Access mode and departure airport choice in San Francisco Bay area

Sunyoung Jun
Department of Economics
University of California, Irvine
Irvine, CA 92697-5100
Sjun@uci.edu

Last update: 10/23/2006

Abstract

This paper estimates a mixed logit model to evaluate the factors valuing on airport ground access mode choice as well as airport choice using data from the 2001/2002 air passenger survey. Along with travel time and travel cost, the additional variables such as accessibility of public transit, the level of convenience, availability of cost reimbursement are introduced in the model to explain the access mode choice. The results show that accessibility and cost reimbursement are positively related to the choice of private modes but negatively related with the level of convenience.

1. Introduction

This paper empirically estimates how air passengers departing from one of three San Francisco Bay Area airports (San Francisco airport, San Jose airport, or Oakland airport) choose a particular departure airport and a transport mode for accessing the airport. The aim of this study is to identify the impact of various explanatory variables (i.e., travel time, travel cost, accessibility of public transit, and cost reimbursement) on access mode choice. It abstracts from other choices like destination airport, airline, the time of day to travel, the duration of the trip, etc.

According to TRB (2002), an airport with more than 45 million passengers per year generates some 5,000,000 vehicle-miles of travel (VMT) per day; a smaller airport of 5 million passengers per year can be associated with 500,000 vehicle-miles per day (TCRP Report 83, pp 15). For example, the San Francisco airport generates 2,884,610 VMT per day and 602,011 VMT per day for the Oakland airport in 1990.[1] VMT generated by ground access trips associated with airports in the San Francisco Bay area consists of about 4% of total weekday daily VMT, as the average weekday daily VMT is about 107,000,000 in 1990.[2]

Therefore, the scale of air-related trip generation at metropolitan areas is of concern to regional transportation and environmental managers. For example, ground access traffic to the airport contributes to a number of problems; congestion, traffic noise, air pollution, etc. Empirically estimated choice model is of direct policy relevance, as it forms a key analytical component of economic models for the assessment of transport policies regarding parking charges, public transport fare, or the introduction of new modes (such as the extension of a light rail system to the airport),

[1] Thomas J. Higgins (1994), "California Airports: Ground Access Vehicle Trips, Emissions and Emission Reduction Strategies", Proceedings of the 23rd Air Transport Conference.
[2] http://www.mtc.ca.gov/maps_and_data/datamart/stats/vmt.htm. I also calculate VMT at SJC using information from T. Higgins (1994). SJC generates 754,920 daily VMT.

etc. However, examining a multiple airport region allows for substitutability of departure airports, so that the increased choice flexibility affects the effectiveness of transport policies. For example, air travelers can respond to changed travel conditions by switching to a different access mode or by choosing a different airport.

I estimate a mixed logit model (in particular, error component specification) to investigate the factors influencing the choice of a transport mode for accessing the airport, as well as the choice of a departure airport, by passengers departing from the San Francisco Bay area. This model imposes less restrictive substitution patterns over alternatives so that it obviates the independence from irrelevant alternatives (IIA) assumption, which is one of limitations in logit models. For example, if BART starts offering service to SFO, all other access mode to SFO will suffer proportional reductions of the share of their market share in logit models. This can be unrealistic such that other access mode rather than the public transit mode may experience larger reductions. However, the substitution pattern in the mixed logit model depends on the specification of the variables and mixing distribution so that it can approximate any substitution pattern.

My paper differs from other mode choice models in the following. First, I explore the Air Passenger Surveys conducted in 2001 and 2002 by Metropolitan Transportation Commission (MTC) in San Francisco, which were recently released to the public. The surveys provide details on the landside trip and factors judged to influence ground access behaviors. Thus, it is suitable for modeling ground access choice. Also, the analysis can be used to determine whether passengers' behavior on access mode choice has changed in between 1995 and 2001-2002.[3] The dataset is augmented with secondary data sources to allow the estimation of detailed discrete choice models: the 2000 Zone-to-Zone highway network level of services, the 2000

[3] It may be interesting to investigate differences on access mode choice in between 2001 and 2002 as the surveys cover before/after September 11, 2001

Zone-to-Zone transit network level of services, geographical information system data for public transit networks, and official website for each airport.

Second, I use more explanatory variables to evaluate the factors valuing airport access mode with special emphasis on private modes (i.e., drive-and park, drop-off, taxi) and collective modes (public transit, shared-ride van). I include “accessibility of public transit services” measured by distance from the origin to public transit network to test whether easy access to public transit services encourages taking public transit modes. The ground access market to the airport is characterized by a high density of demand for a limited number of destinations, so that there is a real possibility of organizing viable collective transport in contrast to commuting travel where both travel origin and destinations are spatially dispersed. Also, I include the dummy variable of cost reimbursement to test whether passengers are more likely to take private modes, which are relatively expensive than collective modes if travel costs are reimbursed. Passengers who do not pay their own travel expenses may become less sensitive to price.

The estimation results can be summarized as follow. First, private modes are preferable than collective modes for residents and non-residents. In addition, “drive and park” option is preferable to other access modes for Bay residents, but “drive-off (often, rental)” option is preferable for non-residents. This is because residents are easy to access their own cars rather than non-residents. Second, travel time and travel cost effect negatively on access mode choice consistent with previous findings. Third, the easier access to public transit service air passengers face, the more likely they choose it. This result suggests that substantial investment in public transit service may increase the market share. In addition, passengers who get cost reimbursement are more likely to choose "private" type mode for the resident, but less likely to choose them for the non-resident. For non-residents, they are less like to drive because they are not familiar with the Bay areas. So, they do not favor of “private mode”. Finally, parameters of error component show the greater substitution pattern within collective modes across air passengers than within private modes.

This paper is organized as follows. Section 2 provides a literature review on transport mode choice. In particular, I review empirical studies on access mode choice models. Section 3 describes a mixed logit model. Section 4 presents the data source, market segments, and empirical results. The final section concludes.

2. Literature review

A sizeable literature on transport mode choice exists. Mode choice is usually analyzed using disaggregate travel demand models that explain behavior at the level of an individual decision-maker or household. Much of the earlier literature estimates models of commuting mode choice given a fixed location of the workplace (cf. e.g. Ben-Akiva and Richards (1976), McFadden et al (1977)). While the early studies have focused on mode choice alone, the recent studies combine mode choice with other choice dimension such as departure time choice, auto ownership choice, number of non-work stops, etc. For example, Bhat (1997) develops a joint model of work mode choice and number of non-work activity stops during commuting, and Train (2000) presents a joint model of the work trip mode choice and auto ownership. These studies consider different travel related choice dimensions and conclude that travelers change behavior to the changed policy not only by switching to different mode, but also by adjusting the other choice.

While many studies have focused on commuting mode choice, there are a relatively small number of studies that analyze airport access behavior. Some of them have investigated the market share of public transport in the airport ground access market (e.g. Clark and Lam (1990), Mandle et al (2000), Leigh Fisher Associates et al

(2000 and 2002)). Those studies show that the market shares of public transport use by air passengers appear to be about 10% to 15% for only 10 U.S. airports, which is relatively very low compared to European (e.g., London (30%), Paris (30%), Geneva (45%), etc) and Asian airports (e.g., Hong Kong (60%), Tokyo (60%)).

Some studies empirically investigate airport access behavior. One of the first studies was by Harvey (1986), who estimates a multinomial logit model separately for business travelers and non-business travelers with five substitutable access modes (drive, drop-off, transit, airporter, and taxi) in the San Francisco Bay area, using data from a 1980 survey of air passengers. The selected explanatory variables are the level-of-service (access time and cost), traveler characteristics (pieces of luggage, household size, and departure from home), and constant terms. The result indicates that travel time and travel cost are important determinants of airport access mode choice, and business travelers are more sensitive to access travel time, but less sensitive to cost than non-business travelers. Also, the results imply that the values of time are $41.61 per hour for business travelers and $19.61 per hour for non-business travelers, which is higher than typical values of time in urban travel.[4] He reports higher value of time for air travelers, suggesting that substantial investments in airport access improvements might be justified.

Hess and Polak (2004b) study the combined choice of departure airport, airline, and access mode for passengers originating from the San Francisco Bay area using both the multinomial logit (MNL) model and the two-level nested multinomial logit (NMNL) model. Their primary dataset is the 1995 air passenger survey. This study leads to two conclusions. First, frequency and access time play an important role in airport choice, and have different impacts across six segmented groups.[5] Second, the use of the NMNL shows significant improvements in model fit over the use of the MNL. This study

[4] Values of time are in prices of 1980

[5] They separate samples between residents and visitors as well as between trip purposes; business, leisure, and visiting friends and relatives.

focuses on modeling structures rather than economic interpretation of explanatory variables.

Most similar to my study, Pels, Nijkamp and Rietveld (2003) develop a two-level nested multinomial logit model with airport choice at the upper level and access mode choice as the lower. They use the 1995 air passenger survey in the San Francisco Bay area to investigate how air passengers departing from San Francisco Bay Area choose a transport mode for accessing the airport and a departure airport. They segment the market into two groups; residents and business travelers, residents and leisure travelers. The study finds the influence of airport access time to be significant. The business travelers have higher value of time ($174 per min for August and $118.2 per min for October) than the leisure travelers ($94.2 per min and $96.6 per min). The paper differs from my current study in the following. First, I estimate a mixed logit model, which provides more flexible substitution patterns across access modes. Second, I use the 2001 and 2002 air passenger surveys that are rich in information concerning access mode choice. Third, I include more explanatory variables, such as the level of convenience and accessibility of public transit services, which likely affect access mode decisions.

3. The econometric model

In this section, I describe a mixed logit model for access mode and airport choice. In common with a multinomial logit model and a nested logit, the mixed logit is derived from the paradigm of random utility maximization. Recent empirical work with mixed logits has been motivated by two different specification but entirely equivalent interpretations: random coefficient specification and error component specification. Here I specify an error component structure.

The error components interpretation takes account of correlations among the utilities for different alternatives. The indirect utility derived by individual n from alternative j is given by:

$$U_{nj} = \alpha' x_{nj} + \gamma_n' z_{nj} + \varepsilon_{nj} \tag{1}$$

where x_{nj} and z_{nj} are vectors of observed variables relating to individual n and alternative j, α is a vector of fixed parameters, γ_n is a vector of random terms pertaining to individual n with zero mean, and ε_{nj} is independently, identically distributed extreme value. The γ_n parameters, which are interpreted as error components, are combined with ε_{nj} to define the unobserved random portion of utility:

$$\eta_{nj} = \gamma_n' z_{nj} + \varepsilon_{nj} \tag{2}$$

Since the researcher does not observe γ_n, the probability is obtained by

$$P_{nj} = \int \frac{\exp(\alpha' x_{nj} + \gamma'_n z_{nj})}{\sum_{i \in J} \exp(\alpha' x_{ni} + \gamma'_n z_{ni})} \cdot f(\gamma_n) \cdot d\gamma_n \tag{3}$$

where $f(\gamma_n)$ is a density function of γ_n defined by the researcher. In general, the equation (3) is not easy to calculate the choice probability because the integral does not have a closed form. Therefore, Maximum simulated likelihood (MSL) estimation can be used.

By specifying z_{nj} in particular ways, various substitution patterns can be obtained. If z_{nj} is identically zero, then there is no correlation in utility over alternatives. In this case, the error component logit offers an approximation to the standard logit model. On the other hand, if z_{nj} is non-zero, then this induces a non-zero covariance between the utility of alternatives i and j:

$$Cov(\eta_{ni}, \eta_{nj}) = E(\gamma_n' z_{ni} + \varepsilon_{ni})(\gamma_n' z_{nj} + \varepsilon_{nj}) = z_{ni} W z_{nj} \qquad (4)$$

where W is the covariance of γ_n. This framework permits representation of any desired pattern of correlation between alternatives. Also, we can obtain an approximation to nested logit. Let the vector z_{nj} consist of dummy variable for each nest k set to one if alternative j is a member of nest k, and to zero otherwise. Formally,

$$\gamma_n' z_{nj} = \sum_{k=1}^{K} \gamma_{nk} d_{jk} \qquad (5)$$

where $d_{jk} = 1$ if j is in nest k and 0 otherwise. Since γ_{nk} enters the utility of each alternative within nest k, this induces correlation among these alternatives. Then, it is convenient to let the error components be independently normally distributed with the variance of each nest k common across individuals n : $\gamma_{nk} \sim iid\, N(0, \sigma_k^2)$.

4. Empirical Analysis

4.1. Data sources

The primary data source of this study is the air passenger surveys, which were conducted in 2001 and 2002 by the Metropolitan Transportation Commission (MTC) in the San Francisco Bay area.[6] The primary purpose of departing passenger surveys is for ground access planning, so it provides details on the landside trip and factors judged to influence ground access behavior. In Table 1 the number of departing passengers surveyed along with the total number of enplanements at each airport in 2001 and 2002 is given for each airport.

Table 1. Departing passengers surveyed and total enplaned passengers, by airport and year

	2001			2002		
	SFO	SJC	OAK	SFO	SJC	OAK
Passengers surveyed	2,580	1,616	1,734	3,710	2,779	2,432
Passengers enplaned*	13,846,425	5,865,502	5,485,948	12,250,289	5,067,502	5,968,718

* Data source: National Transportation Statistics by Bureau of Transportation Statistics

In Table 2 the percentage of travelers according to access trip mode is given for each airport. It is clear that shares of different access mode are similar across years; i.e. the percentage of private vehicles used by passenger is very high for all airports. However, there are a number of differences across airports. First, the percentage of transit service is relatively low at SJC compared to SFO and OAK. All airports have public transportation options as access mode, but whether passengers likely use them depends on the city of origin and the airport chosen. For example, high percentage of transit service at OAK may result from the possibility of direct access to Oakland airport by BART. Therefore, I test later whether public transit accessibility to airports will increase the use of public transit mode. Second, travelers departing from SFO more often use different alternatives other than personal vehicles and public transit services compared to SJC and OAK.

[6] The 2001 and 2002 surveys were held different days for each airport from August through September; for 2001, SFO (August 28, September 1, 7, and 9), SJC (August 27, 30, and 31, September 3, 5, and 8), OAK (August 29, September 2, 4, and 10), for 2002 SFO (August 27 and 31, September 6 and 8), SJC (August 26, 29, and 30, September 2, 4, 7, and 15), OAK (August 28, September 1, 3, 9, and 13).

Table 2. Distribution of passengers according to access trip mode (%), by airport and year

	2001			2002		
	SFO	SJC	OAK	SFO	SJC	OAK
Private vehicle	51	63	66	46	67	63
Rental vehicle	17	23	15	20	19	15
Taxi	8	5	2	8	7	3
All private modes	**76**	**91**	**83**	**75**	**93**	**81**
Shuttle bus from train	2	1	7	2	1	8
Regular transit bus	1	0	1	1	0	1
Scheduled bus to airport only	4	1	2	4	0	3
All transit services	**8**	**2**	**10**	**7**	**2**	**12**
Hotel courtesy shuttle	4	2	4	4	2	2
Pre-arranged exclusive limousine	3	2	1	3	1	2
Pre-arranged shared-ride van	6	1	2	9	2	3
Chartered tour group bus	3	1	0	2	0	0
All such services	**16**	**7**	**7**	**18**	**5**	**7**
Total	**100**	**100**	**100**	**100**	**100**	**100**

The air passenger survey is combined with various secondary data sources. First, I use the 2000 Zone-to-Zone highway network level of services and the 2000 Zone-to-Zone transit network level of services obtained from the MTC[7]. These sources provide travel times from a passenger's initial origin in the San Francisco Bay area to the airports, allowing me to take account of differences in travel time between peak and off-peak hour driving. Also, money travel costs are provided.[8] Second, I use geographical information system data for public transit networks in the Bay areas obtained from the MTC. From these sources, I calculate the distance from the initial

[7] I input travel analysis zone (TAZ) for each passenger into the survey data using the 2000 MTC Travel Analysis Zones (1454) (source: http://www.mtc.ca.gov/maps_and_data/GIS/data.htm). MTC maintains a set of travel analysis zones for use in MTC planning studies. These TAZs are typically small area neighborhoods or communities that serve as the smallest geographic base for travel demand model-forecasting systems. The zone system used in the MTC survey is 1454 zone system developed in 2002. The MTC 1454 zone is equivalent to the 2000 census tract. The 2000 census tract information can be found in Bay area census website (www.bayareacensus.ca.gov). From the file which compares TAZ and census tract, SFO, SJC, and OAK match "239", "434", and "874" respectively.

[8] Money cost contains operating cost as well as toll for highway network level of service

origin to that service route[9] as a measure of accessibility of public transit. In addition, the number of flight frequency at the airport level is calculated using the "Worldwide Through Flights Schedules" Database obtained from OAG.[10], and the "Origins and Destination Survey" (DB1A), provided in summarized form by Severin Borenstein to get the average fare. Finally, travel costs for various access modes are collected from each official airport websites[11] and companies' websites[12] (Appendix 1 for the detail explanation of data).

For air travel, a passenger has to choose a departure airport, {SFO, SJC, OAK} and access mode to that airport, {drive and park, drop-off, taxi, public transit, shared-ride van}, given that other choices related to air travel are already made. An important question is whether the alternatives in mode choice are truly independent of each other. For example, drive-and-park, drop-off, and taxi would appear to offer a similar quality of service (i.e., direct service, high comfort, schedule convenience). Therefore, the set of alternatives for access mode is partitioned into two nests; private (drive and park, drop-off, taxi) and collective (public transit[13], shared-ride van[14]). Then, I estimate the model which accommodates shared unobserved random utility attributes along both different type mode (private versus collective) and departure airport. The variables that enter the model are defined in Table 3.

4.2. Market segments

---

[9] Clearly, it is better to measure the distance from the origin to the bus-stop or the station. However, it is not possible to know geographical information for those stops. The MTC is collecting them right now.
[10] http://www.oag.com
[11] SFO (www.flysfo.com), SJC (www.sjc.org), OAK (www.flyoakland.com)
[12] Bay porter express (www.bayporter.com), Sonama County airport express (www.airportexpressinc.com), and http://c.rathbone.home.att.net/sflondon.htm
[13] The American Public Transportation Association (APTA) defines public transportation as "transportation by bus, rail, or other conveyance, either publicly or privately owned, which provides to the public general or special service on a regular and continuing basis". In this current study, public transit includes those ground transportation services that are traditionally defined as public transportation as well as scheduled buses.
[14] It also includes pre-arranged exclusive limousine.

Table 3. Variable definitions

Variable	Definition
drive and park	1 for drive and park, 0 otherwise
drop-off	1 for drop-off, 0 otherwise
taxi	1 for taxi, 0 otherwise
public transit	1 for public transit (bus, rail), 0 otherwise
shared-ride van	1 for shared-ride van, 0 otherwise
travel time	in vehicle time + out of vehicle time if applicable
travel cost	travel cost + parking cost + rental cost if applicable
accessibility	shortest distance from the origin to the network (direct)
convenience	# of luggage carried * dummy variable (=1 if access mode is collective type
reimbursement	cost reimbursement (Yes or No) * dummy variable (=1 if access mode is private
frequency	total number of flight
fare	weighted average fare

The market segments most frequently identified as relevant to airport access behavior can be defined by at least two dimensions. The first dimension is the purpose of trip (Business or Non-business). The business traveler may be relatively insensitive to cost because they often do not pay their own travel expenses. So, the business traveler is less likely to select public transit services, which are priced lower than competing modes.

The second dimension is the status of residency (Resident or Non-resident). This is because the resident has more access to his or her personal automobile than does the non-resident. Therefore, it is expected be seeing that the resident may be less prone to select public transportation services because of increased levels of personal automobile availability.

The ideal analysis is to estimate distinct models for: resident business travelers, resident non-business travelers, non-resident business travelers, and non-resident non-business travelers. This is because there is possibility that the determinants of choice will differ in each case. In this paper, the market for ground access service to airports is segmented into two by the status of residency (residents versus non-residents), not by the trip purpose. However, a similar examination of the business/non-business segment is left for future work. Table 4 shows proportions of resident originating passengers by airport and year.

Table 4. Proportions of resident originating passengers by airport and year

	2001			2002		
	SFO	SJC	OAK	SFO	SJC	OAK
Resident	56%	46%	58%	42%	52%	57%

4.3. Empirical results

I estimate the error component specification and estimation results are shown in Table 5. I only consider air passengers who have three possible departure airport choices. One of the most interesting results is that private type modes are preferable than collective type modes and the difference in preference is bigger for the non-resident than the resident. In addition, the "drop-off" variable shows negative effect for the resident but positive effect for the non-resident on access mode choice in both years, which I expected. The resident may have more access to their personal automobile than does the non-resident. I also find that travel time and travel cost are important determinants of airport access mode choice.

The next hypothesis I test is to see whether ease accessibility of public transit mode encourages passengers to use it. The variable "accessibility" is measured as distance from the trip origin to public transit services[15], which provide direct services to airports, and interacted with the dummy of public transit mode. For Bay residents, the result reveals that passengers are more likely to choose public transit services as they have easier access to them. This result suggests that substantial investment in public transit service may increase the market share. However, public transit mode is less likely chosen for the non-resident, suggesting that the non-resident are unfamiliar with the public transit network system in the Bay area. As Harvey (1986) did, I also include the "convenience" variable interacted with a dummy variable of "collective" mode. The amount of luggage carried by air passengers can be a strong deterrent to using public transit as access model. For the resident and the non-resident, the number of luggage is negatively correlated with choices of collective modes only for 2002. However, I find that the amount of luggage has the positive effect on access mode choice for 2001, even though they are statistically insignificantly estimated.

Furthermore, I test whether passengers are more likely to choose "private" modes if travel costs are reimbursed. I include a dummy variable when passengers do not pay for their own travel expenses, then interact with a dummy variable of "private" mode. The cost reimbursement increases the possibility of choosing "private mode" for residents, but not for non-residents. For non-residents, they are less like to drive because they are not familiar with the Bay areas no matter travel cost is reimbursed or not. So, they do not favor the private mode**.**

According to parameters of error component, it shows the greater substitution pattern over air passengers within collective modes than within private modes for both groups.

5. Conclusion (not complelted)

[15] If there are several pubic transit services available from their trip origin, I take the shortest distance.

In this paper, I focus on airport ground access mode and airport choice with special emphasis on mode type (private versus collective). This paper proposes that there is at least a possibility of organizing viable collective transport that may cause the reduction in the volume of highway traffic generated by airport access and egress trips.

Table 5. Results

	2001				2002			
	Resident		Non-resident		Resident		Non-resident	
Variables	coeff	std.err	coeff	std.err	coeff	std.err	coeff	std.err
drop-off	**-2.474**	0.122	**1.307**	0.139	**-2.391**	0.099	**1.996**	0.096
taxi	**-3.649**	0.134	**-0.499**	0.196	**-3.499**	0.113	0.062	0.128
public transit	**-6.296**	0.879	**-29.202**	10.754	**-5.862**	0.589	**-28.291**	8.793
shared-ride van	**-7.383**	0.846	**-30.956**	10.985	**-7.278**	0.554	**-29.092**	8.849
travel time	**-0.042**	0.002	**-0.088**	0.013	**-0.039**	0.002	**-0.067**	0.007
travel cost	**-0.028**	0.003	**-0.019**	0.005	**-0.037**	0.003	**-0.011**	0.002
accessibility	*-0.029*	0.015	0.038	0.054	**-0.067**	0.016	0.029	0.024
convenience	0.007	0.046	0.156	0.120	-0.075	0.067	-0.363	0.234
reimbursement	**0.772**	0.381	*-4.087*	2.062	0.047	0.287	-1.324	1.369
frequency	**0.019**	0.003	**0.064**	0.011	**0.013**	0.003	**0.039**	0.006
air fare	**-12.210**	1.120	**-33.008**	5.054	**-4.900**	0.770	-0.451	0.728
Error components								
private-sfo	-0.019	0.024	2.546	0.510	-0.002	0.010	**1.446**	0.402
collective-sfo	**4.081**	0.620	**21.840**	6.823	**-3.488**	0.394	**24.431**	6.390
private-sjc	-0.004	0.008	2.536	0.556	-0.003	0.011	**1.486**	0.637
collective-sjc	**2.736**	0.546	**13.114**	4.244	**-2.411**	0.357	**14.858**	4.502
private-oak	-0.002	0.007	0.048	0.076	0.001	0.005	0.007	0.034
collective-oak	**4.119**	0.690	**21.590**	7.134	**3.819**	0.452	**20.276**	4.995
sfo	-0.017	0.043	0.078	0.639	-0.024	0.025	0.337	0.400
sjc	0.016	0.015	0.168	0.704	-0.019	0.022	*1.218*	0.662
oak	-0.006	0.012	0.126	0.084	-0.001	0.010	0.004	0.053
LogL	-2504.210		-2244.394		-4257.080		-3578.286	
Obs	1540		1302		2559		2036	

References

Ben-Akiva, Moshe E. and Richards, Martin G. (1976), "A Disaggregate Multinomial Model for Work Trips in the Netherlands", *Transportation Research Record 569*, 107-124

Bhat, Chandra R. (1997), "Work Travel Mode Choice and Number of Non-work Commute Stops", *Transportation Research Part B*, Vol. 31, No. 1, 41-54

Brownstone, D. (2001), 'Discrete Choice modeling for Transportation', in D. Hensher (ed.), Travel Behaviour Research: The Leading Edge. Amsterdam: Pergamon, 97-124

Clark, M.C. and Lam, W.H.K. (1990), "Airport ground access considerations", Airports into the 21st Century, Hong Kong Institution of Engineers, Hong Kong, 5-7

Harvey, G (1986), "Study of Airport Access Mode Choice," *Journal of Transportation Engineering*, Vol 112 (5), 525-545

Hess, Stephane and Polak, John W. (2004b), 'On the use of Discrete Choice Models for Airport Competition with Applications to the San Francisco Bay area Airports", paper presented at the 10th triennial WCTR Conference, Istanbul

Higgins, T. Z. (1994), "California Airports: Ground Access Vehicle Trips, Emissions, and Emission Reduction Strategies." *23rd Air Transport Conference*, June 22–24, 102–106

Leigh Fisher Associates, in association with Matthew A. Coogan and MarketSense (2000), "Improving Public Transportation Access to Large Airports", Transit Cooperative Research Program Report 62, Transportation Research Board, National Academy press, Washington, D.C.

Leigh Fisher Associates, in association with Matthew A. Coogan and MarketSense (2002), "Strategies for Improving Public Transportation Access to Large Airports", Transit Cooperative Research Program Report 83, Transportation Research Board, National Academy press, Washington, D.C.

Mandle, P.B., Mansel, D.M., and Coogan, M.A. (2000), “Use of public transportation by airport passengers”, *Transportation Research Record* 1703, 83-89

McFadden, Daniel, Antti P. Talvitie, and Associates (1977), “Demand Model Estimation and Validation”, Urban Travel Demand Forecasting Project, Phase I Final Report Series, Vol. V. Berkeley: University of California Institute of Transportation Studies, Special Report UCB-ITS-SR-77-9

Pels, E., Nijkamp, P., and Rietveld, P. (2003), “Access to and competition between airports: a case study for the San Francisco Bay Area”, *Transportation Research A*, 37 (1), 71-83

Train, K. (2000), “A Structured Logit Model of Auto Ownership and Mode Choice”, *Review of Economic Studies*, Vol. XLVII, pp. 357-370. Reprinted in Transportation Economics: Theory and Practice, edited by Patrick McCarthy, Blackwell Publishers, Ltd, 2000

Train, Kenneth (2003), ‘Discrete Choice Methods with Simulation’, Cambridge University Press, New York

Appendix 1 Construction of the variables

1. Travel time (in vehicle time + out of vehicle time)

: Drive and park, Drive-off, Taxi – it is obtained from MTC highway zone-to-zone travel file and depending on the time of day driving and on the vehicle occupancy. There is no out of vehicle time for drive-off and taxi, but out of vehicle time is assigned for drive and park depending on where a passenger parks (e.g. 0 min: short-term parking, drive-off, and taxi, 15 min: long-term parking and off-airport parking)

: Public transit, Shared-ride van – it is obtained from MTC transit zone-to-zone travel file. There is no out of vehicle time for shared-ride van, but out of vehicle time consists of waiting time, auto access time, and walking time for public transit

2. Travel cost (driving cost + parking cost + rental cost)

: Drive and park – it consists of driving cost and parking cost. Driving cost is obtained from MTC highway zone-to-zone travel file depending on the time of day and the vehicle occupancy and parking cost is obtained from official airport websites for on-airport parking and several private websites for off-airport parking[16] and is multiplied by the number of duration parked. On-airport parking cost also differs from which parking lot a passenger uses (e.g. short-term rate VS long-term rate)

: Drive-off – it consists of driving cost and rental cost. Driving cost is obtained from MTC highway zone-to-zone travel file and rental cost is calculated based on information from various websites provided by rental companies

: Taxi

- To SFO : $2.85 + distance (miles) * $2.25 + $2
- To SJC : $2 + distance (miles) * $2.5 + $1.5
- To OAK : $2 + distance (miles) * 2.45

---

[16] www.airportparkingreservation.com

: Public transit – it is obtained from MTC transit zone-to-zone travel file

: Shared-ride van – it is obtained from official airport websites and various door-to-door service companies. Rates vary by county

3. Accessibility of public transit – First, I select public transit networks that provide service to the airport directly. Then, I measure distance from the origin to the network
4. Frequency – total number of flight from the origin airport to the destination airport
5. Fare – weighted average fare from the origin airport to the destination airport by carriers