Lecture Notes in Electrical Engineering 1209

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Developments and Applications in SmartRail, Traffic, and Transportation Engineering

Proceedings of ICSTTE 2023

Springer

Lecture Notes in Electrical Engineering 1209

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ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-981-97-3681-2 ISBN 978-981-97-3682-9 (eBook)
https://doi.org/10.1007/978-981-97-3682-9

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Preface

This proceeding contains the papers presented at the International Conference on SmartRail, Traffic, and Transportation Engineering (ICSTTE 2023), held on July 28–30, 2023, in Changsha, China. The conference is sponsored by Beijing Jiaotong University, China Electrotechnical Society, and The Chinese Institute of Electronics. It was organized by Central South University and supported by the National Engineering Research Center for Safety and Operation and Maintenance of Urban Rail Transit System, CRRC Changchun Rail Transit Co., CRRC Qingdao Sifang Rolling Stock Co., Intelligent Railway Committee of China Railway Society, CRRC Industrial Research Institute, and The International Academy of Science and Engineering for Development (IASED). The conference was an excellent forum for the fusion of ideas and knowledge.

Many submissions were received in response to the conference call for papers. The papers were rigorously evaluated, considering originality, technical quality, presentation quality, and overall contribution. In all, 89 articles were accepted for publication and were grouped into seven sections as follows:

Section 1: Urban and Transportation Planning

Section 2: Highway Transportation: Operations and Management

Section 3: Highway Transportation: Planning, Design, ITS, Safety, and Security

Section 4: Railway Transportation: Planning, Operations, ITS, Safety, and Security

Section 5: Maritime Transportation: Design, Operations, ITS, Safety, and Security

Section 6: Air and Multimodal Transportation: Planning, Operations, ITS, Safety, and Security

Section 7: Other Considerations of Transportation Engineering

We hope that this book, with its broad coverage of various transportation modes and emerging technologies, will be helpful to researchers and practitioners in transportation engineering.

Said Easa

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Air and Multimodal Transportation: Planning, Operations, ITS, Safety, and Security

Urban and Transportation Planning

Weekday Travel Demand Distribution Pattern of Ride-Hailing Service Based on Didi Daily Order Data in Beijing

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Abstract. A city is a multi-layered open complex giant system, including graph networks of road, rail, air, and water transportation system. Focused on time-dependent mobility patterns, this study analyzed the weekday daily travel pattern of transportation network company (TNC) riders based on Didi daily order data in Beijing in May 2021. Especially, trips arrived in and departed from traffic analysis zones with rail stations and airports was visualized on to analyze the trip distribution by time of day. Citywide OD matrices at traffic analysis zone level for ride-hailing service vehicles was then derived and OD Matrix Estimation (ODME) was also conducted for OD matrices of car, bike and electric bike based on traffic counts data collected in 2019. Based OD matrices of different vehicle class, using bi-conjugate Frank-Wolfe algorithm built in Cube Voyager platform, the highway assignment procedure was processed to estimate volume by mode for links in the roadway network by different time of day. Ride hailing service users travel along major freeway corridor during peak hours to major employer and commercial centers in city proper area. Results of volume forecasting can be validated using screenline traffic count data.

Keywords: Travel Demand Distribution Pattern · OD Matrix Estimation · Traffic Assignment · Didi Daily Order Data

1 Introduction

Ride-hailing services have revolutionized the way people commute. With the click of a button, users can easily request a ride from their smartphones and have a driver arrive at their location within minutes. These services provide a convenient and affordable alternative to traditional taxi services, allowing users to track their ride in real-time, rate their driver, and pay through the app. In addition, ride-hailing services have also helped reduce traffic congestion and air pollution by encouraging carpooling and the use of more fuel-efficient vehicles. With the continued growth and innovation in the ride-hailing industry, it's clear that these services will continue to shape the future of transportation.

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L. Jia et al. (Eds.): ICSTTE 2023, LNEE 1209, pp. 3–12, 2024.
https://doi.org/10.1007/978-981-97-3682-9_1

Additionally, ride-sourcing services have been found to reduce the number of cars on the road and decrease traffic congestion, particularly in urban areas. However, concerns have been raised about the impact of ride-hailing services on public transportation and the environment, as well as the labor practices of ride-hailing companies. As ride-hailing services continue to grow in popularity, further research will be needed to fully understand their impact on transportation and society as a whole and fill the gap between transportation operation management and travel demand of ride-sourcing service users.

2 Literature Review

Part of recent research has largely focused on the patterns and characteristics of ride-hailing service demands. These studies mainly focused on the analysis of service users' travel behaviour and attitudinal factors affecting the use of ride-sourcing service on the demand side without considering factors in traffic infrastructure from the supply side. Ma et al. (2019) took Chinese transportation network company, DiDi as an example, and developed an integrated model to examine the role perceptions of risk played in a service user's decision to cease using a particular service from a transportation network company. Jing et al. (2021) figured out crucial latent factors that influenced TNC riders' decisions to use or reuse ride-sourcing services after security measures were taken. In Toronto, to understand the effects of latent attitudinal factors on using ride hailing services, Loa et al. (2021) analyzed data from a web-based questionnaire.

Some researchers narrowed down their work to a subgroup of TNC riders, or travel behavior in response to an emergency without paying attention to the whole picture of travel behavior of all residents in a typical weekday. Mitra et al. (2019) conducted a research on the 2017 National Household Travel Survey to explore the factors affected the adoption of ride-sourcing services and the frequency of transportation network company (such as Uber and Lyft) trips among senior citizens. Similarly, collected data from 241 senior citizens who self-reported about loneliness and social disconnectedness and based on the survey, Talmage et al. (2020) explored the effects of information and communication technology and ride-sourcing services to relieve these phenomena. The focus of Tonder et al. (2020) was on service quality and researchers selected a subgroup of customers' citizenship behavior and their research approaches included structural equation modelling and bootstrapping affective commitment relevant to service quality. Hawkins et al. (2020) analyzed the demand for trips of ride hailing service during the interruption of the metro rail service.

Other researchers primarily analyzed the environmental and socio-economic benefits and standards of ride-sourcing services. As an important part in the sharing economy, ride-sourced services contributed to the sustainable development and resolved environmental and socio-economic issues. To show the environmental and socio-economic influence of ride-hailing services, Mezuláník et al. (2020) compared characteristics of the drivers, vehicles, and trips of ride-sourcing services and traditional taxi services. After a review of current empirical study about ride-sourcing services, Reilly et al. (2019) found the decent work standard created by Richard Heeks for digital online labor markets can be used to the location-based service delivery market.

A combination of traditional travel demand model and ride-sourcing service order data may shed light on the interaction between the operation of roadway infrastructure and travel behavior of transportation network company riders.

3 Data and Methods

3.1 Data

Didi is a ride-hailing platform that operates in many cities around the world, providing an efficient and convenient transportation option for millions of people. The platform generates large amounts of data on ride bookings, pick-up and drop-off locations, trip duration, and other variables. This data can be analyzed to gain insights into travel patterns, demand trends, and user behavior. For example, Didi order data can be used to identify areas with high demand for ride-hailing services, optimize driver allocation and routing, and improve the overall user experience. Additionally, Didi order data can be used to inform transportation planning and policy decisions, such as identifying areas where public transportation infrastructure may need to be improved or expanded. As Didi continues to grow and expand its services, the data it generates will become increasingly valuable for transportation researchers, policymakers, and urban planners. Table 1. Demonstrates the data dictionary of the Didi order data with building arrival information and order data of May 17th 2021 in Beijing were examined in this study.

Table 1. The data dictionary of Didi order data with building arrival information.

Field Name	Explanation
date	Date of each order record
hour	Time Stamp of trip arrival
startlat	Latitude of trip origins
startlng	Longitude of trip origins
destlat	Latitude of trip destinations
destlng	Longitude of trip destinations
distance	Travel distance of each trip

3.2 TNC Trips Associated with Major Airports and Railway Stations

As shown in Figs. 1, 2, 3, 4, 5, 6, 7 and 8, major airports and rail way stations, such as Beijing Capital International Airport, Beijing West Railway Station, Beijing Railway Station, Beijing South Railway Station, were selected as key origins and destinations to analyze ride-sourcing service trips with trip ends associated with these regional transportation hubs by time of day. Some TNC riders of these trips transferred from a railway station to an airport or from one railway station to another because ride hailing service can help reduce travel time and is more comfortable for passengers with large luggage. Some ride-hailing service riders were likely to commute to work every day and they might get off the train from Beijing West Railway Station or Beijing South Railway Station and then move to adjacent business districts in the morning and vice versa in the evening. The connection between employment centers and Beijing Capital International Airport became stronger during evening peak hours, and some ride-sourcing service riders seemed to be on business trips to another city by air after work. Additionally, when public transit was not available from 0:00–6:00, ride hailing services provided easy access to Beijing Capital International Airport for passengers.

7:00-10:00 16:00-20:00 Night Early morning

Fig. 1. Weekday Trips of Ride Hailing Services from Beijing Capital International Airport.

7:00-10:00 16:00-20:00 Night Early morning

Fig. 2. Weekday Trips of Ride Hailing Services to Beijing Capital International Airport.

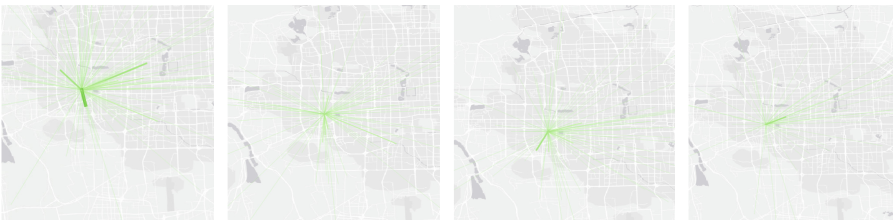

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Fig. 3. Weekday Trips of Ride Hailing Services from Beijing West Railway Station.

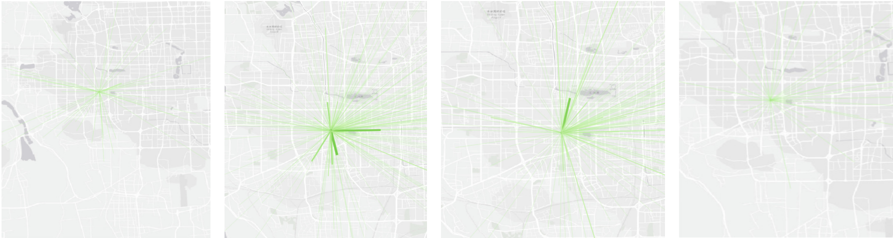

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Fig. 4. Weekday Trips of Ride Hailing Services to Beijing West Railway Station.

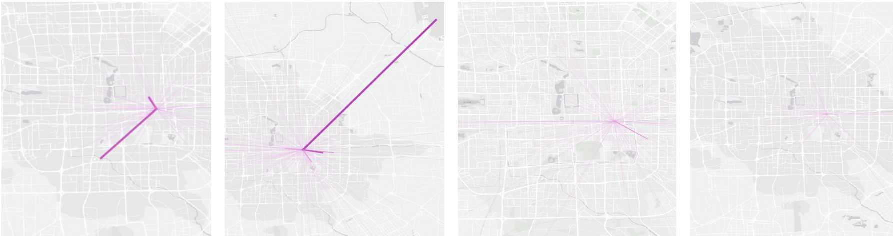

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Fig. 5. Weekday Trips of Ride Hailing Services from Beijing Railway Station.

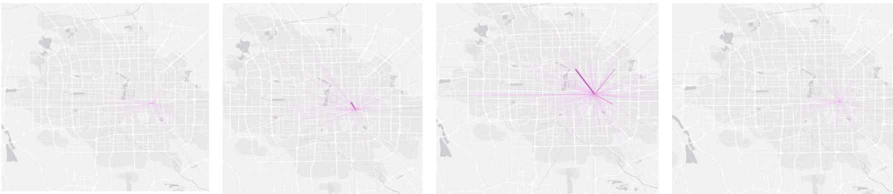

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Fig. 6. Weekday Trips of Ride Hailing Services to Beijing Railway Station.

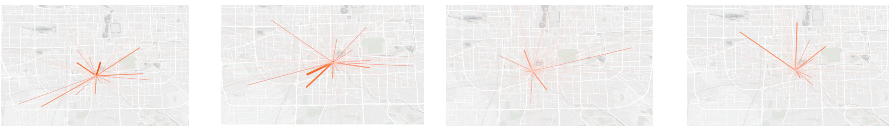

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Fig. 7. Weekday Trips of Ride Hailing Services from Beijing South Railway Station.

3.3 Analysis Approach

Origin-destination matrix estimation (ODME) is the process of estimating the origin-destination travel demand matrix for a given transportation network. The OD matrix represents the number of trips between each pair of origins and destinations in the

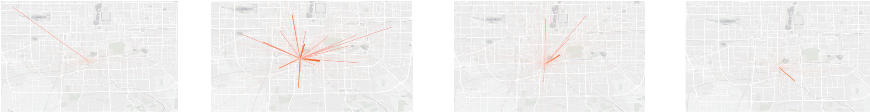

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Fig. 8. Weekday Trips of Ride Hailing Services to Beijing South Railway Station.

network. ODME process estimating the number of trips between each pair of zones in the network based on the collected count data for roadway segments intersecting with screen lines. This involves using a trip distribution model that takes into account factors such as travel time, distance, and mode of travel.

Traffic assignment is a crucial aspect of transportation planning that involves allocating traffic volumes to different routes or modes of transportation. The goal of traffic assignment is to optimize the use of available transportation infrastructure and minimize travel time, congestion, and environmental impacts. Various methods are used for traffic assignment, including static and dynamic assignment, user equilibrium, and system optimum. These methods take into account factors such as travel demand, network topology, travel time, and mode choice.

Table 2. The process of the Bi-Conjugate Frank-Wolfe (BCFW) algorithm.

The Bi-Conjugate Frank-Wolfe (BCFW) algorithm
Initialize the link flows x(0) and the dual variables y(0) and A_{bar} (0) to zero. For each iteration k = 0, 1, 2, ..., do the following: a. Compute the gradient of the cost function f(x) at the current link flows x(k). b. Compute the search direction d(k) by solving the bi-conjugate system of linear equations A * d(k) = -g(k), where A is the bi-conjugate matrix of the Jacobian matrix of the cost function and g(k) is the gradient vector. c. Compute the step size alpha(k) that minimizes the cost function along the search direction, i.e., alpha(k) = argmin{f(x(k) + alpha * d(k))}. d. Update the link flows and the dual variables using the Frank-Wolfe update rule: x(k +1) = x(k)+alpha(k) ∗ d(k) y(k +1) = y(k)+alpha(k) ∗ (c−A∗ x(k +1)) y_{bar} (k +1) = y_{bar}(k)+alpha(k) ∗ (c_{bar} −A_{bar} ∗ x(k +1)) where c and c_{bar} are the demand vectors for the origin and destination nodes, respectively, and A_{bar} is the transpose of the bi-conjugate matrix of A. Repeat step 2 until convergence is achieved, i.e., the relative change in the link flows is below a certain threshold or the maximum number of iterations is reached.

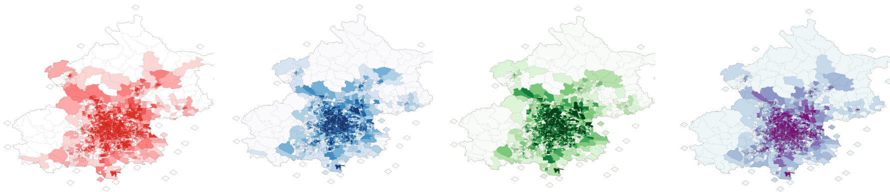
User equilibrium is a concept in transportation planning that refers to a state in which each individual traveler chooses the shortest and fastest route to their destination, given the existing traffic conditions. In other words, no traveler can improve their travel time by switching to a different route. The Frank-Wolfe algorithm is an iterative optimization method that can be used to find the user equilibrium in a transportation network. The algorithm works by iteratively updating the flow distribution on each link in the network based on the difference between the observed and predicted travel times. The algorithm continues until the flow distribution converges to the user equilibrium state. The Frank-Wolfe algorithm is widely used in transportation planning and has been shown to be effective in finding the user equilibrium in large-scale transportation networks. The Bi-Conjugate Frank-Wolfe (BCFW) algorithm is a variant of the Frank-Wolfe algorithm that is designed to handle non-smooth and non-convex optimization problems. Specifically, the BCFW algorithm is used for solving optimization problems with linear or quadratic constraints. The BCFW algorithm is based on the concept of bi-conjugacy, which is a property of matrices that allows for the application of conjugate gradient methods to non-symmetric matrices. As Table 2. Shows, the algorithm works by iteratively solving a sequence of linear sub-problems, each of which involves finding the optimal step size along a search direction that is chosen based on the bi-conjugate gradient of the objective function. One of the key advantages of the BCFW algorithm is that it can handle large-scale optimization problems with a large number of constraints and variables. Additionally, the algorithm is highly parallelizable, which makes it suitable for distributed computing environments.

Cube Voyager is a transportation modeling software developed by Citilabs. It is designed for transportation planners and engineers to simulate and analyze travel patterns and transportation systems. One of the key functions of Cube Voyager is traffic assignment. Traffic assignment is the process of assigning traffic flows to different transportation routes based on various factors such as travel time, distance, and cost. Cube Voyager can simulate different traffic scenarios and predict the impacts of different transportation policies on traffic flow, congestion, and travel time. With Cube Voyager, transportation planners and engineers can make informed decisions about transportation planning and policy by predicting the impacts of different scenarios on traffic flow, congestion, travel time, and emissions.

In this paper, citywide OD matrices at traffic analysis zone level for ride-sourcing service vehicles was then derived and OD Matrix Estimation (ODME) was also conducted for OD matrices of car, bike and electric bike based on traffic counts data collected in 2019. Based OD matrices of different vehicle class, using bi-conjugate Frank-Wolfe algorithm built in Cube Voyager platform, the highway assignment procedure was processed to estimate volume by mode for links in the roadway network by different time of day.

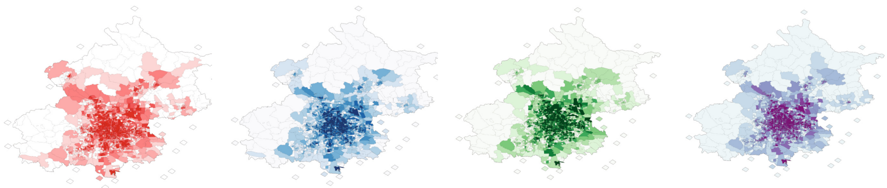
4 Results and Discussion

As mentioned above, OD matrices of private vehicle, ride hailing service vehicle, bike, and electric bike are assigned using the highway program embedded in Cube Voyager software. Results of volume forecasting can be validated using screenline traffic count data. Figure 9 and Fig. 10 demonstrate the travel demand pattern in Beijing by time of day. Figure 11 and Fig. 12 indicate the pattern of ride hailing service demand in the city proper of 6 highly urbanized districts in Beijing. One of the advantages of ride-hailing services is that they provide a convenient and affordable transportation option, especially in urban areas where public transportation may not be readily available or reliable. Figure 13 shows the volume of ride-sourcing service vehicle distribution of traffic assignment and TNC vehicles concentrated on the Jingtong, Jingcheng, and Jingzang Freeway in the north and east part of Beijing, which are the major inter-district commute corridors connecting major residential communities in suburban area and employment centers, for example, CBD and Zhongguancun. Figure 14 demonstrates similar spatial distribution patterns among trips of private car, bike, e-bike, and Didi, which indicate that ride-hailing service as a complementary mode to existing transportation modes for long-distance trips with dispersed origins and destinations during the morning peak hour.



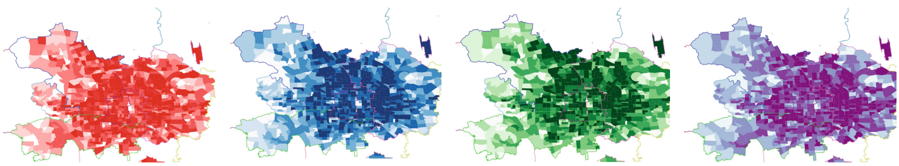
7:00-10:00 16:00-20:00 Night Early morning

Fig. 9. Weekday Trip Origins of Ride Hailing Services in Beijing.



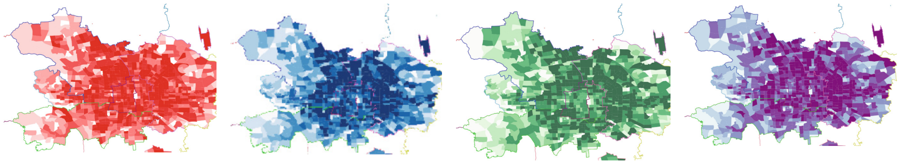
7:00-10:00 16:00-20:00 Night Early morning

Fig. 10. Weekday Trip Destinations of Ride Hailing Services in Beijing.



7:00-10:00 16:00-20:00 Night Early morning

Fig. 11. Weekday Trip Origins of Ride Hailing Services in the City Proper of Beijing.



7:00-10:00 16:00-20:00 Night Early morning

Fig. 12. Weekday Trip Destinations of Ride Hailing Services in the City Proper of Beijing.

7:00-10:00 16:00-20:00 Night Early morning

Fig. 13. Weekday Traffic Volume Distribution of Ride Hailing Vehicles within 6th Ring Road of Beijing.

Car	City Core	City Proper	Suburban Communities	Satellite Cities	Satellite Cities in Outer Suburbs	Others
City Core	238,686	87,489	1,227	22,996	5,097	12,015
City Proper	84,772	121,262	3,256	35,692	3,569	17,202
Suburban Communities	2,838	5,673	1,211	1,383	87	1,874
Satellite Cities	21,826	32,723	695	76,170	3,311	23,611
Satellite Cities in Outer Suburbs	9,885	7,874	236	4,737	23,096	8,438
Others	20,898	28,125	2,431	36,199	13,823	46,052

Ebike	City Core	City Proper	Suburban Communities	Satellite Cities	Satellite Cities in Outer Suburbs	Others
City Core	137,846	50,593	89	3,342	0	8
City Proper	37,615	33,481	384	5,300	190	277
Suburban Communities	474	2,968	210	60	0	260
Satellite Cities	2,148	5,807	73	21,944	21	1,871
Satellite Cities in Outer Suburbs	0	241	0	21	2,994	184
Others	168	717	115	2,628	275	2,320

bike	City Core	City Proper	Suburban Communities	Satellite Cities	Satellite Cities in Outer Suburbs	Others
City Core	56,429	6,941	0	61	0	0
City Proper	5,171	17,940	150	890	94	90
Suburban Communities	1	1,211	246	10	0	232
Satellite Cities	61	1,278	25	11,984	6	514
Satellite Cities in Outer Suburbs	0	186	0	10	2,825	64
Others	0	159	70	697	103	1,244

TNC Trips	City Core	City Proper	Suburban Communities	Satellite Cities	Satellite Cities in Outer Suburbs	Others
City Core	17,968	5,120	47	719	34	299
City Proper	6,698	10,077	142	1,170	100	430
Suburban Communities	117	337	227	19	1	99
Satellite Cities	1,361	1,711	21	8,735	11	907
Satellite Cities in Outer Suburbs	71	245	1	11	1,351	114
Others	273	644	170	823	86	1,123

Fig. 14. Trip Distribution Patterns of Car, Bike, E-bike, and Ride-Hailing Service in AM Peak Hour.

5 Conclusion

Ride-sourcing services have become increasingly prevalent in China recently, with companies such as Didi Chuxing, Kuaidi Chuxing, and Caocao Chuxing, dominating the market. Ride-hailing services have been credited with reducing traffic congestion and improving air quality in some cities. However, there have also been concerns about safety and security, particularly following several high-profile incidents involving ride-hailing drivers and passengers. Despite these challenges, ride-hailing services remain a popular and important mode of transportation in China. Ride hailing service users mainly travel along major freeway corridor during peak hours to major employer and commercial centers in city proper area. These services offer a convenient and affordable option for transportation, particularly in urban areas where public transportation can be crowded and inconvenient.

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