How Does On-Demand Ridesplitting Influence Vehicle Use and Purchase Willingness? A Case Study in Hangzhou, China

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Abstract—Shared mobility refers to the shared use of a motor vehicle, bicycle, or other low-speed transportation modes, which has significant influences on transportation systems. Among different types of shared mobility, ridesplitting is developing the most rapidly because of the emergence of transportation network companies. In this study, we present exploratory evidence of on-demand ridesplitting's impacts on the vehicle use and purchase willingness using the emerging ridesourcing real-world data (i.e., app-based, on-demand ride services like Uber and DiDi Chuxing) in Hangzhou, China. We explore ridesplitting users' travel habits and their transportation modal shift behavior if the ridesplitting services are unavailable, and how ridesplitting impacts the use of public transit and private cars. In summer 2017, an online survey was conducted with respondents who had completed ridesourcing journeys within one month before the investigation. We compare the survey results with two-week ridesourcing order data provided by DiDi Chuxing, 20% of which are ridesplitting orders (including DiDi Hitch and Express ridesplitting). Considering the modal shift from public transit to ridesplitting, the findings indicate that (I). In the short term, ridesplitting services reduce the number of vehicles on road (decreased by 3,051 veh/day, nearly 2.6‰ of the vehicle ownership in the urban area of Hangzhou). (II). In the intermediate term with the development of ridesplitting, the total decreased number of vehicles is estimated to be 4,129 veh/day (nearly 3.6‰ of the vehicle ownership). An interesting phenomenon is that Hitch's influences on the vehicle usage in the intermediate term is not obvious as the influence in the short term due to travelers' modal shift from public transit. (III). In the long term, ridesplitting will reduce the car purchase willingness and influence people's travel behavior to some extent. This paper shines light on quantitatively exploring the influence of on-demand ridesplitting on the vehicle use and purchase willingness.

I. Introduction

Sharing economy is a developing phenomenon based on renting and borrowing goods or services, rather than owning them. It can improve efficiency, provide cost savings, and in the long term, will influence people's purchase habits. As one aspect of the sharing economy, shared mobility (e.g., carsharing, ridesplitting, bike sharing, scooter sharing, ridesharing, and on-demand ride services) can make people's travel more convenient and much easier to access transportation facilities. Carsharing means that individuals have temporary access to a vehicle as long as they pay a fee to the carsharing operator. While ridesplitting means a form of ridesourcing where riders with similar origins and destinations are matched to the same ridesplitting driver and vehicle in real time, and the ride and costs are split among users [1]. In the field of logistics, crowdshipping is part of shared mobility. Crowdshipping literally means shipments performed via the crowd, and it also helped reducing congestion, pollution and social costs [2].

Shared mobility already exists for decades. Traditional carsharing is a part of the traditional rental industry and can be gained from car rental operating companies. However, this pattern is not flexible enough for daily travel and one-way use. With the continuous development of the industry, one-way carsharing (e.g., ZipCar, Commuauto, and Velib) and free-floating carsharing (e.g., Car2go) services appeared gradually a few years ago. But such services are still unfriendly for passengers without driving licenses or disabled. On the contrary, each ridesplitting travel can be highly customized compared with public transit. Unfortunately, ridesplitting is only popular among acquaintances due to many reasons, making this kind of shared mobility not convenient as other travel modes.

In the past several years, transportation network companies (e.g., Uber, Lyft, and DiDi) emerged and developed rapidly. They provide on-demand ride services or ridesourcing for passengers by using their smartphone apps [3]. Taking DiDi Chuxing as an example, users release their travel schedules on the platform, and the platform will match an e-hailing taxi, DiDi Express vehicle, or ridesplitting services according to the users' choices. Compared with the traditional ridesplitting among acquaintances, on-demand ridesplitting via the ridesourcing platform is more efficient and convenient for the public. In DiDi Chuxing's platform, two kinds of ridesplitting services (i.e., Express ridesplitting, and Hitch) are provided. Express ridesplitting is a ridesplitting service when customers use DiDi Express (a ridesourcing service in DiDi, similar with taxi) and have the option to share rides with other passengers in a shared trip. DiDi Hitch matches drivers and passengers who share similar routes. Different from Express ridesplitting, the Hitch drivers are private car travelers, so they would drive no matter there are ridesplitting passengers or not. Note that the majority of Express drivers work full-time while most Hitch drivers work part-time. The differences between Express ridesplitting and Hitch are summarized in Table 1.

With the economy development, the vehicle ownership and number of vehicles on road increase year by year, which is a big burden for urban transportation systems. For instance, the vehicle ownership of the Hangzhou metropolitan area and central Hangzhou reached 2.598 million and 1.157 million in 2017, respectively [4]. Based on our previous work on the analysis of the license plate data in Hangzhou, there was an average 1.010 million vehicles daily in the streets [5]. Meanwhile, since the infrastructure construction speed is much slower than the increase of travel demand, traffic congestion becomes more and more serious in megacities. In many cities of China, government rations the number of new vehicle licenses to reduce the ownership growth rate and restricts the vehicle usage during specific time periods or in certain areas to control the number of vehicles on road. These strategies are effective in the short run, but they make individual travels by car inconvenient. By contrast, ridesplitting is an efficient way to reduce vehicle purchase willingness and the number of vehicles on road without enforcing strategies. The emerging on-demand ridesplitting has been particularly welcomed by city residents due to its convenience, highly customized flexibility, and low cost by splitting fare in shared trips.

> Taking DiDi Chuxing as an example, users release their travel schedules on the platform, and the platform will match an e-hailing taxi, DiDi Express vehicle, or ridesplitting services according to the users' choices.

One vehicle can service more than one passenger during a ridesplitting trip, so the magnitude of its impact on the number of vehicles on road can be quite significant. However, people using ridesplitting services come from different travel modes, which may have diverse influences on the traffic operational performance. For example, ridesplitting can replace a number of taxis in the road network and compete with public transit systems (e.g., bus, and metro) in passengers' regular long-distance travels. Among them, the modal shift from public transit and non-motorized travels will increase the number of vehicles on road and thus have a negative impact on traffic conditions. In the long term, individual passengers' travel habits may change, e.g., more or less usage of private cars and public transit. Even people's willingness to purchase a private car may be influenced by the popularity of ridesplitting services.

There have already been some related studies conducted in this area. In a survey by Shanghai Transportation Trade Association [6], 80% of Shanghai city residents were willing to choose ridesplitting for their daily travels, which showed the big impact of shared mobility on Chinese travel habits. At the same time, a report published by McKinsey [7] showed that 37% of the consumers surveyed believed that owning a car seemed less important now that other forms of transportation were available, and a significant number of consumers believed they could meet their needs by renting (40%), leasing (34%), or co-owning cars (26%), rather than purchasing on their own.

The findings above have shown the great influence of ridesplitting. However, to the best knowledge of authors, it is still not fully understood to quantify the on-demand ridesplitting services' impacts on the vehicle use and purchase willingness using real-world ridesourcing data under a city-wide scale. Besides, the consideration of multimodal shift behavior makes the research more complicated, mainly due to the modal shift from public transportation and non-motorized travels after the emergence of ridesplitting services.

This paper focuses on quantifying the on-demand ridesplitting's impacts on the vehicle use and purchase willingness in terms of different stages. Using the real-world ridesourcing order data provided by DiDi and questionnaire data collected from ridesourcing passengers, we explore the short-term and intermediate-term impacts on the number of vehicles on road for Hitch and Express ridesplitting, respectively, and the long-term impact on the vehicle purchase willingness. This paper provides quantitative evidence of the ridesplitting's impacts, and helps government agencies and legislators better understand ridesplitting and make decisions to regulate the growing shared mobility market.

Table 1. Comparison between express ridesplitting and hitch.

Feature	Express Ridesplitting	Hitch
Operating mode	On-demand	Pre-order
Business philosophy	Quick & comfort	Sharing & environmental protection
Price	Short distance with discount	Long distance with low price
Dynamic pricing	Yes	No
Speed of orders strived	Quick	Not sure
Operating purpose of drivers	Profit	Reduce travel expenses
Ride-sharing license	Need	No need
Driver type	Most full-time	Most part-time

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The rest of this paper is organized as follows. Section II presents the literature review on the vehicle use, purchase willingness, and emerging on-demand ridesplitting via ridesourcing platforms. In Section III and IV, the data description and processing methodology are described, respectively. The results of a case study conducted in Hangzhou are shown in Section V. Section VI draws the conclusions and outlooks the further research.

II. Literature Review

Shared mobility has been studied for decades in the literature. During the past few years, it became wider popular and had a huge impact on urban transportation systems. As an innovative mobility mode, shared mobility services enhances urban traffic efficiency [8]–[9]. It also serves as an effective solution that extends the catchment area of public transportation to bridge gaps in the existing transportation networks. The on-demand access to shared mobility provides a more flexible mode for passengers who need to access or egress from public transportation stations, compared with the fixed and scheduled routes and vehicles. While shared mobility can keep passengers from driving alone to share seats with others, so that it potentially plays a key role in solving the first- and last-mile problems [10].

On-demand ride services' payments are only permitted via the platform, which is different from traditional taxi services. Some examples of on-demand ride service platforms include Uber, Lyft, and DiDi. It is a good opportunity to use empty seats of cars which are available [11]–[12]. In addition, many differences between on-demand ride services and other travel patterns have been studied. Rayle et al. [13] indicated ridesourcing could help satisfying the previously unmet demand for a convenient, point-to-point travel service. Although taxis and ridesourcing shared similarities, the findings showed differences existing in users and their experience. The wait times of ridesourcing were markedly shorter and more consistent than those of taxis, while ridesourcing users tended to be younger, owning fewer vehicles and more frequent to travel with companions. Ridesourcing, like taxis, appears to be a substituted and complement mode for public transit; most of the ridesourcing trips would take substantially longer time if they are served by public transit. For on-demand ride services, the behavior of operators is also important. For instance, a monopoly ridesourcing platform would maximize the joint profit with its drivers without any regulatory intervention [14]. Pfrommer et al. [15] studied shared mobility systems considering the efficient operation via the combination of intelligent routing decisions for staff-based vehicle redistribution and real-time price incentives for customers.

Ridesharing exists in many cities around the world, with the advances in mobile technologies increasing their popularity. There were estimated 638 ride-matching services in the U.S. and Canada [16]. The development of ridesharing platforms spurred expansion to regions and employers throughout North America. Key developments include regional and employer partnerships, financial incentives, and social networking to younger populations to achieve critical mass. But some companies who have begun real-time ridesharing and automated ride-matching technologies, they still require a high subscriber base. Handke and Jonuschat [17] showed that ridesharing might be widely used in the future with sacrificing a little comfort of passengers, for the reasons such as detour. It is possible that many people approve ridesharing. Some survey results showed that about 45% of people would be interested or potentially would be interested in ridesharing [13].

Nowadays, ridesplitting occupies a large proportion of resident travels and gradually has an unneglectable impact on urban transportation systems. Shaheen [18] pointed out that sharing vehicles resulted in fewer traffic jams and fewer cars on roads overall, by cutting down the number of vehicles needed by households and society as a whole. A research conducted by Martin and Shaheen [19] documented that one of the most notable effects of roundtrip ridesplitting was the reduced vehicle ownership. Each ridesplitting vehicle removed 9 to 13 vehicles (postponed and sold) from the road, 25% of members sold a vehicle and 25% of members postponed a vehicle purchase due to carsharing across a sample of approximately 9,500 participants [20]. Based on an SP survey in the Tehran Metropolitan Area (Iran), when all interested travelers chose carpooling, independence of knowing appropriate ridesharing or not, then it might decrease about 780,000 vehicle trips per day and reduce the annual fuel consumption by 336.53 million liters [21].

The influence of ridesplitting on the traffic is attractive to traffic managers. One study of Madrid presented that the number of vehicles could be reduced by 59% if passengers were willing to share rides with others who worked or lived within 1 km. If users were only willing to share rides with people they knew, the potential of ridesharing became negligible, if they were willing to share ride with friends of friends, the potential reduction was up to 31% [22]. By simulating traffic for several ridesharing adoption scenarios,

In order to reflect the real-world situation, two sets of data collected from different sources in Hangzhou, China, are involved in this paper, i.e., the real-world ridesplitting order data extracted from the on-demand ride service platform, DiDi Chuxing, which completed 7.43 billion rides in 2017 and had a market share in private cars of 80% and in taxis of 99% in China, and the online survey data conducted by investigating ridesourcing customers who had just completed their trips and paid the fare via the on-demand ride service platform app.

Alexander and González [23] evaluated the impact of ridesharing on the cumulative vehicle travel time and distance. They found that under the scenarios of moderate to high adoption rates, ridesharing may have noticeable impacts on congested travel times. Grino [24] investigated the operational challenges of bike sharing systems, she emphasized the rebalance operation and modeled a new concept of mobility, namely Car2work, which is built based on the successful integration of the existing ridesharing concept and the existing traffic network. And based on the results from a series of five surveys of City CarShare members and nonmembers [25], there was clear evidence of a net reduction in the vehicle miles traveled and fuel consumption of CarShare members.

There are some studies concerning the impact of ridesharing. Shaheen et al. [26] mentioned that about half of the traditional carsharing operators expressed concern that personal vehicle sharing had a potential for negative environmental impacts. They argued that the actions that residents shared their personal vehicle would increase VMT/VKT through the increased rate of vehicle usage, and the sharing might encourage households to keep personal vehicles they otherwise might sell. Further research is needed to document and understand the social and environmental impacts of personal vehicle sharing.

This paper focuses on quantifying the ridesplitting's impacts on the vehicle use and purchase willingness in Hangzhou, China, considering the multimodal shift behavior from public transportation and non-motorized travels.

III. Data

In order to reflect the real-world situation, two sets of data collected from different sources in Hangzhou, China, are involved in this paper, i.e., the real-world ridesplitting order data extracted from the on-demand ride service platform, DiDi Chuxing, which completed 7.43 billion rides in 2017 [27] and had a market share in private cars of 80% and in taxis of 99% in China [28], and the online survey data conducted by investigating ridesourcing customers who had just completed their trips and paid the fare via the on-demand ride service platform app.

A. Ridesplitting Order Data

DiDi Chuxing is the largest on-demand ride service platform in China. The ridesplitting services provided by DiDi Chuxing include Express ridesplitting and Hitch. We collected two-week ridesourcing order data from DiDi Chuxing in Hangzhou, China. The sampling rate is 50%. Every individual ridesourcing order includes the pickup/drop-off locations and time stamps, trip ID, order ID, passenger ID, driver ID, ride beginning time, ride ending time, actual travel distance, planning travel distance, type of services, and whether ridesplitting is matched or not. The total number of orders is 4,265,503, including 3,427,006 successful orders (that is, 80.3% orders can be completed via the platform) in the dataset. The number of successful ridesplitting orders (including Express ridesplitting and Hitch) is 668,181 (i.e., nearly 20% of the completed orders). Based on the sample order data and the sampling rate, the average daily ridesourcing and ridesplitting order's composition in Hangzhou are displayed in Fig. 1. Using the column "passenger ID," we can include the daily average ridesplitting passengers from the ride order dataset. The results show that 2,332 and 32,626 users are for Hitch and Express ridesplitting, respectively.

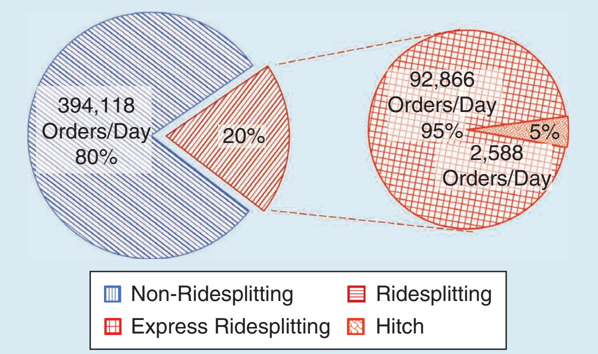

FIG 1 Composition of ridesourcing (left) and ridesplitting (right) orders on DiDi Chuxing platform in Hangzhou, China.

In the ridesourcing dataset, passengers who share their trips by splitting ride and fare are marked. Based on the pickup locations and time stamps of a sequence of ridesplitting orders over the same shared trip, we can figure out the operational characteristics of the ridesplitting orders. In order to facilitate the presentation, we define one ridesplitting order of a specific passenger as one trip segment or simply an order, a shared journey from the first passenger getting aboard to the last passenger alighting from the car is called one shared trip. The distribution of the number of ridesplitting orders per shared trip is shown in Fig. 2. Nearly 70% of the shared trips contain two shared trip segments. The shared trips with only one shared trip segment are all Hitch trips. The temporal distributions of the ridesplitting orders, Hitch orders, and Express ridesplitting orders are shown in Fig. 3. The red dashed line represents the number of shared trips in daily orders. There are rarely ridesplitting orders at night for the reason that the on-demand ride service platform prohibits Express ridesplitting orders during 1–6 AM. Except for the nighttime, the percentage of shared trips in the ridesplitting orders almost remains unchanged for the whole day (about 46%).

The spatial distribution of all successful ridesourcing orders, ridesplitting orders, Express ridesplitting orders, and Hitch orders are shown in Fig. 4. The spatial patterns of different order types show no significant differences, and they share the same aggregation regions, but the distribution densities are quite different. Similar to the successful ridesourcing orders in Fig. 4(a) and Express ridesplitting orders in Fig. 4(c), Hitch orders' pickup locations spread all over the city, however, the distribution density of the Hitch orders is especially low.

The travel distance distribution on DiDi platform is shown in Fig. 5. The average travel distance is 6.1 km. It shows that most travel distances are concentrated in the range between 1 km and 10 km. Therefore, decreasing the number of vehicles on road can effectively reflect the influence of on-demand ridesplitting services. If necessary, the decreased number of vehicles on road multiplied by the average vehicle kilometers traveled (VKT) equals to the value of decreased VKT in the city.

For demonstrative purposes, we extract one shared trip with six over-lapped Express ridesplitting orders from the dataset and plot the origins and destinations of the six orders on the road network of Hangzhou, which is illustrated in Fig. 6. The shared trip length is nearly fifty kilometers and serves six individual passengers by sequence who split their fare in order to save monetary costs. The real-world

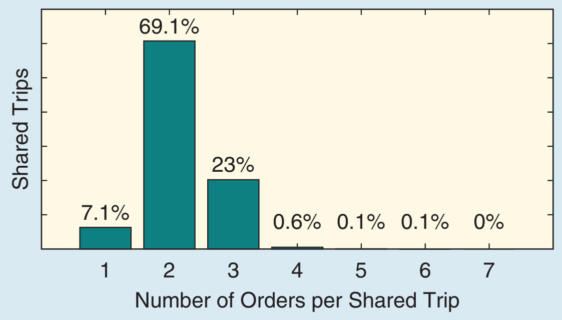

FIG 2 Distribution of ridesplitting orders per shared trip (anonymized).

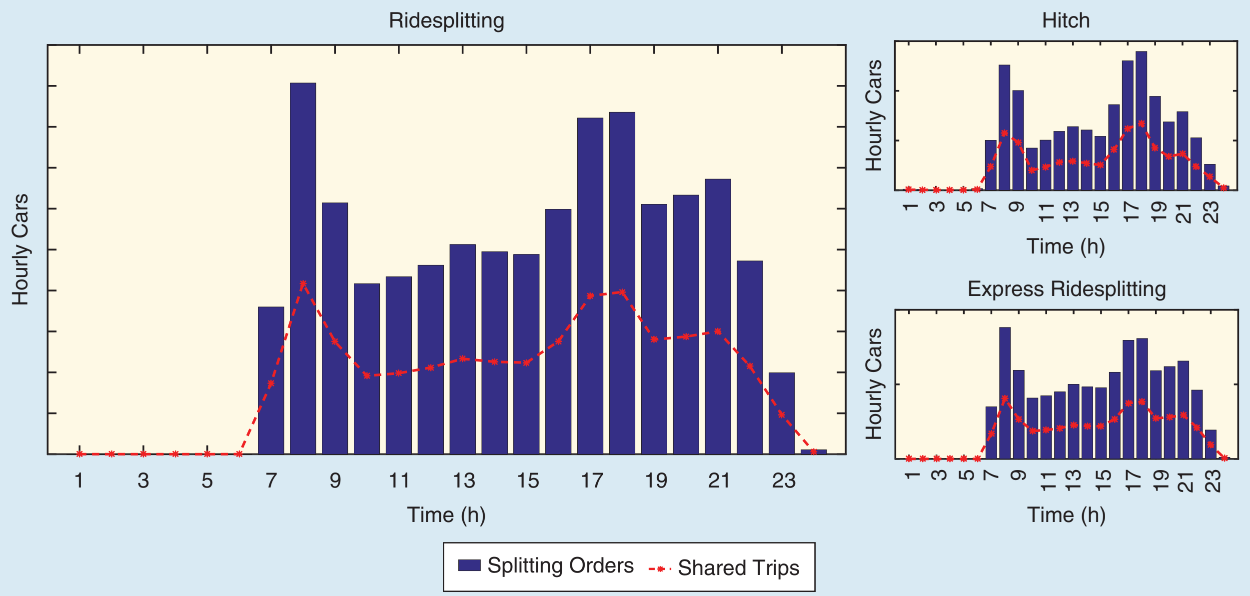

FIG 3. Temporal distributions of ridesplitting orders (anonymized).

shared trip example starts in the suburb area (origins 1 and 2), travels through the downtown area (origins 4 and 5), and ends in another suburb area (destinations 5 and 6). Note that the en-route matching of passengers with the driver and route recommendation has been optimized via the on-demand ride service platform, which indicates that the driver does not necessarily manually schedule the whole shared trip before picking up the first ridesplitting passenger.

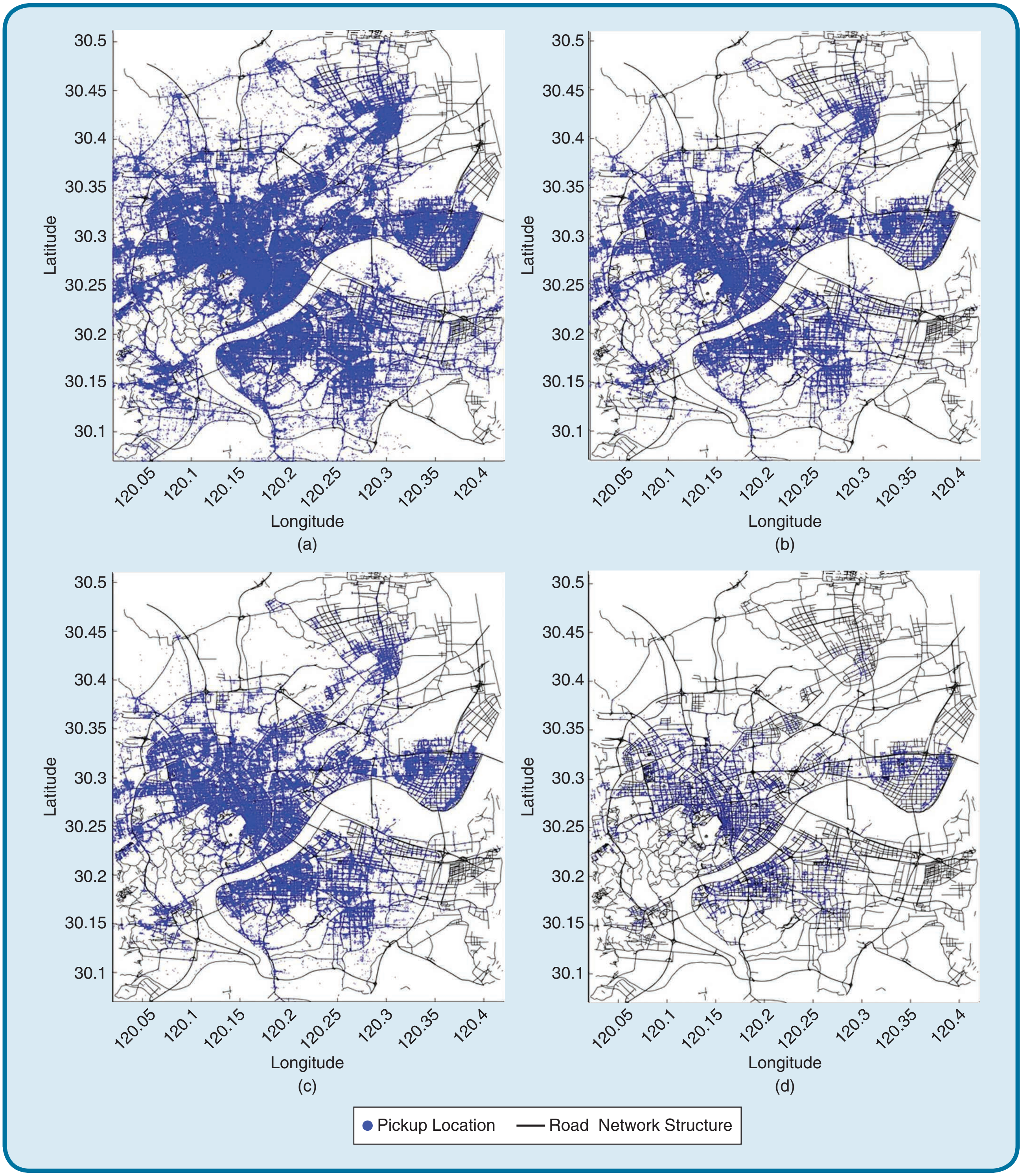

FIG 4 Spatial distributions of pickup locations via the on-demand ride service platform in Hangzhou, China. (a) All successful ridesourcing orders, (b) ridesplitting orders, (c) express ridesplitting orders, (d) hitch orders.

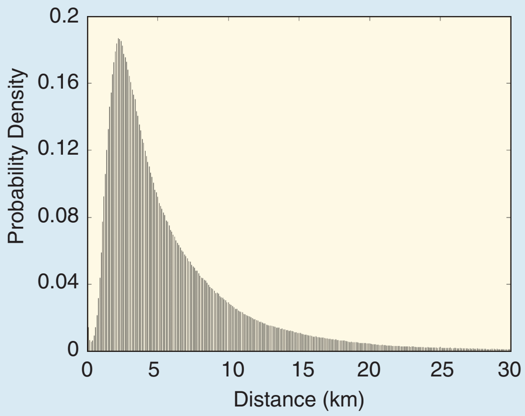

FIG 5 The travel distance distribution on DiDi platform.

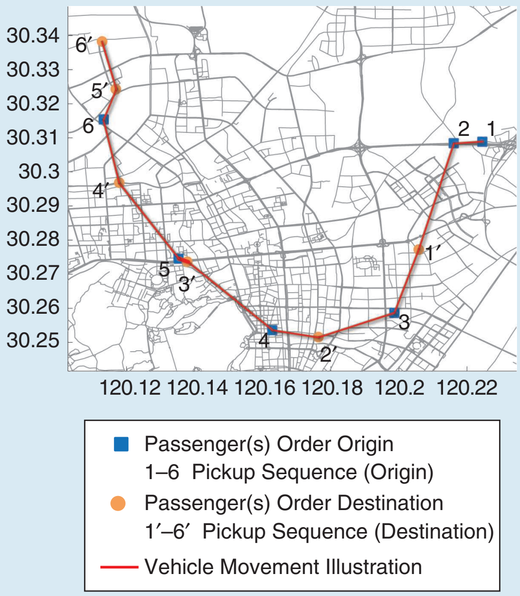

FIG 6 A real-world shared trip with six ridesplitting orders in Hangzhou.

Due to the shared trips via ridesplitting services, a long trip is able to satisfy more than one passenger who should have used private automobiles, taxis, or ridesourcing cars without sharing rides with others. Thus, the number of vehicles on road will decrease, which is a positive effect. In addition to replacing private automobile trips, ridesourcing also attracts travelers who use public transit or induces additional car travels. Considering the ridesplitting's flexibility and celerity, some passengers may shift mode from public transit systems (e.g., bus and metro) or non-motorized travels (e.g., bike, e-bike, and pedestrians), which may induce more passengers using ridesourcing or ridesplitting services. Eventually, the shift may increase the number of vehicles on road, which is a negative effect. In summary, ridesplitting services both complement for and compete with public transit, at least with respect to individual trips.

However, the ridesourcing order data only involve one type of the multiple transportation modes, which is not enough to calculate the influence on the vehicle use and purchase willingness. To clarify the relationship among different modes, we design a revealed preference and stated preference (RP/SP) survey toward passengers who once used on-demand ridesplitting services.

B. Questionnaire Data

To collect data of ridesplitting users and trips, researchers conducted an online survey in Hangzhou, between June 30 and July 4, 2017. 2680 randomly selected users of the on-demand ride service platform (i.e., DiDi app) who had completed ridesplitting journeys within one month were involved in the online survey. The survey was conducted by providing the respondents with a private link to an online survey site via the short message. The online questionnaire contains three categories for different respondents, namely the Hitch part, Express ridesplitting part, and non-ridesplitting part. Each part consists of nearly 30 questions. The questionnaire's completion rate among the users was 35.9%, and finally, 962 participants' survey data were involved in the survey. Each respondent spent 9.5 min on average to accomplish the questionnaire. After denoising, the survey data contain 744 useful and valid sample questionnaires.

Because the questionnaire was randomly disseminated among all ridesplitting passengers, our sampling method is reliable and representative. In the calculation part, we separately analyze the users' behavior of different ride services. The ratio of Hitch and Express ridesplitting in the questionnaires has no influence on the calculation results and the sample's representation. In the questionnaire part, the most important thing is to make sure that there is a sufficient sample size to analyze the ridesplitting users' behavior before and after the emergence of on-demand ridesplitting services and their original travel modes. In the related studies, Rayle et al. [11] used 380 completed questionnaires to compare the taxis, transit, and ridesourcing services in San Francisco. In order to find the motivations for casual carpooling participations, Susan et al. [29] observed and counted participants and vehicles at four casual carpooling locations, interviewed participants riding in carpooling vehicles ($N = 16$), and conducted intercept surveys ($N = 503$). Compared to numbers of investigators in the related studies, the sample size in this paper is relatively sufficient and representative to describe the ridesplitting user in Hangzhou, China.

In the ridesourcing data randomly extracted from the on-demand ride service platform, Hitch travel is a small part of the ridesplitting system, which only occupies 2.7% of the total ridesourcing data, while Express ridesplitting dominates 97.3%. In order to receive adequate responses for Hitch passengers, we design to judge participants with two questions at the beginning of the questionnaire "You are a Hitch user or not?", if the answer is "No", then the participants should answer "You are an Express ridesplitting user or not?" The logic diagram is shown in Fig. 7. Then the questionnaire is designed for three types of passengers according to their responses. First, the passengers who have used Hitch before will be required to answer the Hitch part. Second, if the passengers have only used Express ridesplitting before, they will switch to answer the Express ridesplitting part. Third, for the passengers who never choose ridesplitting services, they will answer the remaining part of the questionnaire.

In the questionnaire, demographic and socioeconomic attributes of Hitch and Express ridesplitting users are collected. As shown in Table 2, there are no obvious differences between these two types. Passengers between age 18 and 40 (79.3%) are the majority ridesplitting users, and enterprise staff occupies almost half of all participants (46.8%). Passengers with RMB 50,000 to 349,999 household income (77.7%) are more likely to choose ridesplitting. Passengers who own private cars also consider splitting the ride with others (72.2%).

As the rapid development of ridesplitting via the on-demand ride service platform, some passengers' travel habits have gradually changed. To answer the question *"How Does On-Demand Ridesplitting Influence Vehicle Use and purchase willingness?"*, in this survey, we asked every respondent which transportation mode would be chosen if ridesplitting services were not available (stated preference), how the usage frequency of the multimodal mobility (e.g., bike, taxi, and private car) was impacted by the popularity of ridesplitting (revealed preference), whether he/she planned to purchase a car, and whether the willingness to purchase a car changed due to the availability of ridesplitting services (stated preference). The other questions include: recall the latest ridesplitting experience, reasons for ridesplitting, destination, travel distance, departure time, modal shift before the ridesplitting appearance and when ridesplitting services are not available, differences in travel time/fare/distance, etc.

Table 3 shows the statistics of the modal shift estimated by using the survey data. The results show that the emergence of ridesplitting significantly changes people's travel behavior (both by car and public transit). More than 90% respondents involved in this survey indicate that they will reduce the private car use, nearly 27% respondents among them will reduce private cars three times or more in one week, and about 42% respondents express that they will reduce the taxi use. On the contrary, ridesplitting also attracts some passengers from public transit and non-motorized travels, i.e., 37.2% from bus transit, 21.4% from the metro, and 18.3% from bikes.

IV. Methodology

In this paper, we assume that Hitch drivers are all part-time, Express drivers are all full-time. The changed number of vehicles on road can be calculated by the following equation using the ridesplitting orders data:

$$N_{\text{short-term}} = \sum_{i}^{I} n_i - I_{\text{Express-ridesplitting}} - \tilde{N} \tag{1}$$

where $N_{\text{short-term}}$ is the decreased number of vehicle usage per day in all shared trips, I is the number of daily ridesplitting shared trips, n_i is the number of ridesplitting orders in shared trip i (from 1 to I), $I_{\text{Express-ridesplitting}}$ is the number of Express ridesplitting shared trips, and $\tilde{N}$ is the number of people who shift mode from public transportation or non-motorized travels to ridesplitting.

Using the order data collected from DiDi Chuxing platform, it is difficult to figure out which part of passengers using ridesplitting services are attracted from public transit. We combine the order data and the app-based survey on the DiDi platform. Based on the survey results, $\tilde{N}$ can be calculated by

$$\tilde{N} = \alpha \times \sum_{i}^{I} n_i \tag{2}$$

where α represents the stated preference percentage of public transit and non-motorized travels in the replacement modes before the ridesplitting appears or when ridesplitting is unavailable.

Considering the respondents investigated are passengers who have finished ridesplitting travels, we assume that the blank caused by usual travel habits' change will be covered by ridesplitting services. Although the change may not immediately occur, it will eventually be realized in the near future. To evaluate the change of the whole transportation system, the impact on the number of vehicles on road calculated by the questionnaire data should be processed into the form of per capita impact, given by

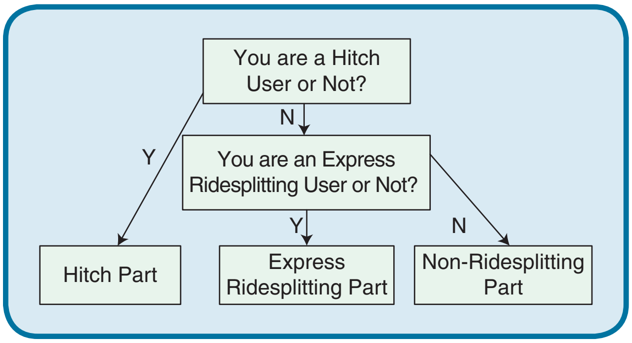

FIG 7 Logic diagram for three categories of respondents.

Table 2. Socio-demographic characteristics (%).

Demographic Attributes		Hitch N = 443	Express Ridesplitting N = 301	Ridesplitting N = 744
Individual-Level Attributes				
Gender	Male	59.6	57.1	58.6
	Female	40.4	42.9	41.4
Age	Younger than 18	0.5	1.3	0.8
	18 to 30	32.3	40.9	35.8
	31 to 40	46.3	39.5	43.6
	41 to 50	17.2	14.6	16.1
	51 to 60	2.5	3.0	2.7
	Older than 60	1.4	0.7	1.1
Occupation	Civil Servant	4.5	4.7	4.6
	Institution Employee	14.7	16.9	15.6
	Enterprise Staff	48.8	43.9	46.8
	Freelancer	16.7	18.9	17.6
	Student	4.3	6.3	5.1
	Other	9.7	9.0	9.4
	Retired or Unemployed	1.4	0.0	0.8
	Soldier	0.0	0.3	0.1
Education	Below high school	3.6	2.7	3.2
	High school	21.7	19.3	20.7
	Bachelor's degree	41.3	45.9	43.2
	Master's degree	6.3	6.6	6.5
	Doctor's degree	1.4	1.7	1.5
	Others	25.7	23.9	25.0
Marital Status	Single	26.2	35.9	30.1
	Married	70.7	60.8	66.7
	Other	3.2	3.3	3.2
Household-Level Attributes				
Composition	Members ≥ 3	92.6	91.4	92.1
	Have members age < 18	58.0	55.5	57.0
	Have members age > 65	42.7	45.9	44.0
Income (RMB)	Under ¥50,000	4.3	5.7	4.8
	¥50,000 to ¥150,000	28.7	26.6	27.8
	¥150,000 to ¥250,000	29.6	30.6	30.0
	¥250,000 to ¥350,000	21.9	16.9	19.9
	¥350,000 to ¥500,000	8.4	8.6	8.5
	More than ¥500,000	7.2	11.6	9.0
Car ownership	None	23.3	25.9	24.3
	One	54.2	48.5	51.9
	Two	19.6	21.3	20.3
	Three or more	2.9	4.3	3.5

*Note: RMB ¥665 = US$100.

$$N_{\text{dec-per-week}} = m_{\text{car}} - \frac{m_{\text{car}} + m_{\text{public}} + m_{\text{non-motorized}}}{\bar{n}} \quad (3)$$

where $N_{\text{dec-per-week}}$ means the changed number of vehicles on road per week influenced by one respondent. m_{car} is the changed amount of car usage per week, m_{public} is the changed amount of public transit usage per week, and $m_{\text{non-motorized}}$ is the changed amount of non-motorized travels per week. $\bar{n}$ means that one shared trip can satisfy $\bar{n}$ ridesplitting orders or trip segments, and can be calculated by Eq. (4) using the order dataset, given by

$$\bar{n} = \frac{\sum_{i}^{I} n_i}{I} \quad (4)$$

Based on the calculation results from the questionnaire data, the changed number of vehicles on road per day due to ridesplitting's influence in the intermediate term can be calculated by

$$N_{\text{intermediate-term}} = \frac{N_{\text{dec-per-week}}}{7} \cdot P \quad (5)$$

where $N_{\text{intermediate-term}}$ is the decreased number of vehicle usage per day due to ridesplitting's influence in the intermediate term, P is the average daily amount of ridesplitting passengers.

In the long term, it is obvious that ridesplitting may have an influence on the willingness to purchase a car. The impact on the respondents investigated is easy to be quantified using the survey data, which reveal the willingness to purchase a car and whether the willingness changes due to the emerging ridesplitting services.

If there are no ridesplitting services, then the vehicle purchase willingness of the respondents investigated can be calculated by Eq. (6). If the ridesplitting services are available, then the vehicle purchase willingness of the respondents investigated is calculated by Eq. (7).

$$\eta = \frac{c_{\text{plan}}}{\Theta} \times 100\% \quad (6)$$

$$\eta' = \frac{c_{\text{plan}} + c_{\text{add}} - c_{\text{dec}} - \lambda \cdot c_{\text{postpone}}}{\Theta} \times 100\% \quad (7)$$

where η and η' are the vehicle purchase willingness of the respondents investigated with and without ridesplitting services, respectively, Θ is the number of the group investigated, c_{plan} is the number of people who plan to purchase a car before the emergence of

Table 3. Impacts of ridesplitting services on multimodal mobility.

Daily Change	Hitch		Express Ridesplitting		Sum	
Private Car	**Count**	**%**	**Count**	**%**	**Count**	**%**
Almost unchanged	26	7.7	13	5.8	39	6.9
Reduce 3 times or more	82	24.1	71	31.8	153	27.1
Reduce 1–2 times	222	65.3	134	60.1	356	63.3
Increase 1–2 times	10	2.9	4	1.8	14	2.5
Increase 3 times or more	0	0.0	1	0.5	1	0.2
Sum	340	100	223	100	563	100
Bus						
Almost unchanged	267	60.3	183	60.8	450	60.5
Reduce 3 times or more	60	13.5	39	13.0	99	13.3
Reduce 1–2 times	108	24.3	70	23.3	178	23.9
Increase 1–2 times	6	1.4	5	1.6	11	1.5
Increase 3 times or more	2	0.5	4	1.3	6	0.8
Metro						
Almost unchanged	333	75.2	232	77.1	565	76.0
Reduce 3 times or more	44	10.0	29	9.6	73	9.8
Reduce 1–2 times	58	13.0	28	9.3	86	11.5
Increase 1–2 times	8	1.8	8	2.7	16	2.2
Increase 3 times or more	0	0.0	4	1.3	4	0.5
Taxi						
Almost unchanged	247	55.8	156	51.8	403	54.2
Reduce 3 times or more	103	23.2	66	21.9	169	22.7
Reduce 1–2 times	81	18.3	66	21.9	147	19.8
Increase 1–2 times	10	2.3	6	2.0	16	2.1
Increase 3 times or more	2	0.4	7	2.3	9	1.2
Free-floating bike sharing						
Almost unchanged	326	73.6	237	78.7	563	75.7
Reduce 3 times or more	36	8.1	31	10.3	67	9.0
Reduce 1–2 times	45	10.2	24	8.0	69	9.3
Increase 1–2 times	28	6.3	29	9.6	57	7.6
Increase 3 times or more	8	1.8	10	3.4	18	2.4
Public bike sharing						
Almost unchanged	321	72.5	223	74.1	544	73.1
Reduce 3 times or more	45	10.2	26	8.7	71	9.6
Reduce 1–2 times	60	13.5	33	10.9	93	12.5
Increase 1–2 times	13	2.9	11	3.6	24	3.2
Increase 3 times or more	4	0.9	8	2.7	12	1.6
Sum	443	100	301	100	744	100

ridesplitting services, c_{add}, c_{dec}, and $c_{postpone}$ are the numbers of people who have added, decreased, and postponed purchasing cars after the emergence of ridesplitting services, respectively. In the calculation, it is obvious that postponing the car purchase is not equal to cancel, and there is a complex set of reasons that could affect the future purchase of cars by people who postpone their purchase plans. As a result, the effect of postponing should be multiplied by a discount multiplier, which should be set between 0 and 1. The sensitivity analysis of λ will be presented in Section V.C.

V. Results

In the short term, the impact on vehicle use can be calculated mainly by the current ridesourcing order data. With the development of ridesplitting, passengers' travel habits change gradually. Therefore, the impact in the intermediate term should be counted by travel habits data obtained from the survey. Finally, we use the purchase willingness to evaluate the impact on vehicle purchase willingness in the long term.

A. Short-Term Impact on Vehicle Usage

Researchers calculate the decreased number of vehicles on road for the reason of ridesplitting. If the modal shift from public transportation is not considered, the amount of declined road vehicle usage is 52,731 veh/day due to ridesplitting, among which 2,588 veh/day are for Hitch, and 50,143 veh/day are for Express ridesplitting.

As aforementioned, the modal shift from public transportation to ridesplitting will have a negative effect on the decreasing number of vehicles on road. Therefore, we count the percentage of replaced modes (i.e., bus, metro, taxi, Express, DiDi Private Car, electric bicycle, and public bike sharing). Among them, researchers categorize the bus, metro, electric bicycle, and public bike sharing as public transportation. Then we distinguish Hitch from Express ridesplitting, and the results are shown in Fig. 8.

According to the questionnaire data, the percentage of public transportation in the replacement mobility modes if there is no Hitch or Express ridesplitting is 57.3% and 51.9%, respectively. Considering the modal shift from public transportation, Hitch decreases the number of road vehicle usage by 1,105 veh/day, and Express ridesplitting decrease the number of road vehicle usage by 1,946 veh/day. In summary, we estimate that ridesplitting can decrease the number of road vehicle usage by 3,051 veh/day (nearly 2.6% of vehicle ownership in the urban area of Hangzhou, which decreases VKT by 18,611.1 km per day in Hangzhou).

Fig. 9 shows the trend of the decreased number of vehicles on road considering the modal shift from public transportation. During the morning and evening peaks, the reduced amount is obviously larger than the daily average. In the midnight and early morning (0–6 AM), ridesplitting rarely influences the number of vehicles on road, which indicates that the degree of influence is related to the current travel demand.

B. Intermediate-Term Impact on Vehicle Usage

Using the data in Table 2, researchers can calculate the saved number of vehicles on road per day induced by ridesplitting. At first, the number $\bar{n}$ of ridesplitting orders

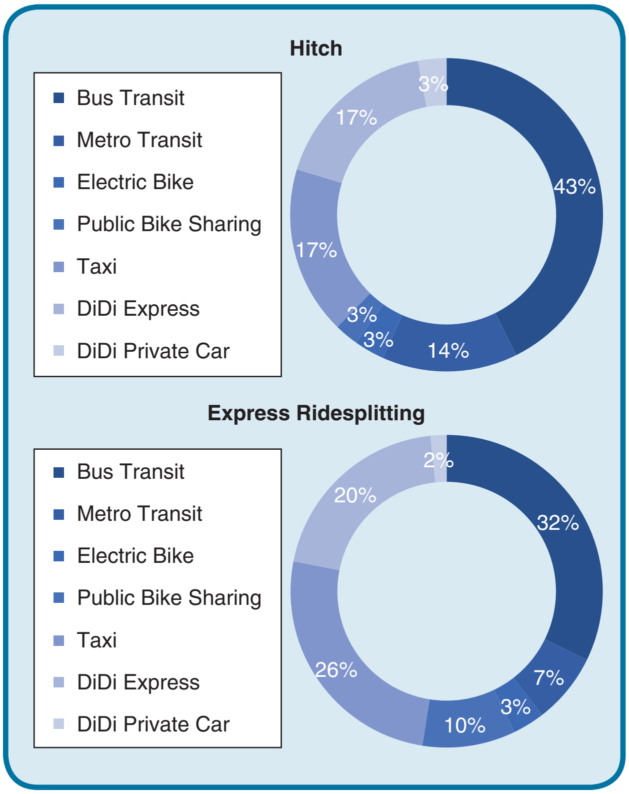

FIG 8 Stated preference of mode choice without ridesplitting services.

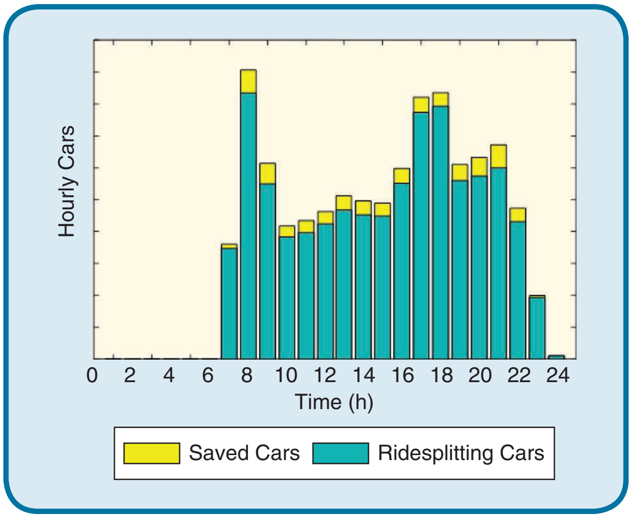

FIG 9 Temporal distributions of the decreased number of vehicles on road in short term (anonymized).

or trip segments that can be satisfied in one shared trip should be calculated using order dataset. The result shows that $\bar{n}$ equals 2.2 orders per shared trip. Given all the information above, we can calculate the intermediate-term impact on the vehicle usage, and the results are summarized as follows:

1) Individual Ridesplitting Users

The frequency of car usage decreases by 2.6 veh/week and 2.7 veh/week for each Hitch user and Express ridesplitting user, respectively. The frequency of public transportation usage decreases by 1.8 usage/week for each Express ridesplitting user. Taking the two aspects of impacts into account, researchers conclude that if the ridesplitting users' habit is formed, the number of vehicles on road decreases by 2.6 veh/week, and 0.7 veh/week for each Hitch user and Express ridesplitting user, respectively.

2) Whole Transportation System

Given the daily amount of ridesplitting passengers as 2,332 and 32,626 for Hitch and Express ridesplitting, respectively, from the real-world order data, researchers conclude that the number of vehicles on road usage will decrease by 866 veh/day and 3,263 veh/day for all Hitch users and Express ridesplitting users, respectively. The total decreased number of road vehicle usage is 4,129 veh/day in Hangzhou (nearly 3.6‰ of the vehicle ownership in the urban area of Hangzhou, which decreases VKT by 25,186.9 km per day in Hangzhou). It is obvious that the result considering the change in travel habits is quite different from the short-term impact in Section V.A.

What draws the researchers' attention is the interesting results that the influence of Hitch on the vehicle usage in the intermediate term is 866 veh/day, which is not as obvious as the influence in short term. The reason can be inferred as follows: flexibility and high customization makes ridesplitting popular, but this kind of characteristics may make the on-demand ride service platform cannot afford the increasing demand of ridesplitting services, especially for Hitch, which is usually unavailable due to the commuting time and destination limitations. As a result, some of the Hitch passengers attracted from public transit will choose to travel by DiDi Express or private cars rather than public transit if they find Hitch is not available during their trips, which is a negative impact on vehicle usage.

However, the overall impact of ridesplitting on the vehicle usage in the intermediate term is more significant than that of the short term. The reason for this phenomenon can be speculated as follows: Compared with Hitch, Express ridesplitting is usually more convenient and timely for passengers in most time periods. As a result, most of the passengers attracted from driving a private car by Express ridesplitting eventually travel by Express ridesplitting. Moreover, because of the larger group of DiDi Express passengers, the impact of ridesplitting becomes increasingly evident, and the influence on the road vehicle usage will continue to increase with the formation of passengers' habits in using ridesplitting services.

C. Long-Term Impact on Vehicle Purchase Willingness

In the short term and intermediate term, ridesplitting can reduce the vehicle use directly and influence travel habits of passengers. While for the long term, ridesplitting influences the purchase habits, which may be postponed or canceled. This kind of influence is not easy to be quantitatively assessed, so only the change of ridesplitting users' purchase habits is considered in this paper. Table 4 shows the results of the survey. Nearly 24.3% of the ridesplitting participants did not have cars in their households, and most of them (61.3%) had plans to purchase cars before they chose ridesplitting. The emergence of ridesplitting provides participants with an option which is as convenient and comfortable as private cars, so they postponed (22.5%) or canceled (3.6%) the purchase plan. It also shows that nearly three quarters of the participants have one or more cars in their households, who use ridesplitting as a substitute for private cars. 56.8% of these participants would like to purchase a new car before the emergence of ridesplitting, while, after using ridesplitting, 21.3% postponed the car purchase plan, and 1.6% of them even canceled.

The comparison of the participants with and without car purchase plans shows that ridesplitting can help reduce the purchase willingness, and the influence on participants without cars is larger than the participants who already

Table 4. Willingness to purchase a car before and after the emergence of ridesplitting.

		Household Car(s)				
Before	After	None	One	Two	Three or More	Sum
With car purchase plan	No impact	82	165	76	6	329
	Postpone purchase	25	45	14	9	93
	Cancellation	4	2	2	1	9
Without car purchase plan	No impact	52	119	37	7	215
	Increase willingness	6	14	5	0	25
Other*		12	41	17	3	73
Sum		181	386	151	26	744

*The majority of responses in the "Other" category include replacing older cars with new ones or selling existing cars for car owners/households, and other unknown reasons for non-car owners/households.

While the survey was conducted in Hangzhou, ridesplitting services users in Hangzhou have different socio-demographic characteristics from users in other cities. As such, the results of this paper cannot represent the overall impact of ridesplitting in all cities.

have a household car(s). There are various impacts for the different household car(s), the percentages of postponing purchase in non-car households (22.5%), one-car households (21.2%), and two-car households (15.2%) show that ridesplitting passengers with fewer cars are more impressionable for ridesplitting. For the participants without any car purchase plans, ridesplitting may also increase their willingness to purchase a car. The percentages are only 10% for non-car households, one-car households, and two-car households, respectively.

If there are no ridesplitting services, the vehicle purchase willingness of the respondents investigated is 57.9%. If the ridesplitting services are available, the vehicle purchase willingness can be calculated as Fig. 10 based on different values of λ, i.e., postponing's discount multiplier. When λ equals 0.5, the vehicle purchase willingness of the respondents investigated is 53.8%, which means that the vehicle purchase willingness of the group investigated is decreased by 4.1% compared with the vehicle purchase willingness if there are no ridesplitting services. Fig. 10 shows that the vehicle purchase willingness with ridesplitting services are always smaller than the vehicle purchase willingness without ridesplitting services, when λ ranges between 0.2 and 0.8. The numerical results shine some light and indicate that ridesplitting can effectively reduce the vehicle purchase willingness.

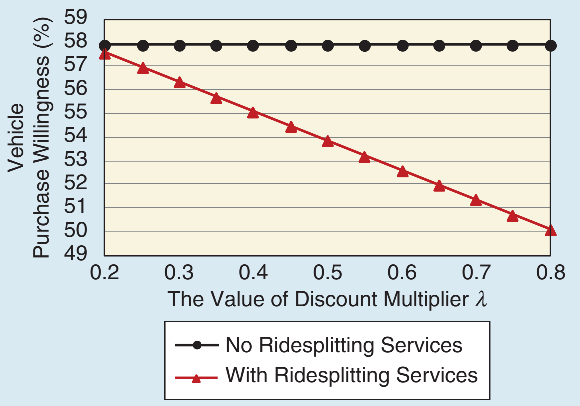

FIG 10 Sensitivity analysis of postponing's discount multiplier λ.

VI. Conclusions

Based on the real-world ridesourcing order data in Hangzhou and questionnaire data collected from ridesplitting users via an online survey, this paper explores ridesplitting users' travel habits and their transportation modal shift behavior if the ridesplitting services are unavailable, and how ridesplitting impacts the vehicle use and purchase willingness.

At present, considering the modal shift from public transportation and non-motorized travels, DiDi Hitch decreases the number of road vehicle usage by 1,105 veh/day, and Express ridesplitting decreases the number of road vehicle usage by 1,946 veh/day in Hangzhou. As a result, ridesplitting can decrease the number of the vehicle usage by 3,051 veh/day (nearly 2.6‰ of vehicle ownership in the urban area of Hangzhou).

With the development of ridesplitting, more and more passengers will be attracted from using private cars or non-motorized travels, and their travel habits gradually form, so the total number of vehicle use for the intermediate term will decrease by 4,129 veh/day in Hangzhou (nearly 3.6‰ of vehicle ownership in the urban area of Hangzhou), which causes a great improvement compared with the current situation.

In the long term, ridesplitting will influence people's travel habits and reduce people's car purchase willingness. Using TNC operational data and user survey data, this paper provides evidence that ridesplitting can efficiently decrease the number of vehicle use for different stages, and reduce the vehicle purchase willingness.

While the survey was conducted in Hangzhou, ridesplitting services users in Hangzhou have different socio-demographic characteristics from users in other cities. As such, the results of this paper cannot represent the overall impact of ridesplitting in all cities. The results still represent a good starting point for deeper and wider analyses of the ridesplitting's impacts on urban multimodal transportation systems. The future work can concentrate on more detailed traveler behavior influenced by ridesplitting, and the ridesplitting's impacts on drivers.

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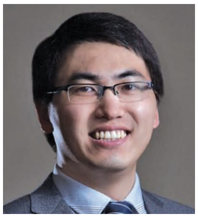

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References

[1] S. Shaheen, A. Cohen, and I. Zohdy, "Shared mobility: Current practices and guiding principles," Tech. Rep., 2016.

[2] E. Marcucci, M. L Pira, C. S. Carrocci, V. Gatta, and E. Pieralice, "Connected shared mobility for passengers and freight: Investigating the potential of crowdshipping in urban areas," in *Proc. 5th IEEE Int. Conf. Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, 2017, pp. 839–843.

[3] J. Bai, K. C. So, C. S. Tang, X. M. Chen, and H. Wang, "Coordinating supply and demand on an on-demand platform: Price, wage, and payout ratio," *Manuf. Serv. Oper. Manage.*, 2016.

[4] L. Yin, Y. Jingpei, and D. Lixue, "Hangzhou built an electronic medical record for 1.12 million cars." Accessed on: 2017. [Online]. Available: www.hzzx.gov.cn/cshz/content/2017-07/06/content_6596426.htm

[5] X. M. Chen, S. Zhang, and M. Zahiri, "Cellular signaling data driven simulation-based dynamic traffic assignment and its applications to a real-world road network," in *Proc. 2016 IEEE 19th Int. Conf. Intelligent Transportation Systems (ITSC)*, pp. 2083–2088.

[6] R. Wu and C. Wang, "Government authorized a third party to build carpool service system." Accessed on: 2013. [Online]. Available: www.shcti.cn/cc/vxhhk.jsp

[7] D. Z. Paul Gao, S. Sha and W. Baan, "Finding the fast lane: Emerging trends in China's auto market." Accessed on: 2016. [Online]. Available: www.mckinsey.com/industries/automotive-and-assembly/our-insights

[8] J. Ke, H. Zheng, H. Yang, and X. M. Chen, "Short-term forecasting of passenger demand under on-demand ride services: A spatio-temporal deep learning approach," *Trans. Res. C*, vol. 85, pp. 591–608, 2017.

[9] X. M. Chen, X. Chen, H. Zheng, and C. Chen, "Understanding network travel time reliability with on-demand ride service data," *Frontiers Eng. Manage.*, vol. 4, no. 4, pp. 388–398, 2017.

[10] S. Shaheen and N. Chan, "Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections," *Built Environ.*, vol. 42, no. 4, pp. 573–588, 2016.

[11] L. Rayle, D. Dai, N. Chan, R. Cervero, and S. Shaheen, "Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco," *Trans. Policy*, vol. 45, pp. 168–178, 2016.

[12] X. M. Chen, M. Zahiri, and S. Zhang, "Understanding ridesplitting behavior of on-demand ride services: An ensemble learning approach," *Trans. Res. C*, vol. 76, pp. 51–70, 2017.

[13] L. Rayle, S. Shaheen, N. Chan, D. Dai, and R. Cervero, "App-based, on-demand ride services: Comparing taxi and ridesourcing trips and user characteristics in San Francisco," Tech. Rep. UCTC-FR-2014-08, 2014.

[14] L. Zha, Y. Yin, and H. Yang, "Economic analysis of ride-sourcing markets," *Trans. Res. C*, vol. 71, pp. 249–266, 2016.

[15] J. Pfrommer, J. Warrington, G. Schildbach, and M. Morari, "Dynamic vehicle redistribution and online price incentives in shared mobility systems," *IEEE Trans. Intell. Transp. Syst.*, vol. 15, no. 4, pp. 1567–1578, 2014.

[16] N. D. Chan and S. A. Shaheen, "Ridesharing in North America: Past, present, and future," *Transp. Rev.*, vol. 32, no. 1, pp. 93–112, 2012.

[17] V. Handke and H. Jonuschat, *Flexible Ridesharing: New Opportunities and Service Concepts for Sustainable Mobility.* New York: Springer, 2012.

[18] S. Shaheen, "Carlink: A smart carsharing system," *J. World Transport Policy Practice*, vol. 5, no. 3, pp. 121–128, 1999.

[19] E. W. Martin and S. A. Shaheen, "Greenhouse gas emission impacts of carsharing in North America," *IEEE Trans. Intell. Transp. Syst.*, vol. 12, no. 4, pp. 1074–1086, 2011.

[20] J. B. Greenblatt and S. Shaheen, "Automated vehicles, on-demand mobility, and environmental impacts," *Current Sustain./Renewable Energy Rep.*, vol. 2, no. 3, pp. 74–81, 2015.

[21] S. Seyedabrishami, A. Mamdoohi, A. Barzegar, and S. Hasanpour, "Impact of carpooling on fuel saving in urban transportation: Case study of Tehran," *Proc.-Social Behav. Sci.*, vol. 54, pp. 323–331, 2012.

[22] B. Cici, A. Markopoulou, E. Frias-Martinez, and N. Laoutaris, "Assessing the potential of ride-sharing using mobile and social data: A tale of four cities," in *Proc. 2014 ACM Int. Joint Conf. Pervasive and Ubiquitous Computing*, pp. 201–211.

[23] L. P. Alexander and M. C. González, "Assessing the impact of real-time ridesharing on urban traffic using mobile phone data," *Proc. UrbComp*, 2015, pp. 1–9.

[24] R. R. Grino and W. Recker, "Modeling shared-use urban mobility systems to increase system performance," Ph.D. dissertation, Univ. California, Irvine, CA, 2015.

[25] R. Cervero, A. Golub, and B. Nee, "City carshare: Longer-term travel demand and car ownership impacts," *Transp. Res. Rec.*, no. 1992, pp. 70–80, 2007.

[26] S. A. Shaheen, M. A. Mallery, and K. J. Kingsley, "Personal vehicle sharing services in North America," *Res. Transp. Bus. Manage.*, vol. 3, pp. 71–81, 2012.

[27] D. Chuxing, "DiDi completed 7.43 billion rides in 2017." Accessed on: 2018. [Online]. Available: www.didichuxing.com/en/press-news/9tpnya3z.html

[28] C. Custer, "DiDi kuaidi partners with Lyft and invests 100m to take on Uber." Accessed on: 2015. [Online]. Available: www.techinasia.com/didi-kuaidi-partners-lyft-uber

[29] S. A. Shaheen, N. D. Chan, and T. Gaynor, "Casual carpooling in the San Francisco bay area: Understanding user characteristics, behaviors, and motivations," *Transport Policy*, vol. 51, pp. 165–173, 2016.

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