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Will commute drivers switch to park-and-ride under the influence of multimodal traveler information? A stated preference investigation

Hongcheng Gan [a,*], Xin Ye [b]

[a] Department of Transportation Engineering, University of Shanghai for Science and Technology (USST), No. 516, JunGong Road, Shanghai 200093, PR China
[b] Key Laboratory of Road and Traffic Engineering of Ministry of Education, College of Transportation Engineering, Tongji University, 4800 Cao'an Road, Shanghai 201804, PR China

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ABSTRACT

The knowledge about en-trip mode switching behavior with presence of multimodal traveler information is very limited so far. This study investigated the impacts on commute drivers' en-trip mode switch decisions of smartphone multimodal traveler information systems (SMTIS) which integrate dynamic information of auto-drive and subway park-and-ride (P&R). This is based on data collected from a stated preference survey in Shanghai, China. A panel mixed probit model which accounts for potential correlations of observations among a same driver and heterogeneity in preferences for travel time savings and comfort level of subway car was developed. The panel model has a much better goodness of fit than a model without consideration of panel effect and heterogeneity. The results show that SMTIS have significant impacts on commuter drivers' decision about switching from auto drive to P&R; the impacts depend on personal attributes including gender, age, education level, income, and P&R use experience; the sensitivity to time savings in the case non-incident induced delays, and the sensitivity to comfort level of subway, both vary significantly among the driver sample.

1. Introduction

With the fast developing information and communication technologies and the increasing popularity of Smartphone, it has been a trend to deploy Smartphone based multimodal traveler information systems (SMTIS) (e.g. Brazil & Caulfield, 2013; Chorus, Molin, Wee, Arentze, & Timmermans, 2006; Frei & Gan, 2015; Gan 2015; Götzenbrucker & Köhl, 2012; Kenyon & Lyons, 2003; Minea, Badescu, & Dumitrescu, 2011; Natvig & Vennesland, 2010; Natvig & Westerheim, 2007; Zhang et al., 2011). Such systems can disseminate, during the whole trip, real time information concerning traffic congestion on selected routes, public transit arrival and departure time, route planning and navigation, and emissions information of alternate modes. It is expected SMTIS can encourage car drivers to use greener travel modes such as bus, rail transit, park and ride (P&R), thus facilitating more efficient infrastructure utilization and the enhancement of city mobility/stainability (e.g. Brazil & Caulfield, 2013; Chorus et al., 2007; Gan, 2015; Kramers, 2012). This is particularly true in China. Chinese government has recently released the national 'Internet + Transportation' Strategic Guideline. In line with this national

* Corresponding author.
E-mail address: hongchenggan@126.com (H. Gan).

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guideline, local governments in many big cities are planning to develop mobile internet based multimodal traveler information systems. This naturally motivates the study of travelers' behavior in response to real-time multimodal information, since a profound understanding of traveler behavior is a prerequisite for better design and wiser investment of SMTIS.

Only a small bulk of publications explored travelers' mode choice behavior under multi-modal information so far. Kenyon and Lyons (2003), through questionnaire surveys, found multi-modal information has effects on overcoming habitual and psychological barriers to consideration of alternative modes. Abdel-Aty and Abdalla (2006) investigated travelers' mode/route choice behaviors under multi-modal information using stated preference data in a 'bus/car' context. Bachok, Yue, Zito, Australasia (REAAA) Conference, and Korea (2009) evaluated a hypothetical rail-bus information integration strategy and estimated a multinomial logit model to predict feeder bus marked shares. Brazil and Caulfield (2013) investigated the impacts of 'Smartphone delivered alternate modes emissions information' on mode choice behavior in a 'car/bus' context, and developed a logit model. Chorus et al. (2007) estimated discrete choice models to describe drivers' mode choice decisions using stated preference data in a 'car/train' context. Most of these studies did not explicitly address SMTIS. A recent review of SMTIS related studies by Gan (2015) and Frei and Gan (2015) showed that so far only a very small number of publications have addressed behavioral aspects of multimodal traveler information systems and establish behavioral models, and most of them only explored pre-trip mode choice decision and did not include P&R. Gan (2015) using stated preference data of Shanghai drivers, estimated a logit model to describe commute drivers' en-trip mode switch behavior with presence of Smartphone multimodal information about car driving and subway P&R. Frei and Gan (2015), extending the work by Gan (2015), addressed the issue of heterogeneity in sensitivity to traffic delay by a mixed logit model.

Regarding P&R studies, existing publications addressed such topics as the optimal P&R facility location problem (e.g. Kepaptsoglou, Karlaftis, & Zongzhi, 2010; Khakbaz, Nookabadi, & Shetab-Bushehri, 2013), equilibrium model of user P&R point choice behavior (e.g. Olsen, 2013; Palma & Nesterov, 2006), the relation of private car utilization patterns and P&R facility space number and density of a city (e.g. Moeinaddini, Asadi-Shekari, & Shah, 2014), empirical study of P&R facility utilization patterns (e.g. Hamid, 2009), survey of P&R motivations and air quality norms in Europe (Dijk, de Haes, & Montalvo, 2013), the influence of P&R facility on vehicle kilometer traveled (e.g. Duncan & Cook, 2014; Meek, Ison, & Enoch, 2011; Mingardo, 2013; Parkhurst, 1995; Parkhurst, 2000), analysis of stated intention of travelers' park and cycle ride (P + CR) use (e.g. Ando, Yamazaki, Haraand, & Izuhara, 2012), empirical analysis of P&R facility choice behavior (e.g. Clayton, Ben-Elia, Parkhurst, & Ricci, 2014), and attitudinal survey of P&R and non-P&R users (e.g. Kwon & Kwon, 2001). However, these studies did not address the mode choice decision behavior in the context of dynamic traffic information.

The above literature review shows that so far the link between P&R facility, en-trip mode switching behavior, and multimodal information has been rarely addressed. It is therefore of much interest to investigate travelers' en-trip mode switch decisions under SMTIS that incorporate auto and P&R options.

Given the above context, this study, in contrast to earlier studies by other scholars, investigates commute drivers' en-trip mode switch behavior with the presence of SMTIS which enables a direct comparison of level-of-service attributes among 'auto drive' and 'P&R' options. This study is conducted in the context of Shanghai, China, through a stated preference (SP) survey of Shanghai drivers. It addressed a realistic two-alternative situation for commute trips: "auto only" and subway "park-and-ride" (i.e. auto access + rail transit). This study extended the work of Gan (2015) through conducting an in-depth study on heterogeneity in travel time and subway crowdedness sensitivities among driver population, and addressing potential correlations among observations of the same individual. These extensions reach a better understanding of the commute drivers' mode switch behavior under SMTIS, and help to improve the explanatory power of the developed mode switch model and obtain more useful insights for SMTIS deployments.

The rest of this paper is organized as follows. First, this paper describes the survey method for collecting data on en-route mode switch behavior under SMTIS. Then, it presents the modeling approach to quantify the SMTIS impacts. Next, it discusses model estimation results. Finally, it gives concluding remarks.

2. Data

A stated preference experiment was designed to collect behavioral data on travelers' response to smartphone multimodal information since currently no real SMTIS applications including P&R exist in China. The experiment was designed on the basis of a realistic 'auto-driving' vs 'subway park & ride' commute trip scenario as depicted by Fig. 1. Respondents were asked to assume that their home and workplace are respectively on the west and the east of Huangpu River. The auto-driving option is a roadway route mainly comprised of an expressway. The P&R option requires a driver to drive to a P&R facility and transfer to subway.

Travel mode attributes values under normal conditions are presented in Fig. 1. The auto-driving option takes 38 min. The P&R option takes 45 min and its cost is 14 Yuan (a 10-Yuan parking fare plus a 4-Yuan subway fare) (1 Yuan $\approx$ 0.16 Dollars).

For the SP experiment, experimental factors include auto delay, reason of delay, P&R cost, and level-of-comfort of subway car. Auto delay has three levels: 15 min, 25 min, and 35 min. Reason of delay has two types: incident-induced and not incident-induced. P&R cost has three levels: 14 Yuan (i.e. no discount), 10 Yuan (about a 30% off discount) and 7 Yuan (a 50% off discount). Level-of-comfort of subway car has two levels: 'with seat and not crowded' and 'without seat and crowded'. Orthogonal design was applied to generate nine travel scenarios (see Table 1) which are in accordance with nine SMTIS messages. In the survey experimenters asked respondents to imagine that as they left from their residence parking lot,

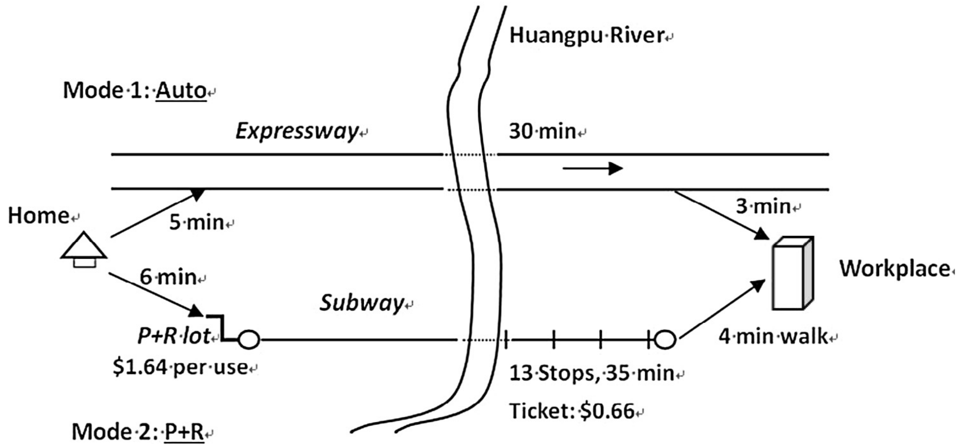

Fig. 1. Travel scenario in the SP survey.

Table 1
SP experiment design.

Scenario	Expressway delay (min)	Incident induced delay?	P&R cost (yuan)	Comfort level of Subway
1	25	Yes	7	With seat and not crowded
2	15	No	7	Without seat and crowded
3	25	Yes	14	Without seat and crowded
4	15	Yes	10	With seat and not crowded
5	35	Yes	7	With seat and not crowded
6	35	No	14	With seat and not crowded
7	25	No	10	With seat and not crowded
8	35	Yes	10	Without seat and crowded
9	15	Yes	14	Without seat and crowded

their Smartphone displayed SMTIS information notifying them of updated traffic conditions relevant to their trip. Fig. 2 gives a sample SMTIS message which was shown to respondents by a pictorial presentation printed on the questionnaire sheets. Fig. 2 has been translated into English here. A SMTIS message consists of five dynamic components: travel time for auto and P&R, cause of delay for auto, cost for P&R, level of comfort for subway, and level of congestion for auto. Given a SMTIS message, respondents were asked to make an en-trip mode switch decision, i.e. 'stay with auto driving' vs 'switch to subway P&R'.

This study conducted a questionnaire survey at a car wash store near the P&R facility in Wenshui Road Railway Station on January 19 and 20 of 2013. Questions of the questionnaire consist of two parts: (a) socioeconomic and other relevant

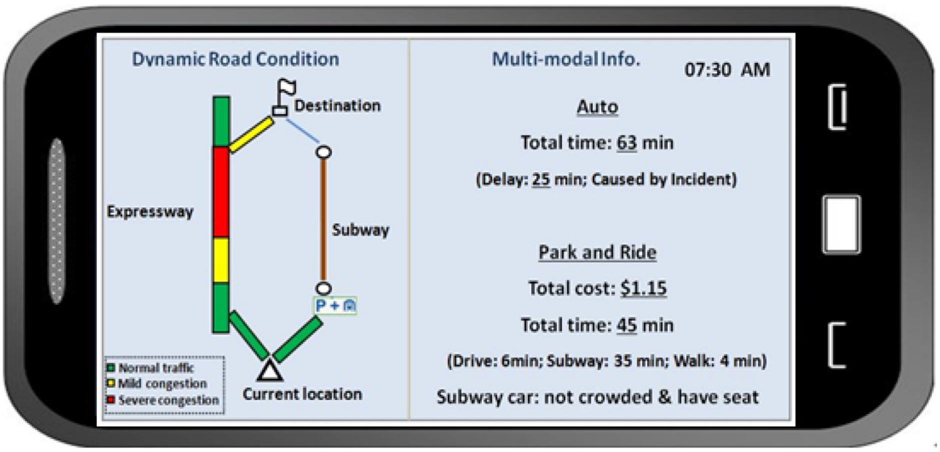

Fig. 2. A sample mode choice question in the SP survey.

characteristics such as gender, age, income, education level, and P&R use frequency; (b) mode choice response to SMTIS messages. Over two hundred drivers visited the car wash store during the period of survey and were invited to participate into the survey. Two hundred and six drivers agreed to be interviewed and completed the questionnaire. Among these respondents, one hundred eighty-one people had auto as their pre-trip mode choice. Since we focused on commute drivers' en-trip mode switch behavior, data of these one hundred eighty-one respondents were used by this study. Thus 1629 (181×9) mode choice observations are collected for analysis and model development.

3. Descriptive data analysis

3.1. Sample characteristics

In the sample, eighty-four percent of drivers are male, which reflects real Shanghai situations (Gan & Bai, 2014). The sample covers drivers in different age groups. Slightly over one fifth (22.7%) of the sample are between 18 and 30 years old, about forty percent (39.8%) are between 31 and 40, about one fourth (25.4%) are between 41 and 50, and the rest (12.1%) is older than 50. The sample also covers a wide variety of drivers regarding driving experience. Some drivers have a 'less than 3 years' driving experience (14.9%), some have a '3–5 years' driving experience (24.3%), some have a '6–10 years' driving experience, and the driving experience of the rest is 'over 10 years' (28.8%). For education level, most respondents (82.9%) in the sample have a college or higher degree, while the others (17.1%) have at most a high school diploma. About one fifth of the respondents (18.8%) have ever used P&R before while the others have no experience of P&R use. For income, the percentages of the 'below 8000 Yuan', '8001–10,000 Yuan' and 'over 10 thousand Yuan' monthly incomes are 36.4%, 26.5%, and 37.1% respectively, with an estimated mean value of 8949 Yuan. Overall, the sample has a sufficient variation in personal attributes.

3.2. Driver response to SMTIS

Table 2 presents mode switch percentages under 9 different travel scenarios. Scenario 5 has the highest P&R share of 60.8% due to a 28-min travel time saving, only a 7-Yuan P&R cost, and high subway comfort level. Scenario 1, 6 and 8 have a P&R share above 50% due to a big travel time saving, or low P&R cost along with high subway comfort level. Scenarios 2, 4 and 9 have low P&R shares between 20% and 30% since the travel time difference is only 8 min. Scenarios 3 and 7 have their P&R shares at a moderate level of 30–40% due to 18-min travel time difference. Table 2 shows that SMTIS have significant impacts on commute drivers' mode switch decision. The following section will quantify the SMTIS impacts through developing an appropriate econometric model.

4. Modeling approach

The data used for modeling analysis belong to panel data since each respondent in the SP survey responded to nine different scenarios. The econometric model is formulated as a mixed probit model for panel data:

$$U_{it}^{*} = x_{it}\beta + z_{it}\gamma_i + \sigma v_i + \varepsilon_{it}. \quad (1)$$

In the above formula, U_{it}^{*} is a random utility function for the P&R mode for driver "i" under scenario "t". "x_{it}" contains some variables changing across drivers but not changing across scenarios (e.g. age, gender), and some variables changing across scenarios but not changing across drivers (e.g. travel time saving, comfort level of subway). "x_{it}" also contains a constant "1" for an alternative specific constant. "v_i" is a random effect changing across drivers but not changing within each driver. "v_i" is specified to capture common unobserved random variables that affect a driver's mode choice. "ε_{it}" is a random variable changing across both drivers and scenarios. "β" is a vector of constant coefficients and "σ" indicates the standard deviation of "v_i". "z_{it}" is a vector of variables that have a random coefficient. The random coefficients "γ_i" vary across drivers but do not

Table 2
P&R choice proportions by scenarios.

Scenario	P&R (%)	Travel time savings (minute)	P&R cost (Yuan)	Crowded on subway?
1	53.0	18 (I)	7	No
2	20.4	8 (C)	7	Yes
3	39.8	18 (I)	14	Yes
4	27.1	8 (I)	10	No
5	60.8	28 (I)	7	No
6	58.6	28 (C)	14	No
7	49.2	18 (C)	10	No
8	54.7	28 (I)	10	Yes
9	27.6	8 (I)	14	No

Note: In the third column, travel time savings is calculated as travel time difference between Drive and P&R, the '(I)' means cause of delay is incident, and the '(C)' means cause of delay is congestion.

vary across scenarios for the same driver. It is assumed that, "γ_i" are normally distributed with mean value "γ" and standard deviation "$\sigma\gamma$", and "ε_{it}" and "υ_i" are both standard normally distributed. "γ_i", "ε_{it}" and "υ_i" are assumed to be mutually independent. In this study, travel time savings and comfort level of subway are treated as explanatory variables that take a random coefficient.

Now we have the following conditional probabilities.

$$P(y_{it} = 1|\gamma_i, \upsilon_i) = P(U^*_{it} > 0|\gamma_i, \upsilon_i) = \Phi(x_{it}\beta + z_{it}\gamma_i + \sigma\upsilon_i), \tag{2}$$

$$P(y_{it} = 0|\gamma_i, \upsilon_i) = 1 - \Phi(x_{it}\beta + z_{it}\gamma_i + \sigma\upsilon_i). \tag{3}$$

where "y_{it}" is a dummy variable indicating whether P&R mode choice is chosen by driver "i" under scenario "t". Eqs. (2) and (3) can be summarized as follows.

$$P(y_{it}|\gamma_i, \upsilon_i) = [\Phi(x_{it}\beta + z_{it}\gamma_i + \sigma\upsilon_i)]^{y_{it}}[1 - \Phi(x_{it}\beta + z_{it}\gamma_i + \sigma\upsilon_i)]^{1-y_{it}} \tag{4}$$

Then the unconditional probabilities are

$$P_i = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\phi(\upsilon_i)\mathrm{f}(\gamma_i)\prod_{t=1}^{T}P(y_{it}|\gamma_i, \upsilon_i)d\gamma_i d\upsilon_i. \tag{5}$$

where $\phi(.)$ represents probability density functions of standard normal distribution, and $\mathrm{f}(\gamma_i)$ is the probability density function of "γ_i" (i.e. $(1/\sigma\gamma)\phi[(\gamma_i - \gamma)/\sigma\gamma]$). T equals nine in this study. Simulation technique is employed to evaluate the integral in Eq. (5) as:

$$P_i \approx \frac{\sum_{r=1}^{R}[\prod_{t=1}^{T}P(y_{it}|\gamma_r, \upsilon_r)]}{R} \tag{6}$$

Two hundred sets of Halton quasi-random numbers (Bhat, 2001) following the standard normal distribution are drawn to evaluate the integral (i.e. R = 200). Then, the simulated log-likelihood function for the entire sample can be formulated as:

$$LL = \sum_{i=1}^{N}\ln(P_i), \tag{7}$$

where N is 181 in this study. The simulated log-likelihood function can be maximized for estimating all the model coefficients in vector β as well as σ, γ, Φ 020$\sigma\gamma$. In this study, model coefficients are estimated in Gauss System.

5. Estimation results and discussions

Table 3 provides model estimation results of the mixed probit model which accounts for panel effect and heterogeneity in sensitivity to time savings and subway comfort level. The random coefficient of variable 'Travel time savings under congestion' and the random coefficient of variable 'Rail transit comfort level' were found to be statistically significant. The standard

Table 3
Model Estimation Results.

Variables	Coefficient	*T*-test
Constant	−2.2168	−9.510
Female	−0.6182	−3.870
Driver is 18–24 years old	3.6947	8.130
Education level is middle school or below	−1.6898	−8.550
Monthly income (1000 Yuan)	−0.1121	−5.220
Have used P&R before	2.1791	13.370
Travel time savings under incident	0.1375	19.820
Subway is crowded	–	–
σ	3.0551	19.710
γ for 'Travel time savings under congestion'	0.1288	16.020
γ for 'Rail transit comfort level	−0.7379	−5.870
σ_γ for 'Travel time savings under congestion'	0.0181	4.090
σ_γ for 'Rail transit comfort level'	0.6575	6.440
Model performance measurements		
L(β)	−558.931	
L(c)	−1115.171	
L(0)	−1129.137	
ρ^2 (c)	0.4988	
ρ^2 (0)	0.5050	

deviation "σ" of the random effect is estimated at 3.0551 and appears highly significant. It means that, in addition to random coefficients of two explanatory variables, there are still other common random components associated with each driver when he/she made choice in each scenario. These results verify that, there exist of heterogeneity in sensitivity to time savings and heterogeneity in sensitivity to rail transit comfort level among the driver sample, and there are correlations among repeated mode choices of a same respondent (i.e. panel effect).

As given in Table 3, the likelihood ratio index value of the mixed probit model is about 0.5, showing a satisfactory overall goodness-of-fit of the model. The authors also estimated a simple probit model which does not account for panel effect and heterogeneity for one to have a clearer feeling of the explanatory power of the mixed probit model. The likelihood ratio indexes ρ^2 (0) and ρ^2 (c) of the simple probit model are respectively 0.1406 and 0.1513, which are much lower than those of the mixed probit model. These results show the superiority of the mixed probit model over the simple probit model.

The constant term is negative, indicating that driving is generally the preferred mode over P&R if there is no delay on expressway. This result is consistent with the fact that the pre-trip mode choice of all the respondents in the sample is driving.

Table 3 shows that personal attributes that have a statistically significant effect on en-trip mode switch behavior include gender, age, education level, income, and P&R use experience.

First, female drivers are less likely to switch to P&R when notified of unexpected expressway delay by SMTIS messages, as indicated by the negative sign of the variable 'Female'. This is presumably due to the crowdedness in subway cars during peak hours in Shanghai, which may result in increased discomfort of female passengers compared to their male counterpart. Also, parking, walking and waiting may be perceived to have a larger disutility for female travelers compared to male travelers. However, the relatively small number of female participants in the survey suggest that, this gender related finding may be context-specific and more explorations are needed to obtain more evidences.

Second, young drivers with an age below 25 are more likely to choose P&R mode, as indicated by the positive coefficient of variable 'Younger than 25'. That is probably because young people have good physical condition and are therefore less hesitant to enter the crowd of rail transit.

Third, drivers with low education level are less likely to use P&R mode, as evidenced by the negative coefficient of the education level variable. That is probably because well educated people probably have greater environmental awareness and are more aware of negative externality imposed on others if they stay with auto drive.

Fourth, the likelihood of switching to P&R decrease with income, as indicated by the negative coefficient of the income variable. The reason behind is presumably that an increasing sense of self-respect with raised income may prevent drivers from entering the crowd of subway.

Fifth, the positive coefficient of variable 'Have used P&R before' indicate that drivers who have used P&R before are more willing to switch to P&R when facing unexpected expressway delays than drivers without P&R use experience. This is presumably because, though people usually are reluctant to choose an option with which they have no experience, they are more willing to use it after they try it and benefit from it.

For the variable 'Travel time savings under congestion', the mean and the standard deviation of the random coefficient are respectively 0.1288 and 0.0181, which are statistically significant. However the standard deviation is small relative to the mean. These results indicate that a bigger travel time saving on average increases a driver's willingness to switch to P&R, and different drivers have different values of time savings when facing non-incident delays although the difference among the driver sample is relatively small.

For the variable 'Travel time savings under incident', it takes a constant coefficient of 0.1375, which is slightly greater than the mean coefficient value of 'Travel time savings under incident' (0.1288). This result shows that, generally travel time savings are a bit more valued by drivers in the case of incident than in the case of congestion, and drivers are more uniformly sensitive to incident-induced delay than to non-incident induced delay.

For the variable 'Subway is crowded', the mean value of the coefficient is −0.7379 and the standard deviation is 0.6575. It is interesting that these two coefficients are close to each other in terms of their absolute value. This indicates that, although drivers generally dislike crowdedness in rail transit, their sensitivity to this factor differ substantially from one to another. This finding seems reasonable since some travelers in Shanghai may have already got used and become less sensitive to crowdedness in its metro system.

The above findings have useful implications for SMTIS deployment and transportation management. First, the significant effect of SMTIS information about travel time savings and subway comfort level suggests that it is worthwhile for Shanghai government to invest on advanced monitoring and surveillance systems that can collect sufficient traffic and passenger flow data and provide reliable travel time and subway comfort level estimates to drivers. Second, the existence of heterogeneity in the preferences for travel time saving and subway comfort level also provides insights for putting forward efficient marketing strategies for SMTIS. Drivers who are highly sensitive to travel time and subway comfort level can be the main target of such strategies. Third, the findings regarding P&R use experience suggests that it is worthwhile for Shanghai government to initiate programs that can attract people with no P + R use experience to try P&R. For example, governmental agencies can offer some discounts or even a free ride opportunity to drivers who never experience P&R but have potential to use P&R. With pleasant P&R use experience, those drivers will be much more willing to use it in the future. Forth, the findings regarding education level suggest that is helpful to educate citizens to raise environmental awareness through various media such as newspapers, Internet, television, driving school education, and free non-profit lectures.

6. Concluding remarks

The en-trip model choice behavior with the presence of multimodal information which integrates an auto-driving option and an subway P&R option is explored through developing a mixed probit model using data collected from an Shanghai SP survey. The results show that multimodal information has a good potential of persuading commute drivers to switch from auto-driving to subway P&R. Contributing factors that influence mode switch decisions were revealed. The en-trip mode switch propensity increases when travel time saving is greater, the subway car is not crowded and seat is guaranteed, and a person is male, has college degree or above, has used P&R before, and is younger than twenty-five. The probability of mode switch decreases with income. The mode switch model, through addressing potential correlations among repeated observations from a same individual and heterogeneity in the values on alternative attributes, fit the SP data quite well, and obviously outperforms the simple probit model without panel effect and heterogeneity. It is found that the degree of sensitivity to travel time savings under non-incident-induced delays varies significantly among the driver sample and that there is a significant heterogeneity in the values on subway comfort level.

In the current study, the cost for the auto drive option is not explicitly specified in the stated preference experiment. We notice that it might be helpful to specify the financial cost of both the auto drive option and the P&R option in our stated preference experiment to give a more realistic feeling of the provided travel options and hopefully elicit more reliable behavioral data. Future study can address this issue.

Shanghai government is trying to make Metro (subway) be the backbone mode for accommodating surging travel demand. This study suggests that it is worthwhile for the government to invest in smartphone apps that integrate dynamic information about auto and subway P&R options. Such smartphone apps might help to reshape densely-populated metropolitan cities such as Shanghai to be a more sustainable urban community. The findings and insights obtained from the modeling attempt of this study may be a basis on which sound and effective policies and strategies about SMTIS deployment can be identified.

Our study enriches the body of behavioral study of multimodal traveler information systems which is a heated research field in transportation planning, operations, and management. The very limited knowledge on en-trip travel behavior with the presence of dynamic multimodal information calls for more exploratory research. Cross-cultural studies are welcome. More complex travel contexts such as trips including more mode options can be addressed in the future.

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