Forecasting Cybercar Use for Airport Ground Access: Case Study at Baltimore Washington International Airport

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Abstract: Nested logit models calibrated on revealed preference (RP) and stated preference (SP) data have been used in this paper to study the potential market of a cybernetic transportation system for airport ground access. This innovative concept of transit mode could complement mass transit and nonmotorized transport modes, providing passenger service for any location at any time. Our analysis is based on a data set collected at Baltimore Washington Thurgood Marshall International (BWI) airport; the proposed cybercar service was designed to connect the Greenbelt metro station to the airport. The explanatory variables used in the utility functions of the RP/SP joint models are level of service attributes, characteristic specific to the new service offered, and socioeconomic variables. The estimated models are used to predict the market share of automobile, taxi, cybercar, and modified transit. In addition, elasticity tests are performed in order to study individuals' sensitivity to the change of travel time and travel cost for automobile and cybercar. The estimation and application results in this paper can be used as a reference for the CityMobil program of the European Union to popularize this fast, convenient, and environmentally friendly cybercar. Meanwhile, the results provide useful behavioral data and models on the potential of advanced technological transportation system for airport ground planning in the United States.

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Introduction

The Washington-Baltimore region has its unique attractiveness because of the location of the federal government and the numerous tourist attractions. Therefore, air transportation in this region is of great importance for international, inter-regional passenger, and goods movements. Given the emerging economic and environmental problems, efficient and comfortable transportation linkage between the airports and the surrounding communities is a high priority for planning agencies.

Baltimore Washington Thurgood Marshall International (BWI) airport is located close to the downtown Baltimore and is serving the Washington-Baltimore metropolitan area together with Ronald Reagan Washington National Airport (DCA) and Washington Dulles International Airport (IAD) (see Fig. 1). The ground transportation linkage between BWI and most counties in Maryland State as well as Washington, D.C. has been discussed in the document "Washington-Baltimore Regional Airport System Plan Ground Access Element Update" in March of 2007, by the Metropolitan Washington Council of Governments. According to this document, nonautomobile ground access to BWI airport is provided by public transit service (light rail, No. 17 bus line, and MARC Commuter Rail Service), express Metro bus service (B-30 bus line and C-60 bus line), fixed route bus service (Red bus line and Amtrak service), and paratransit (shuttle, taxi, private car/limousine service, and courtesy buses). In spite of this diversity of nonautomobile modes, the predominant mode is still the automobile, which accounts for 93% of the region's trips to the airport (Washington-Baltimore Regional Air Passenger Survey data 2005). Therefore, this unsustainable situation is always heavily discussed by planners and modelers.

In this paper, we study the degree of acceptance for a new environmentally friendly cybernetic transportation system (CTS) whose concept emerged in Europe in the early 1990s. The terms of CTS cover a number of urban transportation technologies ranging from automated vehicles on separate guideways, referred to in the United States as personal rapid transit (PRT), to roadway vehicles that can operate on automatic control in mixed traffic. The CTS normally consists a fleet of vehicles (cybercar) which are under control of a central management system with on-demand and door-to-door capability (McDonald and Voge 2002) shared by several passengers. The system has been implemented in European countries mainly at airports and recreational parks. Cybercar has the potential to form a part of the public transportation system and to complement mass transit and nonmotorized transport, providing passenger service for any location at any time. Demonstration experiments have been under way in several places in Europe as part of the Citymobil project of the European Union. The first cybercar system went into operation in December 1997 at Schiphol airport [nested logit (NL)] with a fleet of four automated electric vans that ran fully autonomously on a demand basis. In early implementations, cybercars were designed for short trips at low speed in a controlled environment. Currently, cybercars only operate in dedicated environments and are not meant to be pri-

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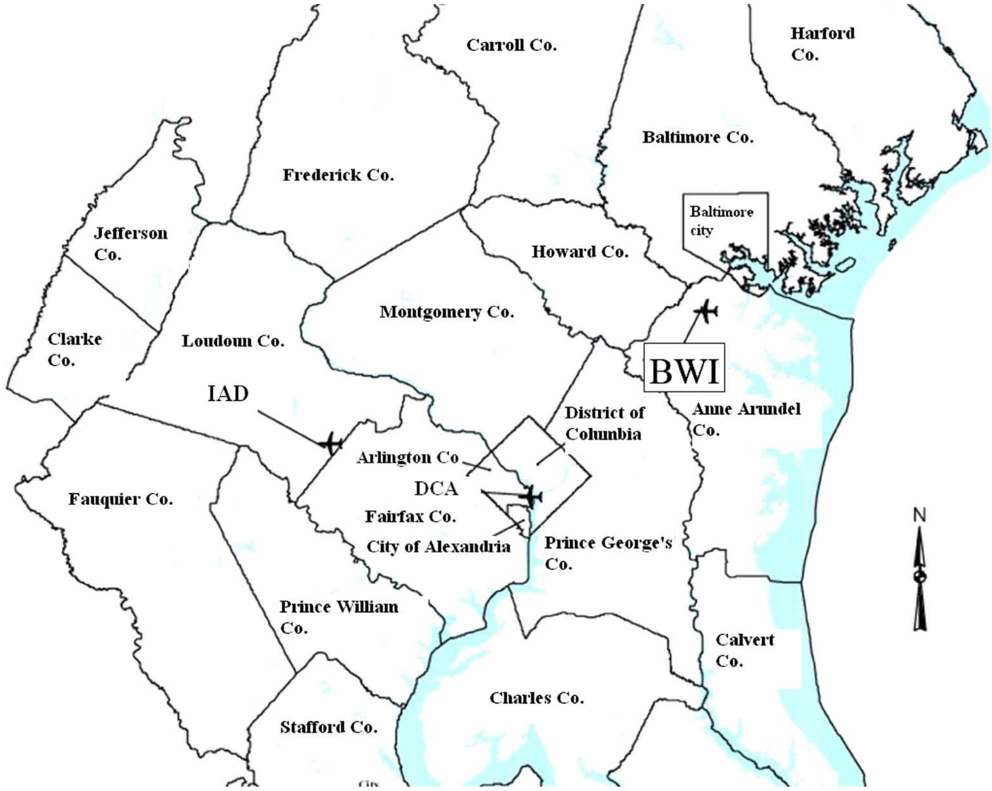

Fig. 1. Overview location of BWI

vately owned. In the long term, they are expected to operate on fully automatic control and on a large network in mixed traffic. If these systems develop, entire cities may well be reserved to cybercars. An alternative would be to have a "dual-mode" cybercar which would be manually driven outside the cybercar zone (although with strong assistance to avoid accidents and improve comfort) and would be in automated mode inside the zone. Such vehicles could be private or public (in car-sharing mode).

As a kind of PRT system, Cybercar has the potential to provide improved airport surface transportation. A rigorous analysis of costs and benefits of this system is difficult; numerous assumptions on direct and indirect factors are in fact to be made and the value of travel time needs to be calculated for inclusion in the costs. According to Muller and Woods's paper (Muller and Woods 2005), considering the separate operation, station design, connection to the existing parking lot, etc., PRT system costs more to build than a traditional shuttle bus system. Operating costs are almost identical. But the PRT system reduces all relevant system performance parameters such as trip times and net present values by 50% or more. Besides, the shared seated ride for all passengers in a comfortable and environmentally friendly small vehicle ideally avoids intermingling with other passengers and brings the joy into flying by reducing waiting in line, losing one's way, and the continual barrage of public address announcements.

However, so far no behavioral data or quantitative studies exist to support the cybercar introduction on airport ground transportation system. It is therefore the objective of this paper to study travel behavior under the existing airport ground access system and the potential market of the new cybercar by calibrating discrete choice models based on revealed preference (RP) and stated preference (SP) data. The results obtained with the joint model are applied to forecast the market share and the elasticity with respect to changes in the attributes of the alternatives.

This paper is structured as follows. Previous studies on mode choice models for airport accessibility are summarized in the "Literature Review" section. After that, we provide an overview of the behavioral model used for the quantitative analysis (including logit model [multinomial logit (MNL)], NL, and joint RP/SP models). Survey design and administration constitute the following section. Then, we present results of the model estimation, model application, future market shares, and elasticity calculations. The final section briefly summarizes the findings and gives suggestions for further studies.

Literature Review

Review of Access Mode Choice Model to the Airport

The development of mode choice models for air passenger ground access has been an ongoing research for more than 30 years. Their formulation has progressed from simple MNL models to more complex NL models and even to more advanced models. A general agreement has been achieved on the explanatory variables that should be included, on the attributes that affect individuals' choices, and on how the various modes and submodes should be nested (Gosling 2008). Ellis (1976) developed a formal MNL model as one of the earliest efforts for air passenger airport ground access mode choice study in the early 1970s, and this model was continued to be applied in the following 10 years by many researchers (Leake and Underwood 1977; Sobieniak et al. 1979; Spear 1984). An MNL model presents a number of limitations, for instance, the independence of irrelevant alternatives (IIA) (Ben-Akiva and Lerman 1985). In the mid-1980s, NL came out and was first used to study the surface access to London Heathrow Airport by Howard Humphreys and his partners in

1987. Subsequently, NL models became widely used in other airports' models including Miami International Airport in 1995, Boston Logan International Airport which nests only resident submodels in 1996 (Harrington et al. 1996), London [Heathrow (LHR), area airports Gatwick (GTW), Stansted (STN), Luton (LTN)] in 2002, and Hartsfield-Jackson Atlanta International Airport (H-JAIA) in 2003. These nests generally grouped automobile and nonauto modes in different nests; most of the models reviewed are based on RP data. The studies on Chicago O'Hare International Airport and Chicago Midway Airport (2004) constitute an exception; RP and SP data are combined and NL structure is introduced to nest business and nonbusiness trips. Recently Gupta et al. (2008) formulated a NL model with airport choice at the upper level and ground access mode choice at the second level. However, a MNL model was found to be statistically preferable to NL. Results from this paper indicate that air passenger travel behavior is significantly different for business and nonbusiness travelers, and that access time and access cost are the most important determinants of air passenger's choice; demographics and trip characteristics are also significant (Gupta et al. 2008). In a different context NL model has been used to describe passenger preferences concerning airports and airlines; major findings from this research work indicate that frequency and access time to the airport are both significant (Pels et al. 2001).

Review of Joint RP/SP Models

Forecasting the demand for new technology systems in transportation requires information about users' preferences for the services that do not exist in the current system. SP data are commonly used to collect behavioral choice information in hypothetical contexts. Hess et al. illustrated the advantages of SP data in their paper presented in 2006; they asserted that SP data can retrieve a significant and meaningful effect of changes in air fares while impacts of airline allegiance cannot often be identified in RP studies (Hess et al. 2007).

As outlined by Morikawa in the early 1990s, SP data should be combined with RP data in order to gain information about respondents' actual behavior (Morikawa 1989). Morikawa, Ben-Akiva, and Yamada used joint RP and SP data to estimate a mode choice model made by intercity travelers in Netherlands and to forecast market shares before/after the introduction of a new train service in Japan (Morikawa et al. 1991). Brownstone et al. also highlighted the advantages of merging SP and RP data in their study about alternative-fuel vehicle models; they used the mixed logit model with error component formulation in their paper published in 2000 (Brownstone et al. 2000). estimated a combined RP and SP route choice model for public transportation trips and selected in-vehicle time, number of transfers, transfer time, headway, and price as explanatory variables.

A joint RP/SP model has been estimated to study accessibility at Chicago O'Hare International Airport. The SP data were collected in order to evaluate the effects of changes in level of service characteristics (service headway, cost, and availability of baggage check-in at the mode's terminal) on individual preferences.

Model

This section discusses the basic model structure for MNL, NL, and RP/SP joint models.

Multinomial and NL Model

We assume that the individual utility is a random function and is divided into two parts: the systematic (or representative) component V_{in} and the random component ε_{in} which has Gumble distribution. The utility could be denoted as

$$U_{in} = V_{in} + \varepsilon_{in} \tag{1}$$

The probability of choosing alternative i by decision maker n is given by

$$\begin{aligned} P(i/C_n) &= \Pr(U_{in} > U_{jn}, i \neq j, \forall\, j \in C_n) \\ &= \Pr(V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn}; i \neq j, j \in C_n) \end{aligned} \tag{2}$$

For logit model the probability of the nth individual will choose alternative i denoted by

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{J_n} e^{V_{jn}}} \tag{3}$$

Mostly, V_{in} is expressed as linear form of the exogenous variables

$$V_{in} = \sum_{k=1}^{K} \beta_k X_{ink} \quad (i \in C_n) \tag{4}$$

where β_k denotes the vector of the kth unknown parameter and X_{ink} denotes the kth characteristic variable of people n choosing alternative i.

It is well known that logit models exhibit the property of IIA. NL models can be appropriately used to overcome this limitation of logit. In NL models the ratio of probabilities of any two alternatives in the same nest is independent of attributes of all other alternatives, but in different nests, the ratio can depend on attributes of the alternatives in the two nests (Koppelman and Bhat 2006). The set of alternative J can be partitioned into K subsets denoted by $B_1, B_2, \ldots, B_k$; the ε_{jn}'s are correlated within nests. Hence IIA holds within each subset of alternatives but not across subsets (Train 2003). The probability of choosing alternative $i \in B_k$ is

$$P_{in} = \frac{e^{V_{im}/\lambda_k}\left(\sum_{j \in B_i} e^{V_{in}/\lambda_k}\right)^{\lambda_k - 1}}{\sum_{l=1}^{K}\left(\sum_{j \in B_l} e^{V_{jn}/\lambda_l}\right)^{\lambda_l}} \tag{5}$$

The parameter λ_k is a scale factor which measures the degree of independence in unobserved utility among the alternatives in nest k and it is between 0 and 1. A higher value of λ_k means greater independence and less correlation. So when $\lambda_k = 1$, it means complete independence within nest k.

RP/SP Joint Model

The utility functions for RP and SP are specified as follows:

$$U_{in}^{\mathrm{RP}} = \alpha_{in}^{\mathrm{RP}} + \beta x_{in}^{\mathrm{RP}} + \beta^{\mathrm{RP}} x_{in}^{\mathrm{RP}} + \varepsilon_{in}^{\mathrm{RP}} \quad \forall\, i \in C^{\mathrm{RP}}$$

$$U_{in}^{\mathrm{SP}} = \alpha_{in}^{\mathrm{SP}} + \beta x_{in}^{\mathrm{SP}} + \beta^{\mathrm{SP}} x_{in}^{\mathrm{SP}} + \varepsilon_{in}^{\mathrm{SP}} \quad \forall\, i \in C^{\mathrm{SP}} \tag{6}$$

where β = coefficients common to RP and SP utilities, while β^{RP} and β^{SP} = coefficients specific to the utilities of RP and SP alternatives, respectively. The probability functions include scale factors, λ^{RP} and λ^{SP}, representing the scales (proportional to the standard deviations) of the distributions of unobserved factors

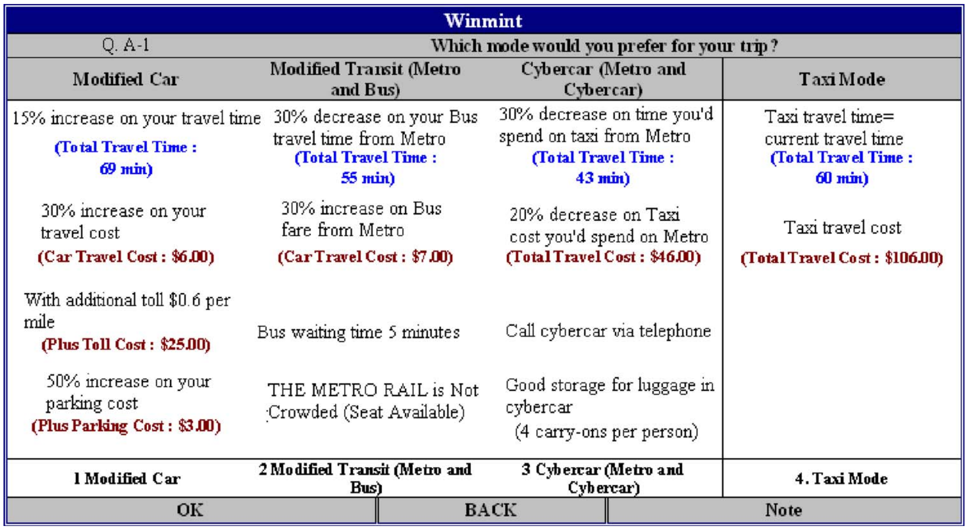

Fig. 2. Computer interface of the between mode choice survey

around these means in RP and SP situations, respectively (Train 2003). It is not possible to determine both λ^{RP} and λ^{SP}; instead we normalize λ^{RP} to 1, which makes the other scale parameter equals to the ratio of the two original scale parameters. It should be noted that the coefficients in the model now are divided by a parameter $1/\lambda^{SP}$ for the SP observations.

Scale factors are estimated with β, β^{RP}, and β^{SP} at the same time on both types (RP and SP) of data. Meanwhile, the alternative-specific constants are estimated separately for RP and SP data to reflect market share for existing and new modes (as described in the previous section). The probability functions are Eqs. (7) and (8)

$$P_i^{RP} = \frac{\exp[\lambda^{RP} + \beta x_i^{RP} + \beta^{RP} x_i^{RP}]}{\sum_{j=C^{RP}} \exp[\lambda^{RP} + \beta x_j^{RP} + \beta^{RP} x_j^{RP}]} \tag{7}$$

$$P_i^{SP} = \frac{\exp[\lambda^{SP} + \beta x_i^{SP} + \beta^{SP} x_i^{SP}]}{\sum_{j=C^{SP}} \exp[\lambda^{SP} + \beta x_j^{SP} + \beta^{SP} x_j^{SP}]} \tag{8}$$

Survey Design and Data Collection

A survey was designed in order to collect behavioral data on airport ground access. The survey, executed in mid-April 2008 at the BWI airport, was computer assisted with WinMint 2.1 (HCG 2000); the respondents were intercepted in the waiting area of the airport, and the responses were recorded during a face-to-face interview. The final sample contains information from 274 respondents. Both RP data and SP information were collected. RP survey was designed to obtain the information of the recent trip to the airport and report: origin, final destination, departure and arrival time, trip purpose, and a number of sociodemographic characteristics of the respondents. The SP survey captures the passenger's acceptance of the cybercar service. It is composed of two games: (1) a between mode experiment comparing existing modes (car, transit, and taxi) with modified level of service characteristics and the cybercar and (2) a within mode experiment in which two cybercar alternatives with different attributes constitute the choice set. Each respondent was presented with up to nine scenarios in each game whose variations (travel time, cost, etc.) of the scenarios were all based on the respondent's previous RP choices. An example of the scenarios proposed is pictured in Figs. 2 and 3. In the SP Game 1 a maximum of four attributes characterizes the alternatives; travel time, travel cost, toll, and parking cost are the variables describing the alternatives. Table 1 shows how the levels of services are set for different modes in SP Game 1. Here, the percentage of time and cost calculation is based on what the respondents answered in the RP survey. In the SP Game 2 the cybercar service offered is function of the following variables: waiting time, travel cost, dropping off location, driving system (automated or human driven), and system operation (guide ways or on regular roads). In particular, two automated services on regular roads were prospected to travelers: one was automated on specially equipped and/or reserved e-lanes, the other on mixed traffic with a professional driver. Variables and their levels of variations are described in Table 2.

Empirical Results

Model Estimation

Behavioral data collected at BWI airport have been used to estimate a joint RP/SP model. The model aims to estimate the main variables affecting individual choices, the values of travel time savings by mode, and the propensity to use a CTS as well as to forecast the market shares under the future conditions prospected in the SP survey. The structure of the model is represented in Fig. 4. The RP choice set includes seven alternatives, car driver, car passenger, conventional transit (bus, metro plus bus, metro plus taxi, and shuttle), and taxi. The four transit and paratransit alternatives which include bus, metro plus bus, metro plus taxi, and shuttle have been grouped into a nest. The SP choice set includes four mode alternatives (from the between mode experiment), modified car, modified transit, cybercar, and two service alternatives (from the within mode experiment). Table 3 shows the estimation results, coefficients common to RP and SP models, and coefficients that are uniquely determined by either the RP or the SP data and scale factors.

Level of service variables common to RP and SP (i.e., travel time and travel cost) has the expected sign. The low values obtained for the *t*-statistics are explained by the exiguous number of

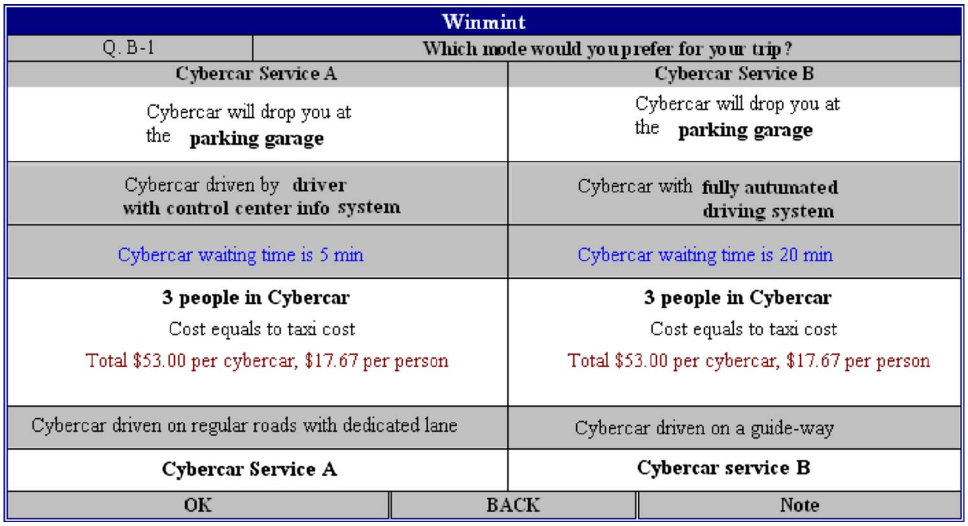

Fig. 3. Interface of the within mode choice survey in interview

respondents; a larger data set will certainly improve our results. The value of travel time savings is the ratio of time and cost parameters ranging from $13/h [value of travel time savings (VTTS) for transit users] to $64/h which represents the willingness to pay for potential cybercar users. Eq. (9) presents how to calculate the value of time. Car driver VTTS is about $22/h, while taxi VTTS is $56/h. It appears that individuals traveling to the airport are willing to pay for this new service

$$\mathrm{VTTS} = \frac{\beta_{\mathrm{time}} \times 60}{\beta_{\mathrm{cost}}} \tag{9}$$

From the analysis of variables specific to the SP Game 1 we can observe that the best comfort level offered for the transit mode (seats available) is positively significant while the worst comfort level (crowded and no seats available) is negatively significant. The best storage condition of cybercar, good storage for luggage that is four carry-ons per person, is positively significant and makes the service more attractive to potential users. The calling service coefficient although not very significant is negatively evaluated by the respondents who clearly prefer a continuous service. Interaction terms between travel time and sociodemographic characteristics have also been estimated; again the low number of observations limits the power of our analysis. When the travel time is estimated by trip purpose, the willingness to pay for the cybercar is higher for business trips than for vacation trips. When the travel time is estimated by income segments, people with higher income generally have higher VTTS.

Variables specific to SP Game 2 describe the service offered with the new CTS. Waiting time estimated on three levels of variation (10, 15, and 20 min) is negative and significant. Besides, people prefer to be dropped at the terminal gate and do not like the option that offers the final stop at the parking lot. Travelers to the airport do not like walking too much with luggage and are in general worried about being on time at the check-in. About the maneuvering system, cybercar driven automatically is negatively evaluated by the respondents although the corresponding coefficient is not very significant. The Citymobil project has also identified a future scenario in which automated vehicles can mix with traditional traffic; in our airport application we have proposed a cybercar in mixed traffic with professional driver. The respondents have positively evaluated the option running in mixed traffic conducted by human driver. People feel, in general, uncomfortable with the fully automated system and prefer system operated by humans. This result confirms the feedback registered during the survey. Furthermore, respondents do not like the cyber running on the guide way and prefer cybercar on roads, as the corresponding variable is negatively significant.

Lambda1 and lambda2 are the scale factors which result from the normalization of SP1 and SP2 data with respect to RP data [see Eqs. (7) and (8)]. Scale parameters lambda1 and lambda2 reflect the variance of unobserved factors in SP data relative to RP data. The smaller the value of the lambda is, the bigger the variance of unobserved factors present in SP data is. Lambda1 is smaller and around 1 representing the scale of SP1 data; it means that the variance of unobserved factor is bigger in SP1 data than in RP data. We found that lambda2 is greater than 1, indicating less variance in SP2 data than in the RP data.

We conclude this section by summarizing the main findings that could be used when planning a cybercar service for airport ground access. Individuals who are willing to use cybercar have a high value of travel time. Travelers do not like to call the cybercar by telephone but prefer a continuously arriving service just like the traditional transit with timetable. Besides, the cybercar should be driven by a human and not be fully automated. Passengers like to be dropped off at the terminal gate. Cybercars on regular roads are preferred to cybercars on a guide way.

Model Application

We use the model in Table 3 not only to calculate the trade-off coefficients but also to have reliable market forecasts for both existing and new modes available at airport sites. This was done by applying the procedure proposed by Daly and Rohr (1998), which suggests maintaining the same constants in the RP and SP observations. We performed the following three estimation runs:

1. First, we estimated the trade-off coefficients using a model structure with separate sets of constants for the different data types (base model). Therefore we proceeded to two further estimations to adjust the alternative-specific constants.
2. "A Run" is the first adjustment procedure applied to the base model. All the coefficient values of RP model are fixed and the SP observations are excluded. That means only RP data

Table 1. Attributes and Levels of Variation Description for SP Game 1

SP Game 1		
Variables	Modes	Level description
Travel time	Modified car	15% increase on car travel time
		30% increase on car travel time
	Modified transit	30% decrease on bus travel time
		15% decrease on bus travel time
	Cybercar	30% decrease on taxi travel time
		10% decrease on taxi travel time
	Taxi	Estimated from trip distance
Travel cost	Modified car	10% increase on gas cost
		20% increase on gas cost
		30% increase on gas cost
	Modified transit	10% increase on bus travel cost
		20% increase on bus travel cost
		30% increase on bus travel cost
	Cybercar	70% of taxi cost
		80% of taxi cost
		90% of taxi cost
	Taxi	Estimated from trip distance
Car toll	Modified car	\$0.20/mile
		\$0.40/mile
		\$0.60/mile
Waiting time	Modified transit	Bus waiting time 3 min
		Bus waiting time 5 min
		Bus waiting time 7 min
Service type	Cybercar	Cybercar on a continuous service
		Call for Cybercar with push-button at metro station
		Call Cybercar via telephone
Parking cost	Modified car	25% increase on parking costs
		50% increase on parking costs
		100% increase on parking costs
Comfort	Modified transit	Seats available
		Not crowded with no seats available
		Crowded with no seat available
Storage	Cybercar	Four carry-on per person
		Two carry-on per person
		One carry-on per person

are used to adjust the alternative-specific constants of the existing alternatives.

3. "B Run" is the second adjustment procedure that uses SP data alone to readjust the alternative-specific constants of the new alternatives. All the attribute coefficients and the RP alternative-specific constants are fixed to the values obtained from A run and just alternative-specific constants of the new alternatives are estimated.

The resulting alternative-specific constants are consistent for forecasting. The coefficients derived by applying the three step procedure above have been used to calculate market shares shown in Fig. 5.

In forecasting we consider six modes: car, taxi, (old) transit with actual characteristics, (new) transit with a better service, shuttle, and cybercar. Figs. 5 and 6 show the predicted market share of various modes. Fig. 5 reveals that cybercar will occupy half of the market among the possible airport ground access modes. Fig. 6 shows the market share with respect to sex, personal income, and education. The results indicate that females prefer car and cybercar more than males, but when considering the public transit, we obtain the opposite result. People who have the highest income level still prefer the car and also intend to try cybercar more than people whose income level is low. The middle income people will have the highest probability to choose cybercar. Meanwhile, reasonably, people with low income intend to choose modified public transit. People with lower education intend to choose the cybercar and show the highest probability to choose this high technological vehicle. However, people who have a graduate degree still prefer driving car to take the cybercar. As people holding the graduate degree are not the majority and the real market is dominated by people with the general academic degree, cybercar will still be popular among the masses according to the prediction.

Table 2. Attributes and Levels of Variation Description for SP Game 2

Variables	Level description
Dropping area	Cybercar dropping off passenger right at the terminal building
	Cybercar dropping off passenger at the parking
Manuvering system	Cybercar with fully automated driving system
	Cybercar driven by human driver with ITS system
	Cybercar driven entirely by human driver
Waiting time	Cybercar waiting time 5 min
	Cybercar waiting time 10 min
	Cybercar waiting time 15 min
	Cybercar waiting time 20 min
Travel cost	Cybercar cost 70% of taxi
	Cybercar cost 85% of taxi
	Cybercar cost equal to that of taxi
Track structure	Cybercar driven on a guide way
	Cybercar driven on regular roads with dedicated lane

Elasticity

Choice probabilities in logit models are a function of the attribute variables that define the utility of the alternatives. Therefore, it is necessary to study the extent to which the probabilities change in response to change in the values of attributes. Elasticity is defined as the percentage change in the response variable with respect to

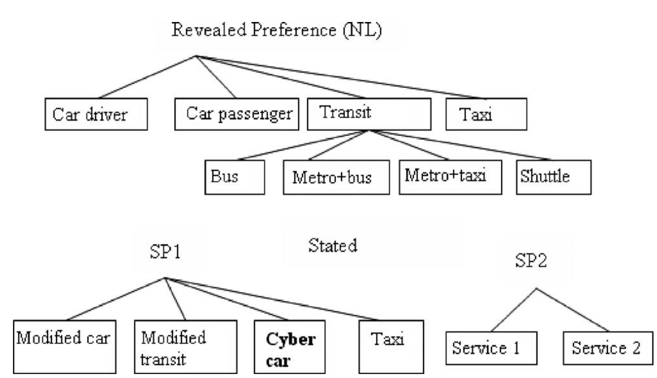

Fig. 4. BWI airport mode choice model nesting structure

Table 3. Estimation Results of RP/SP Logit Model of BWI Airport

Variable name	Coefficient	Standard error	t value	Variable name	Coefficient	Standard error	t value
RP and SP general							
Car time	−0.01449	0.0077	−1.9				
Transit time	−0.00869	0.0141	−1.4				
Taxi time	−0.03713	0.0282	−1.6				
Cost	−0.04051	0.0152	−2.7				
RP specific (nested logit)							
ASC_car passenger	1.174	0.667	1.8				
ASC_bus	−1.706	0.0811	−21.0				
ASC_taxi	−0.3551	0.142	−2.5				
Car ownership	0.8398	1.41	0.6				
Lambda3	0.3751	0.201	1.9				
SP specific							
SP 1				SP 2 (cybercar service)			
ASC_cybercar	0.9937	0.0768	12.9				
Car toll	−0.02502	0.0134	−1.9	Waiting time (10 min)	−0.2267	0.122	−1.9
Park cost	−0.05921	0.0256	−2.3	Waiting time (15 min)	−0.2120	0.121	−1.8
Cybercar time	−0.04400	0.0248	−1.8	Waiting time (20 min)	−0.5454	0.227	−2.4
Level of service	0.5158	0.271	1.9	Drop at terminal	0.3569	0.151	2.4
Transit comfort *(seat available)*							
Transit comfort *(not crowded, no seat)*	−0.3312	0.238	−1.4	Driven automated	−0.1058	0.0898	−1.2
Cybercar comfort (good storage, four carry-ons per person)	0.3323	0.198	1.7	Driven by human driver	0.1029	0.0884	1.2
Cybercar call via telephone	−0.1508	0.165	−0.9	Running on guide way	−0.1626	0.0911	−1.8
Business purpose*cybercar time	−0.0065	0.00500	−1.3				
Vacation purpose*cybercar time	0.004207	0.00401	1				
Lambda1	0.8983	0.363	2.5	Lambda2	1.750	0.677	2.6
Convergence achieved after 30 iterations				"Rho-squared" with respect to zero=0.2316			
Analysis is based on 2,356 observations							
Likelihood with zero coefficients=−2,729.5128				Rho-squared with respect to constants=0.1080			
Likelihood with constants only=−2,351.2648							
Final value of the likelihood=−2,351.2648							
Value of time: Car \$21/h; transit \$13/h; taxi \$56/h; cybercar \$64/h							

a 1% change in an explanatory variable. In logit models, the response variable is the choice probability of an alternative, P_i in which i stands for an alternative, and the explanatory variable is the attribute X_{ik} that k is the kth attribute. Similarly, the cross-elasticity is the proportional change in the choice probability of an alternative (P_j) with respect to a proportional change in some attribute of another alternative (X_{ik}). Five elasticities are calculated from the model estimated, and the calculations include direct and cross-elasticities:

- 10% increase in cybercar cost;
- 10% reduction in cybercar cost;
- 10% increase in car cost;
- 20% increase in cybercar time; and
- 20% increase in car time.

The results are shown in Tables 4 and 5.

In general, the elasticity results appear reasonable. In Table 4, the elasticity values calculated for 10% increase in cybercar cost indicate that modified transit probability will be affected the most, followed by the probability of the car and then the taxi. If the cybercar cost decreases by 10%, we found a similar trend, with reverse signs. When the car cost increases by 10%, car's elasticity values become negative so people are less likely to choose car. The increasing cost of car driving generally comes from the boost in oil prices which has an impact on almost every traffic mode, so people become restricted when the trip cost generally increases. In our case study a 10% increase in car cost produces small ef-

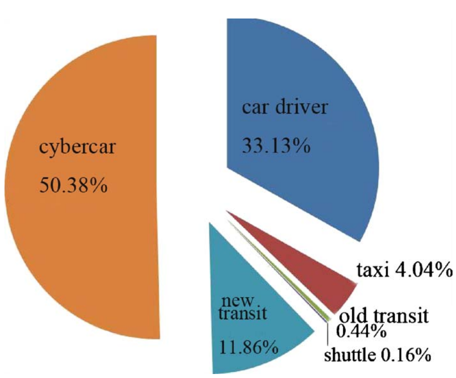

Fig. 5. Predicted market shares of BWI airport ground access modes

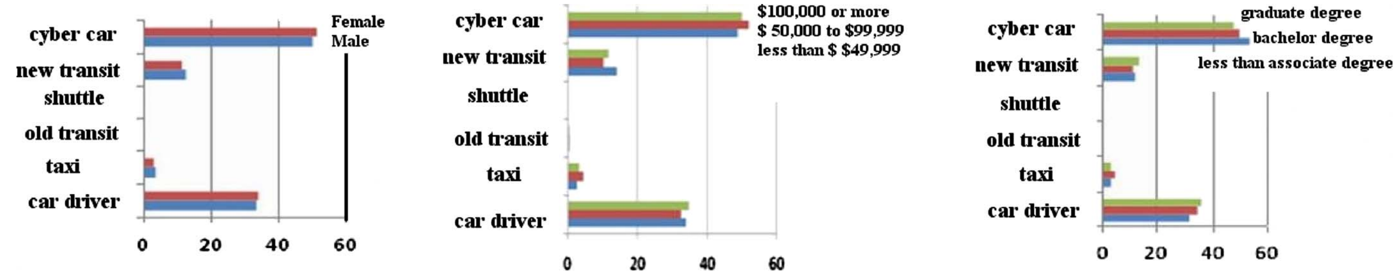

Fig. 6. Predicted market shares of modes with respect to sex (%), income (%), and education level (%)

fects on other modes. Similar to the results in Table 4, Table 5 shows that the elasticities due to changes in cybercar time are much higher than the elasticities due to an increase of 20% in car time. Therefore, people appear to be more sensitive to the change of cybercar time. We also find a high value for the elasticity of modified transit (0.90) for a 20% increase in cybercar cost. An increase in car time will also affect significantly the probability of choosing transit.

Conclusion

A NL model based on RP and SP has been developed to study the potential market of CTS for airport ground access. The cybercar has been adopted in a few places in Europe and could have a market in the United States as well. The data used for this study were collected at the BWI airport, and the cybercar service was designed to connect the Greenbelt metro station to the airport.

The most significant result of this paper is that the cybercar will occupy almost half of the market share at BWI. Results also show that travelers have a high propensity to pay to use this reliable, flexible, and environmentally friendly transit alternative. People with higher income or traveling for business are found to have higher VTTS, although more observations would help in getting more significant results. On the technological side, passengers prefer a service having good storage space that drops passengers at the terminal, conducted by a human driver, and running on regular roads. When considering socioeconomic characteristics, we found that passengers with lower and medium income or without bachelor degree are more likely to use this mode. The elasticity tests indicate that people appear more sensitive to cybercar time and cost change than to variations in car attributes.

The estimation and application results in this paper can be used as a reference for the Citymobil program of the European Union or by airport planning agencies in charge of operation system design. Some extensions still need to be pursued in the future. Mixed logit model may be used to estimate taste heterogeneity on joint RP and SP data. Besides, the study could be extended to the other airports around Washington, D.C. that include DCA and IAD airports. A comparative analysis would help to validate the results obtained at BWI.

Table 4. Elasticity of Cost for Cybercar and Car

Mode	Cybercar cost (increase by 10%)	Cybercar cost (decrease by 10%)	Car cost (increase by 10%)
Car	0.308776	−0.336	−0.00128
Taxi	0.273109	−0.305	0
Old transit	0	0	0
Shuttle	0	0	0
Modified transit	0.433071	−0.462	0
Cybercar	−0.3269	0.354	0

Table 5. Elasticity of Time for Cybercar and Car

Mode	Cybercar time (increase by 20%)	Car time (increase by 20%)
Car	0.6329	−0.00256
Taxi	0.5672	0.010504
Old transit	0	0.097087
Shuttle	0	0
Modified transit	0.9090	0
Cybercar	−0.6749	0

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