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Authors

Dai, Lu
Foertsch, Andrew
Shi, Xiaomeng
et al.

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INVESTIGATING THE POTENTIAL OF USING A MULTIMODAL APPROACH TO REDUCE AIR PASSENGER DELAY

A Case Study of Hongqiao Transportation Hub

Lu Dai, Corresponding Author
Master, Department of Civil and Environmental Engineering
Graduate Student Researcher, National Center of Excellence for Aviation Operations Research
University of California, Berkeley
2230 Virginia Street, Berkeley, CA 94709
Tel: 510-501-6652; Email: dailu@berkeley.edu

Andrew Foertsch
Master, Department of Civil and Environmental Engineering
University of California, Berkeley
105 Fox Blvd Massapequa, NY 11758
Tel: 516-301-7699; Fax: 516-795-3187; Email: afoertsch.student@berkeley.edu

Xiaomeng Shi
Ph.D. Candidate, Jiangsu Key Laboratory of Urban ITS, Southeast University
Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies
School of Transportation, Southeast University
2 Sipailou, Nanjing, Jiangsu 210096, China
Tel: +86 15805150722; Email: shixiaomeng@seu.edu.cn

Haozhe Cong
Deputy-director, Department of Traffic Safety Education Research
Road Traffic Safety Research Center
The Ministry of Public Security
Beijing 100062, China
E-mail: conghaozhe@126.com

Yujia Ke
Master, Department of Civil and Environmental Engineering
University of California, Berkeley
Berkeley, CA 94709
Tel: 510-935-8267; Email: yujia_ke@berkeley.edu

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ABSTRACT

In China, civil aviation and high speed rail have developed independently as transportation modes able to serve long distance trips. Being substitutes has caused a highly competitive relationship to exist, with both services having terminals built independently of one another. However, a new form of transportation hub that integrates a high speed rail terminal and an airport at one centralized location, has the ability to introduce a new complementary relationship between the two modes. Specifically, in the event of flight delays and cancellations, an Multimodal Transportation Hub could present a unique alternative for inconvenienced passengers to transfer between the airport terminal and the train station to complete their trip.

The purpose of this study is to quantify what percentage of people would prefer to transfer to high speed rail service rather than waiting for the next available flight, given that their previously scheduled flight has been cancelled. Using Hongqiao Transportation Hub as a case study, this study firstly presents a survey that was conducted to examine the effectiveness of the multimodal transportation hub. A total number of 715 respondents completed the entire survey, each giving responses to 12 questions (8580 stated preference observations in total). Secondly, a Discrete Choice Model is developed to explain respondent's anticipated behavior. Given that their previous scheduled flight was cancelled or significantly delayed, factors that influencing passengers' choice are clearly defined. Finally, based on the survey results and the analysis of Discrete Choice Model, some policy issues and model limitations are discussed.

Keywords: Multimodal Transportation Hub, High Speed Rail, Mode Choice Behavior, Discrete Choice Model, Stated Preference Survey

1 INTRODUCTION

High-speed rail (thereafter: HSR) is a type of rail transport that operates in excess of 160 miles per hour, making it significantly faster than traditional rail traffic. Throughout the world, high-speed rail networks have been constructed by nations to connect major cities within their borders. Only in Europe dose HSR cross these borders, making international travel possible. The country that has constructed the largest HSR network is China, whose network accounts for two-thirds of the world's total HSR track miles. Furthermore, in China, enclosed managements are implemented for every train running speed over 120 km/h (*1*). Such uninterrupted operation guarantees the travel time reliability of the HSR system. Hence, HSR has better on-time performance than airlines based on the average punctuality rate (over 90% vs. less than 90%) (*2*). Apart from the travel time reliability, HSR also serves better customer traveling experience than airline in terms of more comfort and steady operations, convenience and less restriction of luggage. Therefore, gleaning insight into the trade-offs between the competitive and coordinative nature of HSR and airline,there is a potential to use HSR as a complement of airline to help attract more air passengers.

In certain European and Asian markets, HSR is integrated with airport service at centralized locations. These locations then become Multimodal Transportation Hubs, giving passengers the ability to switch between regional flights, high-speed rail trains and urban transportation systems such as city buses and subways. In the event of flight cancellations, an Multimodal Transportation Hub could present a unique alternative for inconvenienced passengers to transfer between the airport and the train station to ultimately take HSR to their destination, provided that time savings could be achieved. It is difficult, however, to quantify what percentage of people would prefer to transfer to HSR instead of preferring to wait for the next available flight, given that their previously scheduled flight has been significantly delayed or cancelled.

A quick analysis proves that numerous parties stand to benefit from an in-depth understanding of multimodality as a solution to air passenger recovery. Specifically:

- Airlines can efficiently allocate finite assets such as airplanes,
- Airlines understand the trade-offs that passengers are willing to make when their previously scheduled flight is significantly delayed or cancelled;
- Passengers can be presented with alternatives that effectively meet their needs and arrive to their destinations in a more timely and cost effective manner when their willingness to travel with certain modes are better understood.
- Furthermore, policies can be considered to induce specific passenger behaviors that may be desired by policy makers;
- Airports can address increasing passenger demand while potentially holding flight supply constant by using an efficient multimodal approach to regional transportation needs, thus helping airports recover from any perturbations in flight plans.

2 LITERATURE REVIEW

At present, increasing attention is being paid to building analytical models that precisely forecast travel demand by better quantifying the passenger behavior. Many research studies have been completed on the choice behaviors of passengers.

One such a model that also included a trip generation model, destination choice model, mode choice model and route choice model was the integrated nested travel model for an intercity HSR project in Japan. Based on the frequency of service, cost, travel time and travel distance, the distribution rate of passenger flows was analyzed (*3*). Another example of such a study was conducted in Brazil and helped explain the main factors that influence the travel mode choice and their varying level of importance (*4*).

A separate issue studied in recent years was passenger recovery through flight schedules. A new analytical framework and optimization model to reduce passenger disutility due to delay and misconnection was proposed in (*5*). This was achieved by incorporating different alternative transportation modes. A different approach to solve the same problem was proposed in (*6*). The authors aimed at reducing the operational costs of airlines and passenger losses by constructing a model to reallocate disrupted passengers to subsequent flights or trains. This signified an understanding and trend in the research that multimodal solutions to transportation problems could serve as a viable solution to common issues such as passenger recovery.

A large number of previous related studies have already analyzed the relationship between air trips and high speed rail from different perspectives. Based on the survey data of four kinds of transport modes, intercity bus, train, high speed rail and air, the multinomial model presented by Li show that travel distance, travel cost, operation time, safety, comfort, punctuality, network ticket and car ownership are the most important factors influencing regional travel mode choice for both compulsory activities and leisure activities (*7*). Another study included a binary logit model describing the competitive relationship between high-speed rail and civil aviation along the Wuhan-Guangzhou HSR line (*8*).

However, far less researchers have examined high speed rail as a potential complement to civil aviation. In the event of flight cancellations, Multimodal Transportation Hubs could play an important role for inconvenienced passengers to transfer between the airport and the train station to ultimately take HSR to their destination. Also, there is a lack of analytics on the choice behavior and its difference in the business trips and leisure trips. In view of this, this study would conduct a survey that concentrated on the effectiveness of the multimodal transportation hubs (Hongqiao Transportation Hub, China) and developed the discrete choice model to analyze the passengers' travel behavior, given that their previously scheduled flight has been significantly delayed or cancelled.

3 METHODOLOGY

3.1 Modelling the Problem

One of the world's largest multimodal transit hubs is the Hongqiao Transportation Hub, located in Shanghai, China. This hub connects one of Shanghai's international airports with the intercity High Speed Rail System, Shanghai Metro system and public ground transportation system. It has over 300,000 daily users. Our case study was conducted on this multimodal transportation hub. Shanghai is one of the four direct-controlled municipalities of China and the most populous city proper in the world with a population of more than 24 million as of 2014. It is a global financial center and transport hub located in the Yangtze River Delta. It sits on the south edge of the estuary of the Yangtze in the middle portion of the East China coast.

3.2 Data Collection

3.2.1 Questionnaire Design

To further understand the modality styles of passengers and what factors will influence the travel mode that people decide to take to make a journey, a survey was conducted to examine passengers that could or have traveled through Hongqiao Transportation Hub. Specifically, this survey examines the effectiveness of the multimodal transportation hub, which enables transfers to be made between flights and high speed rail at one location, giving passengers more than one potential alternative mode of travel. The survey posed questions relating to trip itineraries that began in Hongqiao Airport only.

In each itinerary and each scenario, the survey informed the participant that he or she has already booked a flight ticket and arrived at Hongqiao airport to depart on a direct flight. The passenger's luggage has already been checked, the passenger has already passed through security and is currently waiting at the appropriate departure gate. However, at the time the flight was scheduled to depart, this passenger is notified by the airline that the flight has been cancelled. The individual now has three alternatives that they can choose from. These are:

- Waiting for the next available flight offered by the same airline;
- Transferring to the next available flight with a different airline;
- Transferring to a High Speed Rail train within Hongqiao Transportation Hub that will take them directly to their destination city;

In the survey, responders were presented with three different trip itineraries (short distance, medium distance and long distance). Before designing the survey, we collected the real-world China's HSR system schelude and the flight schedule in the Hongqiao airport. We applied Python code to automatically match the next available flight offered by the same airline, the next available flight with a different airline and the HSR train to the current scheduled flight. Since transferring from current flight departure gate to other transportation modes would take additional time, such as separate security screening time or other processing steps, we considered 30 minutes transferring time in our matching algorithm in assumption that such delays could in themselves be a factor in decision-making. Thus, an itinerary information table including current flight schedule and three alternatives was created.

The itinerary information includes the destination, departure date, departure time, arrival date, arrival time, on-time performance, airline and additional fees of the scheduled canceled flight, the next available flight operated by the same airline, the next available flight operated by a different airline, and the next available high speed rail train. Furthermore, for each cancelled flight, each survey respondent was assigned one of the following four combinations for trip type and luggage service:

- Business trip with luggage transfer service to the train;
- Leisure trip with luggage transfer service to the train;
- Business trip without luggage transfer service to the train;
- Leisure trip without luggage transfer service to the train.

We assigned each trip either a business trip or a leisure trip randomly in Python. We assume that, a business trip means that time is of the essence and the passenger's employer has agreed to cover all trip costs. In contrast, a leisure trip implies that time may not be so critical and all trip costs would be paid by the passenger.

Each alternative has different characteristics associated with it. Responders are required in the survey to select the alternative which they would select, given a set of alternative specific attributes. The socio-demographic characteristics of responders is also recorded in the survey to be used in the development of the discrete choice model.

In addition, to verify the confidence level of the stated anwers, two verification items were designed: 'Have you ever been to the Hongqiao Hub?' and 'Have you ever made a transfer from aircraft to HSR in Hongqiao?'. A critia based on these two questions is supposed to used to select certain group of respondents. This might be useful for the sample size selection process in the future study. However, currently, we simply used restricted random sampling method.

3.2.2 Variables

Past research has identified important factors that passengers consider when deciding on a mode of transportation to take given that their previous scheduled flight is significantly delayed or canceled. These factors can be divided into two categories: alternative specific attributes, and personal characteristics. Both categories and some examples are shown in the following table (Table 1).

Based on previous research and common knowledge, estimates can be inferred for most of these variables. Most notably, high values for cost and time will vary negatively with projected demand. Conversely, Frequent Flyer Programs with specific airlines will influence passengers to remain with their original airline choice due to factors such as loyalty. In addition, since business trips are time-critical and assumed to be paid for by the respondents employer, it is reasonable that business passengers will choose to change their flight to any airline in order to get to their destination as soon as possible.

TABLE 1 Statistically Significant Variables Used In Discrete Choice Analysis

Attributes of The Alternatives	Characteristics of The Decision-maker
Departure Time	Gender
Arrival Time	Age
Total Travel Time	Education
On-time Performance	Income
Alternative Cost	Trip Purpose
N/A	Frequent Flyer Program Membership

3.2.3 Survey Result

Data was collected from an online Stated Preference survey in April, 2017 worldwide. The survey consisted of socio-demographic information, travel history and alternative analysis. Survey respondents took the survey on the Sojump platform, a popular and professional online survey platform without advertisement, and were asked to volunteer forwarding this survey in their social media networks. 90% of the survey respondents forwarded this survey and most of them have already built a strong online social network. The selection of respondent groups mainly depends on the respondents' social networks. Thus, half of respondents are students in our survey (Figure 1) since the authors are students. The researchers explained the objectives of the study within the survey and asked the responders to choose between making a trip with the same airline, any airline or high speed rail, given that their original flight was cancelled.

Finally, a total number of 715 respondents completed the entire survey, which makes 8580 stated preference observations (12 scenarios for each participant). The statistical information of all the respondents is shown below (Figure 1). Once collected, the response data was downloaded from sojump in excel spreadsheet format. After performing data cleaning using Python, mode choice analysis was performed, the results of which are presented in Part 4.

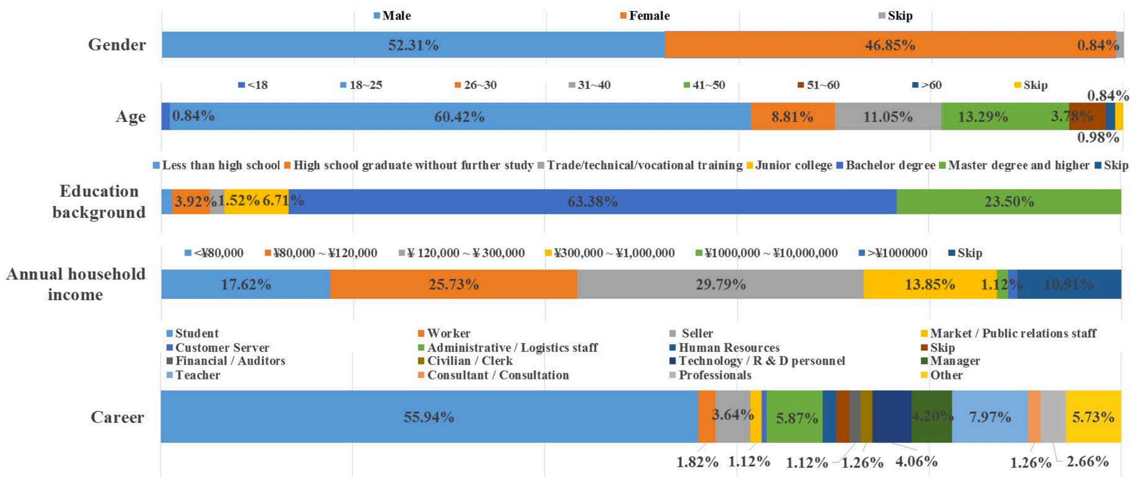

FIGURE 1 Characteristics of all the 715 respondents.

3.3 Data Analysis

3.3.1 Multinomial Logit Model

A Multinomial Logit Model (MNL) is the most frequently used disaggregate model, especially in the field of transportation. Based on the Stochastic expected utility theory, the probability of passenger *n* choosing alternative *i*, P_{in} is:

$$P_{in} = Prob\ (U_{in} > maxU_{jn}; i \neq j, j \in C_n) \tag{1}$$

where C_n is person n's choice set, $i \in C_n, j \in C_n$;
j is all the alternatives other than alternative i;
$U_{in} = V_{in} + \epsilon_{in}$ is the utility that passenger *n* choosing alternative *i*, where V_{in} is the deterministic utility and ϵ_{in} is the random utility, they are independent to each other and ϵ_{in} follows a Gumbel distribution.

Therefore, the probability that passenger *n* choosing alternative *i* is expressed as follows:

$$P_{in} = \exp(V_{in}) \,/\, \sum_{i \in C_n} \exp\,(V_{in}) \tag{2}$$

3.3.2 Nested Logit Model

The research team discussed two possible ways of nesting the three alternatives. One is based on the transport mode (Figure 2) and the other one is based on whether an additional fee is required (Figure 3). Using these nesting structures, a Nested Logit Model was specified in R. Though both models do explain some of the heterogeneity that exists among the Chinese population, it was determined that the Multinomial Logit Model more accurately fits the mode choice behavior.

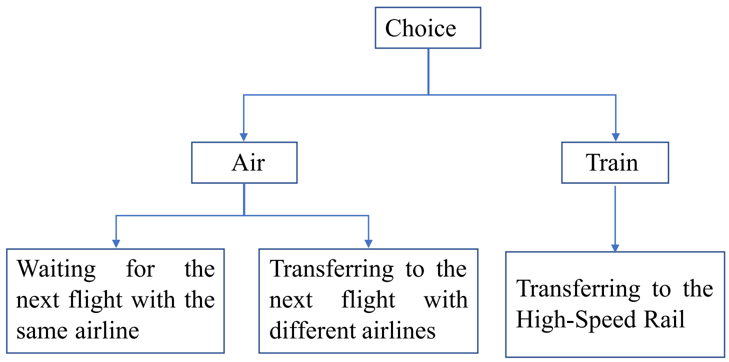

FIGURE 2 Structure of Nested Logit Model based on the Transport Mode.

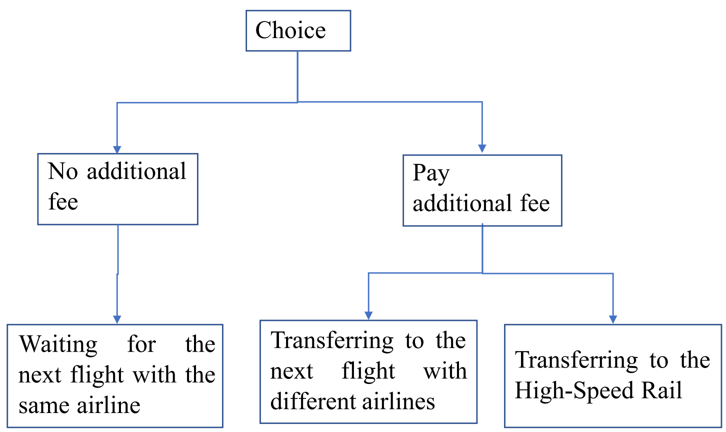

FIGURE 3 Structure of Nested Logit Model based on the additional fees.

4 RESULTS

The behavioral model specification included multiple significant variables, all of which can be observed in the following table based on a 95% confidence level (Table 2). The most significant variables were: difference in travel time among alternatives, additional cost of specific alternatives and trip type of either business or leisure.

TABLE 2 The Estimation Results of Multinomial Choice Model (Significant Variables)

Exogenous Variable	Coefficient	Standard Error	t-stats	P-value
ASC Same Airline	-1.5843	0.193	-8.224	0
ASC Different Airline	-0.988	0.182	-5.434	0
Travel Time Difference (hours, Different Airline)	-0.144	0.022	-6.646	0
Travel Time Difference (hours, Train)	-0.3699	0.042	-8.779	0
Student (hours, Same Airline)	0.1955	0.053	3.683	0
Hard Worker (Same Airline)	-0.3666	0.081	-4.544	0
Education (Same Airline)	0.1571	0.031	5.131	0
Education (Different Airline)	0.0776	0.027	2.828	0.005
Cost (Different Airline)	-0.0239	0.007	-3.312	0.001
Cost (Train)	-0.1243	0.011	-11.573	0
Frequent Flyer Program (Same Airline & Different Airline)	0.3165	0.076	4.168	0
Luggage is Transferred (Different Airline & Train)	0.1462	0.047	3.128	0.002
Trip Type - Business (Different Airline & Train)	0.6373	0.047	13.558	0
Gender - Male (Different Airline & Train)	0.1705	0.047	3.639	0

Model Specification is as follow:

$$u_{1n} = -1.5843 + 0.1955x_2 - 0.3666x_3 + 0.1571x_4 + 0.3165x_6 + \epsilon_{1n} \tag{3}$$

$$u_{2n} = -0.9880 - 0.1440x_1 + 0.0776x_4 - 0.0239x_5 + 0.3165x_6 + 0.1462x_7 + 0.6373x_8 + 0.1705x_9 + \epsilon_{2n} \tag{4}$$

$$u_{3n} = -0.3699x_1 - 0.1243x_5 + 0.1462x_7 + 0.6373x_8 + 0.1705x_9 + \epsilon_{3n} \tag{5}$$

where:
u_{1n} is the utility of Waiting for the next available flight offered by the same airline;
u_{2n} is the utility of Transferring to the next available flight with a different airline;
u_{3n} is the utility of Transferring to a High Speed Rail train within Hongqiao Transportation Hub;
x_1 is the travel time difference after transferring to other mode choice (hours);
x_2 is the dummy variable that if the responder is a student, $x_2 = 1$, otherwise $x_2 = 0$;
x_3 is the dummy variable that if the responder is a hard worker (whose job is manager or professionals, such as architects, engineers, accountants, lawyers, doctors, etc.), $x_3 = 1$, otherwise $x_3 = 0$;
x_4 is the education level;
x_5 is the travel cost (CNY);
x_6 is the dummy variable that if the responder is a frequent flyer member of this airline, $x_6 = 1$, otherwise $x_6 = 0$;
x_7 is the dummy variable that if the luggage is transferred, $x_7 = 1$, otherwise $x_7 = 0$;
x_8 is the dummy variable that if it is a business trip, $x_8 = 1$, otherwise $x_8 = 0$;
x_9 is the dummy variable that if the responder is a male, $x_9 = 1$, otherwise $x_9 = 0$;

ϵ_{1n}, ϵ_{2n}, ϵ_{3n} are the unobserved random variable of each alternative, which follows the Gumble distribution.

Based on the results, travel time difference and travel cost are found to be negatively correlated with all travel alternatives. This is behaviorally consistent and was expected.

The coefficient of Student dummy variable is positive for the alternative that waiting for the next available flight offered by the same airline. This could be because students who don't have much income will rarely choose to pay the additional fees for transferring to other transportation modes. In contrast, most of the hard workers are the high-income earners. For them, the value of time is higher than the additional fees. They would rather pay the money to reduce the waiting time in the terminal. Gender (male or not) is also captured in the model. It makes sense that male and female have different sensitivities to the fare (*9*).

Higher educations of respondents correlated to an increased likelihood of flying by air instead of taking the train. While the reason for this is not entirely clear, it could be possible that higher educated individuals prefer airplanes in China because they are faster and or safer. Obviously, it's less likely that Frequent Flyer members will transfer to other airlines or high speed rail since they may lose some benefits such as mileages.

TABLE 3 Summary Statistics for The Model Specification

Summary statistics	
the number of observations	8,580
$\boldsymbol{\rho^2}$	0.049
$\boldsymbol{\bar{\rho}^2}$	0.048
Log-Likelihood	-8,960.500
LL-Null	-9,426.666

The likelihood ration index value is roughly 0.05, which is smaller than expected. But it doesn't mean that a low value is inherently bad. The study doesn't need precise predictions. This study is trying to predict human behavior and psychology. It is entirely expected that $\boldsymbol{\rho^2}$ will be low in such field. Humans are simply harder to predict than, say, physical processes. Furthermore, although the $\boldsymbol{\rho^2}$ value is low, the model specification is statistically significant and could also draw important conclusions about how changes in the variables are associated with changes in the response value. Regardless of the $\boldsymbol{\rho^2}$ value, the significant coefficients still represent the mean change in the response for one unit of change while holding other factors in the model constant. Obviously, this type of information can be extremely valuable and the interpretations of the significant variables are the same for both high and low R-squared models (*10*).

Another interesting observation is the correlation that exists between the transfer of luggage from the airport to the final mode of transportation. Currently, inter-air-carrier travel does not guarantee the seamless transfer of luggage between airlines. This requires that passengers claim their baggage before checking it in with their new air carrier. The same procedure is required when transferring between flights and trains, even if both transportation modes are in the same area. This requirement places a burden on the passenger and encourages travel itineraries to be planned entirely with one airline. However, when asked if the removal of this burden would influence passenger travel, passengers revealed that their travel behavior may change. This conclusion is valid at the 99% confidence interval.

Using the behavioral model, forecasting was used to predict shifts in passenger behavior for specific mode shares under given conditions. Forecasting was employed in 5 distinct cases, and the results for each case are depicted in the figure below (Figure 4).

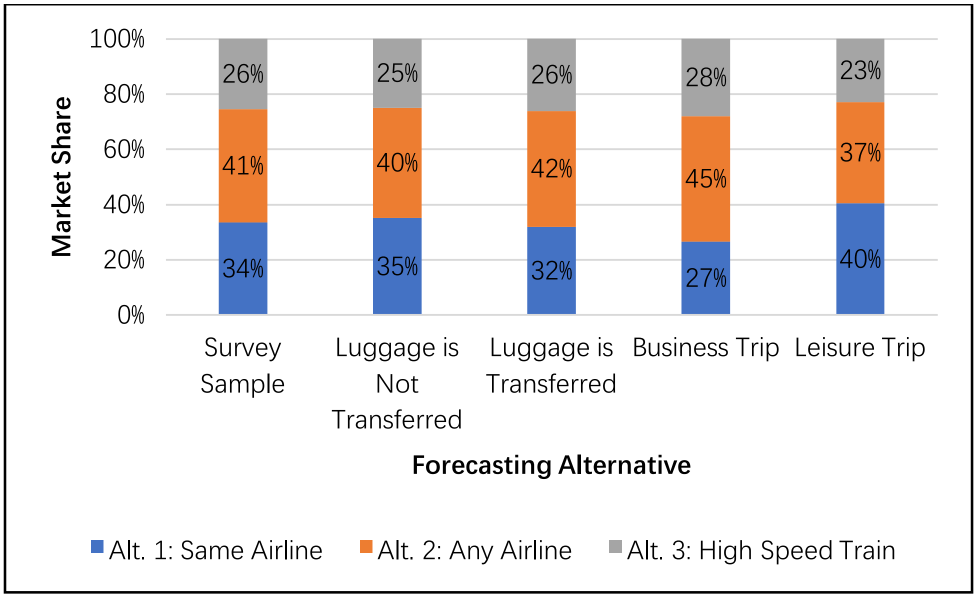

FIGURE 4 Forecasting scenarios.

5 CONCLUSIONS AND LIMITATIONS

There are a few conclusions that can be drawn from this experiment. First, Chinese Travelers primarily consider travel time, cost, and trip type as the most significant factors when deciding between transportation modes. Second, the cost of the different alternatives, though significant, has a low sensitivity. Therefore, it takes large changes in price to affect people's mode share, on the scale of hundreds or thousands of CNY. Third, the forecasts of the luggage transferring policy would have a negligible change (~5%) on mode share if all other characteristics remained constant.

This project is subject to multiple limitations that are listed below.

1. The survey sample was assumed to perfectly represent the Chinese population. Before any policy actions are taken, these conclusions should be verified by using Chinese socio-demographic characteristics and weighing the results obtained by this survey using iterative proportional fitting techniques;
2. Survey bias is a large problem when developing a discrete choice model. Since the survey was a stated preference survey instead of a revealed preference survey, there are no guarantees that the stated preferences of the respondents will correspond accurately with their actual choices. Furthermore, the survey that was presented to the respondents to imagine themselves as both business and leisure travelers in the same survey. From feedback obtained from certain respondents, it became clear that not all respondents "imagined" the same situations that they were choosing between. This introduces additional bias into the results;

3. The forecasting was performed on the same group of individuals used to build the model. For future work, some type of hold-out validation or cross validation should be used to more accurately quantify the effects of policy implications on a population.

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