3], [7]. It is called a "generalized nested logit model for airport and access mode choice" as it is not restricted to specific airports or a certain number of airport and access mode combinations, but allows to evaluate airport plans like the future Berlin-Brandenburg International Airport (BBI) in the southeast of Berlin or the introduction of new access modes, like a direct high speed intercity train access at already existing airports as this was the case between Cologne and Frankfurt airport in 2002. The case study concluding the paper is a modified excerpt of a study dealing with different future scenarios relating to airport and access mode choice in the Cologne region conducted by the author [5], [6].

As a means to achieve a general applicability of the model airports have been grouped into "airport categories". Airports are categorised from a demand-oriented point of view to form clusters of homogenous airports regarding their general picture of their flight plan.

The model has been developed as a part of the doctoral thesis of the author, Marc Ch. Gelhausen [4]. The model is of particular interest for airport managers as well as high speed rail providers since it shows the dependence between the market share of an airport and access mode combination and its quality regarding their attributes, e.g. travel time, travel cost and weekly flight frequency to a given destination.

2. THE CONCEPT OF ALTERNATIVE GROUPS

The fundamental hypothesis of discrete choice models is the assumption of individual utility maximisation. 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 [10]:

(2.01) $$U_i = V_i + \varepsilon_i$$

The random component of the utility function is introduced for various reasons, i.e. a lack of observability of relevant attributes of alternatives or their incomplete measurability [10].

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 of 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 [14]:

(2.02) $$P(a_i = a_{opt}) = \frac{e^{\mu V_i}}{\sum_j e^{\mu V_j}}$$

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 [1]:

(2.03) $$\frac{P(a_i = a_{opt})}{P(a_j = a_{opt})} = \frac{\frac{e^{\mu V_i}}{\sum_k e^{\mu V_k}}}{\frac{e^{\mu V_j}}{\sum_k e^{\mu V_k}}} = \frac{e^{\mu V_i}}{e^{\mu V_j}}$$

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 to estimate the model parameters, excluding alternative-specific variables, on a subset of the alternatives [11], [12], [13], [14] and the possibility of an evaluation of new alternatives without the need to re-estimate alternative-unspecific model parameters [2]. The problem of estimating alternative-specific variables from a subset of alternatives will be discussed below.

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 in (2.01) 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 [10]:

(2.04)
$$U_i = V_i + \varepsilon_i^a + \varepsilon_k^c$$

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. (2.05) is 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.

(2.05)
$$\Omega = \begin{bmatrix} \sigma_{11}^2(\mu_1^c) & \sigma_{12}^2(\varepsilon_1^c) & 0 & 0 \\ \sigma_{21}^2(\varepsilon_1^c) & \sigma_{22}^2(\mu_1^c) & 0 & 0 \\ 0 & 0 & \sigma_{33}^2(\mu_2^c) & \sigma_{34}^2(\varepsilon_2^c) \\ 0 & 0 & \sigma_{43}^2(\varepsilon_2^c) & \sigma_{44}^2(\mu_2^c) \end{bmatrix}$$

Each cluster k is characterized by an individual scale parameter μ_k^c 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 [10]:

(2.06)
$$P(a_i = a_{opt}) = P(a_i = a_{opt} \mid a_i \in c_k) * P(c_k = c_{opt})$$

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 [10]:

(2.07)
$$V_k^c = \frac{1}{\mu} \ln \sum_{i \in k} e^{\mu V_i}$$

The choice probability of an alternative i in nest k can be written as [10]:

(2.08)
$$P(a_i = a_{opt}) = \frac{e^{\mu V_i}}{\sum_{j \in k} e^{\mu V_j}} * \frac{e^{\mu_k^c V_k^c}}{\sum_l e^{\mu_l^c V_l^c}}$$

The hierarchical structure of (2.08) does not imply a sequential decision process. An extension to more than two levels is possible [1].
In the nested logit-model the IIA-property does only hold for two alternatives of the same cluster:

(2.09)
$$\frac{P(a_1 = a_{opt} \mid a_1 \in c_1) * P(c_1 = c_{opt})}{P(a_2 = a_{opt} \mid a_2 \in c_1) * P(c_1 = c_{opt})} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}} = \frac{e^{\mu V_1}}{e^{\mu V_2}}$$

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

(2.10)
$$\frac{P(a_1 = a_{opt} \mid a_1 \in c_1) * P(c_1 = c_{opt})}{P(a_2 = a_{opt} \mid a_2 \in c_2) * P(c_2 = c_{opt})} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}} * \dfrac{e^{\mu_1^c V_1^c}}{\sum_l e^{\mu_l^c V_l^c}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_2} e^{\mu V_j}} * \dfrac{e^{\mu_2^c V_2^c}}{\sum_l e^{\mu_l^c V_l^c}}} = \frac{\dfrac{e^{\mu V_1}}{\sum_{j \in c_1} e^{\mu V_j}}}{\dfrac{e^{\mu V_2}}{\sum_{j \in c_2} e^{\mu V_j}}} * \frac{e^{\mu_1^c V_1^c}}{e^{\mu_2^c V_2^c}}$$

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

If it is feasible to form groups of at least approximatively similar clusters and to assign an identical covariance matrix to all clusters of the same group, an estimation of alternative-unspecific model-parameters on a subset of alternatives equal to the logit-model is possible. Each group of clusters must be represented by at least one member in this subset to enable the estimation of all cluster-specific scale parameters. Formula (2.11) shows a covariance-matrix of six alternatives belonging to three groups, with two alternatives per group. Figure 2.01 shows the relationship between a group and a cluster for this example.

(2.11)
$$\Omega = \begin{bmatrix} A & 0 & 0 & 0 & 0 & 0 \\ 0 & B & 0 & 0 & 0 & 0 \\ 0 & 0 & B & 0 & 0 & 0 \\ 0 & 0 & 0 & C & 0 & 0 \\ 0 & 0 & 0 & 0 & A & 0 \\ 0 & 0 & 0 & 0 & 0 & C \end{bmatrix}$$

The letters A, B and C represent the covariance structure of a cluster; same letters indicate an equal covariance structure for different clusters. Figure 2.01 illustrates the assignment of clusters to groups.

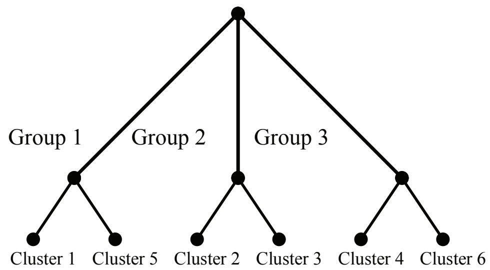


FIG. 2.01: Dependence between Clusters and Groups

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

Applying the concept of grouping in the logit-model is possible, however, serves only to estimating alternative-specific variables, as there are no different scale parameters due to independently and identically distributed random components in the utility function.

The main advantage of this approach does not only lie 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 also in a better way of developing a more generally applicable choice model beyond the alternatives of the estimation dataset, e.g. in the context of scenario analysis.

3. AIRPORT CATEGORIES

Clusters of the same group are characterised 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 grouping of clusters corresponds to an aggregation in terms of similarity of those unobserved factors. Airport and access mode choice is a two-dimensional choice problem, so that a categorisation in respect of both dimensions is necessary, however, as the access mode choice is sufficiently general, only airports need to be categorised.

Airports have been categorised from a demand-oriented point of view whereby the general "picture" of flight services at an airport serves as a quality criterion. The flight service of an airport is 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 destinations are defined:

- Domestic
- Europe
- Intercontinental

Flight types are divided into:

- Low-Cost
- Charter
- Full Service

Table 3.01 summarises the relevant attributes retained for categorising airports.

Attributes (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 Intercontinental Low-Cost Flights (LCINT)	Flights per Week
Number of Intercontinental Charter Flights (CCINT)	Flights per Week
Number of Intercontinental 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 Intercontinental Destinations (NUMINT)	Number of Destinations

TAB. 3.01: Attributes of Airport Categories

Clusters are identified by means of Kohonen's Self-Organizing Map [9]. Figure 3.01 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 part of figure 3.01 illustrates.

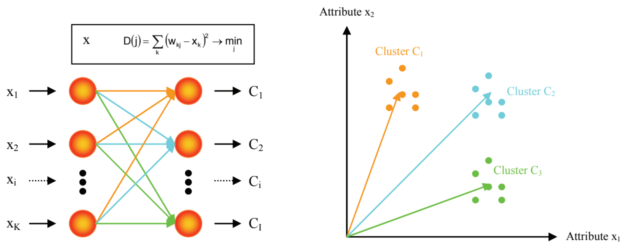


FIG. 3.01: Self-Organizing Map

Table 3.02 shows the parameters for optimal cluster identification. The Self-Organizing Map is not highly sensitive with regard to parameter variations.

Three airport categories have been identified. The output neurons are arranged in a linear grid and the distance between an input vector and synaptic weight vector of the corresponding output neuron is measured Euclidean. A linear neighbourhood function is used and the neighbourhood 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 rather small with 0.01. Each element of the input vector is normalised to the interval [-1; 1].

Table 3.03 shows the synaptic weights for the trained Self-Organizing Map. The colour of the columns equals the colour of the synaptic weights in figure 3.03.

Parameter	Value
Topology of output neurons	Linear
Measure of distance	Euclidean
Neighbourhood function	linear: 2 - 0.002*Iteration
Learning rate	0.01
Number of iterations	10 000
Data normalisation	yes, [-1; 1]
Number of input neurons	12
Number of output neurons	3

TAB. 3.02: Parameters of a SOM for Airport Categorisation

Table 3.04 shows the result of assigning airports, contained in the German Air Traveller Survey 2003, to identified categories. Although the service characteristics of the three Berlin airports vary substantially, they had been interviewed 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 categorisation.

	Airport		
Attributes	Category 1	Category 2	Category 3
LCBRD	0.054281	0.026181	-0.973566
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

TAB. 3.03: Cluster Centroids of Airport Categories

Category	Airport (IATA-Code)
AP 1	Frankfurt a. M. (FRA)
AP 1	Munich (MUC)
AP 2	Düsseldorf (DUS)
AP 2	Hamburg (HAM)
AP 2	Cologne (CGN)
AP 2	Stuttgart (STR)
AP 3	Bremen (BRE)
AP 3	Dortmund (DTM)
AP 3	Dresden (DRS)
AP 3	Erfurt (ERF)
AP 3	Frankfurt Hahn (HHN)
AP 3	Friedrichshafen (FDH)
AP 3	Hanover (HAJ)
AP 3	Karlsruhe/Baden (FKB)
AP 3	Leipzig/Halle (LEJ)
AP 3	Lübeck (LBC)
AP 3	Münster/Osnabrück (FMO)
AP 3	Niederrhein (NRN)
AP 3	Nuremberg (NUE)
AP 3	Paderborn/Lippstadt (PAD)
AP 3	Saarbrücken (SCN)

TAB. 3.04: Assignment of Airports to Categories

Table 3.05 and table 3.06 illustrate some properties of the three identified airport categories in per cent and absolute values. The three, respectively two highest values concerning the flight frequency and the number of different destinations are highlighted in colour.

	LCBRD	CCBRD	FSBRD	LCEUR	CCEUR	FSEUR	LCINT	CCINT	FSINT	NUMBRD	NUMEUR	NUMINT
AP 1	3.18	0.43	20.39	0.87	5.83	55.81	0	1.24	12.25	8.31	60.27	31.42
AP 2	8.97	0.58	28.27	11.65	11.76	37.24	0.02	0.71	0.79	16.23	74.62	9.16
AP 3	1.29	0.86	39.22	32.57	15.57	10.05	0.02	0.42	0	19.94	78.9	1.16

TAB. 3.05: Structure of Flights per Airport Category (in %)

	LCBRD	CCBRD	FSBRD	LCEUR	CCEUR	FSEUR	LCINT	CCINT	FSINT	NUMBRD	NUMEUR	NUMINT
AP 1	106	16	756	32	225	2138	0	49	517	19	144	83
AP 2	104	7	348	129	153	487	0	11	11	17	80	12
AP 3	3	1	80	47	25	39	0	0	0	6	22	1

TAB. 3.06: Structure of Flights per Airport Category (absolute)

Airports of the first category represent hubs. They offer mainly full service flights. Their focus is mainly on European and intercontinental destinations. The number of domestic destinations is relatively low, but they are served with higher frequency. Hub airports offer the highest number of flights and destinations. Airports of the second category serve mainly domestic and European destinations with full service flights. The share of European low-cost and tourism flights is approximately equal but much smaller than the share of full service flights. The structure of flights and destinations of airports of the third category is similar to those of the second category, but their focus is shifted more on domestic full service flights and European low-cost and tourism traffic. These airports are the smallest in terms of number of flights and destinations.

Table 3.07 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.

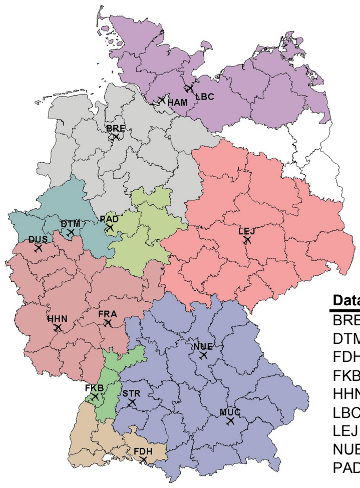
	LCBRD	CCBRD	LBRD	LCEUR	CCEUR	LEUR	LCINT	CCINT	LINT	NUMBRD	NUMEUR	NUMINT
AP 1	96	3.5	75	8.5	37.5	279	0	18	396	1	16.5	43
AP 2	77	0	32	164.5	66.5	162	0.5	2	1.5	2.5	5.5	1
AP 3	0	0	68	9	21	29.5	0	0	0	2.5	10.5	0

TAB. 3.07: Standard Deviation of Attributes by Category

4. MODEL ESTIMATION AND RESULTS

4.1 Preparing the Data Set for Model Estimation

For model estimation the data set is partitioned into several disjoint data subsets. 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 have to be included, as these have been the only airports of their category with an access by train in 2003. The individual data subsets are merged into a single new estimation data set, thereby reducing the number of alternatives from 122 to 21. By weighting each observation the estimation data set remains statistically representative. Figure 4.01 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 colours. Every subset is named according to its airport of the third category.



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. 4.01: Data Subsets and Assignment of Airports

4.2 General Model Estimation and Application

After selecting airports and access modes for a specific application case, they are assigned to categories with the appropriate model parameters. The model can be applied to any number of airports. As a result of the grouping of clusters an application of the estimated model to airports and airport/access mode combinations other than those of the estimation data set is possible. Figure 4.02 summarises the general process of model estimation and its application. The next chapter deals with the estimation of the group-specific model parameters.

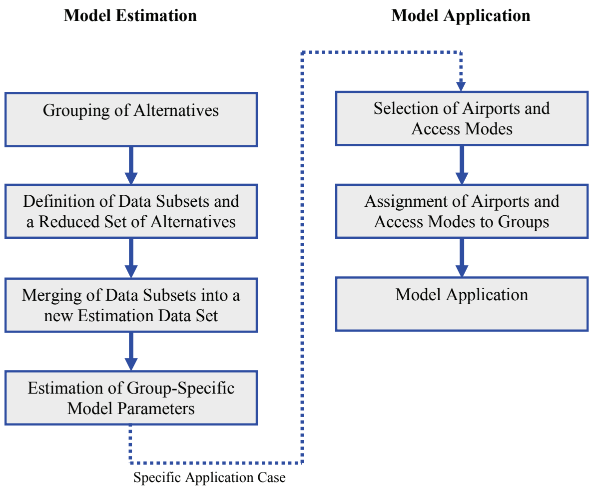


FIG. 4.02: Estimation and Application Process of Airport and Access Mode Choice Model

4.3 Model Definition and Estimation Results

According to the length and purpose of journeys seven different market segments are defined:

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

	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	
Düsseldorf	x	x	x	x	x	x	x
Erfurt	x	x	x	x	x		
Frankfurt a. M.	x	x	x	x	x	x	x
Frankfurt Hahn	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	x	x	x	x	x		
Leipzig/Halle	x	x	x	x	x		x
Lübeck	x	x	x	x	x		
Munich	x	x	x	x	x	x	
Münster/Osnabrück	x	x	x	x	x		
Niederrhein	x	x	x	x	x		
Nuremberg	x	x	x	x	x	x	
Paderborn/Lippstadt	x	x	x	x	x		
Saarbrücken	x	x	x	x	x		
Stuttgart	x	x	x	x	x	x	

TAB. 4.01: Airports and Available Access Modes

Table 4.01 illustrates the actual availability of access modes to the airports of the German Air Traveller Survey 2003 indicated by a cross in the appropriate field. Only 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. 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 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 the access time to public transport. The evaluation of the access quality from the access mode terminal to the air terminal is measured binary because of 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 airline competition on that link. It is assumed that a higher degree of competition indicates a lower fare level. For stop-over flights a maximum of competition is reached because of the great number of possible flights between any origin and destination. The time advantage of a direct flight connection is measured via its existence, its quality is assessed by means of its weekly flight frequency. To consider different price levels, low-cost- and tourism flights are taken into account separately. By reasons of a lack of information exact air fares are not considered. Table 4.02 summarises the explanatory variables and their definitions.

Variable (Abbreviation)	Definition
Access Cost (COST)	Cost in € per Person incl. Parking Fees, Double Trip Length
Access Time (TIME)	Time in Minutes, Double Trip Length
Waiting Time (WAIT)	Inverse of the Daily Frequency
Inverse of the Population Density (INVPD)	Inverse of Residents per km^2
Competition on a Direct Flight Connection(COMP)	Inverse of the Number of Alliances and Independent Airlines on that 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

TAB. 4.02: Definition of Explanatory Variables

Table 4.03 shows the reduced alternative set as used for model estimation, based on the aforementioned airport categories. Each alternative is composed of both an airport category and one of the seven access modes to the airport.

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 Railway	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 2/Bus	AP2BUS
AP 2/Urban Railway	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

TAB. 4.03: Reduced Alternative Set

Figure 4.03 illustrates the nesting structure of airport categories and access modes. Each nest consists of one airport category at the top and seven access modes below, subdivided into private (PR) and public (PU) transport.

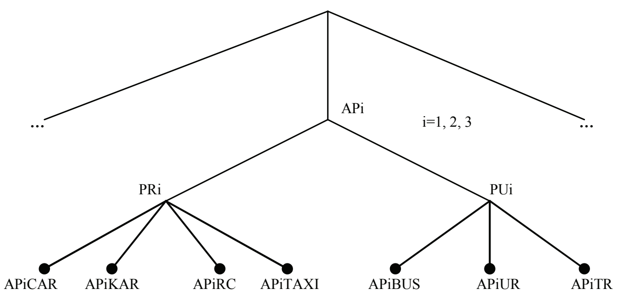


FIG. 4.03 Nesting Structure

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

$$V_i = alt_i + \sum_k b_k * x_{k,i} \quad (4.01)$$

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 their alternative abbreviation. 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. Model parameters are estimated using the maximum-likelihood estimation method, and the BFGS-algorithm is applied for numerical optimisation [8]. The covariance matrix of the estimated parameters is computed by means of the BHHH-estimator [14]. 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. Benchmark is a model without any variables (R2null) and a market share model (R2const). Tables 4.04 - 4.10 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.

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
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%

TAB. 4.04: Domestic Private Travel (BRD 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
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%

TAB. 4.06: Intercontinental Private Travel (INT P)

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%

TAB. 4.05: Domestic Business Travel (BRD 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
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%

TAB. 4.07: Intercontinental Business Travel (INT B)

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
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%

TAB. 4.08: European Private Short Stay Travel (EUR S)

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%

TAB. 4.09: European Holiday Travel (EUR H)

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%

TAB. 4.10: European Business Travel (EUR B)

4.4 Interpretation of the Estimation Results

Airport managers might be interested e.g. to know about the enlargening of the catchment area due to one additional flight per week to a given destination. Mobility providers like railway companies may be interested in the trade-off between travel time and travel cost to determine the nature of their supply to meet their customers' needs and preferences as optimal as possible.

Various trade-offs, in particular between quality measures and costs, may be computed by means of the estimated model coefficients. They describe the subjective value perceived of an alternative attribute in units of a different alternative attribute from the viewpoint of an air traveller, e.g. access time in units of access costs. Table 4.11 lists some ratios of variable coefficients values, which correspond to key trade-offs, ordered by market segment.

A key figure to describe air travellers' preferences regarding their access mode to the airport is the "TIME/COST" ratio describing the value of access time in Euro. In general, private air travellers are more sensitive to access cost than business travellers. According to the choice model, one minute in access time equals e.g. 0.31 Euro for private air travellers and 0.75 Euro for business travellers in domestic air travel. In general, business travellers prefer faster access modes to the airport, while private air travellers tend to choose cheaper modes of transportation. An exception is the market segment of European holiday travel with travellers showing a relative high sensitivity to access time compared to business travellers. This might be due to the high importance of holidays to Germans and their low propensity to save money in holidays.

	BRD P	BRD B	EUR S	EUR H	EUR B	INT P	INT B
TIME/COST	0.31	0.75	0.31	0.49	0.37	0.39	0.57
DIRECT/TIME	-280.42	-238.65	-595.00	-387.01	-180.37	-343.52	-81.98
DFREQ/TIME	-0.83	-0.39	-1.71	-1.80	-2.23	x	x
LC/TIME	x	x	-14.13	-65.76	-34.57	x	x
LCFREQ/TIME	x	x	-12.06	x	-11.79	x	x

TAB. 4.11: Ratio Values of Variable Coefficients

An important ratio of model coefficients to describe the influence of the quality of the flight plan on the catchment area of an airport is "DIRECT/TIME", describing the additional access time, which is worth having a direct flight connection instead of a stop-over flight to a given destination. As its absolute ratio value is lower for private than for business travellers, access time is thus more important than a direct flight connection to the desired destination for air passengers travelling for business purpose than for those travelling for private reasons. As mentioned earlier in this paper, access time is measured as double trip length. Halving these values produces the equivalent ratios for the single distance between the trip origin and the airport. The perceived value of a direct flight connection to the designated destination equals e.g. the value of about 387 minutes access time to the airport and back to the trip origin for a holiday traveller. Measured in single trip length, this comes up to about 194 minutes from the trip origin to the airport. The ratio "DFREQ/TIME" describes the impact of one additional weekly direct flight connection to the designated destination. As table 4.11 shows, the importance of the weekly flight frequency is relatively low compared to the existence of a direct flight connection. The value of one additional flight per week represents e.g. 1.8 minutes access time to the airport and back to the trip origin.

	Frankfurt a. M.				Düsseldorf				Cologne			
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	0.03%	0.17%	0.12%	5.00%	1.14%	19.62%	3.36%	0.99%	14.37%	2.11%	2.80%	2.79%
Kiss and Ride	0.02%	0.15%	0.32%	10.57%	3.23%	30.61%	27.28%	9.57%	54.35%	5.72%	31.84%	20.83%
Rental Car	0.00%	0.00%	0.01%	0.37%	0.02%	0.44%	0.37%	0.06%	0.22%	0.06%	0.27%	0.09%
Taxi	0.00%	0.01%	0.05%	0.84%	0.72%	15.72%	10.23%	2.65%	23.83%	3.89%	12.35%	6.55%
Urban Railway	0.00%	0.00%	0.00%	0.00%	1.98%	21.24%	10.41%	1.14%	0.00%	0.00%	0.00%	0.00%
Train	0.07%	0.22%	0.60%	17.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Airport	**0.12%**	**0.55%**	**1.10%**	**34.06%**	**7.10%**	**87.64%**	**51.64%**	**14.41%**	**92.77%**	**11.79%**	**47.25%**	**30.26%**

TAB. 5.01: Base Scenario with High Speed Train Connection between Cologne and Frankfurt a. M. Airport

The ratios "LC/TIME" and "LCFREQ/TIME" are a measure to describe the influence of a direct low-cost flight connection to a given destination on the catchment area of an airport. These values have to be added to the aforementioned ratios. In European holiday travel, the value of a direct flight connection measured in access time (double trip length) increases by about 66 minutes to 453 minutes, if it is a low-cost flight. This equals 227 minutes travel time to the airport from the trip origin. In European holiday travel the influence of additional weekly flights to a given destination on the catchment area of an airport is independent of the fact whether these are low-cost flights or not. This is not the case for European short stay and business travel. For example, the value of one additional flight per week to the desired destination of the air passenger travelling for private short stay reasons increases by about 12 minutes access time to nearly 14 minutes measured in double trip length.

5. AIRPORT CHOICE IN THE COLOGNE REGION

For an exemplary application of the combined model, the case of air passengers from the Cologne region travelling for private reason and choosing between airports and access modes has been chosen. The region of Cologne is characterized by the two airports of Düsseldorf and Cologne in close proximity and the airport of Frankfurt a. M. as the next hub airport with a large supply of intercontinental flights. A high speed intercity connection between Cologne main station and Frankfurt a. M. airport reduces travel time to less than 85 minutes. These three airports serve almost the whole air transport demand of the Cologne region in domestic and European air travel and a good deal of intercontinental air travel. The residual demand is served by some smaller airports like e.g. Dortmund and Weeze.

Airport and access mode choice of private air travellers is analyzed for a domestic, a European and an intercontinental destination. Berlin in Germany represents a domestic, Barcelona in Spain a European and Dallas in the USA an intercontinental destination. Scenario data like transport supply data have been taken from schedules and other surveys and apply for 2005; the bus alternative is omitted for reasons of lack of data availability for this year. This is no constraint concerning the applicability of the model as described above and furthermore, from a practical point of view, the bus alternative is of minor importance in the chosen scenario cases.

Table 5.01 displays airport and access mode choice of air passengers travelling to the domestic, European and intercontinental destination mentioned for a base scenario. The base scenario is characterised by an airport and access mode availability as displayed in table 4.01 and flight plans of 2005.

Nearly 93% of the air passengers travelling to Berlin (abbreviated BRD P in table 5.01) choose Cologne airport as 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 and the weekly frequency of direct flights to Berlin is 132. Most air travellers choose "kiss and ride" or the taxi to get to 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. Because of the increased access time of about 50 minutes from Cologne and a weekly direct flight frequency of only 94 a much smaller portion of demand (7%) departs from Düsseldorf airport. "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 less than 85 minutes via high speed intercity train or 130 minutes by car from Cologne the share of passengers departing from the airport of Frankfurt a. M. is negligible. The frequency of 106 direct flights per week to Berlin is not so much better than from Düsseldorf and even lower than from Cologne airport and thus cannot offset the longer access time to Frankfurt a. M. airport.

The picture is similar for air passengers travelling for short stay (EUR S) or holiday (EUR H) reasons to Barcelona, Spain, with the airports of Cologne and Düsseldorf switching positions. 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, so that 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 Cologne airport. Frankfurt a. M. airport offers the greatest number of direct flights per week to Barcelona, but because of the absence of any low cost flights its share is only marginal again.

The market share of Frankfurt a. M. airport falls from 34% to 29%, while the share of Düsseldorf and Cologne airport rises between about one respectively two points.

Table 5.03 displays the effects of a direct intercontinental flight connection from Düsseldorf airport to Dallas. As one would expect, Düsseldorf is now first choice with a market share of about 61% 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 16%, the market share of Frankfurt a. M. airport is relatively high compared to Cologne and Düsseldorf airport, due to its hub function and therefore being a category one airport.

	Frankfurt a. M.				Düsseldorf				Cologne			
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	0.03%	0.17%	0.12%	2.28%	1.14%	19.62%	3.36%	4.28%	14.37%	2.11%	2.80%	1.27%
Kiss and Ride	0.02%	0.15%	0.32%	4.83%	3.23%	30.61%	27.28%	41.18%	54.35%	5.72%	31.84%	9.51%
Rental Car	0.00%	0.00%	0.01%	0.17%	0.02%	0.44%	0.37%	0.24%	0.22%	0.06%	0.27%	0.04%
Taxi	0.00%	0.01%	0.05%	0.38%	0.72%	15.72%	10.23%	11.39%	23.83%	3.89%	12.35%	2.99%
Urban Railway	0.00%	0.00%	0.00%	0.00%	1.98%	21.24%	10.41%	3.82%	0.00%	0.00%	0.00%	0.00%
Train	0.07%	0.22%	0.60%	7.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Airport	**0.12%**	**0.55%**	**1.10%**	**15.55%**	**7.10%**	**87.64%**	**51.64%**	**60.92%**	**92.77%**	**11.79%**	**47.25%**	**13.82%**

TAB. 5.03: Scenario with a Direct Flight Connection from Düsseldorf Airport to Dallas

However, for intercontinental flights to Dallas, USA, Frankfurt a. M. airport is first choice, as it is the only airport with a direct flight connection. About 34% of the private purpose air passengers from the Cologne region choose Frankfurt a. M. airport, closely followed by the airport of Cologne with a market share of about 30%. This example shows the trade-off between the value of the existence of a direct flight connection and access time, as has been outlined already in table 4.11 in a more general manner. The value of a direct flight connection is in the upper range for intercontinental private air travel and equals about 170 minutes access time between the origin and the departure airport measured in single trip length. Düsseldorf airport is only chosen by round about 15% of the air travellers, as it has neither a direct flight connection to Dallas nor a better access time than Cologne airport, so it is caught between two stools in this case. There are other reasons why some passengers choose Düsseldorf airport for the Dallas link.

Table 5.02 displays a scenario with a normal train on the ICE track instead of a high speed intercity connection between Cologne main station and Frankfurt a. M. airport as it was the case before 2002; however, on the Rhine track. Access costs decrease from 35 € to 27 € but access time increases form less than 85 minutes to about two hours for the single trip length.

6. SUMMARY AND IMPLICATIONS

The purpose of this paper is to present a novel approach in discrete choice modelling to estimate an airport and access mode choice model based on a generalized nested logit model approach. The model is applicable to airport and access mode choice combinations of any nature and number, so that an evaluation of new airport/access mode combinations or airports 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 are identified in terms of the general picture of their flight offer: Hub airports, medium-sized airports serving mostly domestic and European Destinations by full service flights and small regional airports focusing mainly on domestic full service flights and European low-cost and tourism flights.

	Frankfurt a. M.				Düsseldorf				Cologne			
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%	0.15%	0.08%	5.31%	1.14%	19.64%	3.37%	1.07%	14.38%	2.12%	2.81%	3.00%
Kiss and Ride	0.01%	0.13%	0.22%	11.22%	3.24%	30.64%	27.39%	10.31%	54.37%	5.72%	31.97%	22.44%
Rental Car	0.00%	0.00%	0.01%	0.39%	0.02%	0.45%	0.37%	0.06%	0.22%	0.06%	0.27%	0.10%
Taxi	0.00%	0.01%	0.03%	0.89%	0.72%	15.73%	10.27%	2.85%	23.84%	3.90%	12.40%	7.06%
Urban Railway	0.00%	0.00%	0.00%	0.00%	1.98%	21.26%	10.45%	1.23%	0.00%	0.00%	0.00%	0.00%
Train	0.03%	0.16%	0.36%	11.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Airport	**0.07%**	**0.46%**	**0.70%**	**28.97%**	**7.11%**	**87.72%**	**51.85%**	**15.52%**	**92.82%**	**11.80%**	**47.44%**	**32.60%**

Tab. 5.02: Scenario without High Speed Intercity Connection between Cologne and Frankfurt a. M. Airport

Because of the small market share of Frankfurt a. M. airport in domestic and European travel to Berlin respectively Barcelona major changes only occur in intercontinental travel to Dallas.

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

Decision-relevant attributes determining airport and access mode choice by air travellers can roughly be divided into more access mode-specific attributes like access time and access cost and more airport-specific attributes like weekly flight frequency to a given destination. 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 analysed 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 ability of simulating travellers' combined choices, case studies of airport and access mode choice of air travellers with private trip purposes from the Cologne region have been studied for different scenarios. On the one hand, the impact of the high speed intercity connection between Cologne main station and Frankfurt a. M. airport has been analysed; on the other hand, 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 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. A direct flight connection equals roughly the value of three hours in access time for the single distance between the trip origin and the departure airport. This value increases to even five hours for air passengers travelling for short stay reasons. This segment includes the low-cost market, where travellers avoid more expensive transfer flights of full service carriers and are willing to travel longer in order to get cheap flights. Business travellers are more sensitive to access time. Depending on the destination type a direct flight connection is worth between about 40 and 190 minutes access time for the single distance between the trip origin and the departure airport.

With the exception of air passengers travelling for holiday purpose to European destinations, business travellers are more access time sensitive, while private air travellers tend to choose cheaper modes of transport to the airport. One minute in access time is worth between 0.31 € and 0.49 € for private travellers and 0.37 € to 0.75 € for business travellers.

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 purpose. The attractiveness of an airport has two sides: A "land-side" and an "air-side". Although the latter is still more important to air travellers, the impact of the access quality should not be underestimated as the exemplary application case in this study has demonstrated.

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