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Exploring impacts of on-demand ridesplitting on mobility via real-world ridesourcing data and questionnaires

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Abstract

On-demand ridesplitting is a form of ridesourcing where riders with similar origins and destinations are matched to the same driver and vehicle in real time, and the ride and costs are split among users. With the convenience of all kinds of ridesourcing services, the number of ridesplitting passengers increases, which may have a great impact on the urban mobility. In this paper, we analyze ridesplitting behavior and its impact on multimodal mobility, e.g., vehicle kilometers traveled (VKT) and transportation modal shift, using real-world ridesourcing data extracted from an on-demand ride service platform in Hangzhou, China, and questionnaires filled by on-demand ridesplitting passengers. With the consideration of the VKT shifted from non-passenger/private vehicles, this paper uses the saved VKT of two ridesplitting types, e.g., DiDi Hitch and DiDi Express ridesplitting, to quantify the ridesplitting impact. For the whole ridesourcing ecosystem, ridesplitting is estimated to decrease 58,124 VKT per day in Hangzhou, of which Hitch and Express ridesplitting contribute 2175 km and 55,949 km per day, respectively. The saved VKT of Hitch is much smaller than Express ridesplitting for the following two reasons: (1) Hitch orders are fewer than Express ridesplitting; (2) more than half of the Hitch passengers shift modes from bus/metro transit or other non-passenger/private cars. This paper shines some lights on understanding the emerging on-demand ridesplitting behavior and quantifying its impact on multimodal urban mobility.

Keywords Shared mobility · Ridesplitting · On-demand ride service · Multimodal mobility · Vehicle kilometers traveled (VKT)

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Introduction

Private cars and taxis make urban mobility more convenient due to the flexibility, celerity, comfort, etc. Nevertheless, the rapid development of private cars and taxis has also brought a lot of negative issues. Private cars can only be used within the range of families, and taxis sweep around 24 h a day inefficiently searching for passengers in some time and usually only serve one passenger during one journey. As a result, the empty seat rate of private cars and taxis is high in most time periods, which may result in a serious waste of human and vehicle resources and induce traffic congestion and air pollution.

Nowadays, many cities have adopted rationing policies that private cars with odd or even number plates could only be used on the corresponding days (e.g., Beijing, Hangzhou). The policies help decrease the number of cars on the road network. But for the travelers who are used to driving, they may be not easy to change travel modes. In such circumstances, the car's utilization rate almost remains unchanged. The emerging shared mobility may solve the problem in a different way.

Shared mobility enables users to obtain short-term access to transportation systems as needed, rather than requiring ownership, including carsharing, ridesharing, carpooling, vanpooling, ridesourcing (e.g., Uber, Lyft, and DiDi), and ridesplitting (e.g., UberPOOL, Lyft Line, and DiDi Hitch). In order to clearly distinguish several related terminologies, we summarize the definitions as follows:

- *Carsharing* is the service mode that individuals gain the benefits of private-vehicle use without the costs and responsibilities of ownership. Typically, the carsharing operator provides gasoline, parking, and maintenance. Generally, participants pay a fee each time they use a shared car (Shaheen et al. 2006).
- *Ridesharing* facilitates formal or informal shared rides between drivers and passengers with similar origin–destination pairs (Chan and Shaheen 2012).
- *Carpooling* is an informal form of ad hoc ridesharing. It involves the formation of impromptu carpools of typically three or more commuters per vehicle: one driver and two or more passengers (Chan and Shaheen 2012).
- *Vanpooling* consists of 7–15 passengers who share the cost of the van and operating expenses and may share the responsibility of driving (Chan and Shaheen 2012).
- *Ridesourcing services* (also known as transportation network companies, or TNCs) provide prearranged and on-demand transportation services for compensation, which connect drivers of personal vehicles with passengers. Smartphone applications are used for booking, ratings (for both drivers and passengers), and electronic payment (Rayle et al. 2016).
- *Ridesplitting* involves a person sharing a vehicle and splitting the cost of a ride acquired through a ridesourcing service with someone else taking a similar route (Cohen and Shaheen 2018). It charges less than regular ridesourcing services and allows for dynamic changing of routes as passengers' request in real time. Examples include GrabHitch, uberPOOL, Lyft Line, and Didi Ridesplitting (Stocker and Shaheen 2017).

Recently, with the development of communication technologies, e-hailing taxi services based on the on-demand platform have entered people's field of vision, and gradually trained travelers to make a pre-trip ride appointment on the platform. On-demand ridesourcing provides support for vehicle scheduling through optimization methods, thus it is more efficient and informative than the traditional ridesplitting pattern which is matched by hailing or waiting at a special location. Ridesplitting may attract passengers from all kinds of transportation modes like bus transit, metro transit, taxi, electric bike, public bike sharing. People may consider the VKT ridesplitting saved may be less than the VKT caused by attracting passengers from public transit and/or non-passenger/private vehicles.

Thus, a question naturally arises: *Whether the VKT ridesplitting saves can fill the VKT caused by attracting passengers from public transit and/or non-passenger/private vehicles?*

This paper focuses on exploring real-world on-demand ridesplitting behavior and its impact on multimodal urban mobility, especially on public transit. To the best of the authors' knowledge, this paper belongs to one of the first attempts to reveal the ridesplitting behavior characteristics and impacts of the emerging on-demand ride services based on real-world city-wide mobility data. We propose the methodology of estimating the savings in vehicle kilometers traveled (VKT) induced by ridesplitting services completed on the on-demand ride service platform. The real-world ridesourcing data and questionnaires completed by ridesplitting passengers are used in a case study. We separate ridesplitting trips into two services types, i.e., Hitch and Express ridesplitting, to present the difference. Take the ridesplitting services provided by DiDi Chuxing as an example, the differences between Express ridesplitting and Hitch are summarized in Table 1.

The rest of this paper is organized as follows. "Literature review" section briefly reviews the related ridesplitting studies. "Data" section describes the data used in this paper including ridesourcing data from DiDi Chuxing and questionnaire data from the ridesplitting behavior survey, which is also completed by the platform. "Methodology" section proposes the methodology to explore on-demand ridesplitting behavior and its impact on urban mobility. "Results" section presents the results of the saved VKT and findings from the ridesplitting impact survey. Finally, "Conclusions" section concludes this paper and outlooks on future research.

Literature review

Ridesplitting is not only popular in China, but also universal in many other countries all over the world. In 2015, there were around 500,000 taxi drivers and chauffeurs in the US according to the tabulation of the Current Population Survey, and Uber and Lyft combined

Table 1 Comparison the operation modes DiDi Express ridesplitting and Hitch

Feature	Express ridesplitting	Hitch
Business philosophy	Quick and comfort	Sharing and environmental protection
Service	Profession	Amateur
Operating mode	On-demand	Pre-order
Price	Short distance with discount	Long distance with low price
Dynamic pricing	Yes	No
Speed of orders strived	Quick	Not sure
Operating purpose	Profit	Reduce travel expenses
Ride-sharing license	Need	No need
Driver type	Part-time and full-time	Part-time
Inter-city service	No	Yes

had nearly 500,000 active drivers (Cramer and Krueger 2016). This provision takes care of the benefit of all parties and saves public resources as well.

One of the shared mobility services named carsharing began appearing known as Sefage in Europe, and had developed for approximately 70 years and expanded to 27 nations on five continents (Shaheen and Cohen 2008; Shaheen et al. 2015a, b). Sefage was primarily motivated by economics and had been widely used by the people who couldn't afford to buy a car. Gradually, shared mobility had become more mainstream, and expanded into other places (Shaheen and Cohen 2007). Users tend to be young, well-educated, higher-income, employed, and residing in higher density neighborhoods (Dias et al. 2017). Gender, work schedule, and matching programs were also found to have strong effects on shared mobility (Neoh et al. 2017). Shared mobility has been widely discussed since the appearance, especially the influences on transportation systems, as well as the environmental, land use, and social effects (Katzev 1999; Shaheen et al. 2003, 2004). While the impacts on roundtrip carsharing are fairly extensive, the impacts of the newer service modes of ridesourcing and ridesplitting are not fully studied or understood. This paper summarizes the impacts of share mobility on a few typical aspects as follows:

(1) *Reduction in the vehicle ownership* Ryden and Morin (2005) reported carsharing reduced the need for different private cars in Europe, North America, and Australia. Some people chose to join the carsharing program and sold their vehicles in Europe (Shaheen et al. 2003; Shaheen and Cohen 2008; Ryden and Morin 2005). Ridesplitting also influenced the purchase of new vehicles. Katzev (1999) and Lane (2005) revealed that the influence on delaying or canceling a vehicle purchase was lower in Europe than in the US. Feigon and Murphy (2016) showed these sharers had a tendency to own fewer cars and blended different modes to meet their needs.

(2) *Reduction in VKT* Carsharing can recruit passengers who would drive to work rather than commute via public transit (Shaheen et al. 2004). Shaheen et al. (2000) did a carsharing test, and the results showed that VKT could be reduced by approximately 18.6 km per day. Lane (2005) reported the average monthly VMT (vehicle miles traveled) increase of members gaining access to a car was limited to 29.9 miles, whereas the monthly VMT decrease of members who gave up a car appeared to be several hundreds of miles. Other related studies also used VKT to quantify the transportation impacts, ranging between 28 and 45% in Europe (Katzev 2003; Shaheen et al. 2003; Ryden and Morin 2005), and between 7.6 and 80% in North America (Shaheen et al. 2004; Shaheen and Cohen 2008; Cooper et al. 2000). Compared with the traditional taxi, Anderson (2014) paid attention to these different services whether they had the potential to increase or decrease overall VMT.

(3) *Reduction in greenhouse gas (GHG) emissions* Ryden and Morin (2005) reported that carsharing reduced carbon dioxide emissions from 39 to 54%. Martin et al. (2010) and Martin and Shaheen (2011) conducted a survey of 2088 carsharing respondents, and revealed an average emission reduction for all respondents of 0.58 t of GHG emissions per household per year for the observed impact, and a reduction of 0.84 t over the same period for the full impact. Caulfield (2009) demonstrated the benefits of ride-sharing and the potential for reducing CO2 emissions.

(4) *Increase of the vehicle occupancy rate* Urban taxis operated with low occupancy rates during off-peak hours in different cities, e.g., about 50% in Beijing, 48% in Shanghai, and 49% in Shenyang, China (Che 2008). Conversely, during peak hours or under the conditions such as holidays and bad weather, the taxi demand outstrips supply, and

passengers need to search for a long time and wait for taxis that are usually occupied by 1–2 travelers. As found in a survey conducted in Harbin, China, 58% of the passing taxis had only one passenger, 23% had two passengers, and only 19% of the vehicles had more than three passengers, the average occupancy rate was only 1.61 passengers per vehicle (Yu 2015). The occupancy levels for ridesourcing vehicles averaged 1.8 passengers in contrast to 1.1 passengers for taxis in the matched pair analysis (Rayle et al. 2014).

Other benefits mentioned in the related studies also included the reduction of parking (Shaheen et al. 2015a, b, Henao 2017), user characteristics, behavior, and motivations (Shaheen et al. 2016). Ridesourcing wait times tended to be substantially shorter than taxi hailing and dispatching wait times (Rayle et al. 2014). Ridesourcing also has the positive impact of complementing public transit during late night hours and first/last-mile services (Jin et al. 2018; McCoy et al. 2018). It has been proven to be an effective supplement to traditional taxi service, which regulates spatial and temporal supply–demand imbalance during morning and evening rush periods (Dong et al. 2018). The testing "smart routes" of ridesplitting allowed drivers to make fewer turns and complete ride requests faster (Shaheen et al. 2015a, b).

These benefits have demonstrated that shared mobility is a flexible alternative that could be used in reducing dependence on private car ownership, lowering vehicle emissions and energy consumption, and encouraging active lifestyles by interfacing with bicycle and pedestrian modes. Please refer to Chan and Shaheen (2012) and Shaheen and Cohen (2013) for the detailed growth process.

The studies related to on-demand ridesourcing were conducted to analyze the impact of the emerging service patterns. Nie (2017) paid attention to examining the impact of ridesourcing on the taxi industry, explored where, when and how taxis could compete more effectively, and expressed the hope for making new policies. The question about how ridesourcing impacted the use of public transit and overall vehicle travel had been discussed, The results concluded that ridesourcing competed with public transit for some individual trips, but it might sometimes serve as a complement, and the impacts on overall VMT were uncertain (Rayle et al. 2016; McCoy et al. 2018). Greenblatt and Shaheen (2015) reviewed the history, current developments, projected future trends and environmental impacts of automated vehicles (AVs) and on-demand mobility, and put forward a combination of the two which might cause the lower energy use and GHG emissions.

However, there are some limitations in the existing studies. Most surveys were conducted in several fixed locations, the representativeness may not be universal. Meanwhile, inactive memberships were not recorded in the survey or other data. Those limitations can be remedied with the multiple-source and big online data. In this paper, researchers use VKT to measure the influence of ridesplitting based on the real-world city-wide data extracted from the on-demand ride service platform of DiDi Chuxing in Hangzhou, China, and questionnaires conducted online through the DiDi survey platform.

Data

This paper focuses on understanding ridesplitting behavior and its impacts on VKT and travelers' modal shift behavior. Two sources of data are collected in Hangzhou, China: (1) Real-world ridesourcing order data extracted from the on-demand ride service platform, DiDi Chuxing; (2) An online survey conducted by investigating ridesourcing customers who have completed their rides and paid the fare via the same on-demand ride service app.

Ridesourcing orders

In this paper, two-week sampling ridesourcing order data (October 24–30, 2016, and March 6–12, 2017) are randomly extracted from DiDi in Hangzhou, China. DiDi is the largest transportation network private-car hailing company in China, and the services it offers can be obtained from mobile phone apps. DiDi primarily provides four main types of ridesourcing services, namely, Express, Taxi, Premier, and Hitch. DiDi Express provides more cost-effective economical rides than DiDi Taxi or traditional taxis, and it provides ridesplitting services as well. DiDi Premier provides more comfortable and high-quality ride services, and it can be divided into two parts, named DiDi Premium and DiDi ACE. DiDi Premium offers comfortable and professional services, while DiDi ACE is a luxury and customized service, provided by chauffeurs with luxury cars. DiDi Hitch matches drivers and passengers who share similar routes (Chen et al. 2017).

The sampling rate of the ridesourcing order data provided by DiDi Chuxing is approximately 50% due to data security. The randomly sampled ridesourcing orders ensure that the dataset has the same time and space attributes as the original data. Each individual order record includes the pickup/drop-off locations and the corresponding time stamps, trip ID, trip segment ID (order ID), driver ID, ride beginning time, ride end time, actual travel distance (measured via the smartphone navigation after the ride), planning travel distance (shown on the travelers' smartphone app before the ride), type of ride services, and whether ridesplitting is matched or not (1 yes; 0 no). The personally identifiable information of each ridesourcing order has been properly anonymized to avoid any privacy issues. The information of longitude and latitude locations is obtained by converting the received GPS data into a planar coordinate system.

Figure 1 presents the temporal distributions of the hourly completed ridesourcing orders (either ridesplitting or non-ridesplitting orders) and the percentage of the

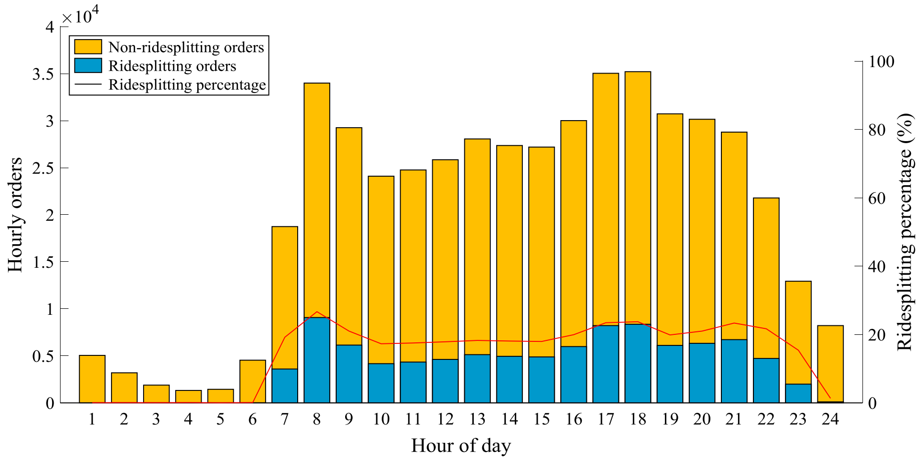

Fig. 1 Temporal distribution of ridesourcing orders

ridesplitting orders. The average daily number of ridesourcing requests is 609,358, among which the number of completed orders is 502,938 (accounting for 82.54% of all ridesourcing requests), while the remaining 106,420 (accounting for 17.46%) requests indicate unmatched or canceled ride orders. The average daily number of successful ridesplitting orders or completed independent ridesplitting orders (including Express ridesplitting and Hitch) is 95,454, i.e., 18.98% of the completed ridesourcing orders. The time-varying percentage of ridesplitting orders indicates that ridesplitting has the same trend as the total ridesourcing orders. In particular, during the AM/PM peaks, the penetration is higher than other time periods, which indicates that passengers are more willing to split rides under the situation of excessive passenger demand or short supply. While during 0-6 AM when ridesplitting is banned according to the regulation of DiDi Express (while Hitch is applicable in the early morning), the ridesplitting penetration falls close to zero.

The daily average spatial distributions for pickup locations of the ridesplitting orders and total ridesourcing orders are shown in Fig. 2. The analogous patterns indicate that ride-splitting orders almost have no spatial difference from non-ridesplitting orders, and they have the similar pickup locations except that the number of ridesplitting orders is relatively small.

This paper focuses on the impacts of ridesplitting. With 50% sampling rate, there are 668,177-row valid ridesplitting data. The first week includes 393,314 rows and the second week contains 274,863 rows. The specific two ridesplitting service types are Hitch and DiDi Express ridesplitting. Distributions of the travel distance and travel time in terms of both ridesplitting types are shown in Fig. 3. Since the Hitch service is usually ordered in advance and Express ridesplitting is randomly matched with en-route trip segments, the travel time and distance that are wasted by the detour of Hitch is much less than Express ridesplitting. The distribution of trip segments in terms of the ridesplitting types are shown in Fig. 4. The trips with two trip segments occupy the most, and the percentage for Hitch to split two rides is 70.88%, which is a little smaller than Express ridesplitting (74.38%), while for the percentage of splitting three rides, Hitch (19.40%) is smaller than Express ridesplitting (24.90%). These four percentages together with the travel time distributions indicate that Express ridesplitting services

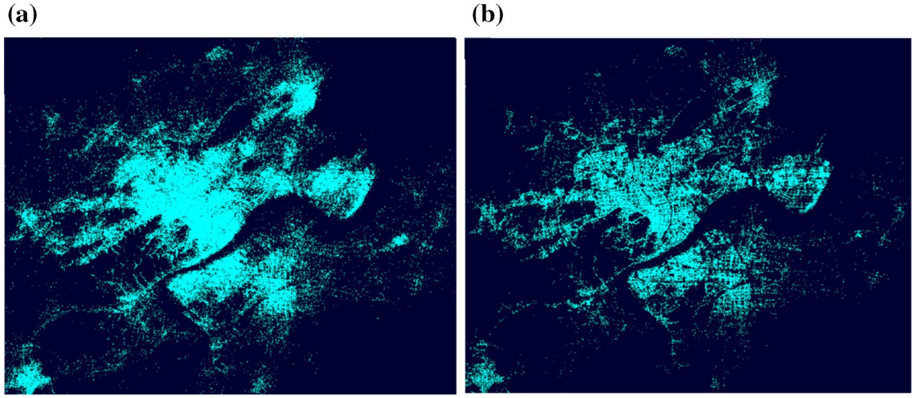

Fig. 2 Spatial distributions of pickup locations via on-demand ride services in Hangzhou, China. **a** All successful ridesouorcing orders. **b** Ridesplitting orders

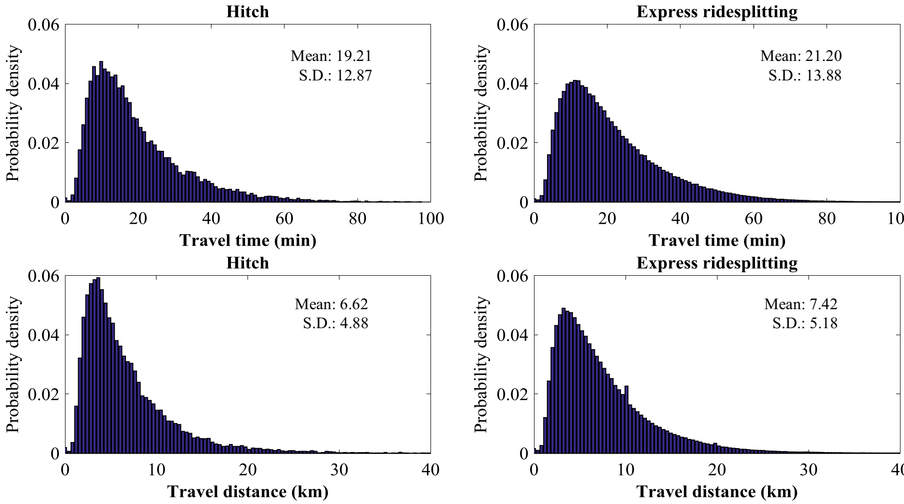

Fig. 3 Distributions of travel distance and travel time in terms of the ridesplitting types

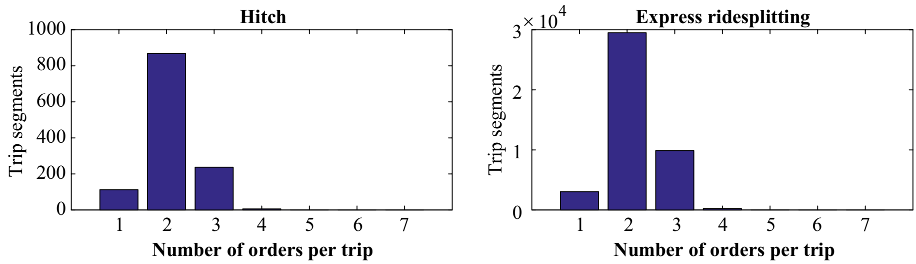

Fig. 4 Distributions of trip segments in terms of the ridesplitting types

waste more time on detouring for passenger pickups than Hitch. As shown in Fig. 3, the average travel distance and travel time of Hitch are similar to Express ridesplitting. Compared with the distributions as reported by Nie (2017), which revealed that the average trip distance of Hitch was more than twice of the Express, we observe that with the wide spreading popularity of ridesplitting, passengers are more accustomed to split rides even in short-distance travels.

Separate analyses of Hitch and Express ridesplitting are important. Different from Express ridesplitting (the drivers of which mainly work in full-time), the Hitch drivers are primarily part-time private car owners, and Hitch drivers would drive to their destinations no matter there are ridesplitting passengers or not. In Figs. 3 and 4, we show the differences between them.

Ridesplitting behavior survey

To explore on-demand ridesplitting behavior and quantify the impacts on urban mobility, the data of multimodal mobility are necessary. However, the data presented in "Ridesourcing orders" section only contain the on-demand ridesourcing data. Hence, we disseminated online questionnaires through the DiDi survey platform when passengers completed their trips in Hangzhou on June 30 and July 4, 2017, respectively, each time issued to people who once used ridesourcing services on the platform. The passengers obtained the chance to respond to the questionnaire once they had just finished a ridesourcing trip and paid the fare via the on-demand ride service platform. Respondents who had filled out the questionnaire could receive a coupon reward provided by DiDi.

The questionnaire is designed for three types of passengers according to their responses. Firstly, the passengers who have used Hitch before are required to answer the Hitch part. Secondly, if the passengers have only used Express ridesplitting before, they will switch to answer the Express ridesplitting part. Thirdly, for the passengers who never choose ridesplitting services, they are directed to answer the remaining part of the questionnaire. The logic diagram shown in Fig. 5 can help collect sufficient investigation data of both Hitch and Express ridesplitting users.

For each part, there are about 30 questions that focus on the impact of ridesplitting on the multimodal mobility of urban transportation systems. The questions include: recall the latest ridesplitting experience, reasons for ridesplitting, destination, travel distance, departure time, frequencies of multimodal mobility (e.g., bike, taxi, and private car), modal shift before the ridesplitting appearance and when ridesplitting services are not available, differences in travel time/fare/distance, willingness to own/purchase private cars, socio-demographic characteristics, etc.

Finally, we collected 962 questionnaires, and the recovery rate was 37.4%. The passengers spent 9.5 min on average completing the online questionnaire. After denoising, the data contain 744 valid questionnaires, including 443 Hitch ones and 301 Express ridesplitting ones. As shown in Table 2, we compare socio-demographic data between the respondents of Hitch and Express ridesplitting. Age 18–40 (79.3%) is the majority ridesplitting users, and enterprise staff occupies almost half of all respondents (46.77%). There are no significant differences between these two types of ridesplitting services. Passengers with CNY 50,000–349,999 household income (77.69%) are more likely to choose ridesplitting. As it shows, not only households without cars prefer ridesplitting, but passengers who own private cars also consider splitting the ride with others (72.18%).

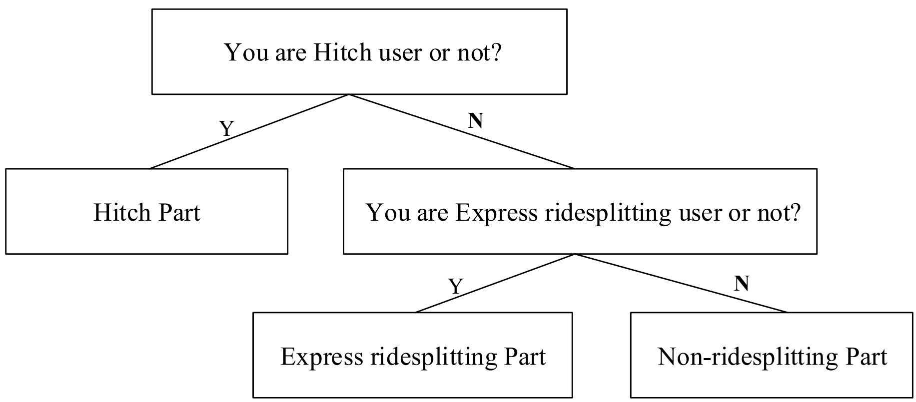

Fig. 5 Logic diagram of the questionnaire design

Table 2 Socio-demographic characteristics

Attribute	Hitch		Express ridesplitting		Sum	
	Count	%	Count	%	Count	%
Gender						
Male	264	59.59	172	57.14	436	58.60
Female	179	40.41	129	42.86	308	41.40
Age						
Under 18	2	0.45	4	1.33	6	0.81
18–30	143	32.28	123	40.86	266	35.75
31–40	205	46.28	119	39.53	324	43.55
41–50	76	17.16	44	14.62	120	16.13
51–60	11	2.48	9	2.99	20	2.69
Under 60	6	1.35	2	0.66	8	1.08
Occupation						
Civil servant	20	4.51	14	4.65	34	4.57
Institution employee	65	14.67	51	16.94	116	15.59
Enterprise staff	216	48.76	132	43.85	348	46.77
Freelancer	74	16.70	57	18.94	131	17.61
Student	19	4.29	19	6.31	38	5.11
Other	43	9.71	27	8.97	70	9.41
Retired or unemployed	6	1.35	0	0	6	0.81
Soldier	0	0	1	0.33	1	0.13
2016 Household income						
Less than 50,000	19	4.29	17	5.65	36	4.84
50,000–149,999	127	28.67	80	26.58	207	27.82
150,000–249,999	131	29.57	92	30.56	223	29.97
250,000–349,999	97	21.90	51	16.94	148	19.89
350,000–499,999	37	8.35	26	8.64	63	8.47
500,000 or more	32	7.22	35	11.63	67	9.01
Number of private cars						
None	103	23.25	78	25.91	181	24.33
One	240	54.18	146	48.50	386	51.88
Two	87	19.64	64	21.26	151	20.30
Three or more	13	2.93	13	4.32	26	3.49
Sum	443	100	301	100	744	100

Methodology

For demonstrative purposes, one particular trip with five ridesplitting trip segments is extracted from the field dataset. As shown in Fig. 6, for instance, there are five overlapped individual trip segments/orders by passengers who have split their rides in the road network of Hangzhou. It is worthy to note that the time stamps and geographical locations of each passenger's pickup/drop-off events have been recorded in the dataset, and the actual travel distance for each ridesplitting trip segment (including the detour distance) is also stored up by the on-demand ride service platform based on the smartphone navigation for every

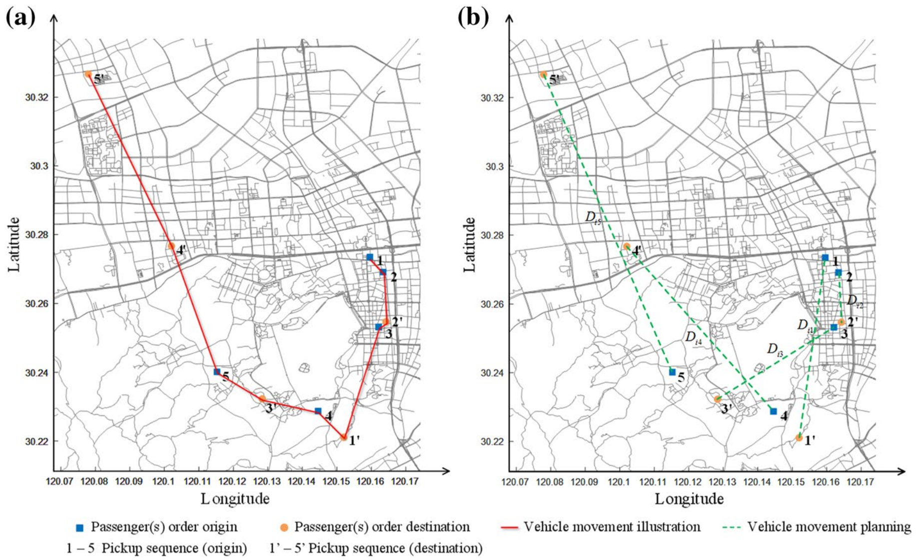

Fig. 6 An illustration of one trip with five ridesplitting trip segments. **a** Movements of one driver trip; **b** Planning non-ridesplitting trip segments

3 s. The vehicle movements (solid lines) and planned movements (dashed lines) are not the actual trajectories of the ridesourcing vehicle, but a simplified illustration of the vehicle movements that clearly present the pickup/drop-off sequence of the five trip segments.

Figure 6a demonstrates the pickup/drop-off locations and vehicle movements of the complete ridesplitting trip, along which we name the vehicle movement from 1 to 1′ as trip segment 1 (the same definition for other trip segments 2 through 5). The blue squares represent the pickup locations, and the orange dots indicate the drop-off locations. Besides, the numbers 1–5 represent the passengers' pickup sequence of the whole trip, and the numbers 1′–5′ represent the passengers' drop-off sequence. When the ridesourcing driver picks up passenger 1 heading for destination 1′, the platform suggests the driver make a detour to pick up passenger 2 who shares the similar route with passenger 1. The driver takes a sequence of suggestions informed by the platform and picks up five ridesplitting passengers for the whole trip. Figure 6b shows the planned trips while the ridesplitting is unavailable or unmatched. Since the on-demand ride service platform provides the ride requesters with both the planned non-ridesplitting travel distance/fare and ridesplitting fare, passengers will choose to send out ride requests of either non-ridesplitting or ridesplitting. Usually, the matched ridesplitting fare will be smaller than the non-ridesplitting fare, but the travel distance of the former choice will be longer due to the detour for picking up other passengers. Comparing Fig. 6a with (b), the total VKT is reduced and traffic congestion can be alleviated by the ridesplitting services.

Inspired by the field observation of the ridesplitting orders in Fig. 6, we define a general scheme of trip i with n_i ridesplitting trip segments (n_i ranges from 1 to 7 in our dataset) in Fig. 7, where i denotes the whole trip numbers, n_i represents the number of trip segments of trip i, $j=1, \ldots, n_i$ and $j' = 1, \ldots, n_i'$ denote the pickup and drop-off location of the jth ridesplitting trip segment, respectively. The actual travel distance of the whole trip i is D_i, while $\tilde{D}_{ij}$ is the planned trip distance for the jth order under the non-ridesplitting condition.

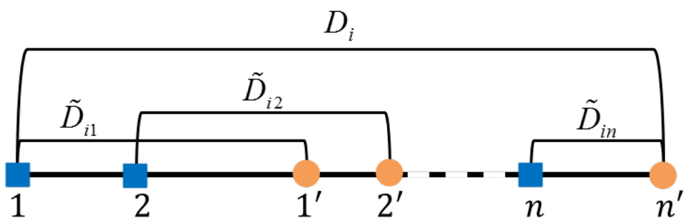

Fig. 7 The *i*th trip with *n* ridesplitting trip segments

However, the value of D_i has not been directly recorded in the dataset, instead, both the actual travel distance D_{ij} and travel time T_{ij} of trip segment *j* in trip *i* have been stored. We calculate the average travel speed in order to estimate the actual travel distance of the whole trip *i* as follows:

$$\bar{v}_{ij} = \frac{D_{ij}}{T_{ij}} \tag{1}$$

$$\omega_{ij} = \frac{D_{ij}}{\sum_{j=1}^{n_i} D_{ij}} \tag{2}$$

$$\bar{v}_i = \sum_{j=1}^{n_i} \omega_{ij} \cdot \bar{v}_{ij} \tag{3}$$

$$D_i = \bar{v}_i \cdot T_i \tag{4}$$

where $\bar{v}_{ij}$ is the observed average speed of ridesplitting trip segment *j*. ω_{ij} is the weight of ridesplitting trip segment *j* along the whole trip *i* and is used to estimate the average speed $\bar{v}_i$ of trip *i*. T_i is the travel time of trip *i* that can be accurately calculated by the time stamp of the picking up the first passenger(s) and dropping off the last passenger(s).

In this paper, the mobility performance is measured by VKT, which consists of two parts, i.e., the Express ridesplitting part and Hitch part. The former can be defined by

$$\text{VKT}_{\text{Express ridesplitting}} = \sum_{i \in \Omega_{\text{Express ridesplitting}}} D_i \tag{5}$$

$$\text{VKT}_{\text{w/o Express ridesplitting}} = r_{\text{Express}} \cdot \sum_{i \in \Omega_{\text{Express ridesplitting}}} \sum_{j=1}^{n_i} \left(\tilde{D}_{ij} + \tilde{D}_{ij,\text{ pickup}} \right) \tag{6}$$

$$\begin{aligned} \text{VKT}_{\text{Express saved}} &= \text{VKT}_{\text{w/o Express ridesplitting}} - \text{VKT}_{\text{Express ridesplitting}} \\ &= r_{\text{Express}} \cdot \sum_{i \in \Omega_{\text{Express ridesplitting}}} \sum_{j=1}^{n_i} \left(\tilde{D}_{ij} + \tilde{D}_{ij,\text{ pickup}} \right) - \sum_{i \in \Omega_{\text{Express ridesplitting}}} D_i \end{aligned} \tag{7}$$

where $VKT_{Express\ ridesplitting}$ is the total VKT of Express ridesplitting trips. $VKT_{w/o\ Express\ ridesplitting}$ is the total VKT in the situation without Express ridesplitting. $\Omega_{Express\ ridesplitting}$ represents the set of Express ridesplitting trips. $r_{Express}$ defines the percentage at which passengers shift modal from non-ridesplitting cars that increase VKT (e.g., private cars, taxis, DiDi Express, DiDi private cars, etc.) to Express ridesplitting, $\tilde{D}_{ij,\ pickup}$ represents the pickup distance for a driver to reach the passenger after accepting or being assigned a ridesourcing order, $VKT_{Express\ saved}$ is the total VKT saved by Express ridesplitting services.

The Hitch part can be defined by

$$\mathrm{VKT}_{\mathrm{Hitch}} = \sum_{i \in \Omega_{\mathrm{Hitch}}} D_i \tag{8}$$

$$\mathrm{VKT}_{\mathrm{w/o\ Hitch}} = r_{\mathrm{Hitch}} \cdot \sum_{i \in \Omega_{\mathrm{Hitch}}} \sum_{j=1}^{n_i} \left(\tilde{D}_{ij} + \tilde{D}_{ij,\ \mathrm{pickup}} \right) + \sum_{i \in \Omega_{\mathrm{Hitch}}} \tilde{D}_i \tag{9}$$

$$\begin{aligned} \mathrm{VKT}_{\mathrm{Hitch\ saved}} &= \mathrm{VKT}_{\mathrm{w/o\ Hitch}} - \mathrm{VKT}_{\mathrm{Hitch}} \\ &= r_{\mathrm{Hitch}} \cdot \sum_{i \in \Omega_{\mathrm{Hitch}}} \sum_{j=1}^{n_i} \left(\tilde{D}_{ij} + \tilde{D}_{ij,\ \mathrm{pickup}} \right) + \sum_{i \in \Omega_{\mathrm{Hitch}}} \tilde{D}_i - \sum_{i \in \Omega_{\mathrm{Hitch}}} D_i \\ &\approx r_{\mathrm{Hitch}} \cdot \sum_{i \in \Omega_{\mathrm{Hitch}}} \sum_{j=1}^{n_i} \left(\tilde{D}_{ij} + \tilde{D}_{ij,\ \mathrm{pickup}} \right) \end{aligned} \tag{10}$$

where VKT_{Hitch} is the total VKT of all Hitch trips, $VKT_{w/o\ Hitch}$ is the total VKT in the situation without Hitch, Ω_{Hitch} represent the set of the Hitch trips. r_{Hitch} defines the percentage at which passengers shift modal from non-ridesplitting cars that increase VKT (e.g., private cars, taxis, DiDi Express, DiDi private cars, etc.) to Hitch. $\tilde{D}_{ij,\ pickup}$ represents the pickup distance for a driver to reach the passenger after accepting or being assigned a ridesourcing order, $\tilde{D}_i$ is the planned trip distance for the Hitch driver. Since Hitch drivers mainly work part-time, Hitch trips are always existing whether splitting rides are successfully matched or not.

$VKT_{Hitch\ saved}$ is the total VKT saved by Hitch services. In this paper, we assume that Hitch drivers would pick passengers up in case that some passengers have a similar route, and the similarity degree is above 80%, in other words, the planned trip distance for the Hitch driver ($\tilde{D}_i$) is almost the same as the actual travel distance of the whole trip (D_i). $VKT_{Hitch\ saved}$ is the maximal VKT that Hitch can save.

$$\mathrm{VKT}_{\mathrm{Ridesplitting}} = \mathrm{VKT}_{\mathrm{Express\ ridesplitting}} + \mathrm{VKT}_{\mathrm{Hitch}} \tag{11}$$

$$\mathrm{VKT}_{\mathrm{saved}} = \mathrm{VKT}_{\mathrm{Express\ saved}} + \mathrm{VKT}_{\mathrm{Hitch\ saved}} \tag{12}$$

where $VKT_{Ridesplitting}$ is the total VKT of ridesplitting trips, VKT_{saved} is the total saved VKT for the ridesplitting service.

Results

Ridesplitting can reduce trips of private cars and taxis, but at the same time, it attracts many trips from other modes, e.g., bus and metro transit, bikes, and pedestrians. So it is necessary to explore the question: *Whether ridesplitting alleviates traffic congestion or makes the traffic worse*? In this section, we use VKT as the performance measure to evaluate the impact of ridesplitting on the multimodal urban mobility, and a Chinese government regulation policy on ridesourcing platforms is presented to analyze the impacts before and after the policy implementation in Hangzhou, China.

Government regulation policy

On November 1, 2016, detailed rules for the implementation of the combined management of on-demand ridesourcing private passenger cars in Hangzhou (namely, *Trial Implementation*) were released to point out the direction for the reform of cruising taxis and on-demand ridesourcing services. The transition period of the government regulation policy lasted for 4 months (from November 1, 2016, to February 28, 2017). Since March 1, 2017, the *Trial Implementation* was tentatively implemented for 1 year. The government regulation policy has been formally implemented since March 8, 2018. So our collected data cover the periods before and after the transition period of *Trial Implementation*. The main contents of the government regulation policy are summarized as follows:

- Firstly, it refines the eligibility of ridesourcing vehicle registration. In addition to the implementation of state regulations, the local authority of Hangzhou refines specific requirements, e.g., local license plate, and auto age of fewer than 5 years.
- Secondly, it refines the eligibility of ridesourcing drivers. Besides the compliance with state regulations, the local authority refines a few specific requirements for drivers, e.g., registered permanent residents of the city or the Zhejiang provincially registered permanent residence issued by the city.
- Thirdly, it regulates the behavior of private ridesplitting. The policy encourages ridesharing, regulates the ridesplitting behavior, and draws the boundary among ridesplitting, illegal operations, and the on-demand ridesourcing services, so as to prevent policy loopholes.
- Other contents include: Allow ridesourcing cars to use taxi waiting areas for passenger pickups.

The daily numbers of ridesourcing drivers who provided on-demand ride services via the platform are presented in Table 3. As long as a driver picks up one or more passengers, she/he will be recorded in the driver set of the day. The sum is the number of drivers for whom have provided ride services via the platform for at least once a week. The field observations show that the number of drivers decreased mainly due to the government regulation policy on the eligibilities of both ridesourcing vehicles and drivers.

VKT of ridesplitting trips

Based on the ridesplitting data described in "Methodology" section, we calculate the VKT of Hitch, Express ridesplitting, and the total ridesplitting services for these 2 weeks separately. The results show that the VKT values for the total ridesplitting

Table 3 Daily ridesplitting drivers before and after the regulation policy implementation

Day of week	Drivers before policy implementation	Drivers after policy implementation	Decrease (%)
Monday	17,054	13,740	19.43
Tuesday	16,602	12,680	23.62
Wednesday	17,082	13,000	23.90
Thursday	16,330	11,845	27.46
Friday	17,623	12,898	26.81
Saturday	17,409	12,443	28.53
Sunday	16,203	13,229	18.35
Sum	38,430	30,713	20.08

orders are 259,931 km before the policy implementation, while 184,167 km after the policy implementation.

Figure 8 shows the hourly profiles of VKT for different types of ridesplitting services. For the first week (October 24–30, 2016), the VKT values fall to zero because the on-demand ride service platform prohibits ridesplitting orders between 1 and 6 AM. There are three peaks, i.e., AM peak (more concentrated), PM peak (more widely spreading), and late evening peak. The third peak represents the non-commuting traffic peak which may be caused by urban residents' entertainments.

In this section, we suppose that all the passengers will choose to take passenger/private cars, e.g., taxis, Express cars, and private cars, in other words, the percentage at which passengers shift the travel mode from non-ridesplitting cars to ridesplitting is 1, i.e., $r = 100\%$. Note that we will relax the assumption in "VKT of ridesplitting trips" section. Thus, the estimated saved VKT due to ridesplitting via the methodology presented in Eqs. (5–12) is shown in Fig. 9. The trends of the saved VKT profiles are similar to Fig. 8, except that the third peak is lower. The difference between the peaks and low ebb is larger than the trends shown in Fig. 8, which indicates ridesourcing saves more VKT in the peak periods.

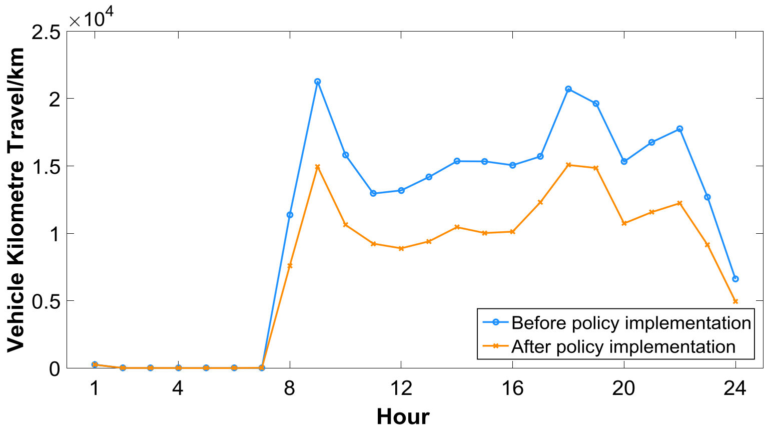

Fig. 8 Temporal VKT distributions of total ridesplitting orders (Eq. 11)

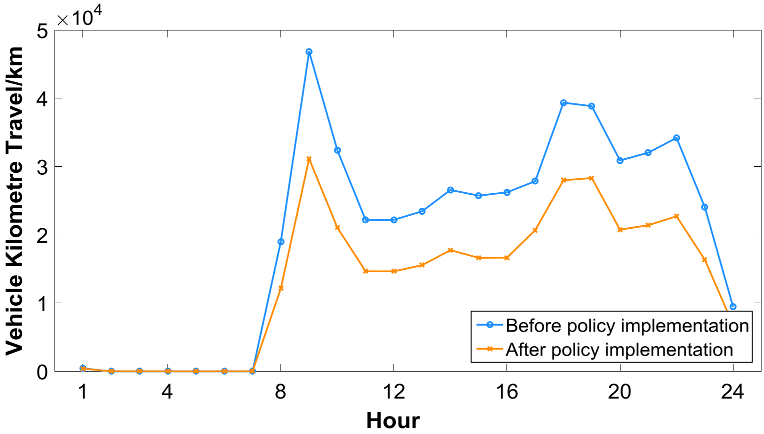

Fig. 9 Temporal saved VKT distributions of total ridesplitting orders (Eq. 12)

Impacts of ridesplitting

Questionnaires include daily multimodal mobility changes while ridesplitting services are emerging. The survey results show that ridesplitting can cut down the use of private cars, and the rate is as high as 90.33% in total, among which 70% respondents reduce the private car use by 1–2 times per day, the other 30% reduce three or more times per day. The result is almost the same for both ridesplitting types (i.e., Hitch and Express ridesplitting). Meanwhile, 42.48% respondents reduce the taxi use. However, it also attracts some passengers from the public transit and non-motorized travel modes, that is, 37.23% respondents reduce the bus use for ridesplitting, and the percentage of Hitch (37.92%) is a little bit larger than that of Express ridesplitting (36.22%). The modal shift from of metro to Hitch (23.02%) is also larger than Express ridesplitting (18.93%), and 21.37% for all ridesplitting trips. As for bicycles, ridesplitting promotes bicycling for the reason that bicycles can solve the 'last mile' problems.

In the revealed and stated preference survey, we set a recall of one ridesplitting experience to collect responses to the following questions: (1) Whether the chosen mode was Hitch or Express ridesplitting? (2) What were the reasons to split rides? (3) How long did the ridesplitting trip take (in minutes)? (4) How far was the travel distance of the ridesplitting (in kilometers)? (5) Which transportation mode will be chosen once the ridesplitting services were unavailable?

There are seven transportation modes on the options list, i.e., bus transit, metro transit, taxi, DiDi Express, DiDi Private Car, electric bike, public bike sharing. We divide these seven types of modes into two categories: (1) Passenger/private vehicles, including taxi, DiDi Express, and DiDi Private Car; (2) Non-passenger/private vehicles, including bus transit, metro transit, electric bike, and public bike sharing. According to the questions (4) travel distance and (5) replaced modes without ridesplitting, researchers obtain the estimated percentage that non-passenger/private vehicles are converted.

The results show that respondents who chose to split rides mainly for the four reasons: (1) Ridesplitting costs are low (22.21%); (2) More comfortable than public transportation (9.85%); (3) Far from bus stations or metro stations (9.77%); and (4) High parking fee or no parking space available (9.24%). The results also show that ridesplitting benefits urban mobility by calculating VKT in different scenarios. Figure 10 shows the modal shift percentages of each mode under the situation when ridesplitting is unavailable. For either Hitch or Express ridesplitting, the modal shift percentage of bus transit is the largest, and almost half VKT of Hitch trips are converted from bus trips. Non-passenger/private vehicles occupy 63% for Hitch. Express ridesplitting passengers have a larger possibility of modal shift from passenger/private vehicles than Hitch passengers.

The dataset attained from the real-world on-demand ride service platform doesn't contain the features of multimodal mobility or modal shift behavior. Therefore, this paper combines questionnaires and the on-demand ride service ridesourcing data to estimate VKT. As aforementioned, ridesplitting reduces the usage of taxis and private cars, but at the same time, it attracts passengers from non-passenger/private vehicles, e.g., bus and metro transit. We mainly consider the passengers who chose to shift modals between ridesplitting vehicles and non-passenger/private vehicles in the stated preference survey. Equations (5–12) are used to calculate the VKT values according to the percentage that passengers converted from passenger/private vehicles to Hitch or DiDi Express ridesplitting cars ($r = 37.05\%$ for Hitch and $r = 52.18\%$ for Express ridesplitting).

The saved VKT due to ridesplitting is estimated via the methodology presented in Eqs. (5–12). Table 4 shows the distributions of trips and trip segments, and the daily saved VKT values for 2 weeks separately, respectively. The results show that ridesplitting has a positive impact on urban mobility by reducing the total VKT. For the whole ridesourcing system, ridesplitting can decrease VKT by 58,124 km per day in Hangzhou. While, Hitch decrease 2175 km VKT, and Express ridesplitting helps decrease 55,949 km VKT per day. Because the number of Hitch orders is smaller than Express ridesplitting, and more than half of the Hitch passengers shift modals from bus/metro transit or other non-passenger/private cars.

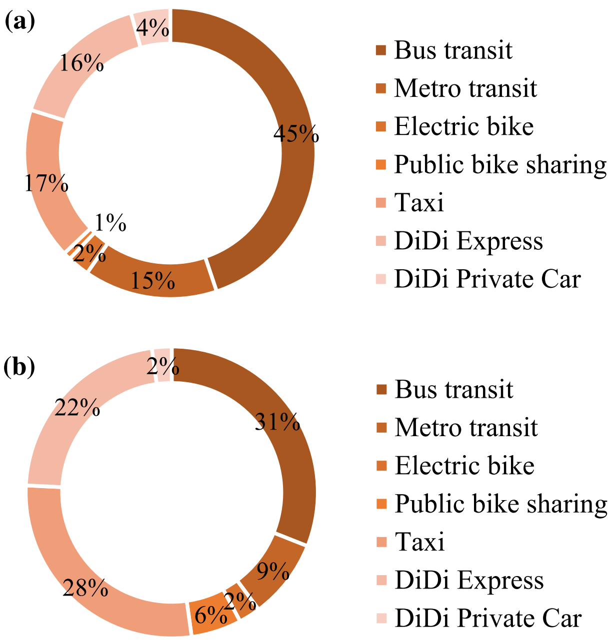

Fig. 10 Stated preference of mode choice if ridesplitting services are not available. **a** Hitch; **b** Express ridesplitting

Table 4 Daily saved VKT before and after the government regulation policy implementation

Item	Drivers before policy implementation	Drivers after policy implementation	Decrease (%)
Trips	7525	6041	19.73
Trip segments	16,054	11,219	30.12
$VKT_{rideslitting}$	37,133	26,310	29.15
Ridesplitting ratio	21.58%	17.13%	20.65
$VKT_{w/o\ rideslitting}$	72,797	48,770	33.01
VKT_{saved}	35,664	22,460	37.02

Ridesplitting ratio: the proportion of ridesplitting orders among ridesourcing orders

In Table 4, comparing the results for the 2 weeks before and after the *Trial Implementation*, we can find that the former week has more Express ridesplitting trips and can save larger VKT than the second week, but the situation for Hitch is the opposite. The new eligibility of drivers may have great effects on the driver set. In a short time, the *Trial Implementation* may bring incentives for ridesplitting services, these are likely to be the decrease in VKT or Ridesplitting ratio. However, for long time scales, the *Trial Implementation* helps incite ridesplitting behaviors, regulate the ridesourcing market, and bind force on both passengers and drivers to a certain degree. So, we firmly believe that the ridesplitting will be widely spread, and the VKT saved is supposed to be larger after the policy implementation.

Conclusions

This paper analyzed the ridesplitting behavior and its impact on urban mobility using real-world ridesourcing data extracted from the on-demand ride service platform, and documented questionnaires accomplished by on-demand ride service users. It aims to answer the question that whether ridesplitting can save VKT for urban road transportation, although it may attract some passengers from public transportation.

To analyze the ridesplitting's impact, researchers estimate the VKT of each ridesplitting trip. While calculating the saved VKT, we take into account the VKT converted from non-passenger/private cars. The results show that ridesplitting can decrease VKT by 58,124 km per day, including 2175 km saved VKT by Hitch and 55,949 km saved VKT by Express ridesplitting per day.

Conspicuously, ridesplitting can benefit society, passengers, drivers, and other stakeholders. Through this article, it concludes that:

- Due to the reduction in the vehicle usage and mileage on roads, it can alleviate traffic jams, and urban road resources can be effectively saved by ridesplitting.
- Ridesharing passengers receive timely and preferential services, meanwhile, the income of taxi drivers or on-demand ride service providers increases due to the higher seat occupancy via ridesplitting, thus, it benefits both passengers and operators.
- With the decrease in the empty seat rate, passengers are easier to find cars during over-demand peak hours or in under-supply regions. Thus, it can reduce the traffic volume and satisfy the passenger demand via cutting the percentage of empty seats.

- Since ridesplitting saves VKT for the whole network, it is conducive to the energy saving and emission reduction.

Nowadays, shared mobility has emerged with the popularity of on-demand ride services. This paper shines some light on understanding the emerging on-demand ridesplitting behavior and quantifying its impact on multimodal urban mobility. Additionally, this paper presents one of the first attempts to quantify the impact of ridesplitting, and it has several limitations: (1) As aforementioned, in order to obtain a sufficient number of questionnaires for Hitch passengers, we set two questions to divide the respondents into three categories, which helps make Hitch responses more reliable, but it may bring deviations to the representation of Hitch and Express ridesplitting respondents from their true proportions; (2) Instead of direct measurements, the total travel distance of a shared trip used in this paper is estimated by the travel time and distance of individual trip segments; (3) The ratio *r* may change with time, but it is assumed to be constant in this paper for simplifying the analysis. Researchers plan to fulfill the above limitations by combining GPS data of individual ridesplitting trips with the collected ridesourcing order data in the future research. Besides, policy analyses looking at spatial impacts are also significant for further studies.

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References

Anderson, D.N.: “Not just a taxi”? For-profit ridesharing, driver strategies, and VMT. Transportation **41**(5), 1099–1117 (2014)

Caulfield, B.: Estimating the environmental benefits of ride-sharing: a case study of Dublin. Transp. Res. D Transp. Environ. **14**(7), 527–531 (2009)

Chan, N.D., Shaheen, S.A.: Ridesharing in North America: past, present, and future. Transp. Rev. **32**(1), 93–112 (2012)

Che, Y.: Design and research of system of taxi intelligent dispatcher and administration based on multi-ride. Master’s Dissertation, Tongji University, Shanghai, China (2008)

Chen, X., Zahiri, M., Zhang, S.: Understanding ridesplitting behavior of on-demand ride services: an ensemble learning approach. Transp. Res. C Emerg. Technol. **76**, 51–70 (2017)

Cohen, A.P., Shaheen, S.A.: Planning for shared mobility. PAS Report 583 (2018)

Cooper, G., Howe, D., Mye, P.: The Missing Link: An Evaluation of Carsharing Portland Inc. Oregon Department of Environmental Quality, Portland, OR (2000)

Cramer, J., Krueger, A.B.: Disruptive change in the taxi business: the case of Uber. Am. Econ. Rev. **106**(5), 177–182 (2016)

Dias, F.F., Lavieri, P.S., Garikapati, V.M., Astroza, S., Pendyala, R.M., Bhat, C.R.: A behavioral choice model of the use of car-sharing and ride-sourcing services. Transportation **44**(6), 1307–1323 (2017)

Dong, Y., Wang, S., Li, L., Zhang, Z.: An empirical study on travel patterns of internet based ride-sharing. Transp. Res. C Emerg. Technol. **86**, 1–22 (2018)

Feigon, S., Murphy, C.: Shared mobility and the transformation of public transit. Project J-11, Task 21 (2016)

Greenblatt, J.B., Shaheen, S.: Automated vehicles, on-demand mobility, and environmental impacts. Curr. Sustain. Renew. Energy Rep. **2**(3), 74–81 (2015)

Henao, A.: Impacts of Ridesourcing-Lyft and Uber-on Transportation Including VMT, Mode Replacement, Parking, and Travel Behavior. The University of Colorado, Denver (2017)

Jin, S.T., Kong, H., Wu, R., Sui, D.Z.: Ridesourcing, the sharing economy, and the future of cities. Cities **76**, 96–104 (2018)

Katzev, R.: Carsharing Portland: Review and Analysis of its First Year. Oregon Department of Environmental Quality, Portland, OR (1999)
Katzev, R.: Car sharing: a new approach to urban transportation problems. Anal. Soc. Issues Public Policy **3**(1), 65–86 (2003)
Lane, C.: PhillyCarShare: first-year social and mobility impacts of carsharing in Philadelphia, Pennsylvania. Transp. Res. Rec. J. Transp. Res. Board **1927**(1), 158–166 (2005)
Martin, E.W., Shaheen, S.A.: Greenhouse gas emission impacts of carsharing in North America. IEEE Trans. Intell. Transp. Syst. **12**(4), 1074–1086 (2011)
Martin, E., Shaheen, S.A., Lidicker, J.: Impact of carsharing on household vehicle holdings: results from North American shared-use vehicle survey. Transp. Res. Rec. J. Transp. Res. Board **2143**(1), 150–158 (2010)
McCoy, K., Andrew, J., Glynn, R., Lyons, W.: Integrating shared mobility into multimodal transportation planning: improving regional performance to meet public goals (No. DOT-VNTSC-FHWA-18-13; FHWA-HEP-18-033). Office of Planning, Environment, and Realty, Federal Highway Administration, United States (2018)
Neoh, J.G., Chipulu, M., Marshall, A.: What encourages people to carpool? An evaluation of factors with meta-analysis. Transportation **44**(2), 423–447 (2017)
Nie, Y.: How can the taxi industry survive the tide of ridesourcing? Evidence from Shenzhen, China. Transp. Res. C Emerg. Technol. **79**, 242–256 (2017)
Rayle, L., Shaheen, S.A., Chan, N., Cervero, R.: App-Based, On-Demand Ride Services: Comparing Taxi and Ridesourcing Trips and User Characteristics in San Francisco. University of California Transportation Center (UCTC), University of California, Berkeley, CA (2014)
Rayle, L., Dai, D., Chan, N., Cervero, R., Shaheen, S.A.: Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco. Transp. Policy **45**, 168–178 (2016)
Ryden, C., Morin, E.: Mobility services for urban sustainability: environmental assessment. Moses Report WP6, Trivector Traffic AB, Stockholm, Sweden (2005)
Shaheen, S.A., Chan, N.D., Bansal, A., Cohen, A.P.: Developments, and Early Understanding. University of California Berkeley Transportation Sustainability Research Center, Berkeley, CA. http://innovativemobility.org/wp-content/uploads/2015/11/SharedMobility_WhitePaper_FINAL.pdf. (2015)
Shaheen, S.A., Chan, N.D., Gaynor, T.: Casual carpooling in the San Francisco Bay Area: understanding user characteristics, behaviors, and motivations. Transp. Policy **51**, 165–173 (2016)
Shaheen, S.A., Chan, N.D., Micheaux, H.: One-way carsharing's evolution and operator perspectives from the Americas. Transportation **42**(3), 519–536 (2015)
Shaheen, S.A., Cohen, A.P.: Carsharing and personal vehicle services: worldwide market developments and emerging trends. Int. J. Sustain. Transp. **7**(1), 5–34 (2013)
Shaheen, S.A., Cohen, A.P.: Growth in worldwide carsharing: an international comparison. Transp. Res. Rec. J. Transp. Res. Board **1992**(1), 81–89 (2007)
Shaheen, S.A., Cohen, A.P.: Worldwide carsharing growth: an international comparison. UCD-ITS-RR-08-10, Institute of Transportation Studies, University of California, Davis, CA (2008)
Shaheen, S.A., Cohen, A.P., Roberts, J.: Carsharing in North America: market growth, current developments, and future potential. Transp. Res. Rec. J. Transp. Res. Board **1986**, 116–124 (2006)
Shaheen, S.A., Meyn, M.A., Wipyewski, K.: US shared-use vehicle survey findings on carsharing and station car growth: obstacles and opportunities. Transp. Res. Rec. J. Transp. Res. Board **1841**(1), 90–98 (2003)
Shaheen, S.A., Schwartz, A., Wipyewski, K.: Policy considerations for carsharing and station cars: monitoring growth, trends, and overall impacts. Transp. Res. Rec. J. Transp. Res. Board **1887**(1), 128–136 (2004)
Shaheen, S., Wright, J., Dick, D., Novick, L.: CarLink: a smart carsharing system. Field Test Report. UCD-ITS-RR-00-4, University of California, Davis, CA (2000)
Stocker, A., Shaheen, S. A.: Shared automated vehicles: Review of business models. In International Transport Forum (2017)
Yu, K.Y.: Taxipooling routing optimization based on reserve pattern. Master's Dissertation, Harbin Institute of Technology, Harbin, China (2015)

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