UPPSALA UNIVERSITET

Master thesis in Sustainable Development 2020/08
Examensarbete i Hållbar utveckling

Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou

Yulu Wang

DEPARTMENT OF EARTH SCIENCES
INSTITUTIONEN FÖR GEOVETENSKAPER

Master thesis in Sustainable Development 2020/08
Examensarbete i Hållbar utveckling

Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou

Yulu Wang

Supervisor: Anna Kramers
Subject Reviewer: Cecilia Katzeff

Published at Department of Earth Sciences, Uppsala University (www.geo.uu.se), Uppsala, 2020

Content

Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou

YULU WANG

Wang, Y., 2020: Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou. *Master thesis in Sustainable Development at Uppsala University,* No. 2020/08, 59 pp, 30 ECTS/hp

Abstract:
The transport sector is responsible for a significant and growing proportion of greenhouse gas emissions. The urgent actions are required to take in the transport sector facing the challenge of growing global change. The major trends, including global urbanization, widespread application of digital technologies, and broad demand for sustainable development, have provided new opportunities for data-driven smart mobility in the future. This research aims to explore potentials of data-driven smart mobility in achieving Sustainable Development Goal 11.2, "provide access to safe, affordable, accessible and sustainable transport systems for all," and Sustainable Development Goal 13.2, "take urgent action to combat climate change and its impacts" and "integrate climate change measures into national policies, strategies and planning" reducing greenhouse gas emissions every year. In order to meet this aim, this research explores the understandings and innovations of data-driven smart mobility in achieving decarbonization in urban, as well as barriers during the current practices. Hangzhou, as the capital city in Zhejiang Province in China, has been selected for the case study to examine data-driven smart mobility approaches. The research results show that the potentials of the data to tackle climate issues lie in the efficient transport operation and travel behaviors change. Data technologies have been widely applied to improve the integration of travel modes and the efficiency of transport management to reduce greenhouse gas emissions in road traffic. However, there are few drivers to mine data resources for travel behavior change. Moreover, data-driven smart mobility initiatives applied in urban areas involve multiple stakeholders but with limited access to data sharing and opening. Considering disruptive effects and potential promises brought by the big data technologies, the implementation of smart mobility requires for public data strategy with a holistic view of the complex urban challenges and global climate change.

Keywords: Sustainable Development, Climate Change, Smart Mobility, Sustainable Transport, Data-driven Transition

Yulu Wang, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden

Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou

YULU WANG

Wang, Y., 2020: Data-driven smart mobility as an act to mitigate climate change, a case of Hangzhou. *Master thesis in Sustainable Development at Uppsala University,* No. 2020/08, 59 pp, 30 ECTS/hp

Summary:
The transport sector is responsible for a significant and growing proportion of greenhouse gas emissions. The urgent actions are required to take in the transport sector facing the challenge of growing global change. The major trends, including global urbanization, widespread application of digital technologies, and broad demand for sustainable development, have provided new opportunities for data-driven smart mobility in the future. This research aims to explore potentials of data-driven smart mobility in achieving Sustainable Development Goal 11.2, "provide access to safe, affordable, accessible and sustainable transport systems for all," and Sustainable Development Goal 13.2, "take urgent action to combat climate change and its impacts" and "integrate climate change measures into national policies, strategies and planning". In order to meet this aim, this research explores the understandings and innovations of data-driven smart mobility in achieving decarbonization in urban, as well as barriers during the current practices.

This qualitative research is conducted with a combination of a literature overview and a case study. A literature overview is used to understand the leading trends of transport study and identify key elements in transport and data science. A case study is conducted to learn the current practice of data-driven smart mobility in Hangzhou. Hangzhou, as the capital city in Zhejiang Province in China, has been selected for the case study in order to examine data-driven smart mobility approaches.

The research result shows that the potential of the data to tackle climate issues lies in the efficient transport operation and travel behaviors change in the current stage. Data technologies have been widely applied to improve the integration of travel modes and the efficiency of transport management in order to reduce greenhouse gas emissions in road traffic. However, there are few drivers to mine data resources for travel behavior change. The social and environmental benefits of wider application of data in transport sector have not been sufficiently highlighted.

Moreover, data-driven smart mobility initiatives applied in urban areas involve multiple stakeholders but with limited access to data sharing and opening. The right to access and reuse data is the main point of discussion of data. The digital transition in the urban transport system involves profound changes in various institutions and authorities. Considering disruptive effects and potential promises brought by the big data technologies, the implementation of smart mobility requires for unified data strategy with a holistic view of the complex urban challenges and global climate change. The final discussion looks into questions about broad data application on behavior changes and more challenges to the urban transport transition in nowadays society.

Keywords: Sustainable Development, Climate Change, Smart Mobility, Sustainable Transport, Data-driven Transition

Yulu Wang, Department of Earth Sciences, Uppsala University, Villavägen 16, SE- 752 36 Uppsala, Sweden

Abbreviations

AI: Artificial Intelligence
CNY: Chinese yuan
EPA: United States Environmental Protection Agency
EU: The European Union
EEA: European Environment Agency
GHG: Greenhouse Gas
ICT: Information and Communication Technology
IoT: Internet of Things
MaaS: Mobility as a Service
PM: Particulate Matter
PRC: People's Republic of China
SDG: Sustainable Development Goal
UN: The United Nations

List of Figures

1. Introduction and background

Climate change is accelerating and impacts people and earth more severely than before. More global efforts are recalled to mitigate climate change as soon as possible. Reducing greenhouse gas (GHG) emissions by 50% by 2030 and holding the global average temperature increase to 1.5°C above pre-industrial levels requires a scale of societal transformation (Exponential Roadmap, 2019). The transport sector accounts for a significant number of GHG emissions. Meanwhile, transportation is fundamental to economic growth and social development and sustainable transport supports in realizing Agenda 2030 for sustainable development and the 17 Sustainable Development Goals (SDGs). Furthermore, smart digital transitions are disrupting in various domains, including urban mobility. The multifaceted potential of data-driven approaches gives promises to strategic policy-making on sustainability transitions. Smart mobility can drive processes in transport modes, transport management and travel behavior, and climate change in various dimensions. This research aims to explore potentials of data-driven smart mobility in achieving SDG 11.2, "provide access to safe, affordable, accessible and sustainable transport systems for all," and SDG 13.2, "take urgent action to combat climate change and its impacts" and "integrate climate change measures into national policies, strategies and planning" reducing GHG emissions every year (UN, 2020).

1.1. Climate change, as an urgent issue

Climate change is becoming the biggest threat to the planet. Climate change refers to continued evolution in the mean and the variability of its properties that can be measured (Hegerl et al., 2007). Both natural internal and external forced changes can lead to climate change that lasts for an extended period, typically decades or longer. Climate warming is caused by the higher incoming energy than outgoing energy in the earth. The term "climate change" is often used to refer to global warming, the long-term surface temperature growth observed since the pre-industrial period, caused by anthropogenic activity primarily the use of fossil fuels (Holly et al., 2019). The unprecedented growth of surface temperature has been observed since the mid-20 century and is predicted to continue with an estimate of 1.5°C of global warming above the pre-industrial level between 2030 and 2052 if there is no more work (IPCC, 2018).

The greenhouse effect expanded by human activity is the main reason for the unprecedented global warming trend observed since the mid-20th century (EPA, 2019; IPCC, 2014; Oreskes 2004). Certain gases, like carbon dioxide (CO_2), methane and nitrous oxide, in the atmosphere block heat from escaping. Such kinds of greenhouse gases trap heat in the atmosphere, and the related increase of greenhouse gases strengthens the greenhouse effect (EPA, 2019). Among different greenhouse gases, carbon dioxide accounts for the most significant share of radiative forcing since 1990, which will continue to grow in the future (EPA, 2019). Greenhouse gases produced by human activities are changing natural greenhouse leading to overall climate warming, approximately 1°C (likely between 0.8°C and 1.2°C) above the pre-industrial period (EPA, 2019, IPCC, 2019). As the main greenhouse gas, the rise in global CO_2 emission is up to 10 times faster than any sustained rise during the past 800,000 years, with about 20 ppm per decade (Lüthi et al., 2008). CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78 % of the total GHG emission increase from 1970 to 2010 (IPCC, 2014).

Climate change has caused increasing impacts on the human and natural systems (IPCC, 2014a). The accelerating surface temperature is about twice as fast as the rest of the earth in the Arctic pole result in the retreat of glaciers, permafrost, and sea ice, and the melting glacier causes sea level rise. More habitats are affected, and immigration increases the complexity of the ecosystem. Temperature rise also has resulted in increasingly extreme weather, such as droughts, floods, unusually warm winter, which also causes underpinning disasters. Climate warming has been considered as a reason for the increased natural global disaster frequency and intensity in many places; a recent example is a bushfire in southeast Australia. (Hennesy et al., 2005; Joanna, 2018; Dunne et al., 2020). Climate change caused by human activities of the increasing use of fossil fuels and land-use changes also has added extreme pressure on ecosystems and pose a threat to biodiversity (Suárez et al., 2002; Oliver & Morecroft, 2014).

Climate change, as a global problem, requires significant, immediate, and unprecedented global cooperation to accelerate the transformation. Climate change can be mitigated by the reduction of GHG emissions and carbon sinks (IPCC, 2104). The Paris Climate Agreement set the goal to limit the temperature increase to 1.5°C above pre-industrial levels (UNFCCC, 2015). Climate policy is facing issues of equity, justice, and fairness. There is a requirement for climate policy to balance various interests in different societies, current needs, and future generations. Although there is a complex coupling of systems between mitigating global warming and eradicating poverty, it is an urgent task to seek practical climate actions and strategic methods to achieve 17 Sustainable Development Goals (SDGs).

1.2. Urban mobility and human related GHG emissions

The world's cities account for 60-80% of energy consumption and 75% of carbon emission, although it occupies only 3% of the world's land (UN, 2015). The world's population continues to grow, with an estimated 7.7 billion people in 2019, and this number could rise to around 8.5 billion in 2030 (UN, 2019). They are accompanied by increased urbanization. According to the UN (2018), about 60% of the world's population would live in urban areas by 2030, which also has a result in growing energy consumption in urban areas. Big cities play central roles in reducing GHG emissions and sustainable development. Urban mobility is urgent to take a shift to a more sustainable model with new technology nowadays.

Mobility is fundamental for economic advancement and social development by connecting people and goods on a large scale (UN, 2016). Movement connects individuals and regions freely as the basement of the national and international trade and global industry, improves social communication and health and well-being (Zhang & Witlox, 2019; IPCC, 2014). Nowadays, road systems have brought accessibility, connectivity, and convenience but at the cost of introducing noise, pollution, urban sprawl, and increased social isolation (Flügge et al., 2017).

The last decade has witnessed the rise of academic interest in the relation between climate change and transportation under the growing awareness about climate challenges (Schwanen et al., 2011). The transportation sector accounts for 14% of global GHG emissions in 2010, among which automobile-oriented transportation has increased fossil fuel consumption that caused the majority of carbon dioxide (CO_2) emissions growth in the air (EPA, 2019). GHG emissions produced by transport sectors are difficultly reduced, and the growing trends have continued in the last few decades (Schwanen et al., 2011). In the European Union (EU), approximately a quarter of total GHG emissions came from transportation in 2017, within which road transport contributes to a 23% increase in GHG emissions over 1990 levels (EEA, 2019). Energy use is the most extensive sharing of GHG emissions (IPCC, 2014), and transportation activities account for about 25% of world energy use (Rodrigue, 2019). The transport sector of passengers (57%) accounts for the most significant final energy consumption (IPCC, 2014). In other words, transport has increased both its relative and absolute levels of GHG emissions.

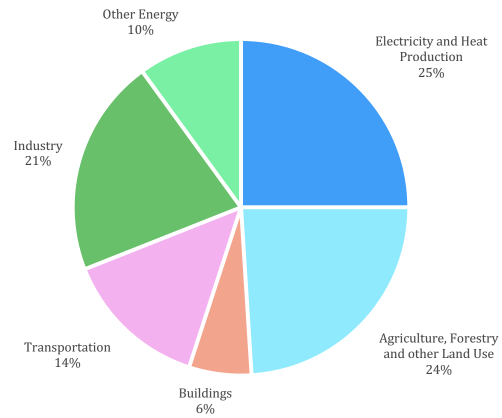


Fig. 1. Global GHG emissions in 2010, source: IPCC 2014

With a global shift to decarbonization and sustainable development, the transport sector is also supposed to reduce GHG emissions. Transport is a complex system with various of infrastructures, services, and management, like means of transportation, fuels, roads, rails, agencies, regulations, prices, norms and values and so on, and by no means, one element in the system can be isolated from the whole (Schwanen et al. 2011; Urry, 2007). It is the same that climate change mitigation in the transport sector needs a combined effort. Many studies about the decarbonization in transportation have considered many strategies focusing on different elements: transportation technologies, the price or commodity value of carbon, the "hard" infrastructure, the "soft" psyche and behavior of users, and the institutions governing transport systems (Schwanen et al. 2011). Transport technologies are used in vehicles, aircraft, and ships to improve energy efficiency or use clean energy. Some researchers consider alternative power and alternative fuels from renewable sources, such as biofuels, hydrogen, and electricity to reduce GHG emissions (Mofijur et al., 2016; Chang et al., 2017; Demirbas, 2007; Salvi and Subramanian, 2015; Lee et al., 2017). Electric vehicles (EVs) are another trend of transport technology that aims to contribute to sustainable transport in the future (Sperling, 2013; Eberle and Von Helmolt, 2010). Even though with the extensive studies of new transport technologies, Schwanen et al. (2011) claim that "technology's longterm contribution to decarbonization is likely to depend on macroeconomic conditions," both global fuel prices and carbon taxation. Therefore, alongside transport technology, economic instruments and policies are also essential to lead a decarbonization market choice.

Moreover, transportation infrastructures that aim to improve the accessibility of sustainable mobility alternatives, such as walking, cycling, public transport, high-speed trains, and so on to reduce the dependency on vehicles (Rafiemanzelata et al., 2017; Pucher and Buehler, 2017). The integration of public transportation and urban land use brings long term benefits to low carbon cities (Cervero, 2016). Finally, the changes to the travel modes, travel behaviors, lifestyles, and values also contribute to environmentally sustainable mobility and decarbonization (Barr and Prillwitz, 2014).

1.3. Data-driven innovation

The fourth industrial revolution has disruptive impacts on every domain. Data-driven technology, as a central feature of the fourth industrial revolution, has disrupted routine in a variety of industries and rewrote new solutions to growing challenges. Although the extensive use of big data in our life, big data is a somewhat buzzy word, which describes a massive volume of data that has been collected, stored, and analyzed. Nowadays, big data applications have spread in every domain of society. Data mined from digital platforms, such as social media and traffic sensors, reflect people's needs, preferences, and experiences. Because of the fast development of the data storage and data process technology, the growing data repository becomes more productive and more accurate.

On the one hand, the more precious data environment can be used for policymaking and governance. On the other hand, the open accessibility to big data repositories for the public and developers has provoked more innovative applications in different domains that help to solve the social problems and promote people's life. To some level, data-driven innovations are more likely to catalyze new national or regional development based on collected changes. Therefore, it was also mentioned to promote sustainable development. The data revolution for sustainable development is an integration of data from new technologies and traditional data in the aim to "produce high-quality information with more details and at higher frequencies to foster and monitor sustainable development" (UN, 2014).

The discussion of data-driven technology is not only about practical technology progress and future promises. Although data-driven technology has promised many benefits in daily life, at the same time, its side effects and risks have raised more and more concerns today. There are growing concern about the negative impacts of the full use of data applications, namely privacy protection and legal regulation. The limitless data collection may cause a considerable known and unknown problems: potential use of data for monitoring and surveillance; data subjects are not aware of the situation of data processing and related consequences (Acquisti, Brandimarte & Loewenstein, 2015); conducting of data collection may result on undefined purpose (Mantelero, 2015). Individuals are not aware of what kind of personal data is collected and how the data are used by the companies that hold them (Diaz and Gürses, 2012). The technology giants, like Google, Apple, Facebook, Alibaba and Tencent, are not willing to share and pool data collected by their dominant services (Chris & Aliya, 2019). There is a growing awareness nowadays that big companies have made a massive number of users' data for malicious surveillance, profiling, or manipulation uses' behaviors, which also calls for more supervision and regulation.

1.4. Smart city and smart mobility

In the city level, urban data computing and underpinning technologies have developed fast in the last decade. Smart cities, as a leading paradigm in urban planning, has gained more and more popularity and prevalence with promises to reduce carbon emission because of digital solutions. With the advancement of storage and analysis technology and the extensive use of smartphones, Bibri (2019) claims that the smart city is becoming more and more data-driven. The big data collected from users is not only used to measure the city and people who live there but also provides a chance to facilitate new transformations.

The Mobility of people and goods is not only critical to economic, social development but also plays a vital role in the fulfillment of freedom. The improvements in the mobility revolution has promoted the human's ability to move and change the history. In the background of rapid, widespread information technologies, Mobility needs more chances to become smarter. Smart Mobility is one of six critical factors of smart city, except smart governance, smart people, smart living, smart economy, and smart environment (EU, 2014). Smart Mobility aims to create intelligent transport systems and efficient, interoperable multi-modal public transport (Bibri, 2019). The trends of technological innovation, such as autonomous driving, sharing mobility service, are leading smart mobility in the future. The emphasis on decarbonization due to climatic challenges is increasingly combined with the rise of smart solutions based on automation and big data collection. Data-driven smart Mobility can not only improve the connectivity in the city but also combat climate change by alleviating congestion, improving energy efficiency, and reducing unnecessary transportation.

However, the promise of growing "smart" trends to tackle urban challenges is accompanied with worries to balance various interest. Mantelero (2015) claims the smart city should not be characterized by "a mere data-driven and efficacy-based approach," but also with concern on "the potential social effects of pervasive interconnected environment and related risks."

1.5. Research aim and research questions

Nowadays, car-oriented transport mode under the context of global urban sprawling contributes to continuous GHG emissions growth. GHG emission is the primary driver of the accelerating global warming. This thesis specific aim is to explore the potential of data-driven smart mobility in achieving Sustainable Development Goal 11.2, "provide access to safe, affordable, accessible and sustainable transport systems for all," and Sustainable Development Goal 13.2, "take urgent action to combat climate change and its impacts." The widespread applications of data analytics in various domains has brought great promises to tackle urban challenges, such as growing urbanization and environmental problems. This thesis looks into the latest data-driven opportunities in the urban transport sector, as well as barriers.

In order to realize the above aims, two research questions are articulated as follows:

> 1. How can data-driven smart mobility contribute to decarbonization and mitigate climate change? Which innovations drive a data-driven transition to realize smart mobility at present?

This part explores the relationship between data-driven smart mobility and climate change. Specifically, what are the data-driven smart mobility? What kind of data needs to be collected to reduce carbon emissions? Except reduce GHG emission, are there any other ways to mitigate climate change? What are the opportunities and limitations of data technologies?

> 2. Hangzhou, as a case, what data-driven intelligence on the transport sector has been implemented at present? What collaboration is needed among stakeholders to achieve a transition to smart, sustainable transportation in urban regions? What are the disadvantages or limitations caused by data collection of public traffic?

The second part of the research aims to learn from the current practice of data-driven smart mobility in Hangzhou. What is the current transport situation in Hangzhou? What kinds of travel modes does Hangzhou have? What kinds of transport policies have been implemented? What is the government's role in the urban transport system? What is the collaboration of stakeholders in the urban transport system? In view of the importance of the transport data, how the city has dealt with data? What are the benefits and limitations brought by data-driven smart mobility?

1.6. Limitations

This project has the following limitations:

First, data-driven smart mobility is multidisciplinary research ranging from information technologies to transport planning, policymaking and social practice. Because of limited time and space, this paper cannot cover every factor of data-driven smart mobility. Instead of going deep to data science or policymaking, this study has a focus on exploring potential solutions to access data-driven smart mobility in urban, at the same time explaining the possible barriers.

Secondly, the project had planned to combine a semi-open interview in the case study, but due to the impact of the pandemic and the inability to contact the relevant government officials, it was not possible to complete the interview. It is a widespread problem with policy research on China that policy documents are not easy to access for the public. On the one hand, the government is relatively cautious about data openness. On the other hand, staff responsible for specific data collation often do not have the authority to disclose data to the community, while officials who do have the authority to do so are less aware of specific information. Elemental civil servants are less willing to be interviewed by individuals.

Finally, there are limited accesses to the government documents, some of which are not directly available to the public or need an application from certain institutions with certificates. Besides, considering the market competition and transport authorities' protection of data, private data technology companies are not willing or not able to share certain data. Therefore, the author's access to the information of policies and the implementation of smart mobility projects in Hangzhou is limited.

1.7. Structure of the report

The research has structured the content as follows. Chapter 1 is the introduction with a necessary discussion about the megatrends, starting point of this research, and an overview of the study. Chapter 2 provides three theories guiding to conduct this research. Institutional theories can be used to understand the deep reasons for smart mobility transition in today's society. The travel behaviors theory was used to design the questionnaire with objectives of travel behavior and attitudes, as well as discuss the data application for travel behavior change, including travel modes and travel attitudes. Moreover, the stakeholder theory was used to map the actors involved with the smart mobility transition in cities. Chapter 3 introduces the methodology of a combination of a literature overview and a case study. A literature overview of the interdisciplinary researches was used to study relevant topics of sustainable transport, smart paradigm, data science, and smart mobility. Document analysis and questionnaires were used to conduct the case study of Hangzhou. Chapter 4 presents the results of the literature overview and case study. The literature overview was conducted in three categories, climate change and sustainable transport, smart trends under urbanization, and smart mobility and transport data. Significant trends and concepts were presented at the beginning of Chapter 4 to gain a holistic view of the study of data-driven smart mobility. The second part of Chapter 4 shows the results of the transport situation and smart initiatives in Hangzhou, as well as the questionnaire results. Chapter 5 gives a conclusion and discussion, further with suggestions for future study.

2. Theoretical framework

2.1. Institutional theory

Institutional theories can be used as a tool to understand social technology development. Information Communication Technology (ICT) cannot automatically create a smart city without human capital (Shapiro, 2006). The digital transition in the urban transport system involves profound changes in various institutions and authorities. Institutions have been acknowledged the essential role in "shaping the space and nature of transition," and institutional theory has been applied to the analysis of socio-technical transition (Andrews-Speed, 2006). The institutional pressures, either from external sources such as users, professions, and government agencies, or internal sources such as legitimated rules and logics embodied within the technologies, push individuals, groups, and organizations to take actions to fit technology. Institutional concepts are used to interpret and analyze the data in the information system.

The institutional theory focuses on the rise and character of the modern world society, where modern governments are affected by global instruction and more linked to the external world (Meyer, 2010). Three elements, including market, hierarchy, and community, are used to examine the role of institutions in climate change policies. Institutions hold the society together and give the social purpose and ability to adapt. Institutions play critical roles in the context setting on climate change by creating and interpreting scientific knowledge and selecting political strategies. At the same time, institutions are central to understanding and responding to global environmental issues (O'Riordan et al., 1998). Institutions apply to structures of power and "socialized ways of looking at the world as shaped by the communication, culturally ascribed values, and patterns of status and association" (O'Riordan, T. & Jordan, A. 1999). "Top-down" rule-bound structures that intervened in the dominant social order provoke huge shifts in economic organization and social behavior. Institutional theory suggests that valued information can be gained from written sources, such as documents, policies and strategies, but also unwritten information, such as behavior, moral beliefs and worldview of individuals (Kriukelyte, 2019).

On the one hand, in the case of Hangzhou, institutional theory can be used to understand the leading role of regional government in the smart transition in the transport sector. On the other hand, the institutional theory is used to guide data collection about the transport situations in Hangzhou through document analysis. Institutions make social practice possible through collective resources in a specific framework with regulations, normative, and rules (Scott, 2018; Mukhtar-Landgren et al. 2016). In the case study, many government documents and resources, including state-level policies and regional policies, have been studied to understand the current smart mobility practice in China. Because of the limitations of accessing print documents, the study mainly used electronic materials, including related academic papers, policy documents in official websites, official media, and company pages.

2.2. Travel behavior theory

The theory of travel behavior is one of the most essential theories in transport management and urban planning (Meng et al., 2019). Travel behavior is recognized as a complex process of travel decision making, including modal travel choice, route choice, time, and destination choice (Wen & Koppelman, 2000). Traditional behavior refers to an observable act (Forward, 2004). Behavior is considered as the result of subjective intrapersonal processes and objective environmental dimensions (Lewin, 1936). Many factors affect travel behavior, such as travel mode, travel time, travel cost, spatial structure of a city, land use and road networks. Van Acker et al. (2010) consider that travel behavior is derived from short term activity decisions, medium-term location decisions, and long-term lifestyle decisions. From different levels, travel behaviors have different impact factors. Three levels, an individual level, the social environment, and the spatial environment, can be used to explain different travel modes (Van Acker et al., 2010).

Even though there is no restricted lifestyle theory, many types of research (e.g., Kitamura et al., 1997; Lanzendorf, 2002; Collantes and Mokhtarian, 2007) claim that lifestyle influences the activity and behavior. Travel behavior is also one kind of social behavior, also influenced by dominant social ideas. On the other hand, from an individual level, travel behaviors are influenced by personal attitudes that are intertwined with self-selection. An attitude can be defined as a psychological construct that is composed of affective, cognitive, and behavioral components (Eagly and Chaiken, 1993). Travel behavior theory has highlighted the role of attitudes and preferences in travel behavior (Boarnet and Crane, 2001; Ye &Titheridge, 2017).

Sustainable travel behaviors can mitigate the impacts of transport on climate, which makes it the largest sectoral emitter (Bell et al., 2016). As cities are still faced with growing automobile traffic today, travel behavior changes are needed to reduce GHG emissions in cities today. In this project, as a supplement to document analysis, a qualitative survey is conducted to understand travel behaviors and travel attitudes towards data-driven smart mobility and climate change of people living in Hangzhou. The travel behaviors theory is used to design the survey questions with objectives, including travel modes and travel attitudes. At the same time, the interpretation of travel behaviors and attitudes from individuals helps to understand the social meaning of transport transition with data features.

2.3. Stakeholder theory

Stakeholder theory is used to identify stakeholders and clarify the relationships between stakeholders. Stakeholder theory has gained wide popularity in social and economic studies, especially with the growing emergence of non-governmental organizations and business companies. A stakeholder is initially defined as a “group of people who can affect or can be affected by the achievement of the organization’s objectives” (Freeman, 1984) and then “those groups who are vital to the survival and success of the organization” (Freeman 2004). The concept was widely redefined as the organization as well in later development (Fontaine, Haarman & Schmid, 2006).

According to Jones and Wicks (1999), stakeholder theory can be divided into two categories, social-based theory and ethics-based theory, while the first one focuses on instrumental and descriptive variants, and the second one focuses on normative issues. Descriptive stakeholder theory is one of the social-based stakeholder theories, which can be used to describe actual behavior (Jones, 1994). Descriptive stakeholder theory focuses on how stakeholders behave and how they view their actions and roles (Fontaine, Haarman & Schmid, 2006).

From data collection, data process, data storage to data regulation, big data applications involve different stakeholders’ cooperation. Stakeholder theory can be used to map the actors involved with the smart mobility transition in cities. The descriptive analysis of the data-driven smart mobility system in Hangzhou involves stakeholders analysis: 1) who are the current stakeholders? 2) what are the roles of stakeholders in the digital transition? 3) how do stakeholders tackle with the data access? The right to access and reuse data is the main point of discussion of data (Kriukelyte, 2019). The stakeholder theory can also be used to identify the complicated relationship among the data-related partnership.

3. Methodology

This qualitative research is conducted with a combination of a literature overview and a case study. A literature overview is used to understand the leading trends of transport study and identify key elements in transport and data science. A case study is conducted to learn the current practice of data-driven smart mobility in Hangzhou. Specifically, the work is divided into the following steps:

3.1. Literature overview

This study makes a literature overview on the interdisciplinary researches in relevance to the topics of sustainable transport, smart paradigm, data science, and smart mobility. The starting point of this study is to find digital solutions for climate change mitigation in the transport sector. In view of the global trends to see sustainable transport and data analytics as promising responses to tackles with climate change problems, the selection of the literature began with keywords searches, such as "sustainable transport", "big data", "smart mobility", on the library website of the Uppsala University and Google Scholar. As an interdisciplinary subject, the researches of smart mobility have different focus ranging from urban transport planning to innovative data technologies. Considering of the research aim and questions, the literature selection narrows down of literature overview on three main fields: "the trend of sustainable transportation", "the smart paradigm in urban mobility", and "smart mobility and data security concerns".

Sustainable transportation is associated with other sustainable development goals. The first part of the literature overview is needed to build a linkage between transportation and climate and learn how to access sustainable transportation. "Climate change," "sustainable transportation/mobility," and "green travel" are the main words used for searching on this topic. The knowledge of smart paradigm in the urban domain is necessary to understand how the data-driven approaches can be used to tackle urban challenges. "Smart city," "smart sustainable/sustainable smart urban/city/urbanism," and "big data" have been researched. Finally, the literature on smart mobility and data concern is also needed to explore the potentials of data-driven approaches and limitations as well. "Smart mobility," "data-driven smart mobility," "mobility as a service (MaaS)," and "data security" are used for searching literature resources in the third section.

Because of fast advances in information technologies in the last few decades, and its wide application, diffusion and integration into numerous domains in urban challenges, there is not dominant research on the data-driven smart mobility, rather with various claims and categories. This research has selected the most cited and newest articles and books related to smart mobility in the context of climate change in order to provide certain credibility. Excepts for several explanations on the development of concepts, most resources used in the literature overview comes after 2010. Besides, most recent reports from institutions and international organizations are also included interaural resources.

3.2. Case study

The case study is widely recognized as a useful method for social science studies. The case study is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context" by using multiple sources (Yin, 1984). The case study enables the researchers to examine the data and knowledge within a specific context (Zainal, 2007).

This research selects Hangzhou as the case to review the current smart mobility approaches driven by big data strategy and accesses the potentials to address climate change. In China, more than 700 cities are or will be engaged in the smart city or digital city competition with the widespread use of ICT, Internet of Things (IoT), and big data (Zhang, 2020). Hangzhou is renowned for its leading position in information technology in China. The case study of Hangzhou is conducted by a combination of document analysis and a questionnaire. The document analysis has a focus on the transport situation, transport regulations, and data practice. Moreover, the survey aims to have a holistic view of travel behavior and travel attitudes towards smart mobility from citizens living in Hangzhou.

Specifically, the following sections are presented:

- Case selection. The background of Hangzhou as a leading smart city.
- Travel modes in Hangzhou, basic transport situation in Hangzhou
- Efforts to mitigate climate change in the transport sector
- Data-driven smart mobility system in Hangzhou
- Open transport data
- Questionnaire results
- Results of case study

3.2.1. Document analysis

Document analysis is a widely used method in qualitative research by reviewing or evaluating documents (Bowen, 2009). Documents act as social facts and are used to process meaning, gain understanding, and develop knowledge (Corbin & Strauss, 2008). In the context of institutional theory, the documents, such as government plans, administrative regulations, laws, and rules, are collected to understand social practice. Document analysis is an effective way to conduct research when there are limits to field observations and interviews. It was used as an effective way to collect data and analysis the practice in Hangzhou because there was limited access to entity documents, field observations, and interviews, especially under a pandemic situation. Electronic material is the main type of data resource. Institutional theory highlights to understand social practice through institutional regulations and resources. The documents analysis has a focus on the transport situation, transport regulations, and data practice. Moreover, because the practice of smart mobility in the urban is independent with different stakeholders, it is also necessary to collect resources from different participants to understand their roles, driven interests, and also conflicts. Many types of documents were collected in this research, mainly including government documents, government statistics, official media, peer-reviewed researches, organizational or institutional reports, company blogs, and public records. Specifically, policies were mainly collected from the State Council of PRC, the Transport Ministry of PRC, and Office of Hangzhou City Traffic Congestion Control; statistics were mainly collected from Hangzhou Bureau of Statistic, academic research, and presses; information about companies were mainly assessed from company home pages.

3.2.2. Survey study

Because of the limits to conduct a field survey, this study conducts a quantitative data collection with an online questionnaire. The questionnaire with 22 questions was conducted in order to gain a holistic picture of travel behavior and travel attitudes of the citizens living in Hangzhou. The questions, mainly designed based on the travel behavior theory. Four topics are covered in the questionnaire: the general information of respondents; travel behavior, including travel modes selection, travel time, travel cost, etc.; attitudes towards decarbonization and climate change; attitudes towards data collection, application and security (For whole survey questions, see Appendix: Smart mobility and low-carbon travel in Hangzhou). Meanwhile, in order to reach as many respondents of different ages and backgrounds as possible, the survey was based on the most popular social media in China, WeChat. Besides, the Tencent Questionnaire with location screening function was used to target people living in Hangzhou.

4. Results

4.1 literature overview

Data-driven smart mobility is an interdisciplinary research field. A literature overview is used to looks into understand the leading trends of transport study and identify key elements in transport and data science. In this section, the results of the literature overview are presented in three sections. First, under the background of climate change, sustainable transport is associated with sustainable development. Second, with the megatrend of global urbanization, the paradigm of smart trends is prevalent in urban studies. Finally, there is an overview of smart mobility study and data concerns.

4.1.1 Climate change and sustainable transport

Climate change refers to a continued shift in the mean and/or the variability of its properties that can be measured (Hegerl et al., 2007). Both natural internal and external forced changes can lead to climate change that lasts for an extended period, typically decades or longer. Climate warming is caused by the higher incoming energy than outgoing energy in the earth. The term "climate change" is often used to refer to global warming, the long-term surface temperature growth observed since the pre-industrial period, caused by anthropogenic activity primarily the use of fossil fuels (Holly et al., 2019). Greenhouse gas is the main reason accounts for climate change. Greenhouse gases are gases that trap heat in the atmosphere (EPA, 2019). Among different greenhouse gases, carbon dioxide accounts for the most significant share of radiative forcing since 1990, which will continue to grow in the future (EPA, 2019). Greenhouse gases, mainly carbon dioxide, produced by human activities have caused an overall climate warming, approximately 1°C (likely between 0.8°C and 1.2°C) above the pre-industrial period (EPA, 2019, IPCC, 2019). CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78 % of the total GHG emission increase from 1970 to 2010 (IPCC, 2014).

The transportation sector accounts for 14% of global GHG emissions in 2010, among which automobile-oriented transportation has increased fossil fuel consumption that caused the majority of carbon dioxide (CO_2) emissions growth in the air (EPA, 2019). And road vehicles account for around 80% of the increase (IPCC, 2014). With a global shift to decarbonization and sustainable development, therefore the transport sector is also supposed to contribute to mitigating climate change by reducing GHG emissions.

According to UN (2015), sustainable transport is the provision of safe, affordable, accessible, efficient, and resilient services and infrastructure for the mobility of people and goods in order to realize economic and social development to benefits today and future generations. Sustainable transport has a close relationship with other Sustainable Development Goals. For example, sustainable transport provides safe and affordable mobility that reduces traffic deaths and hunger. Moreover, efficient and resilient transport reduces adverse environmental impacts and integrates climate change goals.

UN (2015) claimed that policy development and implementation, financing, and technological innovation are the critical areas for efforts to access sustainable transport. Many studies on reducing GHG emissions in the transport sector have considered various of strategies focusing on different elements: transportation technologies, the price or commodity value of carbon, the "hard" infrastructure, the "soft" psyche and behavior of users, and the institutions governing transport systems (Schwanen et al. 2011). Transport technologies are used in vehicles, aircraft, and ships to improve energy efficiency or use clean energy. Some researchers consider alternative power and alternative fuels from renewable sources, such as biofuels, hydrogen, and electricity to reduce GHG emissions (Mofijur et al., 2016; Chang et al., 2017; Demirbas, 2007; Salvi and Subramanian, 2015; Lee et al., 2017). Electric vehicles (EVs) are another trend of transport technology that aims to contribute to sustainable transport in the future (Sperling, 2013; Eberle and Von Helmolt, 2010). Even though with the extensive studies of new transport technologies, Schwanen et al. (2011) claim that "technology's long-term contribution to decarbonization is likely to depend on macroeconomic conditions," both global fuel prices and carbon taxation. Besides, Banister (2008) claims that "the sustainable mobility approach requires actions to the needs to travel, to encourage model shift, to reduce travel length and to encourage greater efficiency in the transport system". Therefore, alongside transport technology, economic instruments, travel behaviors, policies are also essential to lead a decarbonization market choice.

4.1.2. Smart trends under urbanization

- Smart city

Two trends, global urbanization and smart technology contribute to the popularity of smart cities nowadays (Albino, Berardi & Dangelico, 2015; Bibri, 2019). The concept of smart cities is widely used to combat the challenges in city development and management but without a commonly accepted definition (Ruhlandt, 2018; Albino, Berardi & Dangelico, 2015; Gil-Garcia, Pardo & Nam, 2015).

The concept of a smart city has its roots in the "cybernetically planned cities" in the 1960s and been developed associated with networked or wired cities since the 1980s (Bibri & Krogstie, 2017). The smart city was first used in the 1990s. The rise of popularity of smart cities happened after the 2008 global financial crunch when the society was in the hope of fueling business, especially the intervention of IT companies, by rebranding urban in the creation of tech-utopia images (Thornbush and Golubchikov, 2019; Söderström, Paasche & Klauser, 2014). The concept of the smart city shifted its initial focus on smart building, particularly in energy efficiency to a broader domain, finally upscaled to the whole city level after 2008, including transport, government, people, and so on (Thornbush and Golubchikov, 2019).

IBM launched an extensive smarter planet advertisement since the end of 2008, and the smart city was denoted "instrumented, interconnected, and intelligent city in the corporate document (Harrison et al., 2010). Townsend (2013) claims the smart city is always combined with ICT that is applied to infrastructure, architecture, daily objects, and even our body to address social, economic, and environmental problems. Similarly, Song et al. (2017) also highlight the first and foremost character of smart cities is "the strategic, systematic, and coordinated implementation of modern ICT applications." According to Ruhlandt (2018), smart cities can be defined as a mix of human, infrastructural, social, and entrepreneurial capital that are merged using new technologies to address social, economic, and environmental problems. In other words, currently, the smart city is a more holistic concept and involves more aspects in cities and more than a tech-centric image. However, (Söderström, Paasche & Klauser, 2014) criticize smart cities are part of language games around urban management and development and call for moral imperatives in urban governance.

Overall, there is no agreement on the definition because smart cities have been applied in a number of domains. Albino, Berardi, and Dangelico (2015) conclude the applications of the term smart city can be divided into two categories, "hard" fields, such as buildings, energy grids, natural resources, water management, waste management, mobility, and logistics (Neirotti et al., 2014), and "soft" domains, such as education, culture, economy, policy innovations, social inclusion, and government. Kitchin (2014) claims that there are two broad understanding of the notion of the smart city: 1) increasing computing and digitally instrumented devices are used for regulating and managing the city with advanced technology; 2) networked infrastructures enable innovative and creative society development by enhancing the policies related to human capital, education, economic development, and government. Wide application of ICT is the highlighted in the discussion of smart city (Kramers, et al., 2014)

Technologies, people, and institutions are in the central position in smart city building. The university, industry, and government are three leading agencies in the context of smart cities (Lombardi et al., 2012). Six components of a smart city are widely used to cover different aspects in urban, including smart economy, smart people, smart government, smart mobility, smart environment, smart living (Lombardi et al., 2012) (Fig. 2). Ranking smartness in smart cities is another trend. The University of Vienna has ranked 70 middle-sized towns according to the criteria defined in Giffinger et al. (2007). Many measurements are used to rate smartness in cities. Zygiaris (2013) highlights urban environmental sustainability, green economies, real-time system responses made by smart meters and infrastructure sensors, communication and accessibility to data, content, services, and information, intelligently responsive operation, innovation environment for new business opportunities in his measurement system. From product level, Porter and Heppelmann (2014) claim the capabilities of smart are based on four levels, monitoring, control, optimization, and autonomy. Moreover, in the city level, smartness is also considered as a tool to improve efficiency and economic conditions which leading a comparison between a bunch of global cities and international cities.

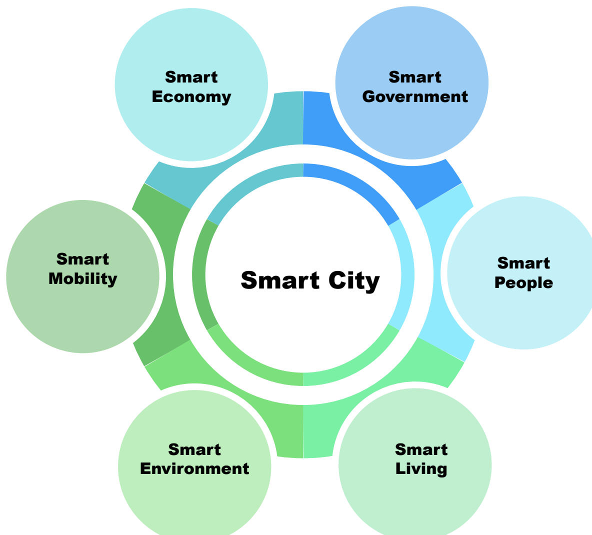


Fig. 2. Six pillars of a smart city diagram, Lombardi et al., 2012

- Big data

Compared with big data, traditional databases, in another term, "small data," are usually collected based on specifically limited samples, such as case study, questionnaire survey, and interview. However, big data is usually based on a continuous basis and can generate more sophisticated, wide-scale, finer-grained, real-time understanding, and control (Kitchin, 2014). The city is the most significant source of big data generation where digital infrastructure and infrastructure have continuously produced "big data". The growing smart cities have integrated ICT strategy and digital infrastructure into the urban fabric for planning and regulatory. Growing real-time data is collected by digital instrumented devices, such as fixed networks, wireless devices, sensors, cameras, transport services, utility services platforms, building management systems, smartphones, and so on. The collected data has been connected, integrated, and analyzed for a better understanding of the city and promote decision and policymaking (Kitchin, 2014).

Big data is not only about the volume, but also about the complexity. Big data has four characters (4Vs), volume, velocity, variety, value (Song et al., 2017). Data is overgrowing in recent years with the advancement of information technologies. For instance, camera sensors in the roads generate a significant number of data every day. The velocity of the data transfer has grown fast with the advancement of network technology and growing needs for social applications. New types of data and format, especially from video and pictures, are expanding various unstructured data. Moreover, data has shown tremendous potential to create economic value by mining, protect, analyze, and use data appropriately.

Kitchin (2014) divides the sources of big data into three categories, directed, automated, and volunteer. Directed data collection refers to traditional forms of surveillance, such as CCTV, photographs, 2D, or 3D mapping. Automated data collection includes digital devices, capture systems, transaction records, clickstream, sensed data, and so on. Typical volunteer data collection is social media. Besides, the third wave of IT-driven transformation embeds sensors, processors, software, and connectivity in products, at the same time, coupled with data storage and process in the cloud (Porter & Heppelmann, 2014). According to (Porter & Heppelmann), intelligence and connectivity of smart technology are based on four areas: monitoring, control, optimization, and autonomous. Monitoring is the ability to measure devices' condition, operation, usage, and external environment through various sensors, while control is the ability to interact with systems with remote commands or algorithms. Algorithms and analytics are targeted to achieve higher-level objectives, such as enhance performance, predict, and repair. Autonomous is the final result of monitoring, control, and optimization that aims to realize communication and intelligence, namely, Artificial Intelligence (AI), machine learning. Machine learning enables computers to automate programming based on continuous education from available data.

- Smart Sustainable urbanism

More and more countries have set decisions to make their cities smart and sustainable cities in the hope of grabbing the benefits of the big data economy. The concept of "smart city" was less concerned about environmental performance but with a focus on social and economic aspects in the beginning. With the exploration of ICT solutions in solving energy reduction, environmental protection, and urban planning, the highlight of the urban smartness is more associated with environment-centric sustainable urban development (Kramers et al., 2014). Ferry (2008) states that the base of the "sustainable urbanism" is "walkable and transit-served urbanism integrated with high-performance buildings and high-performance infrastructure." The development of sustainable urban development is directly associated with these urban approaches: new urbanism, Eco-city, or sustainable city and smart growth (Yigitcanlar, 2018). Three primary global shifts across the world, namely the rise of ICT, the diffusion of sustainability, and the growth of urbanization, have led to broad concepts of smart sustainable urbanism in the mid-2010s (Bibri, 2019).

Data-driven is the main feature of smart sustainable urbanism. The heart of the smart sustainable urbanism is that "a computational understanding of city systems that brings urban life to a set of logic, calculative, and algorithmic procedures," data-intensive science and interlinking urban big data provide synoptic city intelligence (Bibri, 2019). The subject involves multidisciplinary endeavors, such as urban planning, architects, environmental and social scientists, green energy technologists, ICT technologies, computer and data science, and so on. The growing emergence of data analytics and applications are not only used for wise decision making but also are used to measure smartness and sustainability in a city. Data-driven solutions are providing tremendous potential to solve the growing urban and environmental challenges globally. Smart sustainable urbanism has explored strategic urban planning and development approaches and gained more and more popular among urban planners and policymakers around the world.

4.1.3. Smart mobility and transport data

- Smart mobility

Mobility is fundamental for human freedom, social development, and economic growth. With the smart paradigm applied in every domain, smart mobility is one of the most popular directions in transport research. Smart mobility has deep roots in smart city paradigms, especially digital city and green city, and is one of six domains in smart cities, besides smart economy, smart people, smart government, smart environment, and smart living (Benevolo et al., 2016). Smart mobility is a crucial topic in smart city and impacts on a range of aspects composing life quality and stakeholders' benefits from smart city implementation (Benevolo et al., 2016). Smart mobility is expected to solve a range of traffic problems such as road congestion, traffic accidents, air pollution, noise pollution, increasing GHG emissions with a promise of a clean, green, efficient and flexible mobility system (Wockatz and Schartau, 2015; Benevolo et al., 2016). Smart mobility has been seen as an option to seek a sustainable transportation system with promises of improving efficiency, effectiveness, and environmental sustainability through the use of ICT (Staricco, 2013).

There is no common definition on smart mobility, but with broad agreement on the digitalization transition in the transport system, such as ICT approaches (Sjöman et al., 2020; Flügge, B. ed., 2017; Ringenson et al., 2018). The potential of the application of smart mobility is enormous. Flügge (2017) concludes four layers for smart mobility systems in the future: smart services, smart data, smart products, and smart spaces (Fig. 3). First, in the future scenario of smart mobility, the dissolution of different transport modes leads to a focus on the provinces of mobility service based on customers' direct needs. The smart service requires a comprehensive system, including a mobility platform for route optimization and intermodal, smart parking solutions, automated logistics, a flexible mixture of public transport. Second, real-time traffic information, such as geographic related spatial data, is linked to environmental activity information, where open data is freely accessible and useful. Moreover, smart products collect physical information at the same time are available to exchange and analyze real-time information in the cloud platform. Finally, technical infrastructures, such as 5G technology, are necessary to connect physical space.

Additionally, Benevolo et al. (2016) identify four categories of smart mobility actions: 1) Public mobility, such as electric vehicles, automated driving vehicles, integrated ticketing system, etc.; 2) Private and commercial mobility, such as electric vehicles, automated driving, car sharing, bicycle sharing, etc.; 3) Infrastructure and policies to support mobility, such as smart parking, message signs about mobility, bicycle lanes, integrated traffic lights, control of emissions, regulation of access, etc.; 4) Systems for collecting, storing and processing data.

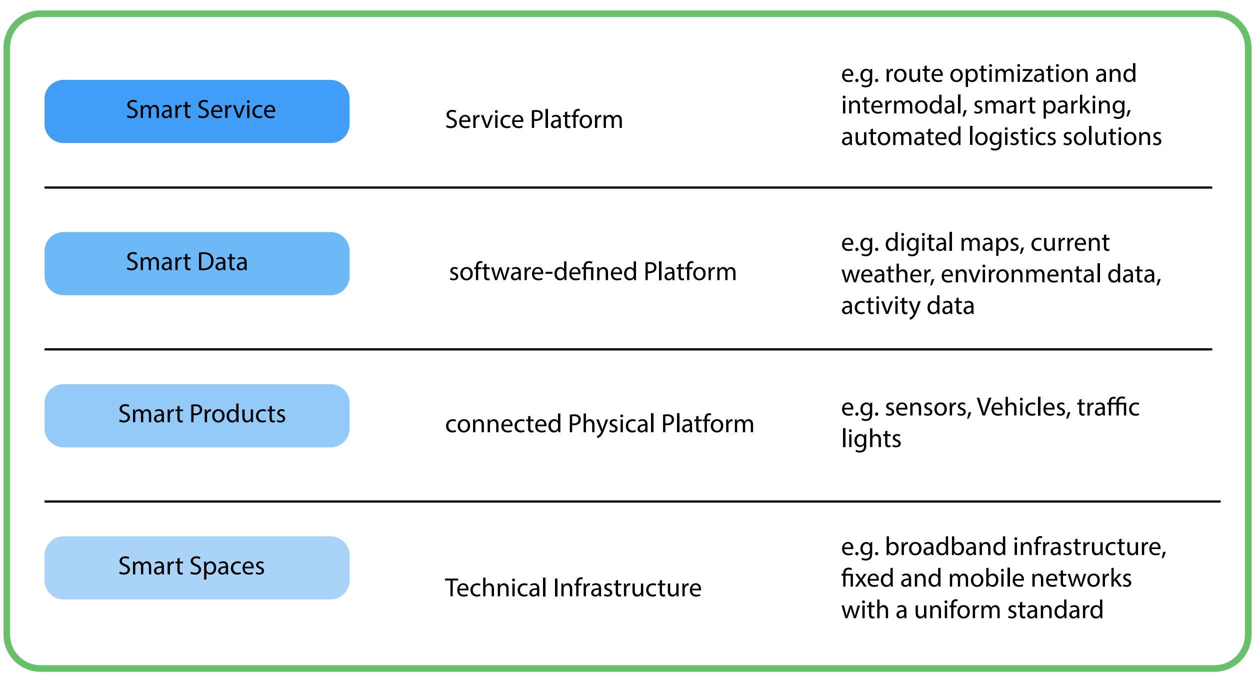


Fig. 3. Structural overview of the smart mobility (Flügge, 2017)

- MaaS

Smart service is in the center of the structural layers of smart mobility. Mobility, compared with other areas, is more likely to involve a service-oriented system bringing changes to roles and responsibilities (Flügge, 2017). Unlike traditional theories of urban mobility, MaaS highlights reaching and accessibility, and underestimates ownership of traveling vehicles. Overall, MaaS combines multi-modal on an easy way, which is based on users needs. The benefits of such kind of technology innovations can digitalize mobility service and therefore reduce or operate transportation demands efficiently.

MaaS, as an innovative understanding of urban mobility, has gained a lot of tractions, which has disrupted traditional transport vehicle ownership and acts as a vision of future mobility(Flügge, 2017). MaaS is a concept used to describe the emerging transport transition of using a digital platform to offer a mix of mobility services that consist of various travel modes (Sjöman et al., 2020; Flügge, 2017; Jittrapirom et al., 2017; Nalmpantis et al., 2019). Mobility service platforms can combine real-time information of the transport modal and create a multi-modal transport system, "indicate the optimal route and allow for intermodal ticket booking without determining one specific transport mode" (Flügge, 2017). This platform connects users and service providers with digital measures (Kramers et al., 2018). The management of an integration of multiple travel modes is the critical point of MaaS. MaaS study has gained traction for mobility management services, "where the customer interface and the business back office are fully integrated" (Mulley, 2017).

ICT-based or ICT-supported mobility service has the potential to reduce GHG emissions from the transport sector by changing mobility models, such as using virtual meetings to reduce business travel and sharing access to spaces and vehicles (Ringenson et al., 2018). The ride-sharing mobility not only provides opportunities for new business models, but also brings many social benefits, such as relief traffic congestion, and a sustainable modal shift (Cramer and Krueger, 2016; Rayle et al., 2016; Hensher, 2018; Paulus, 2019). A sustainable mobility approach can be achieved by reducing travel need and trip lengths, encouraging modal travel shifts, and improving efficiency in the transport management system.

- Data-driven smart mobility

The megatrend of the unprecedented availability of data by the great sources is leading new applications of data-driven technologies. Instead of relying on traditional mathematical models, traffic theory and scant database, the future vision of smart mobility is increasingly data-driven and has a high expectation on big data technology to deliver innovative solutions to address sustainability challenges of movement in the aims to lower energy, reduce GHG emissions, improve air quality and life quality.

Data-driven smart mobility is a term that has gained traction among academia, government, and business. Important transport data collection includes roadway data, vehicle-based data, traveler-based data, and wide-area data (Khan et al., 2017). For roadway data collection, microwave radar is used for vehicle flow, speed, and presence. Infrared sensors are used to measure the behaviors of vehicles. Besides, loop detectors are also widely used in intersection traffic monitoring, incident detection, vehicle classification, and vehicle reidentification applications (Khan et al., 2017; Guo et al., 2015; Coifman, 1998). With the advancement of vision machine learning technology, video data collected by CCTV cameras can be digitized and processed to monitor and manage real-time traffic, incident detection and verification, and vehicle classification. Vehicle-based data includes cars with GPS and electronic toll tags, mobile phones connected with Bluetooth and WiFi. Based on connected vehicle (CV) technologies, the data can be used for more wide applications such as time estimate, route selection, and so on. The third transport data source is based on mobile phone applications, such as a ride-hailing app, social media app where customers provide real-time traffic information voluntarily. Finally, wide-area data collection technology, such as aircraft, space-based radar, monitor traffic flow information through various sensor networks.

Wang & Zeng (2018) divides the data-driven innovation in transportation science into a technology-oriented approach and the methodology-oriented approach (Fig. 4). Technology approaches focus on hardware technology, such as traffic infrastructure, data sensors, and traffic communication devices, while the methodology approach focuses on data processes, data analysis, and decision-making levels. From "soft" view, data science for data analysis and modal building is critical to dig deep value of collected data. For example, different transport modals haven be applied in railway system (Ghofrani et al., 2018), including clustering modals (Shao, Li & Xu, 2016), classification modals (Yin & Zhao, 2016), pattern recognition modals (Hu & Lin, 2016), stochastic modals (Sun et al., 2015), and so on. Many innovators have integrated "hard path" with "soft path" developing integrated data-driven transportation decision support platforms (Wang & Zeng, 2018).

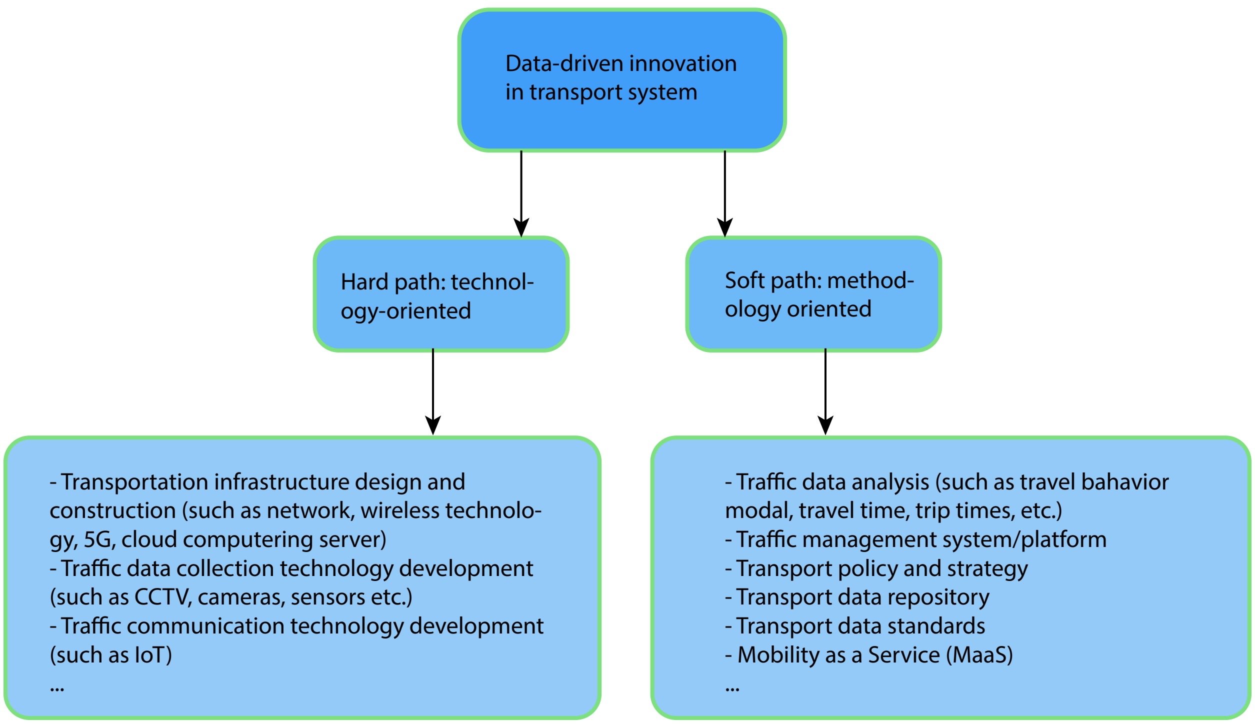


Fig. 4. Data-driven innovation in transportation science (Wang & Zeng, 2018)

Big data are widely used to improve operational efficiency, customer experience, and new business models (Wang & Zeng, 2018). Specifically, data can be applied to predict and estimate various situations, such as real-time travel time prediction (Tak et al., 2016), the estimation of Particulate Matter (PM) 2.5 pollution from truck (Perugu et al., 2016), origin-destination demand prediction (Woo et al. 2016), and the inventory rebalancing through pricing in public bike-sharing systems (Khadilkar).

Furthermore, transport data is also beneficial to the environment by reducing carbon emissions in the city. Typically, transport systems optimization can reduce congestion and GHG emissions based on an optimized route. During disasters caused by extreme weather in the background of climate change, transport data collection and analytic platforms can provide information for vulnerability assessment and early warning (James et al., 2016). The transport data also has the potential for the estimate of GHG emission reduction and costs from the transport sector (IPCC,2014b). By the study of travel behaviors and customer recommendation, data-driven smart mobility is more likely to find opportunities to impact people to choose low-carbon transport mode and reduce unnecessary journeys.

- Privacy and data security

With widespread information technology and smart devices around us, a huge amount of data has been generated or collected every day. Although data-driven technology has promised many benefits in daily life, at the same time, its side effects and risks have raised more and more concerns today. Transport data collectors have potential access to personal data and analyze users' travel habits through location, ticketing, and other transport information. The strategy of mobility services is opening data and creating interoperable data platform in order to dissolve traditional travel modes. The positive impacts of data sharing are characterized, while privacy-oriented use of mobility data is estimated. The limitless data collection may cause a considerable known and unknown problems: potential use of data for monitoring and surveillance; data subjects are not aware of the situation of data processing and related consequences (Acquisti, Brandimarte & Loewenstein, 2015); conducting of data collection may result on undefined purpose (Mantelero, 2015). Individuals are not aware of what kind of personal data is collected and how the data are used by the companies that hold them (Diaz & Gürses, 2012). There is a growing awareness nowadays that big companies have made a massive number of users' data for malicious surveillance, profiling, or manipulation uses' behaviors. Mantelero (2015) claims the smart city should not be characterized by "a mere data-driven and efficacy-based approach," but also with concern on "the potential social effects of pervasive interconnected environment and related risks."

There are many types of private information. Clarke (1997) introduced four types of privacy, the privacy of the person, personal data, personal behavior, and personal communication. Finn et al. (2012) identify seven types of privacy, the privacy of person, thoughts, behavior, communication, association, data and image, and location. Eckhoff and Wagner (2018) proposed five types of privacy, including location information, state of body and mind, social life, behavior and action, and media privacy (images, video, audio, CCTV, and so on.) Anonymity, unlinkability, undetectability, unobservability, pseudonymity, and identity management are six key privacy properties (Pfitzmann and Hansen, 2010).

On the one hand, privacy enhancing technologies (PETs) have been developed in the last decade with more concern about data protection. Process-oriented privacy protection requires improvement in design architectures, testing, and verification, transparency, consent, and control (Eckhoff & Wagner, 2018). On the other hand, from data-oriented privacy, anonymous mobility data is introduced but with limited practicability considering that the data is less valuable with de-identification and can also be re-identification (Mantelero, 2015; Schwartz & Solove, 2011). In addition, data minimization, differential privacy, encryption, secret sharing, and so on have also been used to protect data privacy. Mantelero (2015) highlights the inclusive and participatory environment in a smart context. Data protection should focus on the risk assessments, meanwhile enhance the supervisory authorities. Privacy data protection needs a combination of technologies in every procedure of data collection.

4.2. Case study

This research selects Hangzhou as the case to review the current smart mobility approaches driven by big data strategy and accesses the potentials to address climate change. In China, more than 700 cities are or will be engaged in the competition of smart city or digital city with the widespread use of ICT, IoT, and big data (Zhang, 2020). Hangzhou is in a leading position in smart city competition with substantial resources on information technology. Besides, the city has launched several projects that aim to promote city quality.

The case study of Hangzhou is conducted by a combination of document analysis and a questionnaire. The institutional theory suggests that valuable information can be gathered from resources, such as documents, policies and strategies, behavior, and moral beliefs (Kriukelyte, 2017). The document analysis has a focus on the transport situation, transport regulations, and data practice. Many types of documents were collected in this research, mainly including government documents, government statistics, official media, peer-reviewed researches, organizational or institutional reports, company blogs, and public records. Specifically, policies were mainly collected from the State Council of PRC, the Transport Ministry of PRC, and Office of Hangzhou City Traffic Congestion Control; statistics were mainly collected from Hangzhou Bureau of Statistic, academic research, and presses; information about companies were mainly assessed from company home pages. The analysis of collected data was processed under the guidance of the institutional theory and stakeholder theory and presented from 1) case selection; 2) travel modes; 3) efforts to mitigate climate change; 4) data-driven smart mobility system; 5) transport data open. The design of the questionnaire was based on the behavior theory, with specific objectives of travel modes and travel attitudes. The questions setting and analysis were divided into four sections: 1) basic information of respondents; 2) travel behavior; 3) travel attitudes regarding reducing carbon; 4) travel attitudes regarding data concern.

4.2.1. Case selection: Hangzhou, as a leading smart city in China

Hangzhou is selected as a case to examine data-driven smart mobility approaches implemented in China because it is considered as a leader in smart initiatives in China. Hangzhou is home to many startups and technology companies, such as Alibaba, NetEase, Hikvison, and Dahua technology. With the benefits of advanced technology, the city has started the City Brain project since 2016, and the government aims to build a smarter city in the future. Moreover, as a UNESCO World Heritage Site, the West Lake Cultural Landscape in Hangzhou is described as "an idealized fusion between humans and nature." Hangzhou is known as a young and livable city in China. The government has made great efforts to protect the environment for a long time. For example, Hangzhou started its public bicycle sharing system in 2008 and has the most extensive bicycle sharing system in the world. Because of its leading position in the smart and environmental initials, it is interesting to take Hangzhou as a case for investigation.

Hangzhou is the capital city of Zhejiang province in the east of China, which is close to the Shanghai metropolis, with a population of 21.1 million in the metropolitan area over an area of 34,585 km^2, around 7 million in the city center (National Bureau of Statistics of China, 2010). Hangzhou serves as an economic, political, and cultural center of Zhejiang Province. In the past decades, this city has developed the internet industry with many internet giants setting headquarters in Hangzhou. The city has attracted many young populations since the 2010s. According to government statistics (2019), the regional GDP is CNY 1,350.9 billion in 2018, among which the added value of the digital economy is CNY 335.6 billion, accounting for 24.8% of GDP. At the end of 2019, Hangzhou's residential population exceeded 10 million, reaching 10.36 million, an increase of 554,000 compared with 2018 (Hangzhou Bureau of Statistics, 2020).

In the middle of the 1990s, Hangzhou was a small city with only approximately 430 km2. In 1996, the Zhejiang Provincial Government decided to divide Xiaoshan, Yuhang, and other six townships into the urban area of Hangzhou (Luo Bin et al., 2016). The urbanization process of Hangzhou accelerated between 2000 and 2010. The population of Hangzhou increased from 4.502 million in 2000 to 6.242 million in 2010, with an increase of 38.6%. At the same time, the number of motor vehicles in the main urban area increased from 100,000 to 1 million from 2001 to 2012, with a fast growth rate. The number of vehicles is 2.881 million at the end of 2018, with an increase of 3.1 %, while 2.078 million are private cars, with an increase of 4.0 % (Hangzhou Bureau of Statistics, 2019). The total volume of goods transported is 350 million tons, with an increase of 1.1% compared with 2017, while passenger traffic was 200 million, with a decrease of

9.7% (Hangzhou Bureau of Statistics, 2019). In the main urban area, there are 378 public transportation operating lines, and the mileage of the subway is 117.6 kilometers (Hangzhou Bureau of Statistics, 2019).

The government aims to promote economic development and quality of life through innovation-based urbanization (Anthopoulos, 2019). The city makes efforts to access modern intelligent transport cities (Du et al., 2019). From 2004, the Hangzhou government adopted the Public Transit Priority policy to address growing environmental and traffic problems and has made a transport model shift. The government is engaged in building a smart city and an e-commerce capital. The policies aim to promote information technology industrial development that has fostered a large number of excellent software development and e-commerce companies, such as Alibaba. At the same time, the city has also attracted a large number of talents in software and hardware system services. These have laid a good foundation for the implementation of smart mobility in Hangzhou.

4.2.2. Travel modes in Hangzhou

Hangzhou has most transport modes, including vehicle, bicycle, bus, taxi, subway, boat, and bus rapid transit (BRT) (Banister & Liu, 2013). Except for comprehensive traditional travel modes, Hangzhou is also in a leading position to explore new travel modes.

- Automobile-oriented city

Automobiles are the primary travel mode in Hangzhou. According to the national statistics, around 2.4 million citizens in Hangzhou own a registered vehicle (Yu Li, 2018). Hangzhou is a fast-growing city. It is one of the cities that owns the most cars in China. There are about 2.88 million cars in Hangzhou until the end of 2018. The number of NEV in Hangzhou is 150,000, with an increase of 50,000 in 2018. The city had 31 081 parking spots in 2018 (Ren Yan, 2018). The government implemented a non-contact parking payment system in early 2018 through the cooperation with Alipay, the largest online payment system. Besides, the Hangzhou authorities have implemented a series of regulations or restrictions to control the vehicle number growing in Hangzhou. Even though there are many restrictions towards private car purchases and driving, the central area of the city still has serious traffic congestion problems in rush hours, especially with a growing population in the last decade.

- Public transport: bus, metro and water bus

Hangzhou highlights the priority of public transport when the city organizes urban mobility. Hangzhou Public Transport Company had more than 8000 buses and operated more than 300 bus lines as of 2015 (Zhao, 2015). Multiple branch bus companies operate public buses in different areas. Public buses have the main problem of low speed in rush hours because of a lack of bus lanes and traffic congestion. Hangzhou operated its first metro line in 2012 and is operating four metro lines as of 2019 (Zhao, 2015). The metro has helped to ease traffic congestion a lot. Moreover, as the city is famous for West Lake, there are also water buses operated by sightseeing companies.

- The biggest bike sharing system

Hangzhou has the world's largest bike-sharing service, which acts both as a competition and a complement to the public transport system (Shaheen et al., 2011). The Hangzhou government launched China's first "Public Bicycle Sharing Plan" in 2008, which aimed to provide convenient sharing services for short travel in Hangzhou. The project has reduced traffic congestion and air pollution. There are 10 companies that operated more than 882,000 bicycles when the number of bikes peaked in 2017 (UN Environment Programme, 2018). The Hangzhou Public Bicycle Service Project won the Ashton Award in 2017 because of its contribution to get rid of cars and reduce air pollution (UN Environment Programme, 2018). Moreover, the productive integration of the public bike-sharing program with other public transportation options in Hangzhou also promotes the development of mobility services. The redesigned independent bicycle lane provokes rethinking the priority of the road space in traditional urban space design. In the 1980s, China was known as the "kingdom of bikes." With the growing economic growth since the 1990s, more and more families are turning to vehicles. Since 2008, the "re-emergence" of bike mode in Hangzhou seems unexpected, but it reflected a trend for promoting live quality and reduce GHG emissions.

However, the city was also faced with some problems with the popularity of bicycle-sharing programs. The competition of the bicycle sharing market was particularly intense around 2017 with a huge amount of investments to bike-sharing startup companies. The rapid growth of bicycles in China caused an overcrowded situation, and as a result, many bicycle-sharing companies have closed down. A large number of bicycles have been abandoned or left on the streets. Hangzhou had to reduce the number of bicycles and control the number of bicycles in the city.

- Ride-hailing and car-sharing

App-based ride-hailing started to become popular in China in 2015. Didi launched private car-hailing and social ride-sharing in Hangzhou since 2015 and has become the leading ride-hailing company in China. The ride-hailing service is supposed to use idle vehicles to alleviate the shortage of transport in urban peak hours. Another sharing mobility service in Hangzhou is car sharing in recent years. Approximately 991 car rental companies operated more than 43000 vehicles in Hangzhou as of 2018, 60% of which are new energy vehicles (Yue, 2018). Because of the pressure of vehicle growth, the Hangzhou government has launched strict control of vehicle purchase and license distribution. With the popularity of the "sharing economy" and the demand for easing traffic congestion and reducing carbon emissions, Internet-based car-sharing platforms are developing rapidly. Automotive companies, such as Geely headquartered in Hangzhou, are eager to step into the car-sharing market. Short term rental platforms such as Panda, Rainbow, Muggle, Microbus, and GoFun began to emerge on the streets of Hangzhou after 2017. The car-sharing service started to gain the popularity of citizens who found it was easier and cheaper to use a car-sharing service than owning a private car in Hangzhou.

- New Energy Vehicles (NEV)

Hangzhou has a leading position in using new energy vehicles, which are especially widely used in public transportation. There are 4,778 buses in Hangzhou's central area, of which 2,544 are new energy vehicles. In 2019 the public transport company bought 450 pure electric buses. According to the public transport company, 100% of the buses used in Hangzhou's new built-up area will be replaced with new energy vehicles (Mao, 2019).

Charging stations that supply electric energy for the recharging of plug-in electric vehicles are fundamental for the promotion of electric vehicles (EV). With the advancement of battery technology, electric vehicles have gradually gained popularity. However, the lack of relevant charge infrastructure is another bottleneck to impede the full use of electric vehicles. Hangzhou currently has constructed a network for new energy vehicle charging stations. The central urban district has reached a charging service radius of 3 kilometers. Hangzhou applied the strategy of "Internet + charging infrastructure" as its main feature in the construction of the intelligent management system for energy vehicle charging facilities, which has the functions of finding the location, distance, path, power, usage of public charging pile at any time with App “Hangzhou e Charge.”

4.2.3. Efforts to mitigate climate change in the transport sector

China has long been affected by air pollution because of the manufacturing industry and transportation. In order to mitigate air pollution problems, the Chinese government introduced the “Air Pollution Prevention and Control Action Plan” to reduce the dangerous particulate matter 2.5 (PM2.5) in 2013. The government eliminated the use of coal and shut down coal-fired power stations. In 2013 Beijing ranked 40th in the PM 2.5 pollution concentrations in cities assessed by the World Health Organization (WHO), while this rank lowered to 187th in 2018. The newly released Three-year Action Plan to Win the Blue Sky Defense War 2018-2020 (2018) aims to reduce the emissions of sulfur dioxide and nitrogen oxides by more than 15% in 2015.

Air pollution has long affected most Chinese cities and raised social controversy. Most of the PM 2.5 pollution in Hangzhou comes from emissions of vehicles. With the economic growth and urban sprawl in the last decade, Hangzhou is facing the intensive growth of vehicles, which not only raises the problems of road congestion but also declines the air quality in Hangzhou. The government started to limit the purchase of private cars in 2014 with annual car incremental indicators (Yuan Li & Jian Gang, 2015). In 2014, according to the city’s comprehensive transportation environment, a “dual limit” policy was implemented, that is, peak-hour peak-shift upgrades and car purchase restrictions were implemented. The city’s total car regulation and control were implemented, and the annual car incremental indicators were controlled to 80,000, Much lower than 240,000 in the year before the purchase limit. Car license distribution is also used to control the vehicle growing with a limited number every year. “Three limits,” including limiting the number of cars’ purchase, limiting the number of cars driving in the city center, and limiting the cars with licenses from other cities. The famous West Lake scenery district implements more car restrict regulations because of the massive amount of tourists. (Luo bin et al., 2016). These compulsory measures effectively controlled the automobile traffic in Hangzhou in a short time.

Besides the restrictions to control vehicles growing and driving in the central city, the government is also engaged in developing green travel modes. The government launched China’s first “Public bicycle sharing plan” in 2008, which aims to provide convenient sharing services for short travel in Hangzhou. The government has also developed an innovative battery replacement way for electric taxis. An electric taxi can replace 2 or 3 fully-charged batteries every day and can travel 230 kilometers. The goal of the government is to operate 1,000 electric taxis in the city and finally achieve the goal of zero emissions of taxis (2017). Meanwhile, public bus companies are also engaged in replacing new energy buses and clean energy buses in the future.

Moreover, the government implemented different parking charging standards with higher charging standards in the central area. At the same time, a lot of public parking lots and transfers have been constructed outside the center in order to leave the car outside the city center, which can help to reduce car flux and encourage public transport use in the center.

4.2.4. Data-driven smart mobility system in Hangzhou

The technological transition cannot be understood from the technological level but involves multiple stakeholders. Stakeholder analysis can be used to map stakeholders’ roles, interests, values in urban mobility activities. Data plays a critical role in the analysis of the relation of stakeholders involved in data-driven mobility service. The core objective of data analytics is to make “a wide range of well-informed, strategic, and fact-based decisions” by understanding the observed world (Bibri, 2019). Data collection, data storage, data processing, and decision making are the four main steps of data technology. This section aims to identify main stakeholders, and solve the questions of what kind of data, how the data has been collected and processed in Hangzhou.

- Government

The government plays a critical role in making transportation policy and mitigating climate change since they are responsible for decision making, infrastructure delivery, and urban planning. IPCC (2014) lists some essential items that the transportation sector can adopt to mitigate climate change, such as the operation of black carbon reduction technologies, decreased use of aviation and increased use of renewable biofuels, encourage multimode transportation in urban space, address broader sustainability issues and so on. UN (2016) suggests the governments design and implement policies that make transport sustainable, such as cross-sector integration and institutional cooperation, encourage effective strategies for local levels, balance short-term and long-term planning, and so on.

Like many other cities in China, transport in Hangzhou is also dominated by the regional government. Transport, considered as a critical factor of urban planning and city economic growth, is mainly managed and operated by the government-led public transport companies. Public transport, such as buses, subways, and public bicycles, is invested by government finance, and at the same time, receives strict government regulation. Public transport is quite cheap in Hangzhou because of the large number of government subsidies. For example, prices range from CNY 1-4, usually CNY 2, for a bus. In this sense, the low price of public transport is a common measure took by the government to the encouragement of public transport, reduce the pressure of growing private vehicles and air pollution in China.

The primary investment of public transport is the Hangzhou Urban Investment Group, which was established in 2003 and became the most critical force in infrastructure construction in Hangzhou. Hangzhou Urban Investment Group invested most of the public transport projects, such as public bus and public bicycles. Hangzhou Municipal Transportation Management is the central management department. The public bus is operated by the Hangzhou Public Transport Group, which provides most urban public transport service and concurrently operates taxis, tourist passenger transport, and public bicycle services. Hangzhou Metro Line 1 is operated and managed by Hangzhou Port Group, which is jointly funded by Hangzhou Metro Group Corporation and Hong Kong Railway Group. Metro Line 2 and Metro Line 4 are operated and managed by Hangzhou Metro Group Operation Branch. The water bus is operated by Hangzhou Water Public Sightseeing Bus Co., Ltd. It is the first enterprise in China to operate a water bus, mainly engaged in water bus, water sightseeing, water tourism, and other businesses. Public bicycles are operated by Hangzhou Public Bicycle Transportation Service Development Co., Ltd. The Hangzhou Public Bicycle Transportation Service System was put into trial operation on May 1, 2008. As a convenient, accessible, cheap, and safe travel mean, public bicycles have won the popularity of citizens and became an essential part of the Hangzhou urban public transport system.

Both public transport operations and private transport operations are regulated and surveillance by the regional transport authorities. Around 2015, with the prevalence of the sharing economy in various cities in China, many startups attracted many market investments and were allowed to enter the field of public transportation. Sharing bicycles, sharing cars, sharing scooters suddenly emerged in the streets. In the beginning, the government encouraged startups because they alleviated traffic pressure in the city, brought convenience to the people, and created an excellent entrepreneurial atmosphere. Nevertheless, there were many problems after a few years, such as too many bicycles blocked the sidewalk, safety hazards posed by online ride-sharing drivers. Therefore, the government took more measures in order to regulate private transport sectors. For example, the government raises market entry thresholds; the number of bicycles is limited (Sun & Sun, 2018). According to Hangzhou transport authorities, drivers can continue to provide with car-hailing service with the situation that "online car-hailing platform with a license to operate, drivers with a license to go on duty, vehicles with a license to carry passengers" since 2017 (Tang Tao & Wei Yijun, 2017).

- Partnerships

The data-driven trend in the transport sector is independent of many technology companies' data generation tools. As a city known for the digitalization economy, from data collection infrastructure to data storage and data process technology, Hangzhou has rich experience and is home to many leading digitalization technology companies.

Hangzhou City Brain Project, led by the Municipal Data Resources Authority, brings together nearly 20 top enterprises in the fields of Internet, big data, cloud computing, AI, and other areas to cooperate and build together (Municipal Data Resources Authority, 2018). Alibaba Cloud is a global cloud computing and AI technology company. It is the primary architect of the project, which consists of five major systems - computing platform, data collection system, data exchange center, open algorithm platform, and data application platform. Hikvision provides video-centric intelligent IoT solutions and big data service. Hikvision has core technologies such as video and audio codec, video image processing, video and audio data storage, and innovative technologies such as cloud computing, big data, and deep learning (Hikvision, 2019). Dahua Technology Group provides intelligent algorithms for images, automatic identification of vehicle models, and lines, which can be used for video structured processing, and data mining and analysis based on big data platform in Alibaba cloud. Supcon Technology Group provides smart city solutions and related information system integration services. Foxconn Technology Group designs server for Alibaba Cloud server room. Shumeng Factory focuses on government, industry, and urban areas, the research direction covers new Internet architecture, cloud computing, big data, security, and other fields. The company has participated in the construction of the Zhejiang Provincial Government Cloud Platform, providing data operation and governance. China Mobile, China Unicom, and China Telecom are the three major mobile operators in China. For the Urban Data Brain project, they built a cloud computing data clearinghouse to provide a constant stream of computing power and achieve real-time information transfer and exchange. With the advent of the 5G era, together, they will advance smart mobility in the city.

- Transport data collection

Transport data includes all data related to transport and mobility service, such as the total distance of highways, waterways and railways, the total mileage of bus, number of lines, number of buses, length of metro lines, number of lines, number of stops, payment data, vehicle locations, parking infrastructure locations, and so on. According to Transport Systems Catapult (2015), transport-related data can be divided into nine categories: Place & Space, Environment, People, Things & Movement, Disruption and event-related data, Public Transport Services, Personal Automobility, Freight connections, International Connections, and Consumption & transaction data (2015).

The rapid growth of motor vehicles and transport infrastructure has caused many traffic problems such as traffic congestion, traffic pollution, and traffic accidents. For this reason, real-time and accurate transport data is a prerequisite for smart mobility systems to solve traffic problems. With the advancement of the IoT based on video technology, more and more monitoring devices are being used to record real-time traffic, a huge number of big data is produced every day. Besides, because of the widespread innovative and convenient transport applications, more customer data has been collected by transport service providers. Further, cloud storage and cloud computing enhance urban transport data collection for operation, decision-making. Big data analysis technology will analyze multi-source data, including GPS data, road sensor data, weather data, and congestion information. The analysis platform can identify traffic conditions, evaluate the time consumption and cost, optimize routes. The application of data has a broad of benefits, such as improving the traffic conditions, reducing road congestion, improving safety, and reducing GHG emissions.

Hangzhou stayed ahead of the competition of smart city building in China and was given the titles of "Smart Data City," "Smart Service City," and "Smart Payment City." The city has made significant breakthroughs in the fields of digital government, digital economy, urban governance, and public services in recent years. The innovations on the digital, intelligent, and network-driven technology, management, and service help Hangzhou on the path towards full-field digitalization. The smart mobility initials of smart parking, online payment, real-time traffic monitoring and regulation in Hangzhou has generated thousands of transport data every day. The cooperation between government and Alibaba, with the help of cloud technology, has provided the city with novel analytics and practical solution making Hangzhou more sustainable, efficient, and resilient.

- Real-time traffic monitoring system - City Brain

The cooperation between the Hangzhou government and the tech company Alibaba launched the City Brain project in 2016 that aims to improve the efficiency of traffic management in a growing urbanization city. City brain project uses an AI hub to gather information across Hangzhou through cameras, sensors, and GPS data on the locations of cars and buses (LeBeau et al., 2018). With the advancement of technologies like machine learning, pattern recognition, and the IoT, the platform processes can collect a tremendous amount of information and coordinate more than 1,000 road signals to prevent or ease gridlock (Michelle & Leonie, 2019).

As a data-sharing platform, the city brain conducts an instantaneous analysis of traffic in the city, allocate social resources effectively, and improves traffic management. After the implementation of the project, the commutes time has been shortened based on data analysis. Besides, the traffic light adjusts time according to the traffic flow result in an improvement of efficiency. Fire trucks and ambulances have halved the time to get to the scene of emergencies with the use of AI. Moreover, the city brain integrates traffic police microwave data and video data to sense traffic events, including congestion, violations, accidents, and triggers mechanisms for intelligent processing and automatic notice traffic police, which also helps improve the efficiency of handling traffic accidents.

Furthermore, the city brain projects have also been introduced to some other Chinese cities and Asian cities by Alibaba, such as Kuala Lumpur, with the implementation of smart cities. Alibaba created Alibaba Damo Academy, which aims to research full fields in cities with big data and deep learning technologies. As for urban mobility, the project carries out analytical forecasting and intelligent interventions to address traffic congestion management issues based on the structure of the large-scale road network. The tech-giant in Hangzhou has applied its algorithms and experience working with governments to extend traffic monitoring and regulation systems to other cities that are also facing traffic congestion problems.

- Smart parking system

In a big city, the usage of space is supposed to be as effective as possible. One big problem with parking is that parking lots are in different usage stages at different times. For example, residential parking areas are busy during the night, while office buildings, hospitals, and commercial districts are busy during the day. The Parking Guidance System is introduced to provide drivers with real-time, accurate, and comprehensive information on car parks and parking spaces through the installation of real-time changing information boards at the roadside. Drivers can choose the best route to a suitable car park, increasing the use of empty parking spaces and reducing the time wasted in finding spaces and traffic congestion. Effective Parking

Guidance System can not only bring benefits to save time and cost but also reduces driving time and GHG emissions and therefore is environmentally friendly.

Hangzhou government has introduced the Parking Guidance System into public parking lots since 2009. Parking guidance systems are combined with the current road traffic conditions and driver location through smartphone applications, guidance screens, websites, car GPS, and other diverse information guidance. The parking guidance system has continuously improved in Hangzhou with the development of information technology and used Alibaba cloud computing since 2014. Smart parking improves the reliability and convenience of parking, reduces operating costs, reduces accidents, reduces driving time, reduces pollution and waste emissions, and reduces traffic noise. It is estimated that the annual emissions can be reduced by 30%, significantly alleviating the increasingly severe haze weather (Zhou Qiuxia, 2017).

- Online payment

Alipay is a third party online payment platform, established in Hangzhou in 2004, and is one of the world's largest mobile payment service organizations. Alipay has been applied to the Hangzhou transport payment for a long time. Since March 2016, Hangzhou Bus Group has cooperated with enterprises such as Ant Financial (Alipay), China UnionPay Zhejiang Branch, Shumeng Factory and Guolang Technology to analyze the needs of bus applications, and developed Alipay dual offline (machine tool offline, mobile phone offline) QR code and bus payment integrated machine (Wu, 2018). At the same time, Hangzhou public bus also developed and applied the application of UnionPay QuickPass and virtual bus cards. Besides, with the promotion and application of mobile payment, Hangzhou Public Transport Group and Shumeng Factory jointly established Hangzhou Public Transport Cloud Technology Co., Ltd. ("Bus Cloud" for short). Bus Cloud focuses on the development of bus big data platforms to establish dynamic data models that can provide services, such as mobile payment, distance operation, cloud management, data visualization, and assist bus route planning and bus network optimization (Wu, 2018).

Online payment has made public transport more convenient and smart. However, just like other cities in China, behind the diversification of online payments for transport hides a scramble for user data by Internet companies. Through mobile payment, Internet companies can improve the accumulation of data, obtain data about consumers' life trajectories, and improve their own operation and precise marketing services.

4.2.5. Open ttransport data

The State Council issued Notice of the Platform for Action for Big Data Development and the Management Approach to Information Sharing in Government Information Resources in 2015. The document emphasizes the importance of promoting data sharing in the government sector and promoting open access to public data, requires to establish a mechanism for big data collection, and develop an open catalog of government data sharing (The State Council of PRC, 2015). The document, Action Plan for Advancing Intelligent Transportation Development 2017-2020 (The Transport Ministry of PRC, 2017), highlights the growing trend towards the deep integration of the new generation of information technology and transport. Four goals were set for transport digitalization, including smart infrastructure, smart production (logistics) organization, smart transport services, and smart decision-making and regulatory (The Transport Ministry of PRC, 2017). First, the transport sector encourages the application of IBM in transport infrastructure construction and to promote the innovation and application of information technology such as cloud computing and big data in core business systems such as road maintenance, road network operation monitoring, emergency dispatch, and command. Secondly, in the production organization of logistics and transportation, the promotion of intelligent logistics parks, ports, and passenger transport hubs is the focus of the new transition. Thirdly, as for mobility service, a focus is put on accelerating the opening of traffic data from different government departments and institutions through all kinds of data opening platforms.

The strategic cross-border cooperation between transport enterprises and internet enterprises is necessary to make effective use of both government and social capital. The government encourages online platforms, social media, such as Weibo, WeChat, and other market players to integrate information resources of various modes of transportation, and build a comprehensive transportation and travel information service platform. Finally, the fourth strategy is to build a comprehensive transport data monitoring and evaluation system based on information technology, such as big data, cloud computing, and geographic information system, which can be used for decision making and traffic enforcement.

The right to access and reuse data is the main point of discussion of data (Kriukelyte, 2017). Data sharing is the basement for value-creating. Following the central government's call for the digitalization of the transport sector and sharing transport data, Hangzhou regional government further has opened up several types of government transport data (Office of Hangzhou City Traffic Congestion Control, 2017). The regional government opened transport data, including road traffic and road condition information, information on critical roads to tackle traffic congestion, taxi GPS information, bus route information, passenger station information, passenger fare information, passenger ticket points information, traffic rail information (Fig. 5). Some of the data are available to the public, such as bus routes, information on passenger stations, passenger fares, information on rail lines. While some other information, such as real-time traffic conditions, Taxis' GPS, is only opened to qualified entities, such as institutions of higher education, scientific research institutions, research and development companies, high-tech enterprises. The access to certain data requires an application and has validity duration. In other words, even though the regional government opened some transport according to the central government's policy, the classification of data and duration is rather limited. The normative opening of traffic data still takes a long time and works in Hangzhou.

Data Classification	Data Type	Specific open data	Frequency of data updates	Access approach	Detailed access address or websites	Data repository
Open data approach	static data	Include road ID, average speed	Real time	Application for data	Visit application; Mail application; Online application: http//www.hangzhou.gov.cn	Hangzhou Traffic Police Department
Information on Key Roads	static data	Road-related: road names, road sections and directions, signal and control schemes	Real time			
	static data	Traffic flow related: time, speed	Real time			
	static data	Equipment related: equipment type, equipment number, collection time	Real time			
Taxi GPS information	static data	Taxi ID, GPS time, longitude, latitude, speed, direction, vehicle status, etc.	Data can be requested for up to 3 months within the last 1 year	Application for data	Mail application; Email application; Online application: http://www.hangzhou.gov.cn/col/col810050/index.html	Hangzhou Municipal Transportation Bureau
Bus Route Information	static data	Name of the bus route, signage, first and last bus time, departure and arrival stations, etc.	Half year	Open to the public	Download online: www.hzcb.gov.cn	Hangzhou Municipal Transportation Bureau
Bus Terminal Information	static data	Administrative jurisdiction, name, latitude and longitude, contact information, etc. of the passenger terminal	Half year			
Bus fares	static data	Information on the departure, transit, arrival, seat type, vehicle type, fare, etc.	Half year			
Information on passenger fares	static data	location and contact number of passenger ticketing offices	Half year			
Railway line information	static data	The name of the railway line, station name, the first and last train time, etc.	Half year			

Fig. 5. List of types and approaches to open transport data resources in Hangzhou City (Office of Hangzhou City Traffic Congestion Control, 2017)

Transport data is primarily collected by cooperative projects by government and technology companies. Therefore, they owned most of the transport data. At the call of the central government, the regional government started to open part of the transport data. Zhejiang Province launched the "Government Data Open Platform" in 2015, which has opened up 610 until 2020, and published data in eight areas: economical construction, environmental resources, urban construction, transport, education and science and technology, culture and leisure, people's livelihood services, and institutional groups (Zhejiang Government Data Open Platform, 2020). Main transport data sharing platforms (Government platforms):

- Zhejiang Government Data Open Platform:
  http://www.hangzhou.gov.cn/col/col1255929/index.html

Hangzhou regional government also has its own platform for transport information, such as bus, water bus, bicycle, taxi, road condition, traffic jam.

- Hangzhou - Public Service -Transport and tourism:
  http://hz.zjzwfw.gov.cn/col/col2114/index.html

In addition, cooperative technologies companies do not have the right to open transport data. Some large Internet companies, such as Baidu and Alibaba, open some free transport data API for non-commercial use. Most developers often need to crawl on the Internet to access transport data by themselves or pay for data services to some data companies. For example, Tencent Cloud Market is a data trade platform and provides transport data, such as traffic violation inquiry, car model identification, vehicle inquiry, driver's license information, driver's license identification, vehicle tail number limit, IP address inquiry. Moreover, quite a lot of data technology companies provides the service for data access and data processing algorithm. Transport data sharing platforms (Private platforms):

- Baidu Map China City Congestion Index：
  http://jiaotong.baidu.com/top/report/?citycode=179

- Tencent Cloud Market：
  https://market.cloud.tencent.com/categories/1097

- Paid data services：
  https://www.jisuapi.com
  https://www.juhe.cn

4.2.6. Questionnaire results

This survey is divided into four sections, with a total of 22 questions. The first section is about the general information of respondents, such as gender, age, professions, salary, education, and residential time in Hangzhou. The second section is about travel behavior, including travel modes selection, travel time, travel cost, etc. The third section focuses on the attitudes towards decarbonization and mitigating climate change. The final part studies the traveler's attitudes towards data collection and application.

This survey aims to have a holistic view of travel behavior and travel attitudes towards smart mobility from citizens living in Hangzhou. Due to the limited time and pandemic, a limited number of total of 104 valid questionnaires were collected in this online survey. The survey utilizes WeChat, the most used social media app in China, as the platform for the survey. At the same time, the Tencent Questionnaire with location screening function was used to target people living in Hangzhou.

- Basic information of respondents

A total of 116 questionnaires were collected in this online survey, with 104 valid questionnaires. 61 (59%) are men, and 43 (41%) are women (Fig. 6). The youngest age is 15, and the oldest age is 59. Approximately 58% of the respondents' age is between 21 and 30 (Fig. 7). Two reasons can cause the younger respondents: 1. the members of the questionnaire group in WeChat are relatively young; 2. Youngsters are more likely to be interested in smart mobility.

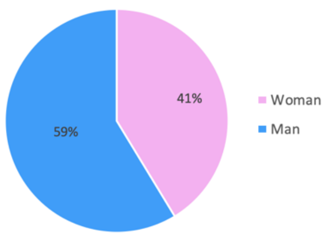


Fig. 6. Gender

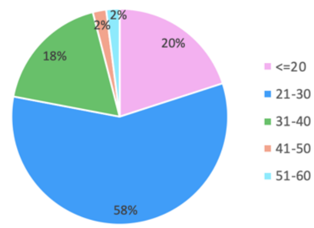


Fig. 7. Age

As can be seen in figure 8, the majority of participants (57.7%) are working, and students account for about one third. As shown in figure 9, more than one-third of respondents have a monthly salary less than CNY 5000 (39.4%), which implies a large percentage of participants are young students. About half the participants (43.3%) have an income range between CNY 5000 and CNY 10000. As for participants' education (Fig. 10), the majority of participants hold a bachelor's degree (38.5%). Participants with a specialist's qualification and a master's degree have the same percentage, 21.2%. Figure 11 shows that about 33% of participants have lived in Hangzhou for more than ten years, and another 33% have lived in Hangzhou more than one year but less than three years, which implies that Hangzhou as a growing city has attracted young population in the last few years.

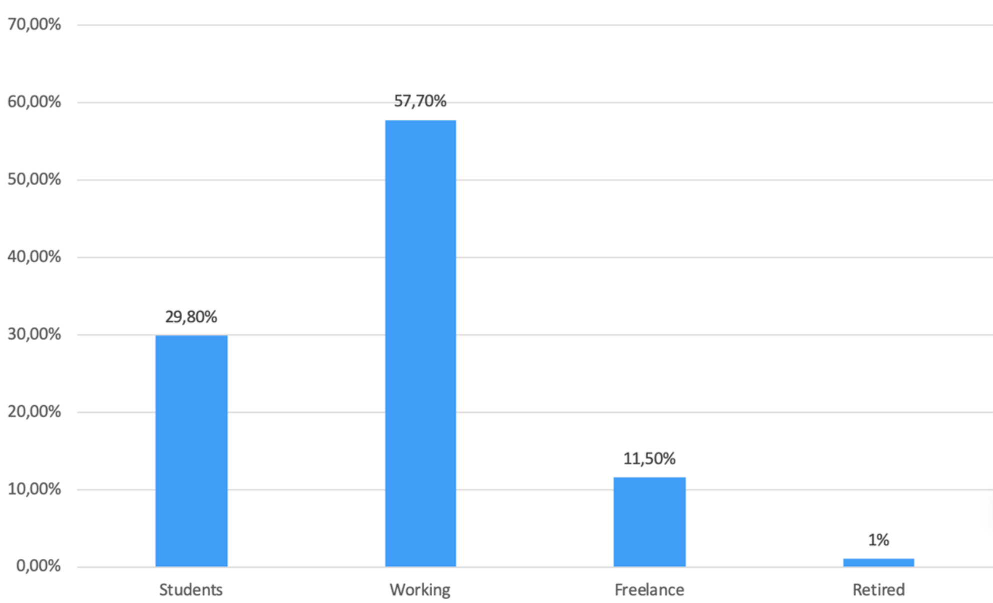


Fig. 8. Occupation

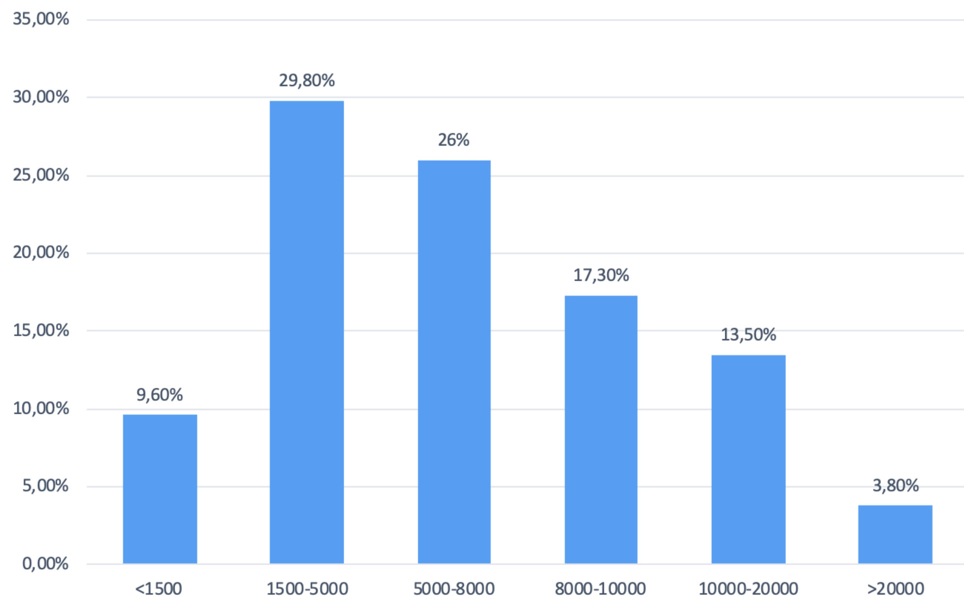


Fig. 9. Salary

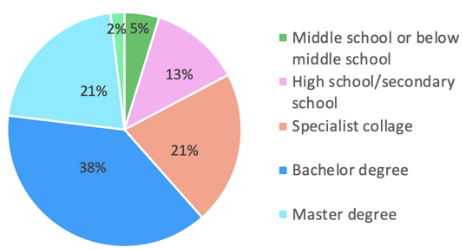


Fig. 10. Education

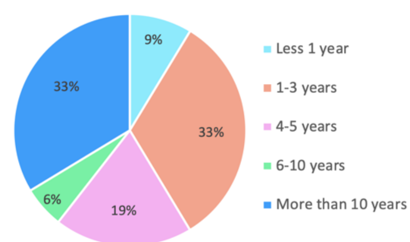


Fig. 11. Residence time in Hangzhou

- Travel behavior

Figure 12 shows that subway (67.3%) and bus (61.5%) are the most used travel mode among participants. 44.2% of the participants also use private cars for traveling in Hangzhou. Bicycle and walking share the same percentage of 34.6%. Electric bicycles, as a convenient vehicle, are also popular in Hangzhou (21.2%). Car sharing and scooter only respectively account for 9.6% and 2.9%, which indicates that although the new emergence of sharing vehicles attracts much attention, the penetration of sharing-car is not high. Traditional public travel and private cars are still dominant travel modes in Hangzhou.

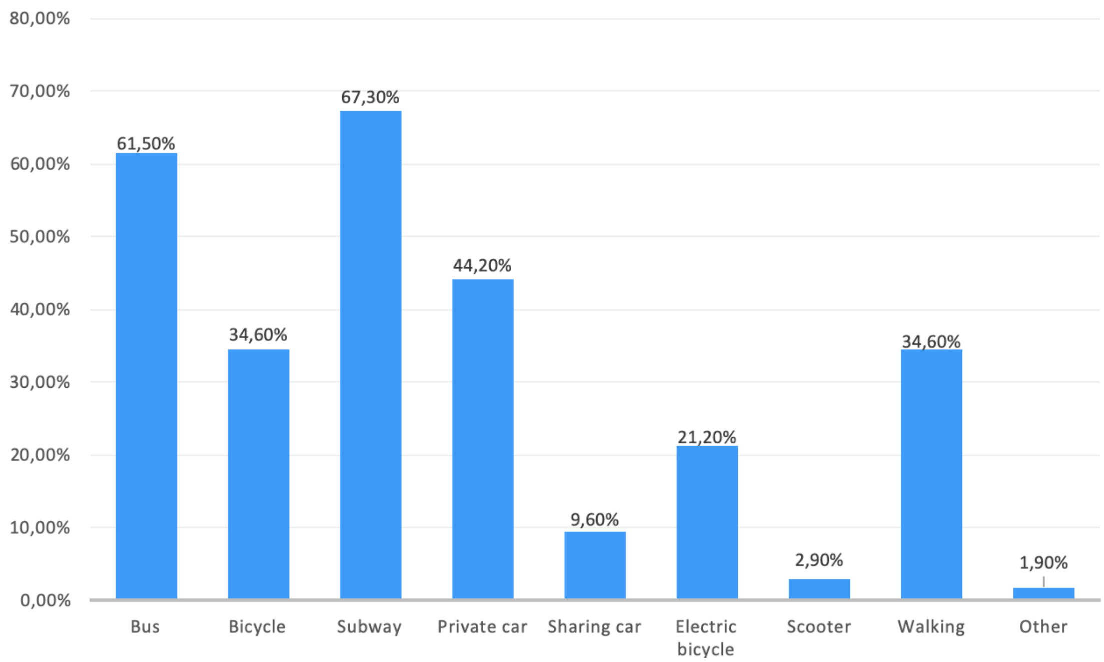


Fig. 12. Travel modes preference

Approximately half of the participants claim they do not own an automobile (49%). This result has a relation with strict regulations toward car purchases and licenses from the Hangzhou regional government. As clearly seen in the figure 13, the majority spend between 10 minutes and half an hour for daily commuting (42.3%), while 32.7% participants spend more than 30 minutes and less than one hour for daily commuting. Monthly travel cost is relatively cheap, because of the government's massive subsidies for public transport. As shown in the figure 14, 83.6% of respondents spend less than CNY 500 every month. As for the primary travel purpose, more than half respondents claimed working is the primary purpose of daily travel (62.5%), following with shopping (13.5%), entertainment and restaurant (12.5%), visiting friends (4.8%), sports (1.9%) and sightseeing (1.9%).

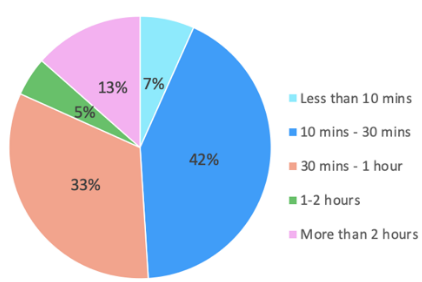


Fig. 13. Travel time

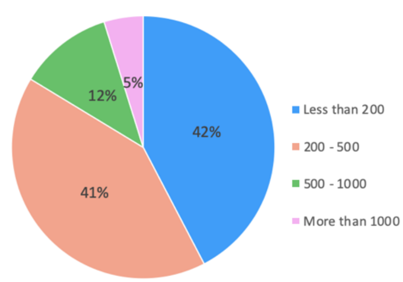


Fig. 14. Travel cost

- Travel attitudes regarding reducing carbon

Many factors can affect the selection of travel modes. As can be seen in figure 15, 33.7% of respondents chose "Time" as the top important, and 26.9% chose "time" as the second important factor contributing to the selection of travel mode. Following with comfort factor, 23.1% rated it as the second important factor and 26.9% rated as the third reason. More than half of respondents considered decarbonization were the least important factors when participants chose a travel mode (38.5%). The pie chart shows that respondents have a strong willingness to react to atmospheric warming (61.5%), while 29.8% said they would occasionally consider reducing carbon when travel (Fig. 16). This result implies that although the citizens are willing to contribute to mitigate climate change and reduce carbon emission, there is less action.

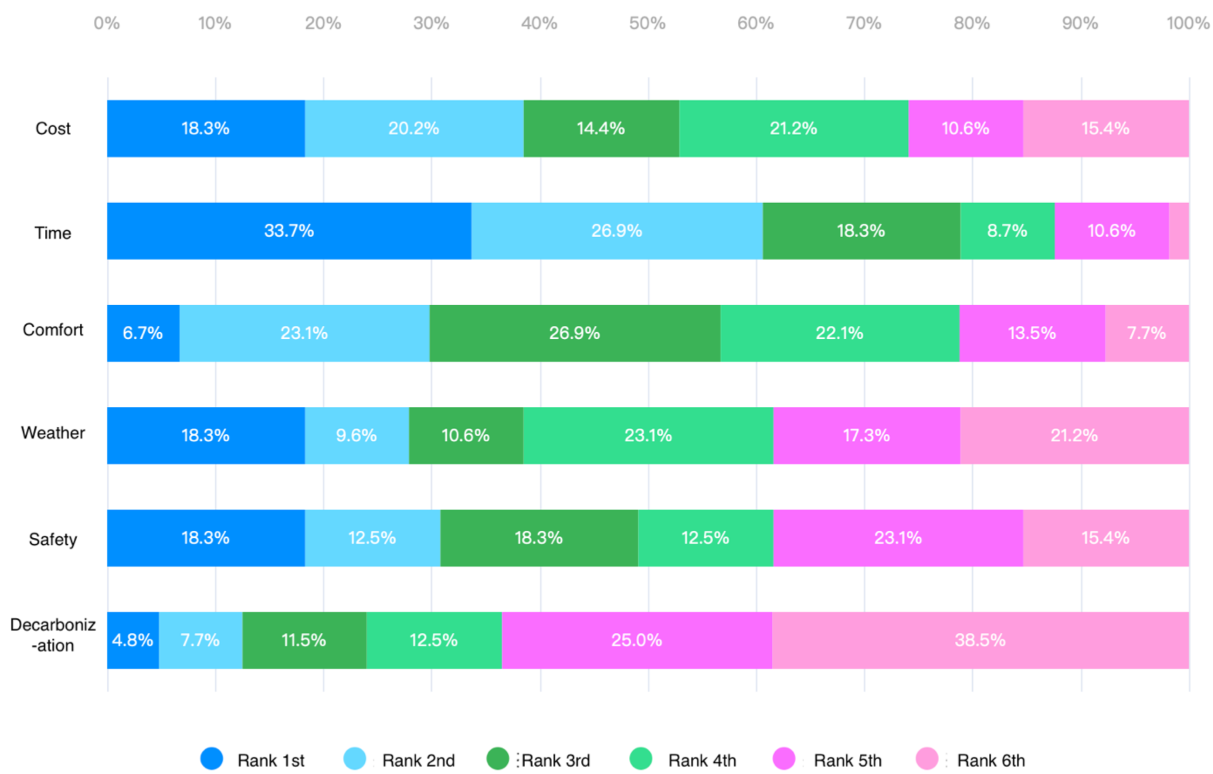


Fig. 15. Ranking of influencing factors for travel modes choice

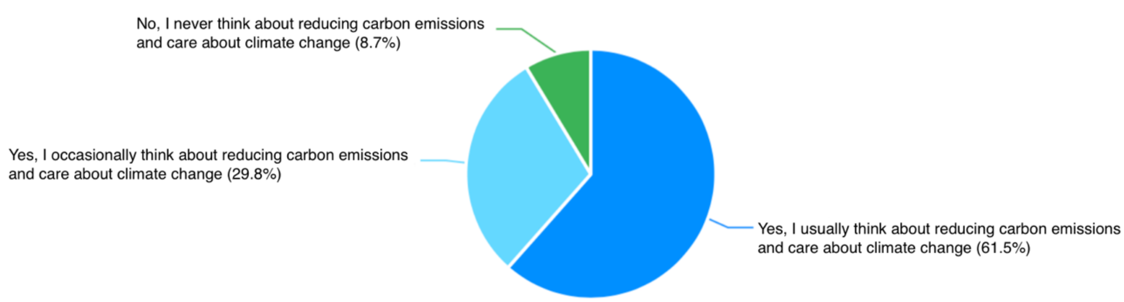


Fig. 16. Attitudes towards climate change

Figure 17 shows respondents' attitudes towards general transport situations in Hangzhou. On a scale from 1to 5, respondents rated the agreement of several opinions regarding transport situations in Hangzhou. Respondents rated the first opinion, "Almost no traffic congestion in Hangzhou," at an average score of

3.54. 27.9% respondents agree and 25% strongly agree the traffic in Hangzhou is in good condition, almost without congestion. The average score of the opinion, "The transport in Hangzhou is very smart" is 4.1, which means most participants feel quite positive about the smart mobility measures in Hangzhou, with about 38.5% agreed that the city has quite smart transport. The agreement of GHG emission, "There are rather less GHG emissions in Hangzhou" is 3.38, which implies the attitudes toward GHG emission situation in Hangzhou were somewhat neutral. More than half of the participants were satisfied with the government's measures to reduce GHG emissions related to transport (61.6%) with an average score of 3.71.

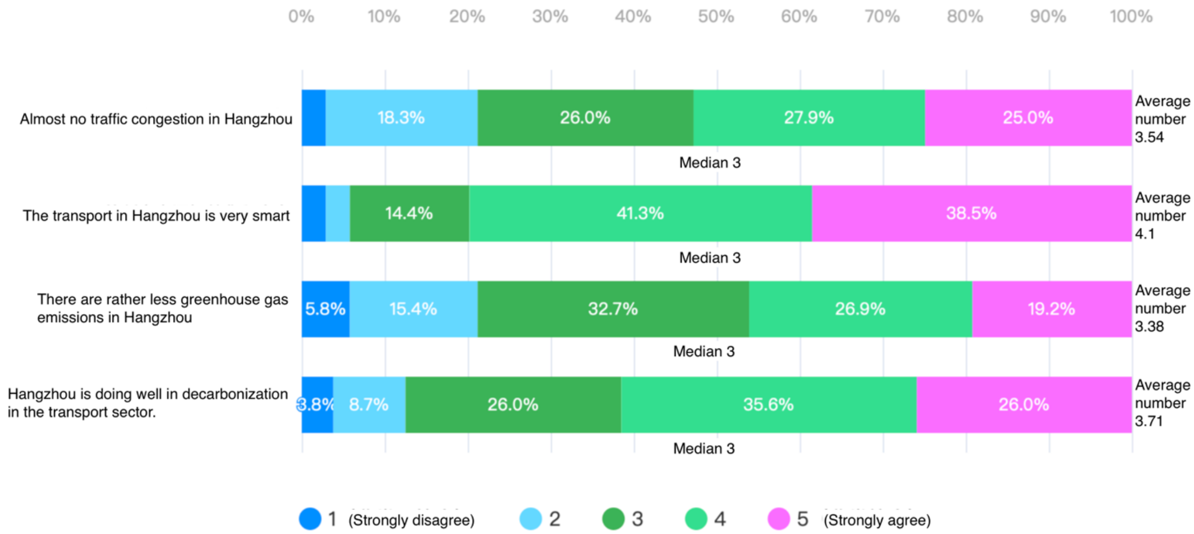


Fig. 17. Attitudes towards transport situation in Hangzhou

Figure18 shows that respondents' overall attitudes regarding government's measures to reduce GHG emission and mitigate climate change are satisfied. Given a score of 1 to 5, the average score for "Hangzhou has much publicity for low-carbon travel" is 3.84. Approximately 82.7% of participants agree or strongly agree that "There are many green travel modes in Hangzhou," resulting in a score of 4.18. The average score of 4.32 towards the opinion "I am very willing to find emission reduction and environmentally friendly ways to travel in Hangzhou". Although when asked to rank the influencing factors, decarbonization is less considered compared to travel time, cost, and comfort; there is a high willingness to participate in reducing GHG emissions and mitigating climate change.

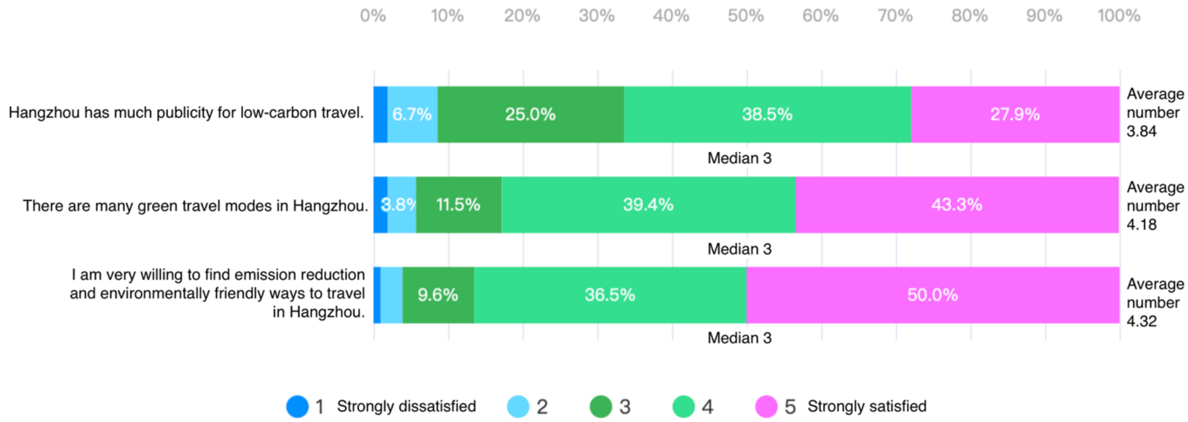


Fig. 18. Satisfaction with the transport measures towards decarbonization in Hangzhou

As for the new sharing mobility service (Fig. 19), almost all respondents claimed they have tried sharing bicycles before (91.3%), which also implies an extensive use of bicycles in Hangzhou. The second popular choice is app-based ride-hailing service (75%), followed by car-sharing (26%), and sharing scooter (12.5%).

When asked what measures can contribute to reducing carbon and other GHG emissions (Fig. 20), "Promoting sharing mobility service, such as sharing bicycles, sharing cars" is the top choice, with 72.1% of participants chosen it. The choices of promoting new energy vehicles, promoting walking and cycling conditions, and real-time traffic monitoring and management to reduce traffic congestion respectively won popularity of 62.5%, 62.5%, and 56.7%. Even though Hangzhou authorities pay much attention to control private car purchases and driving in central areas, two measures respectively received only17.3% and 45.2% support in the survey. The result shows that although the government has implemented strict restrictions on private car purchases and driving in the city, citizens are more willing to improve the environment and mitigate climate change through the advancement of smart mobility. Moreover, only 2.9% of participants support reducing the travel times, which implies, although it is easier to conduct distance communication through the internet nowadays, the desire for traveling is still quite strong. In other words, online communication cannot replace traveling completely.

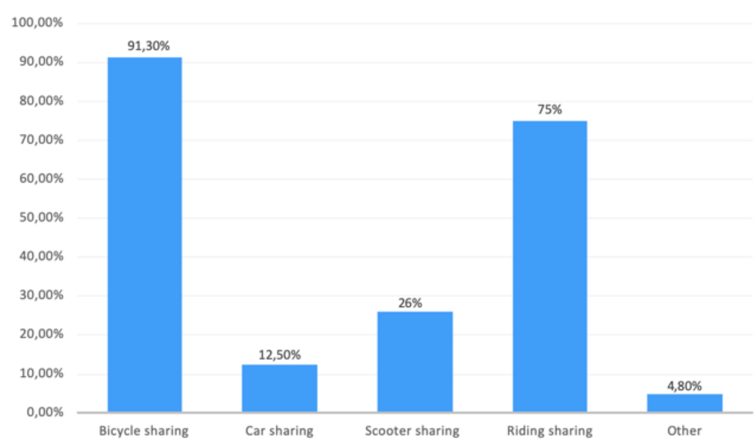


Fig. 19. Prevalence of new modes of transport

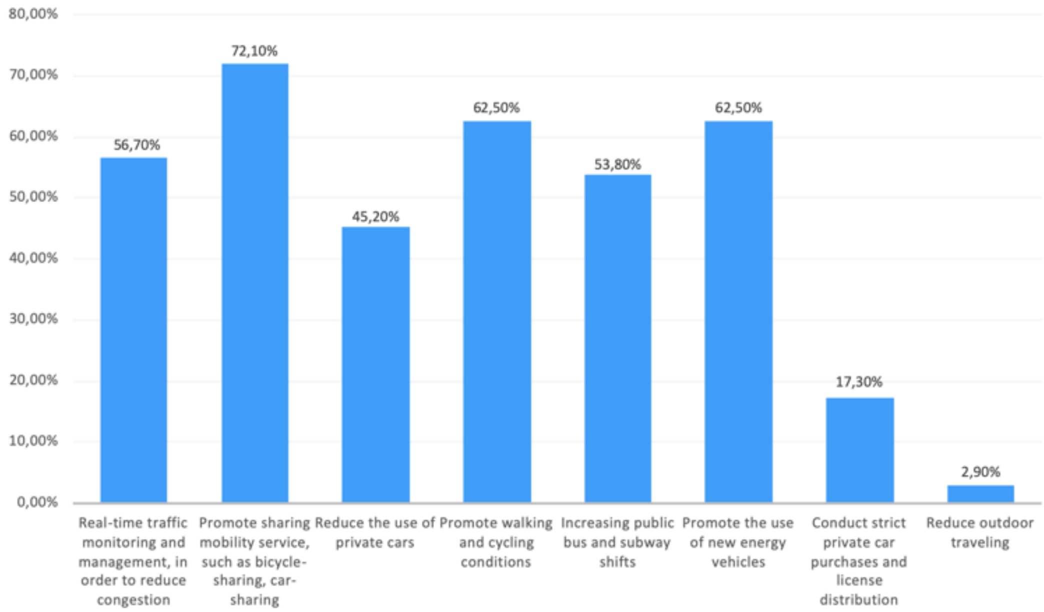


Fig. 20. Opinions on measures effective in reducing carbon emission

There was a growing trend for shopping online during this project when the globe is going through the corona pandemic, and people are forced to quarantine at home. This survey also found that quite a high proportion of participants showed a willingness to continue their enthusiasm in online shopping after the pandemic (66.3%). The pandemic will have a profound impact on a lifestyle change, or specific in this survey, on travel habits in the long term.

- Travel attitudes regarding data concern

Smart words are widely spread with the advancement of various information technology, although people hold different understandings. The participants were asked about their understanding of “smart mobility” in the survey (Fig. 21). Among given words describing smart mobility, the top three keywords are “Real-time road traffic monitoring information” (72.1%), “A more efficient transport system” (63.5%)， “AI” (61.5%). Autonomous vehicles seem to be least relevant as an understanding of smart mobility (27.9%). As for the consideration for data security, only 4.8% of participants claimed that they never thought about data security, while 53.8% often thought about data security problems, and 41.3% occasionally considered this problem.

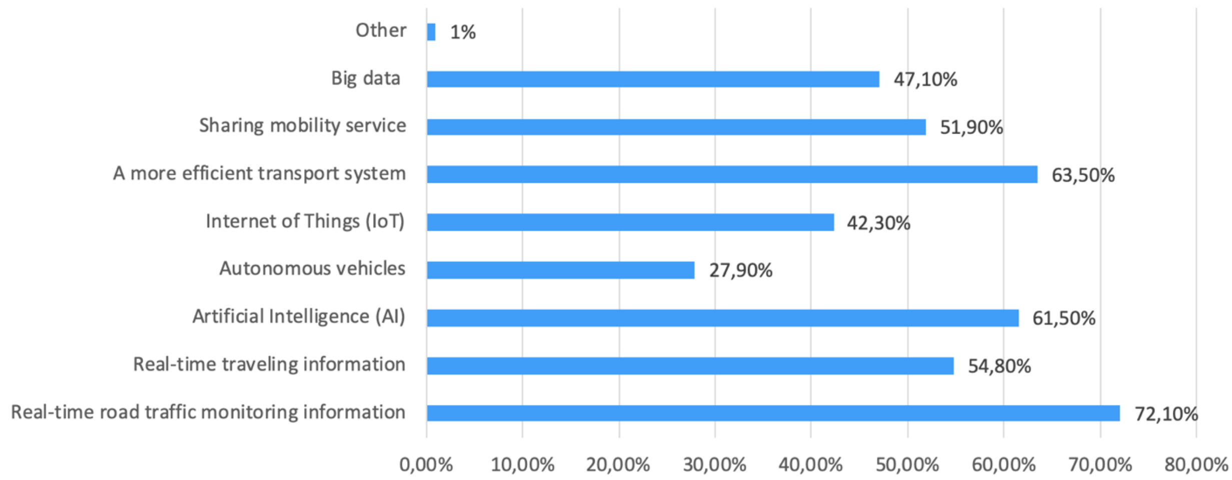


Fig. 21. Understandings on "smart mobility"

According to the study on the accessibility to different transport information (Fig. 22), given the score from 1(very easy) to 5 (very difficult), the most accessible transport information is bus shift schedule (3.01), following with West lake boat shift schedule (3.14), the location and number of sharing bicycles (3.26), the location and number of new energy charging piles(3.29). Although there is the growing smart parking and the promotion of electric vehicles, compared with traditional transport information, individuals still feel it is not easy to find charring piles. The location and number of parking lots and the information about tourist flow are somewhat challenging to access, with a respectively average score of 3.41 and 3.65.

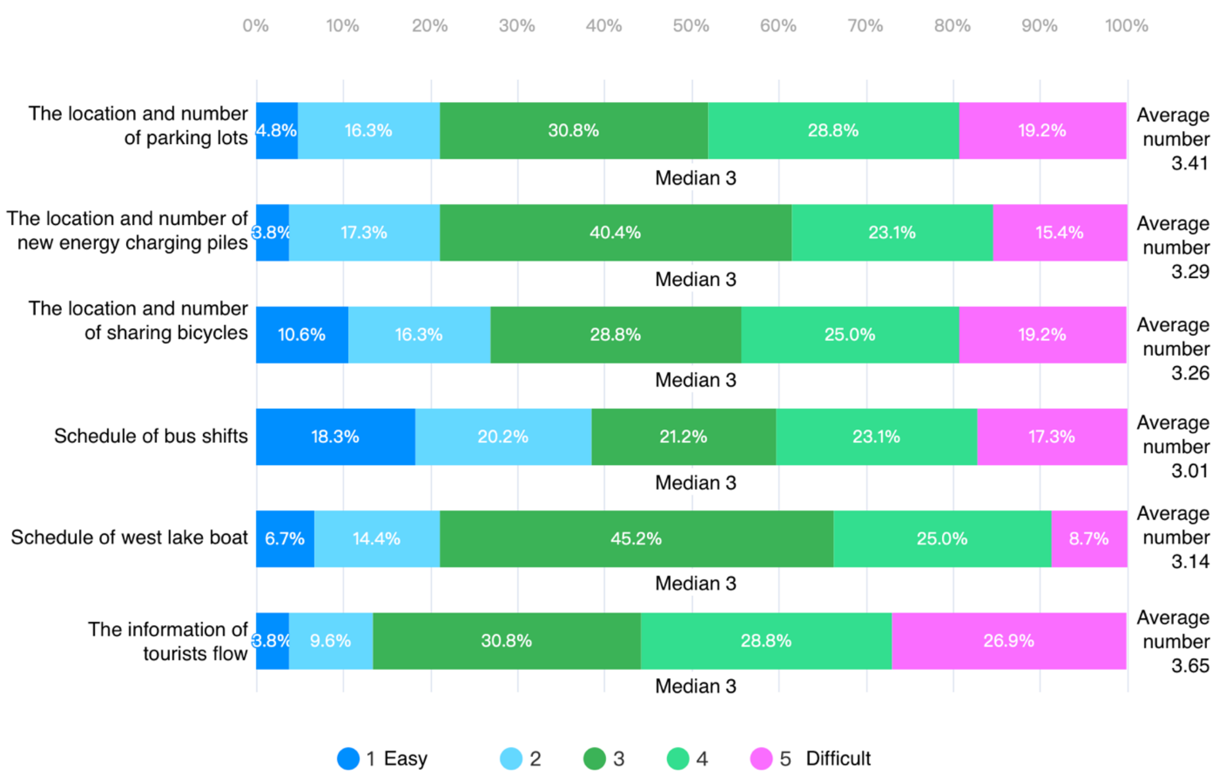


Fig. 22. The accessibility to different transport information

The figure 23 presents respondents' opinion about the transport data collection. The most agreeable opinion is "I do not know where my data has been used" with a score of 3.87 while 38.5% of participants strongly agree with this argument, following with "Mobile phones can access users' location data easily" with a score of 3.81 and "I do not know who have collected my personal data" with a score of 3.75. The willingness to use data in exchange for low-carbon travel (3.67) is higher than in exchange for convenient travel (3.58). 34.6% of participants rated 3 for the argument, "I am willing to transfer personal data for convenience." Even though it is a common phenomenon in today's market that customers transfer their personal data for convenience, people still have reservations about this idea. There is also a high willingness to apply individual travel data for carbon calculation (3.79). The effective traffic regulation is based on the data from numerous cameras and sensors in the streets. Participants rated a quite low score, 2.77 for the idea, "There are too many surveillance devices on the streets of Hangzhou, and I do not have privacy at all." It is interesting to find that participants did not worry too much about the exposure on the streets with many surveillance devices. Although it is common in China that implementing CCTV in the streets for security reasons, it also shows that participants have trust in the surveillance and road data collection in public space. Moreover, although participants are generally unclear about the data application, especially on the smartphone, they have a high willingness to support carbon reduction with personal data. Quite a lot of participants showed neutral or disagree towards this argument, reflecting citizens' understanding and cooperation with these traffic monitoring measures implemented by the government.

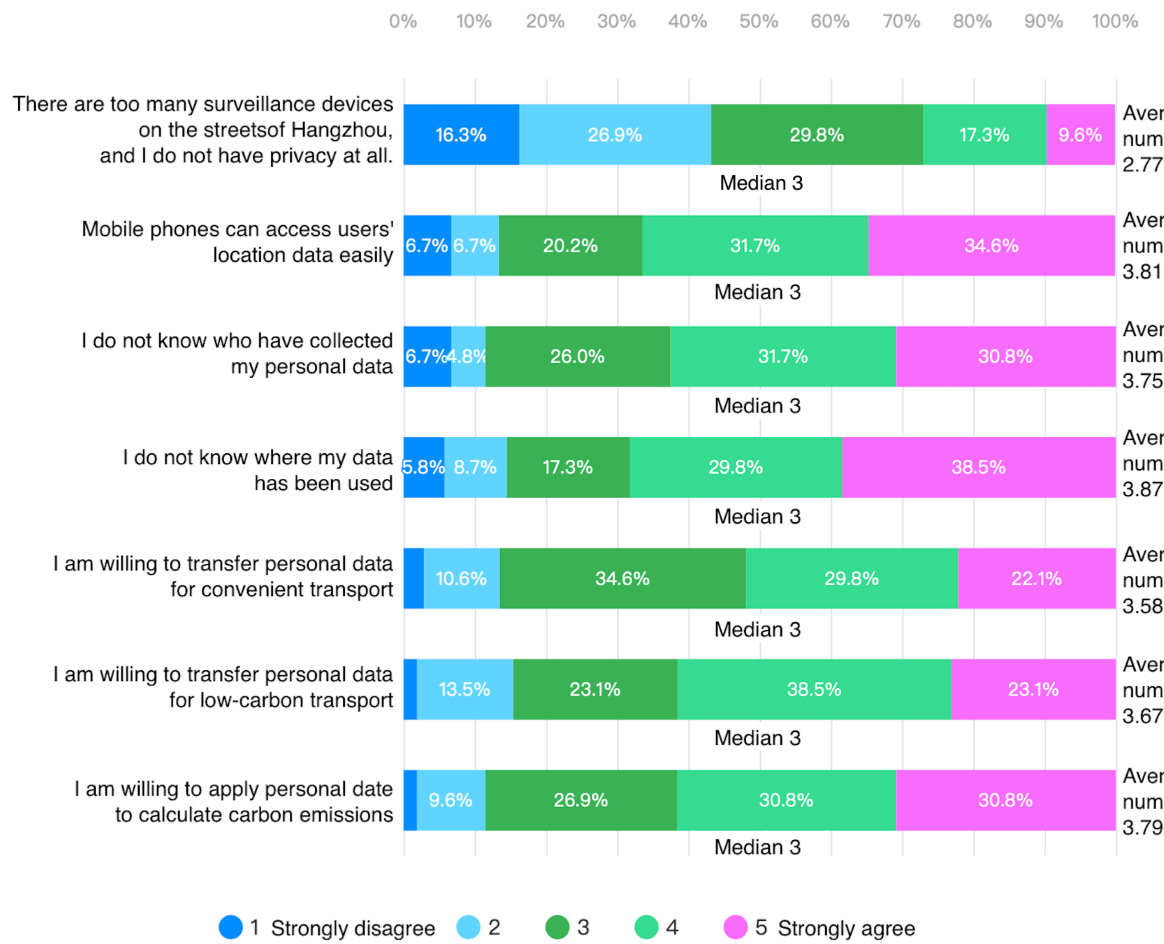


Fig. 23. Opinions on data issue

4.2.7. Results of the case study

The case study of Hangzhou reflects a typical smart city's efforts towards digitalization in the transport sector in China. The city is engaged in developing diversified transport services and working towards the digitalization of the transport system with cooperative projects between governments and companies. Like most cities in China, the government is in a dominant position in transport infrastructure planning and traffic operation in Hangzhou. In order to mitigate climate change and air pollution, the government has set many restrictions on private cars' purchase, car license distribution, and driving in the center. At the same time, the government also encourages green travel modes and promotes sharing mobility services. City Brain, as the milestone project in the digital transition in the city transport, has effectively improved the efficiency of traffic management and accelerated the development of a smart city. The main point of the discussion of data-driven smart mobility is data accessibility and application. Data sharing is the basement for value-creating. However, there is limited data accessibility and sharing in Hangzhou. Finally, the current use of data in the transport sector is mainly focused on improving the efficiency of regulation and operation.

In the analysis of the questionnaire, there are some findings. First, the majority of respondents are young adults below 30 years old. More than half of the respondents live in Hangzhou for less than five years, which implies that Hangzhou has a rather young population. Compared with traditional travel modes, such as bus, subway and cars, new sharing mobility service, such as scooter and sharing cars, still shares a small proportion. Moreover, the results about the travel attitudes imply that even though the citizens have a high willingness to contribute to mitigate climate change and reduce GHG emissions, there are fewer actual actions. The results also show that, although the government has implemented strict restrictions on private car purchases and driving in the city, citizens are more willing to improve the environment and mitigate climate change through smart mobility advancements. Moreover, only a few participants support reducing the travel times, which implies, although it is easier to conduct distance communication through the internet nowadays, the desire for traveling is still quite strong. In other words, online communication cannot replace traveling completely. Although the government and companies have implemented smart parking and promoted NEV for a long time, the accessibility to the information, such as "the location and number of parking lots," "the location and number of new energy charging piles," is still relatively difficult. Finally, as for attitudes towards data collection, it is widely noted that data collection lacks the notice to customers.

5. Conclusion and Discussion

The last decade has witnessed the enormous disruptive impacts of data technologies on various domains in daily life and the urban environment. This paper delves into the promises of data-driven smart mobility to climate mitigation by exploring the general image of the development of smart mobility today. As for the understanding of smart mobility, there is no standard definition of the concept of smart mobility, but with broad agreement on the digitalization transition in the transport system, especially with the widespread of ICT and data technologies. Data-driven smart mobility is a multidisciplinary research field ranging from information technologies to transport planning, policymaking, and social science practice. The governments and the markets are engaged in launching new products or services in order to take advantage of big data and purse a smart mobility future. It is an inevitable trend to integrated data with urban transport strategies and planning in the following years. The potential of the data to tackle climate issues lies in the efficient transport operation and travel behaviors change.

The case study of Hangzhou reflects a typical smart city's efforts towards digitalization in the transport sector in China. As a leading innovative city in China, Hangzhou has most of the travel modes, including traditional travel modes and innovative travel modes. Meanwhile, the city is engaged in developing mobility services. The government is in a dominant position in transport infrastructure planning and traffic operation. In the last decade, the government has promoted its cooperation with many information technology companies in Hangzhou, namely, Alibaba, Hikvision, and Dahua. Sharing mobility services have complemented urban transportation and improved travel efficiency for residents in the last decade.

The real-time traffic monitoring platform, City Brain, optimizes the allocation of traffic management resources and upgrades intelligent urban management, becoming a learning model for domestic cities in China. It is possible to conduct accurate estimations on individuals' travel behaviors and mobility models through various data collection channels from street cameras to personal daily devices. With the application of big data, cloud computing, and AI, smart mobility has reduced road congestion, balance the temporal and spatial distribution of traffic flow, promote road safety and travel efficiency in Hangzhou. At the same time, efficient mobility improves air quality and reduces GHG emissions in Hangzhou. According to Hangzhou Environment Bulletin (2018), compared to 2017, sulfur dioxide (SO_2) in ambient air decreased by 9.1%; nitrogen dioxide (NO_2) decreased by 4.4%; respirable particulate matter (PM_{10}) decreased by 5.6%; fine particulate matter ($PM_{2.5}$) decreased by 11.1%.

5.1. Call for unified data strategy

The core of smart mobility is the integration of travel modes in order to provide smart mobility services, which have the potential to optimize travel demands and reduce environmental impacts. The research on the smart city has been going on for a few decades, but big data application in the transport sector is still young. A profound smart mobility system is based on the accessible and interoperable data platform. Establishing a standard transport data repository and the interoperable data-sharing platform is critical to dig deep value of data.

Many cities are engaged in developing a sound transport data strategy to realize the digital transition in the transport sector. Act on Transport Service in Finland requires all transport service providers, including public and private transport companies, to provide access to interoperable electronic format data (Finnish Ministry of Transport and Communications, 2018). In Norway, the government set the national hub for public transport information, Entur, for collecting, managing, and publishing transport data (Entur, 2019). Nordic countries take a leading position in the research and practice of data-driven mobility. Compared with Helsinki or Oslo's transport data strategy, the biggest problem in Hangzhou is that the city lacks a standard data opening platform, and the analysis and application of data is insufficient.

First and foremost, there is a lack of coordination among government departments and companies due to different interests, technical incompatibilities, inconsistent data structures, lack of legal safeguards, and inadequate institutional systems. The growing smart transport projects call for cooperation among different government departments and different technology companies. The digital transition in the urban transport system involves profound changes in various institutions and authorities. However, according to institutional theory, both political and economic institutions are resistant to change to some extent and have relatively path dependence. On the one hand, the relevant public authorities are cautious about opening data in most cities in China, considering security and privacy. Even when the data is open, the data is in a variety of formats that are difficult for applicants to use directly. Some data requires application, and applicants need to make copies at the doorstep of the relevant department, and the procedure is complicated. The data-sharing platform, like the Zhejiang Government Data Open Platform, is driven by central governmental policy, focuses more on form building, and neglects content digging, where the data format is not uniform and insufficiently shared. Meanwhile, the open data types are decided by related authorities. The transport department collects data related to the bus and taxi industry, the traffic police department collects traffic flow data, and the construction department collects data related to parking. However, the relevant data is not shared, not integrated, and incompatible. Each department hires different software companies, and apply data based on its database for its own management. On the other hand, enterprise data sharing is inadequate. For example, a large amount of data on online bicycle sharing, car sharing is owned by private companies that are not willing to open data because of business competition. However, these data can be used for urban planning and social study. Smart parking data is scattered among several management companies, equipment manufactures, and third-party platforms, such as parking applications on smartphones. As a result, there is not enough data sharing to be used as a basis for coordinating parking resources.

Second, the government mostly perceives its role as regulator and manager, while ignoring its ability to optimize mobility service and improve trip quality. It is a common problem in China because of the "relative homogeneity of its institutions, the societal preference for conformity, the restricted nature of policy discourse" (Andrews-Speed, 2016). The application of transport data is narrow on governance and regulation, lacking in-depth use of data to improve mobility service. The City Brain was initialed to reduce road traffic congestion, and now the government aims to combine the platform with other administrative functions, such as social governance and public security. However, system integration is insufficient. The urban traffic, public security, traffic police, and traffic departments have built many application systems that operate independently and have not yet been integrated, limiting the function of smart mobility.

Moreover, data mining is not enough at the present stage. The governments are engaged in digitizing "hard" infrastructures but paid little attention to the enormous potential of the data to the change transport system and travel behavior in the long term. Although there are many reasons and benefits driving digitalization, smart competition, economic stimulation, and efficient governance are the primarily driven factors. Less attention has been put to combine transport digitalization with environment improvement and climate change. The policies that aim to reduce environment and climate impacts concentrate on traditional routines, such as promoting public transport investment and limiting private vehicles in Hangzhou. Data-driven smart mobility can reduce environmental impacts by improving travel efficiency, reducing travel distance and times, and changing travel behaviors. Environmental policies in the transport sectors should also combine with data innovations. At the same time, ICT, as well as other digital technology, also produces environmental and climate costs. Therefore, it is necessary to look for innovative digital solutions to optimize the combination of data and mobility.

5.2. Opportunities in a growing city

Institutions play important roles in socio-technical transition through normative, regulations, and policies and require self-change to reach broad social change. Smart mobility initiatives in Hangzhou is mostly top-down and led by the government. The government usually has the responsibility to develop a sound data strategy, establish an open data open platform, and develop data sharing standards. Meanwhile, in the urban competition of smart cities and smart transportation, Hangzhou has its advantages, many information technology companies provide hardware and software facilities for smart transportation construction. The partnerships between the government and private sectors are becoming closer, and the transport authorities become more dependent on data technology to make the decision. Its role of monitoring and governance should shift to the coordinator and service providers with the transport transition to mobility service in the future. More accessibility to data and interoperable databases can drive the private sectors to involve the optimization of a sustainable transport system. Therefore, the government should deregulate some transport data and encourage data opening among private participants. Moreover, data protection is gaining more concern in recent years. Although people generally have no awareness of the data collection process and data application, the public authorities should also enhance the supervisory, balance data collection, and risk assessment.

Data-driven smart mobility promises new imagination for the development of the future sustainable smart city. In the movement to reduce carbon emissions and mitigate climate change, in addition to more efficient modes of travel, data-driven transport can further transform traditional transport by influencing people's travel behavior and attitudes. From a time perspective, travel behavior change includes travel modes selection in the short term, urban spatial and transport planning in the medium term, and lifestyle preference in the long term. Data application is not sufficient at this because of limited accessibility. First, people are willing to react to climate change by using more clean and sustainable travel modes and sharing mobility in the survey. However, more people consider less about climate impacts when compare climate factors with other travel factors, such as travel time and travel experience. It implies there is a great space for the improvement of mobility service, and the green travel modes have its support among citizens. Based on abundant green travel modes options, people will consider more about climate change and change travel mode selection. Secondly, through the efficient data analysis of travel behavior and attitudes in urban regions, it is possible to change the automobile-oriented urban design and promote a walkable city. Finally, there is a long-term impact on the travel preference and lifestyle choice. The behavior change is not only from an individual level but also from a spatial planning and social environment level to realize sustainable development.

The primary driven factors in today's smart initials in Hangzhou are still out of efficient governance, smart city competition, and taking economic fruits of big data. Efficient transport management and operation can effectively reduce traffic fatalities, improve accessibility, reduce time and environmental cost, which contributes to SDG 11.2 with more sustainable transportation in the future. Moreover, less GHG emissions can be the main reason account for climate change mitigation in the future with an inevitable trend of urbanization on a global scale. Meanwhile, the design of data sharing and usage platform, as the critical point in the data-driven smart mobility transition, should be integrated with national policy policies, strategies, and planning concerning climate issues (SDG 13.2). Additionally, data technologies can also be applied to carbon calculation, environmental monitoring, and behavior change. Its potentials to tackle climate issues lies in further data mining and analysis. The transport sectors should conduct more deep data analysis and application for environmental and health benefits. Data strategy should combine short-term and long-term goals together, relieving road congestion at the same time reaching climate mitigation, and sustainable development in the future.

5.3. Suggestions for future study

This overview of the current practice of data-driven smart mobility in urban regions points to several issues that can be studied in the future.

First, the current use of data is mainly focused on improving the efficiency of transport management and operation. How to highlights the environmental and public value of data technologies? Behavior change can have huge impacts on the climate issue. Big data has been applied to the consumption analysis for a long time. In the transport sector, travel behavior change can be achieved by customer habits learning and guidance. However, the fact is that fewer interests have driven the travel data usage for travel behavior change. Many questions need to be further answered around behavior change: how we can use transport data analysis to guide travel behavior change? Without economic benefits, who should take responsibility to guide travel behavior change with data resources?

Moreover, many people are thinking about the effects raised by the Corona pandemic on future urban transport systems. During the pandemic, people are not willing to use public transportation because of safety and hygiene reasons. Taxi and sharing riding are decreasing substantially. Meanwhile, people are encouraged to reduce distance travel, increase bicycle riding, walk, and use more telecommunication. The decrease in traffic loads and industry activities is leading to a sharp drop in global air emissions. The pandemic is accelerating the travel behavior change towards sustainability while raises new challenges to public mobility service. The lessons from this period are calling people to rethink economic development with priorities on the environment and public health. Mobility service has been drastically affected by a sudden pandemic. Therefore, besides the economic and environmental benefits, mobility service development should always prioritize public health as the first factor. What influences will the pandemic have on the mobility service and transport system in the future? How can transport data be applied for the protection of public health in the transport system? How can people access green and safe travel modes, an integrated public transport system, and the general accessibility to ICT in this particular time? In a word, the unexpectedly pandemic has added both opportunities and challenges to smart mobility development in the future.
Smart mobility has promised many potentials to tackle new challenges, but still with many questions needed to be answered.

6. Acknowledgements

The completion of this thesis was mostly during quarantine when there is a pandemic around the world. Therefore, I really appreciate everyone helped me during this special time in my life.

First of all, I would thank my supervisor Anna Kramers for her valuable advice, feedbacks and encouragements. She inspired and encouraged me a lot during the period this project was conducted. I have learned a lot from her. I also want to thank my subject reviewer, Cecilia Katzeff, for her advice and patience. And I thank my opponent, Gradeen Rachael, for her comments.

I really appreciate my family, lovely friends, my supervisor, and teachers in the GEO center, some doctors and workers whom I only met once during the quarantine in Hohhot. My deepest appreciation to my parents, who supported me throughout the master's program and thesis time. I also want to thank Ye, who always had patient, helped me with the survey, and listened to me. Without the help and encouragement from them, I cannot finish the thesis on time when facing a world out of control. I feel sorry for what we have been through, and hope everything goes to normal soon.

7. References

Acquisti, A., Brandimarte, L. & Loewenstein, G. (2015). Privacy and human behavior in the age of information, *Science* (New York, N.Y.), vol. 347, no. 6221, pp. 509-514.

Albino, V., Berardi, U. & Dangelico, R.M. (2015). Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology,* vol. 22, no. 1, pp. 3-21.

Andrews-Speed, P. (2016). Applying institutional theory to the low-carbon energy transition, *Energy Research & Social Science*, vol. 13, pp. 216-225.

Banister. D (2008). The sustainable mobility paradigm, *Transport Policy*, Vol. 15, Issue 2, pp. 73-80.

Bell, M., Gault, A., Thompson, M. (2016). Meeting Carbon Budgets—2016 Progress Report to Parliament: Executive Summary. *Committee on Climate Change*. 1–17. Available from: https://www.theccc.org.uk/publications/.

Bibri, S.E. (2019). *Big Data Science and Analytics for Smart Sustainable Urbanism*. Springer.

Bibri, S. E. & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society*, vol. 31, pp. 183–212.

Boarnet, M. & Crane, R. (2001). The influence of land use on travel behavior: specification and estimation strategies, *Transportation Research Part A,* vol. 35, no. 9, pp. 823-845.

Bowen, G.A. (2009). Document Analysis as a Qualitative Research Method, *Qualitative Research Journal*, vol. 9, no. 2, pp. 27-40.

Castells, M. (1983). *The city and the grassroots: a cross-cultural theory of urban social movements*. London, E. Arnold.

Chang, W.R., Hwang, J.J. & Wu, W. (2017). Environmental impact and sustainability study on biofuels for transportation applications. *Renewable and Sustainable Energy Reviews*, vol. 67, pp.277-288.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J.R., Mellouli, S., Nahon, K., Pardo, T.A. & Scholl, H.J. (2012). Understanding Smart Cities: An Integrative Framework, *IEEE*, , pp. 2289.

Chowdhury, M.A., Apon, A. & Dey, K. (2017). *Data analytics for intelligent transportation systems*, Elsevier, Amsterdam.

Chris Giles & Aliya Ram (2019). Tech giants should 'open up their customer data to others', *Financial Times*, March 13. Available at: https://www.ft.com/content/4180f5e6-44b4-11e9-a965-23d669740bfb

Clarke, R. (1997). *Introduction to dataveillance and information privacy and definitions of terms.* Available at: http://www.rogerclarke.com/DV/Intro.html

Coifman, B. & Cassidy, M. (2002). Vehicle reidentification and travel time measurement on congested freeways, *Transportation Research Part A,* vol. 36, no. 10, pp. 899-917.

Collantes, G. O. & Mokhtarian, P. L. (2007). Subjective assessments of personal mobility: what makes the difference between a little and a lot? *Transport Policy*, 14, pp. 181–192.

Corbin, J., & Strauss, A., 2008. *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). Thousand Oaks, CA, US: Sage Publications, Inc

Cramer, J. & Krueger, A.B. (2016). Disruptive Change in the Taxi Business: The Case of Uber, *The American Economic Review,* vol. 106, no. 5, pp. 177-182.

Daisy Dunne, Josh Gabbatiss, Robert McSweeney (2020). Media reaction: Australia's bushfires and climate change, *Carbon Brief*. [Blog]. January 7. Available at: https://www.carbonbrief.org/media-reaction-australias-bushfires-and-climate-change.

Dameri, R.P. & Benevolo, C. (2016). Governing Smart Cities: An Empirical Analysis, *Social Science Computer Review,* vol. 34, no. 6, pp. 693-707.

Demirbas, A. (2007). Importance of biodiesel as transportation fuel. *Energy policy*, 35(9), pp.4661-4670.

Diaz, C. & Gürses, S. (2012). Understanding the landscape of privacy technologies. In: *Proceedings of the Information Security Summit* '12. pp. 58–63.

Eckhoff, D. & Wagner, I. (2018). Privacy in the Smart City-Applications, Technologies, Challenges, and Solutions, *IEEE Communications Surveys & Tutorials*, vol. 20, no. 1, pp. 489-516.

EEA (European Environment Agency) (2019). *Greenhouse gas emissions from transport in Europe*. Available at: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12

Entur (2019). *About Entur*. Available at: https://www.entur.org/about-entur/

EPA (n.d.). *Sources of Greenhouse Gas Emissions, Transportation Sector Emissions*, Available at: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

EPA (2019). *Climate Change Indicators: Climate Forcing*. Available at: https://www.epa.gov/climate-indicators/climate-change-indicators-climate-forcing#ref1

EPA (2019). *Global Emissions by Economic Sector*. Available. at: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Sector

EPA (n.d.). *The Causes of Climate Change.* Available at: https://climate.nasa.gov/causes/

European Parliament (2014). *Mapping smart cities in the EU*. Available at: http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

Exponential Roadmap (2019). *Exponential Roadmap 1.5. Scaling 36 Solutions to Halve Emissions By 2030.* Available at: https://exponentialroadmap.org/wp-content/uploads/2019/09/ExponentialRoadmap_1.5_20190919_Single-Pages.pdf

Finn R. L., Wright D. & Friedewald M. (2012). Seven Types of Privacy. In: Gutwirth, S., Leenes, R., de Hert, P., Poullet, Y. & SpringerLink, *European Data Protection: Coming of Age,* 1. Aufl. edn, Springer Netherlands, Dordrecht, pp. 3–32.

Flügge, B. & SpringerLink (Online service) (2017). *Smart Mobility – Connecting Everyone: Trends, Concepts and Best Practices,* 1st 2017 edn, Springer Fachmedien Wiesbaden, Wiesbaden.

Fontaine, C., Haarman, A. & Schmid, S. (2006). The stakeholder theory. *Edlays education*, 1, pp.1-33.

Ford, J.D., Tilleard, S.E., Berrang-Ford, L., Araos, M., Biesbroek, R., Lesnikowski, A.C., MacDonald, G.K., Hsu, A., Chen, C. & Bizikova, L. (2016). Big data has big potential for applications to climate change adaptation, *Proceedings of the National Academy of Sciences of the United States of America,* vol. 113, no. 39, pp. 10729-10732.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N. & Meijers, E. (2007). *Smart cities: Ranking of european medium-sized cities*. vienna, austria: Centre of regional science (srf), vienna university of technology. Available at: www. smart-cities. eu/download/smart cities final report. pdf.

Gil-Garcia, J.R., Pardo, T.A. & Nam, T. (2015). What makes a city smart? Identifying core components and proposing an integrative and comprehensive conceptualization, *Information Polity,* vol. 20, no. 1, pp. 61-87.

Guo, W., Wang, Z., Wang, W. & Bubb, H. (2015). Traffic Incident Automatic Detection Algorithms by Using Loop Detector in Urban Roads. *Recent Patents on Computer Science*, 8(1), pp.41-48.

Hangzhou Bureau of Statistics (2019). 2018 年杭州市国民经济和社会发展统计公报. [in Chinese]. Available at: http://www.hangzhou.gov.cn/art/2019/3/4/art_805865_30593279.html

Hangzhou Municipal Bureau of Ecology and Environment (2018). *Hangzhou Environment Bulletin*. [in Chinese]Available at: http://epb.hangzhou.gov.cn/picture/old/P020190614548239526265.pdf

Hennessy, K., Lucas, C., Nicholls, N., Bathols, J., Suppiah, R. & Ricketts, J. (2005). *Climate change impacts on fire-weather in south-east Australia*. CSIRO Marine and Atmospheric Research and Bushfire CRC and Australian Bureau of Meteorology. CSIRO Australia. ISBN 1-921061-10-3. Available at: http://www.cmar.csiro.au/e-print/open//hennessykj_2005b.pdf

Hensher, D.A. (2018). Tackling road congestion – What might it look like in the future under a collaborative and connected mobility model?, *Transport Policy,* vol. 66, pp. A1-A8.

Hikvision (2019). *开发服务，数据资源.* Available at: https://open.hikvision.com/docs/e3f1feaeeec0814a02ba21aa7ebdf6dd

Hu C. & Liu X. (2016). Modeling track geometry degradation using support vector machine technique, Joint Rail Conference. *American Society of Mechanical Engineers*, p. V001T01A011.

IPCC (2014a). *Climate Change 2014: Mitigation of Climate Change*. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf

IPCC (2014b). *Climate Change 2014 Synthesis Report Summary for Policymakers.* Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

IPCC (2018). *Global Warming of 1.5°C.* Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Jittrapirom, P., Caiati, V., Feneri, A.-., Ebrahimigharehbaghi, S., Alonso González, M.J. & Narayan, J. (2017). Mobility as a Service: A critical review of definitions, assessments of schemes, and key challenges, *Urban Planning,* vol. 2, no. 2, pp. 13-25.

Joanna Woodburn (2018). NSW Government says entire state in drought, new DPI figures reveal full extent of big dry, *ABC*, August 8. Available at: https://www.abc.net.au/news/2018-08-08/nsw-government-says-entire-state-is-now-in-drought/10088628.

Jones, T. M. (1994). Essay on the Toronto conference. *Business & Society*, 33: 98-101.

Jones, T.M. & Wicks, A.C. (1999). Convergent stakeholder theory. *Academy of management review*, 24(2), pp.206-221.

Khadilkar, H. (2017). Data-Enabled Stochastic Modeling for Evaluating Schedule Robustness of Railway Networks, *Transportation Science,* vol. 51, no. 4, pp. 1161-1176.

Khan, S.M., Rahman, M., Apon, A. & Chowdhury, M. (2017). Characteristics of Intelligent Transportation Systems and Its Relationship with Data Analytics. In: Chowdhury, M.A., Apon, A. & Dey, K. (eds) *Data analytics for intelligent transportation systems,* Elsevier, Amsterdam, pp. 1-29.

Kitamura, R., Mokhtarian, P. L. & Laidet, L. (1997). A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area, *Transportation*, 24, pp. 125–158.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism, *GeoJournal,* vol. 79, no. 1, pp. 1-14.

Kramers, A., Höjer, M., Lövehagen, N., Wangel, J., Centre for Sustainable Communications, CESC, Centra, Skolan för arkitektur och samhällsbyggnad (ABE), Skolan för datavetenskap och kommunikation (CSC), Hållbar utveckling, miljövetenskap och teknik, KTH & Miljöstrategisk analys (fms). (2014). Smart sustainable cities – Exploring ICT solutions for reduced energy use in cities, *Environmental Modelling and Software,* vol. 56, pp. 52-62.

Kramers, A., Ringenson, T., Sopjani, L. & Arnfalk, P. (2018). AaaS and MaaS for reduced environmental and climate impact of transport. In: *ICT4S2018. 5th International Conference on Information and Communication Technology for Sustainability*, vol. 52, pp. 137-152. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-233465.

Kriukelyte, E. (2019). *The transport sector in transition: different pathways of handling transport data in urban regions of Helsinki, London, Oslo and Singapore* (TRITA-ABE-RPT). Stockholm: KTH Royal Institute of Technology. Retrieved from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-254596

Lanzendorf, M. (2002). Mobility styles and travel behavior: application of a lifestyle approach to leisure travel, *Transportation Research Record*, 1807, pp. 163–173.

Li Yuan (2015). 杭州”双限”满一年 交通到底改善了多少？*Hangzhou.com,* May 11. [in Chinese]. Available at: https://ori.hangzhou.com.cn/ornews/content/2015-05/11/content_5765344.htm

Lombardi, P., Giordano, S., Farouh, H. & Yousef, W. (2012). Modelling the smart city performance, *Innovation: The European Journal of Social Science Research: SMART CITIES IN THE INNOVATION AGE,* vol. 25, no. 2, pp. 137-149.

Luo Bin, Ye Ying, Tan Yongzhao & Wang Na, 2016. 杭州市交通拥堵综合治理实践. *Urban Transportation*, pp.35-42. [in Chinese].

Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K. & Stocker, T.F. (2008). High-resolution carbon dioxide concentration record 650,000-800,000 years before present, *Nature*, vol. 453, no. 7193, pp. 379-382.

Mantelero, A. (2015). Data protection, e-ticketing, and intelligent systems for public transport, *International Data Privacy Law*, vol. 5, no. 4, pp. 309-320.

Mao Y. (2019). 明年 1 月起 450 辆纯电动公交车驶上杭州街头, *Hangzhou Daily*, December 26. [in Chinese]. Available at: https://hznews.hangzhou.com.cn/chengshi/content/2019-12/26/content_7649014.htm

Meyer, J.W. (2010). World Society, Institutional Theories, and the Actor, *Annual Review of Sociology,* vol. 36, no. 1, pp. 1-20.

Michelle Toh & Leonie Erasmus (2019) Alibaba's "City Brain" is slashing congestion in its hometown, *CNN Business*. January 15. Available at: https://edition.cnn.com/2019/01/15/tech/alibaba-city-brain-hangzhou/index.html

Mitchell, W.J. (2000). *E-Topia, "Urban Life, Jim e but Not as We Know it".* The MIT Press, Cambridge Mass.

Mofijur, M., Rasul, M.G., Hyde, J., Azad, A.K., Mamat, R. & Bhuiya, M.M.K. (2016). Role of biofuel and their binary (diesel–biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engines emission reduction. *Renewable and Sustainable Energy Reviews,* vol. 53, pp. 265-278.

Mukhtar-Landgren D., Karlsson M. A., Koglin T., Kronsell A., Lund E., Sarasini S., Sochor J. & Wendle B. (2016). Institutional conditions for integrated mobility services (IMS). Towards a framework for analysis. K2 working paper.

Municipal Data Resources Authority (2018). 知道哪些牛企在为杭州城市数据大脑服务吗?（上篇，中篇，下篇）. *Municipal Data Resources Authority.* [Blog]. May 16. [in Chinese]. Available at: https://mp.weixin.qq.com/s/3kTB9U-rkwwNoEPenDsy4Q

NASA (n.d.). *Overview: Weather, Global Warming and Climate Change*. Available at: https://climate.nasa.gov/resources/global-warming-vs-climate-change.

Neirotti, P., De Marco, A., Cagliano, A.C., Mangano, G. & Scorrano, F. (2014). Current trends in Smart City initiatives: Some stylised facts, *Cities,* vol. 38, pp. 25-36.

Office of Hangzhou City Traffic Congestion Control (2017). *关于杭州交通数据开放制度的公告*. [in Chinese]. Available at: http://115.233.209.152/n5/n16/c3089703/content.html

Oliver, T.H. & Morecroft, M.D. (2014). Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities. *Wiley Interdisciplinary Reviews: Climate Change,* vol. 5, no. 3, pp. 317-335.

Oreskes, N. (2004). Beyond the ivory tower. The scientific consensus on climate change, *Science (New York, N.Y.),* vol. 306, no. 5702, pp. 1686.

O'Riordan, T. & Jordan, A. (1999). Institutions, climate change and cultural theory: towards a common analytical framework, *Global Environmental Change,* vol. 9, no. 2, pp. 81-93.

O'Riordan, T., Cooper, C.L., Jordan, A., Rayner, S., Richards, K., Runcie, P. & Yoffe, S. (1998). Institutional frameworks for political action. In: Rayner, S., Malone, E. (Eds.), *Human Choice and Climate Change*, Vol. 1. Battelle Press, Columbus.

Perugu, H., Wei, H. & Yao, Z. (2016). Integrated data-driven modeling to estimate PM2.5 pollution from heavy-duty truck transportation activity over metropolitan area, *Transportation Research Part D,* vol. 46, pp. 114-127.

Pfitzmann, A. & Hansen, M. (2010). *A terminology for talking about privacy by data minimization: Anonymity, unlinkability, undetectability, unobservability, pseudonymity, and identity management*. Available at: https://dud.inf.tu-dresden.de/literatur/Anon_Terminology_v0.34.pdf

Porter, M.E. & Heppelmann, J.E. (2014). How smart, connected products are transforming competition, *Harvard Business Review,* [Online], vol. 92, no. 11, pp. 64.

Rafiemanzelat, R., Emadi, M.I. & Kamali, A.J. (2017). City sustainability: the influence of walkability on built environments, *Transportation Research Procedia,* vol. 24, pp. 97-104.

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

Ren Yan (2018). 今年杭州所有道路停车泊位 基本实现无感支付. *Hangzhou Daily*. August 29. [in Chinese]. Available at: https://mdaily.hangzhou.com.cn/hzrb/2018/08/12/article_detail_1_20180812A048.html

Ringenson, T., Arnfalk, P., Kramers, A. & Sopjani, L. (2018). Indicators for Promising Accessibility and Mobility Services. *Sustainability*, 10(8), p.2836.

Rodrigue Jean-Paul (2019). *Transportation and Energy*. Available at: https://transportgeography.org/?page_id=15592

Ruhlandt, R.W.S. (2018). The governance of smart cities: A systematic literature review, *Cities,* vol. 81, pp. 1-23.

Salvi, B.L. & Subramanian, K.A. (2015). Sustainable development of road transportation sector using hydrogen energy system, *Renewable and Sustainable Energy Reviews,* vol. 51, pp. 1132-1155.

Sarvesh Mathi (2019). *What Drives a Driverless Car? How the tech inside Tesla's and Waymo's self-driving vehicles really works*, Medium OneZero. Available at: https://onezero.medium.com/what-drives-a-driverless-car-5a5f43367354

Schwanen, T., Banister, D. & Anable, J. (2011). Scientific research about climate change mitigation in transport: A critical review. *Transportation Research Part A,* vol. 45, no. 10, pp. 993-1006.

Schwartz, P.M. & Solove, D.J. (2011). The PII problem: privacy and a new concept of personally identifiable information, *New York University Law Review*, vol. 86, no. 6, pp. 1814.

Scott, W. R. (2008). Institutions and organizations: Ideas and interests, 3rd. ed. Oaks, California: Sage Publications.

Shao, F., Li, K. & Xu, X. (2016). Railway accidents analysis based on the improved algorithm of the maximal information coefficient, *Intelligent Data Analysis,* vol. 20, no. 3, pp. 597-613.

Shapiro, J.M. (2006). Smart Cities: Quality of Life, Productivity, and the Growth Effects of Human Capital, *The Review of Economics and Statistics,* vol. 88, no. 2, pp. 324-335.

Sjöman, M., Ringenson, T. & Kramers, A. (2020). Exploring everyday mobility in a living lab based on economic interventions, *European Transport Research Review,* vol. 12, no. 1, pp. 1-17.

Song, H., Srinivasan, R., Sookoor, T. & Jeschke, S. (2017). *Smart cities: foundations, principles, and applications*, 1;1st; edn, John Wiley & Sons, Hoboken, NJ.

Söderström, O., Paasche, T. & Klauser, F. (2014). Smart cities as corporate storytelling, *City,* vol. 18, no. 3, pp. 307-320.

Sperling, D., Delucchi, M.A., Davis, P.M. & Burke, A.F. (1995). *Future drive: electric vehicles and sustainable transportation,* Island Press, Washington, D.C.

Staricco, L. (2013). Smart Mobility Opportunities and Conditions. Tema. Journal of Land Use, Mobility and Environment, vol. 6(3), pp.342-354.

Suárez, A., Watson, R.T. & Dokken, D.J. (2002). *Climate change and biodiversity*.

Sun J. & Sun H. (2018). 太多了！杭州共享单车今年要砍掉三分之一, *Zhejinag Oline*. March 27. [in Chinese]. Available at: http://zjnews.zjol.com.cn/zjnews/hznews/201803/t20180323_6862262.shtml

Sun, L., Lu, Y., Jin, J.G., Lee, D. & Axhausen, K.W. (2015). An integrated Bayesian approach for passenger flow assignment in metro networks, *Transportation Research Part C,* vol. 52, pp. 116-131.

Tak, S., Kim, S., Oh, S. & Yeo, H. (2016). Development of a Data-Driven Framework for Real-Time Travel Time Prediction, *Computer-Aided Civil and Infrastructure Engineering,* vol. 31, no. 10, pp. 777-793.

Tang T. & Wei Y. (2017). 杭州网约车新政策正式实施 滴滴、优步等暂未获运营资质, *Xinhuanet*. March 2. [in Chinese]. Available at: http://www.xinhuanet.com/auto/2017-03/02/c_1120553637.htm

The Transport Ministry of PRC (2017). *交通运输部办公厅关于印发推进智慧交通发展行动计划（2017-2020 年）的通知.* [in Chinese]. Available at: http://xxgk.mot.gov.cn/jigou/zhghs/201702/t20170213_2976478.html

Thornbush, M.J. and Golubchikov, O. (2019). *Sustainable Urbanism in Digital Transitions: From Low Carbon to Smart Sustainable Cities*. Springer.

Townsend, A.M. (2013). *Smart cities: big data, civic hackers, and the quest for a New Utopia*, 1.th edn, W. W. Norton & Co, New York.

Transport Systems Catapult (2015). *The Transport Data Revolution, Investigation into the data required to support and drive intelligent mobility, the report.* Available at: https://ts.catapult.org.uk/wp-content/uploads/2016/04/The-Transport-Data-Revolution.pdf

UN Environment Programme, Champions of the Earth (2018). *自行车回归及减少空气污染倡议 助力杭州实现清洁空气*. [in Chinese]. Available at: https://www.unenvironment.org/championsofearth/zh-hans/news-and-stories/zixingchehuiguijijianshaokongqiwuranchangyi-zhulihangzhoushixianqingjiekongqi

UN (2018). *World Urbanization Prospects: The 2018 Revision: key facts*. Available at: https://www.un.org/en/events/citiesday/assets/pdf/the_worlds_cities_in_2018_data_booklet.pdf

UN, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019: Highlights*. ST/ESA/SER.A/423. Available at: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

UN (2015). *Cities - United Nations Sustainable Development Action 2015*. Available at: https://www.un.org/sustainabledevelopment/cities/

UN, Independent Expert Advisory Group on a Data Revolution for Sustainable Development (2014). *A world that Counts: Mobilizing a Data Revolution for Sustainable Development*. New York. Available at: https://www.undatarevolution.org/wp-content/uploads/2014/12/A-World-That-Counts2.pdf

UN, High-level Advisory Group on Sustainable Transport (2016). *Mobilizing Sustainable Transport for Development*. Available at: https://sustainabledevelopment.un.org/content/documents/2375Mobilizing%20Sustainable%20Transport.pdf

UN (2020). *SDG Indicators, Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development.* Available at: https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202020%20review_Eng.pdf

Urry, J. (2007). *Mobilities*. Polity, Cambridge.

Van Acker, V., Van Wee, B. & Witlox, F. (2010). When transport geography meets social psychology: toward a conceptual model of travel behaviour. *Transport Reviews*, 30(2), pp.219-240.

van Wee, B. (2009). Self-Selection: A Key to a Better Understanding of Location Choices, Travel Behaviour and Transport Externalities?. *Transport Reviews*, 29(3), pp. 279–292.

Wang Y. & Zeng Z. (2018). Overview of Data-Driven Solutions. In: Zeng, Z. & Wang, Y. *Data-Driven Solutions to Transportation Problems*, Elsevier, Oxford; San Diego, pp. 1-9.

Wockatz, P. & Schartau, P. (2015). *Traveller Needs and UK Capability Study.* Transport Systems Catapult, Milton Keynes. Available at: https://ts.catapult.org.uk/wp-content/uploads/2016/04/Traveller-Needs-Study-1.pdf

Woo, S., Tak, S. & Yeo, H. (2016). Data-Driven Prediction Methodology of Origin–Destination Demand in Large Network for Real-Time Service, *Transportation Research Record,* vol. 2567, no. 1, pp. 47-56.

Wu C. (2018). "杭州公交推行一体化公交移动支付"互联网+ 公交"激发公共出行新活力". *城市公共交通*, (2), pp.22-24. [in Chinese].

Ye, R. & Titheridge, H. (2017). Satisfaction with the commute: The role of travel mode choice, built environment and attitudes. *Transportation Research Part D: Transport and Environment,* 52, pp.535-547.

Yigitcanlar, T. (2018). Smart city policies revisited: Considerations for a truly smart and sustainable urbanism practice. *World Technopolis Rev*, 7(2), pp.97-112.

Yin, J. & Zhao, W. (2016). Fault diagnosis network design for vehicle on-board equipments of high-speed railway: A deep learning approach. *Engineering Applications of Artificial Intelligence*, vol. 56, pp.250-259.

Yin, R.K. (1984). *Case Study Research: Design and Methods.* Beverly Hills, Calif: Sage Publications.

Yue Y. (2018). 杭州新添 400 辆共享汽车 租车费每小时 15 元 你会去扫码租车吗？ *City Express.* April 1. [in Chinese]. Available at: https://hznews.hangzhou.com.cn/chengshi/content/2018-04/01/content_6837397.htm

Yu Li (2018). 我国汽车保有量达 2.17 亿辆, 杭州约 244 万辆. *Hangzhou News*, January 18. [in Chinese]. Available at: http://hznews.hangzhou.com.cn/jingji/content/2018-01/18/content_6776409.htm

Zainal, Z. (2007). Case study as a research method. Jurnal Kemanusiaan, 5(1).

Zeng, Z. & Wang, Y. (2018). *Data-Driven Solutions to Transportation Problems*, Elsevier, Oxford;San Diego.

Zhang, S. & Witlox, F. (2019). Analyzing the Impact of Different Transport Governance Strategies on Climate Change, *Sustainability*, vol. 12, no. 1, pp. 200.

Zhao J. (2015). 杭州市公共交通体系现状与问题分析 [J]. *商界论坛物流交通*, (1), pp.250-251.

Zhou Qiuxia (2017). *城市智慧停车诱导交通系统应用* , Master's thesis, Chang'an University. [in Chinese].

Zygiaris, S. (2013). Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems, *Journal of the Knowledge Economy*, vol. 4, no. 2, pp. 217-231.

Hegerl, G.C., F. W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner & P.A. Stott (2007). Under- standing and Attributing Climate Change. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller (eds.) *Climate Change 2007:*

The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Appendix: Smart mobility and low-carbon travel in Hangzhou

Hello and thank you for your time for filling out this questionnaire! I am a master student majoring in Sustainable Development in Uppsala University. I am conducting a study on smart mobility and low-carbon travel in Hangzhou. The information you fill in is for academic research purposes only. It is expected to take 5-10 minutes to complete this questionnaire. Thank you very much for your valuable comments and support!

Section 1

1. What is your gender?
❏ Men
❏ Women
❏ Other

2. How old are you?
______

3. What is your occupation?
❏ Students
❏ Government staff
❏ Enterprise manager
❏ Office staff
❏ Professional staff (doctor, teacher, journalist etc.)
❏ Salesperson
❏ Freelance
❏ Famer
❏ Retired
❏ No work at the moment
❏ Other

4. What is your monthly salary before taxes?
❏ Below 1500
❏ 1500-5000
❏ 5000-8000
❏ 8000-10000
❏ 10000-20000
❏ More than 20000

5. What is your highest level of education completed?
❏ Middle school or below middle school
❏ High school/secondary school
❏ Specialist collage
❏ Bachelor degree
❏ Master degree

❑ PHD or above

6. How long have you lived in Hangzhou?
❑ Less year
❑ 1-3 years
❑ 4-5 years
❑ 6-10 years
❑ More than 10 years

Section 2

7. What are the travel modes you usually use? (Multiple choice)
➢ Bus
➢ Bicycle
➢ Subway
➢ Private car
➢ Sharing car
➢ Electric bicycle
➢ Scooter
➢ Walking
➢ Other

8. Do you own any private car?
❑ Yes
❑ No

9. How long do you spend for daily commute?
❑ Less than 10 mins
❑ 10 mins - 30 mins
❑ 30 mins - 1 hour
❑ 1-2 hours
❑ More than 2 hours

10. How much do you spend on traveling every month?
❑ Less than 200
❑ 200 - 500
❑ 500 - 1000
❑ More than 1000

11. What is your main purpose for daily traveling?
❑ Working
❑ Shopping
❑ Entertainment and restaurant
❑ Sports
❑ Visiting friends
❑ Sightseeing

❑ other

Section 3

12. Rank the following factors that influence your choice of transportation mode according to your level of importance.
Cost
Time
Convenience
Weather
Safety
Low-carbon

13. In your daily activities, will you consider reducing carbon emission and mitigate climate change?
❑ Yes, I usually think about that.
❑ Yes, I occasionally think about that.
❑ I rarely think about that.
❑ No, I never think about that.

14. What is your opinion about the transport situation in Hangzhou?
- Almost no traffic congestion in Hangzhou.
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- The transport in Hangzhou is very smart.
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- There are rather less greenhouse gas emissions in Hangzhou.
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- Hangzhou is doing well in decarbonization in the transport sector.
Strongly disagree is 1, strongly agree is 5, what is your point_____.

15. What is your opinion about the measures towards decarbonization in Hangzhou?
- Hangzhou has much publicity for low-carbon travel.
Strongly dissatisfied is 1, strongly satisfied is 5, what is your point_____.
- There are many green travel modes in Hangzhou.
Strongly dissatisfied is 1, strongly satisfied is 5, what is your point_____.
- I am very willing to find emission reduction and environmentally friendly ways to travel in Hangzhou.
Strongly dissatisfied is 1, strongly satisfied is 5, what is your point_____.

16. Have you ever tried the following travel modes?
❑ Bicycle sharing
❑ Car sharing
❑ Scooter sharing
❑ Riding sharing
❑ Other

17. Which of the following measures do you think will reduce carbon emissions? (Multiple choice)
➢ Real-time traffic monitoring and management, in order to reduce congestion
➢ Promote sharing mobility service, such as bicycle-sharing, car-sharing

➢ Reduce the use of private cars
➢ Promote walking and cycling conditions
➢ Increasing public bus and subway shifts
➢ Promote the use of new energy vehicles
➢ Conduct strict private car purchases and license distribution
➢ Reduce outdoor traveling

18. During the carona pandemic, we increased the needs for online shopping. After pandemic, will you continue to use more online shopping and reduce outdoor traveling?
❏ Yes, I will continue to use more online shopping.
❏ I will return to my usual shopping habits.
❏ No, I'm more used to offline shopping.

Section 4

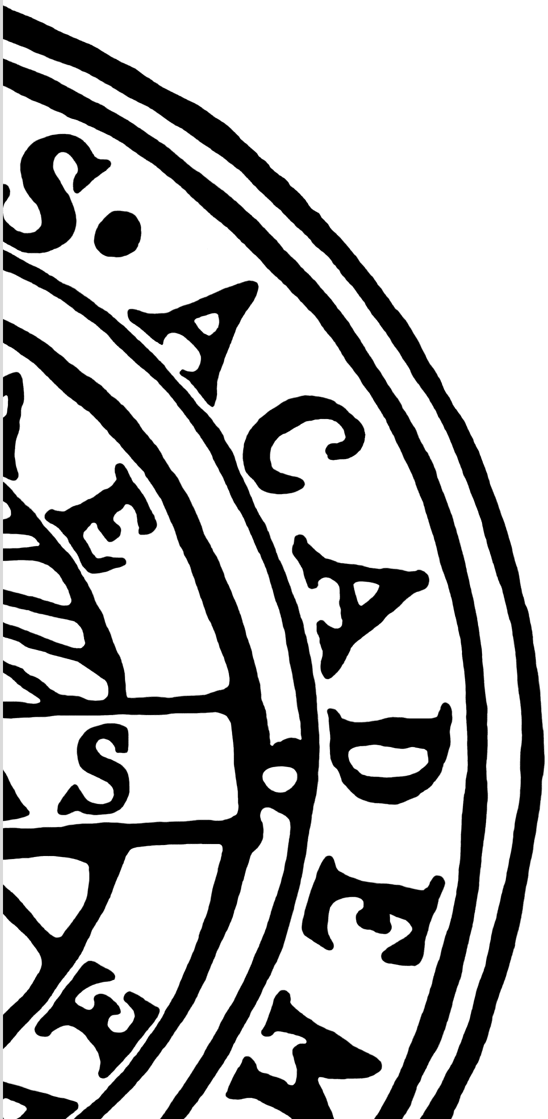
19. What is your understanding of "smart mobility"?
➢ Real-time road traffic monitoring information
➢ Real-time traveling information
➢ Artificial Intelligence (AI)
➢ Autonomous vehicles
➢ Internet of Things (IoT)
➢ A more efficient transport system
➢ Sharing mobility service
➢ Big data
➢ Other

20. Will you worry about transport data safety (Transport data, such as road monitoring data, GPS location, payment data etc.)?
❏ Yes, I usually worry about that.
❏ I occasionally worry about that.
❏ No, I never worry about that.

21. The accessibility to different transport information?
- The location and number of parking lots
Very easy is 1, very difficult is 5, what is your point_____.
- The location and number of new energy charging piles
Very easy is 1, very difficult is 5, what is your point_____.
- The location and number of sharing bicycles
Very easy is 1, very difficult is 5, what is your point_____.
- Schedule of bus shifts
Very easy is 1, very difficult is 5, what is your point_____.
- Schedule of west lake boat
Very easy is 1, very difficult is 5, what is your point_____.
- The information of tourists' flow
Very easy is 1, very difficult is 5, what is your point_____.

22. What is your opinion on the following arguments about data collection?
- There are too many surveillance devices on the streets of Hangzhou, and I do not have

privacy at all.
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- Mobile phones can access users' location data easily
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- I do not know who have collected my personal data
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- I do not know where my data has been used
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- I am willing to transfer personal data for convenient transport
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- I am willing to transfer personal data for low-carbon transport
Strongly disagree is 1, strongly agree is 5, what is your point_____.
- I am willing to apply personal date to calculate carbon emissions
Strongly disagree is 1, strongly agree is 5, what is your point_____.


S·ACADEM