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PERSPECTIVE VIEW OF DRIVERLESS CARS IN BEIJING

+GUO JIFU
+YINGYING ZHANG
+YONG GAO

ABSTRACT

In China, the conflict between fast urbanization and limited recourses leads to traffic problems such as congestion, parking resource shortage and low efficiency package delivery, etc. With the fast development of information technology and control science, the development of driverless cars has stepped to its widely testing period and has provided possible solutions for such problems. This paper tries to propose a perspective view of applying driverless cars on Beijing transportation system. With the promotion of driverless cars in Beijing, up to 168 km2 land use and 320,000 labor force could be released. About 5.3 million travelling hours will be saved every day if Beijing transportation system applies driverless door-to-station and station-to-door service. In addition to releasing up to 1 million labor force, driverless delivery could potentially provide more efficient delivery services. However, challenge still exists while widely applying driverless cars in Beijing, especially for central areas, the highly mixed traffic condition as well as the complex road network will greatly affect the operation of driverless cars.

CONTACT

Guo Jifu
Beijing Transportation Research Center
guojf@bjtrc.org.cn

NYU Marron Institute of Urban Management

Perspective View of Driverless Cars in Beijing

Yingying Zhang[1], Jifu Guo[1,2], Yong Gao[1]

1.Beijing Transportation Research Center, Beijing 100073, China
2. guojf@bjtrc.org.cn

Abstract: In China, the conflict between fast urbanization and limited recourses leads to traffic problems such as congestion, parking resource shortage and low efficiency package delivery, etc. With the fast development of information technology and control science, the development of driverless cars has stepped to its widely testing period and has provided possible solutions for such problems. This paper tries to propose a perspective view of applying driverless cars on Beijing transportation system. With the promotion of driverless cars in Beijing, up to 168 km^2 land use and 320,000 labor force could be released. About 5.3 million travelling hours will be saved every day if Beijing transportation system applies driverless door-to-station and station-to-door service. In addition to releasing up to 1 million labor force, driverless delivery could potentially provide more efficient delivery services. However, challenge still exists while widely applying driverless cars in Beijing, especially for central areas, the highly mixed traffic condition as well as the complex road network will greatly affect the operation of driverless cars.

Keywords: Driverless cars, congestion, parking shortage, package delivery, traffic congestion index (TCI)

1. Introduction

1.1. Fast urbanization in China

China has stepped to the rapid urbanization phase since 1995[1]. The urbanization ratio of Chinese cities increased 31.8% from 1978 to 2010 (see Fig. 1). The annual average urbanization growth ratio of China was about 1%, which is twice as the ratio of other cities in the world. By the end of 2010, there were 657 cities and 666 million urban residents in China. By 2010, there were 10 megacities which hold more than 10 million residents, respectively, and 303 cities which hold more than 1 million residents, respectively. Jing-Jin-Ji, Yangtze Delta, Pearl River Delta, and Chengdu-Chongqing city clusters are formed since 2004[2].

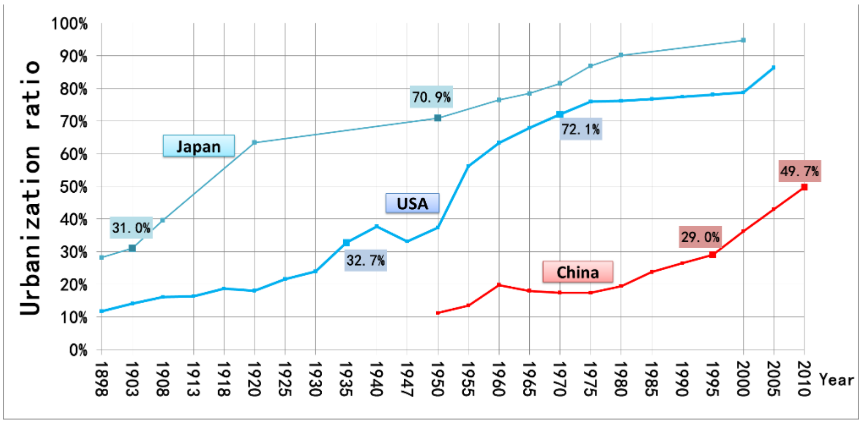

Fig.1 Urbanization trend comparison among countries

Fig. 1 illustrates the comparison of urbanization growth trend among the US, Japan and China. The US took about 47 years to increase its urbanization ratio from 31% to 70.9% (about 40%), from 1903 to 1950. Following the US's step, Japan used 35 years to increase its urbanization ratio from 32.7% to 72.1% (about 40%), from 1935 to 1970. In 1995, the urbanization ratio of China was 29%. This number increased to 49.7% within 15 years. Following this trend, it is very possible that the urbanization ratio of China will reach 70% by 2025, which means, it may only take China 30 years to increase its urbanization ratio by 40%. Therefore, the urbanization ration of China is growing much faster than those of the US and Japan. Along with the fast speed urbanization, cities in China are also expanding quickly.

1.2. Fast city expansion in Beijing

The cities in China has been expanding fast after 1990s. Fig.2 shows the expansion of construction density in Beijing from 1987 to 2010. For example, the urban land use for new-built constructions in Beijing increased 490 km² from 2005 to 2010[3].

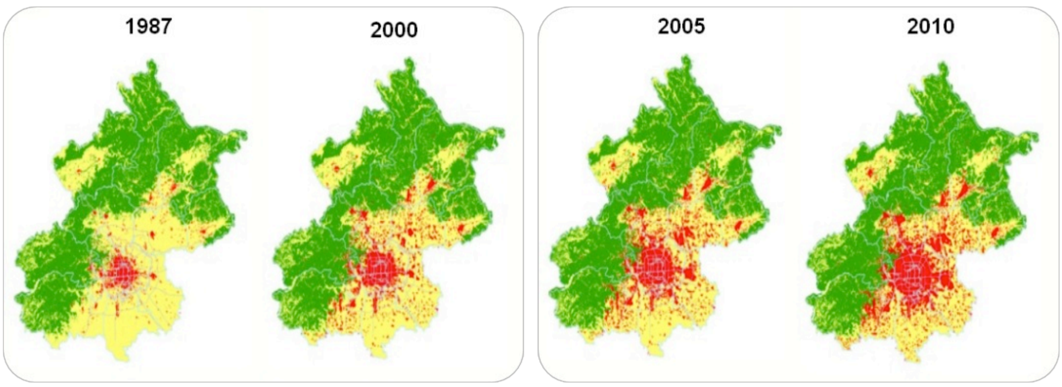

Fig.2 City expansion of Beijing

City expansion has led to the growth of travel distance. The average travel distance in Beijing within the Sixth-Ring-Road (regarded as central city area by the government of Beijing) increased from 5.8km to 7.6km from 2000 to 2010[1]. The growth of travel distance has led to the dependence of private cars. From 1985 to 2010, the number of private cars averagely increased

24% every year, which is much faster than other Asian cities such as Tokyo and Seoul (compared in Fig.3).

The fast increasing number of residents has led to fast motorization. The conflict between the fast urbanization and the recourse limitation has resulted in many traffic problems in Beijing, such as congestion, parking resource shortage and low efficiency package delivery, etc.

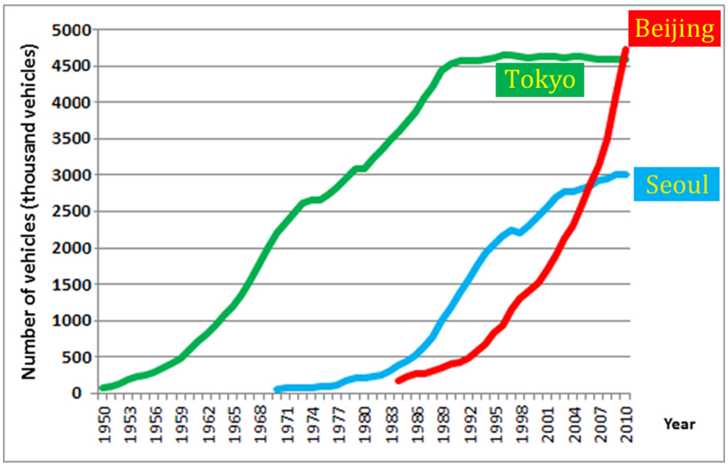

Fig.3 Vehicle ownership growth trend comparison

1.3. Development of driverless cars

Driverless car technology was studied and tested firstly in the US [4]. By 2013, four U.S. states, which are Nevada, Florida, California and Michigan, have passed relative legislations allowing the test on driverless cars. Google since 2010, Stanford University since 2013, and several other institutions have been testing driverless cars on American roads, respectively. The British government has also approved relevant regulations allowing the test of driverless cars.

The Google Self-Driving Car project is innovated by Google. This project aims at developing technologies for autonomous cars. This cars have traversed San Francisco's Lombard Street, famed for its steep hairpin turns, and through city traffic. The cars have also driven over the Golden Gate Bridge and around the Lake Tahoe[5]. In May 2014, Google presented a new concept of their driverless cars that had neither a steering wheel nor pedals, and unveiled a fully functioning prototype in December, 2014, which they planned to test on San Francisco Bay Area roads beginning in 2015[6]. Google plans to make these cars available to the public in 2020[7]. Auto manufacturers such as Audi, BMW, Ford, Nissan, Mercedes-Benz, and Tesla plan to offer automated cars to the public between 2016 and 2020. Based on data extrapolated from the Bureau of Labor Statistics, it is expected that 42 to 50 percent of the US vehicle fleet will be replaced every tenth years[8].

The British-Delphi Automotive Company designed a 3,500-mile journey in 2013 to test the limits of self-driving technology across a variety of situations, such as urban roads, traffic jams, motorways and parking. They got a great success in testing their cars in California and on the streets of Las Vegas[9].

In China, many institutions, such as Tsinghua University, National Defense University and Tianjin Academy of Military Transportation, have also been developing driverless technique independently. National Defense University designed and completed a 286-km-journey test in 2011[10]. Tianjin Academy of Military Transportation also completed a one-hour-highway-journey test in 2012[11]. They accomplished car following, lane changing and overtaking missions successfully.

1.4. Objectives

Therefore, driverless cars, which have been well developed, could provide a possible way to partially solve the traffic problems along with the fast city developing in Beijing. This paper tries to provide a perspective view of applying driverless cars on the transportation system of Beijing. The objectives of this paper are:

- To review the development of transportation and the traffic problems resulted from fast city development in Beijing,
- To introduce the practices that Beijing has taken to partially solve the traffic problems, and
- To evaluate the impact of applying driverless cars on the transportation systems in Beijing.

2. Development of transportation in Beijing

2.1. Fast growing travel demand in Beijing

2.1.1. Growth of traffic volume

Fast growing population and fast growing economy produce more travel demands. More and more public transport travelers are switching to automobile travelers. More and more residents in Beijing would like to purchase private cars and to drive for work and for entertainment. As a consequence, the annual average daily traffic volume in Beijing (see Fig.4) increased from 133.46 million person-kilometers to 313.85 million person-kilometers, from 2000 to 2010[1].

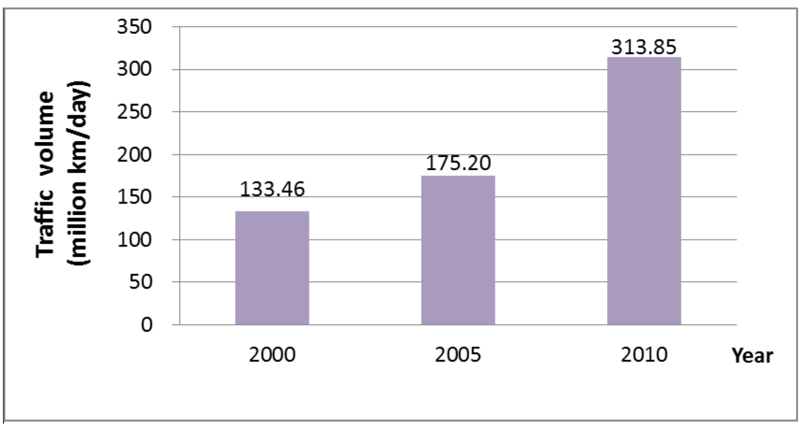

Fig. 4 Annual average daily traffic volume in Beijing

2.1.2. Growth of commute travel

The expansion of Beijing city and the fast growth of city population led to the huge demand of commute travel in morning- and evening-peak hours. The subway volume illustrated in Fig. 5 (IC card users only) shows that the subway daily passenger volume increased significantly since 2006[12]. According to the figure, the subway daily volume in 2014 is nearly five times of that in 2006. The volume drops (significantly low volume in January or February of each year) is because it was the Chinese Spring Festival and most citizens would leave Beijing and go back to their hometown for vacations. Low demand of transportation led to low subway volume.

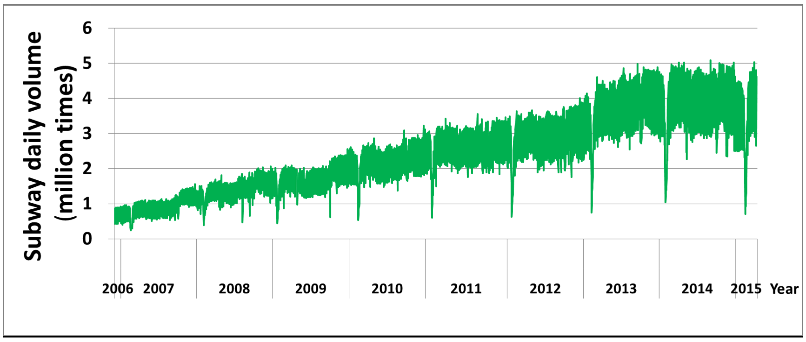

Fig.5 Statistics of daily subway volume (IC card user)

An example of subway peak-hour volume of current Beijing subway system is presented in Fig.6. It can be seen that Line 1, line 4, line 5, line10 and line 13 carries more than 40,000 passengers during morning peaks[13]. This number is already beyond the capacity of these lines. For example, the passenger volume of Line Changping is about 140% of its capacity during morning peaks.

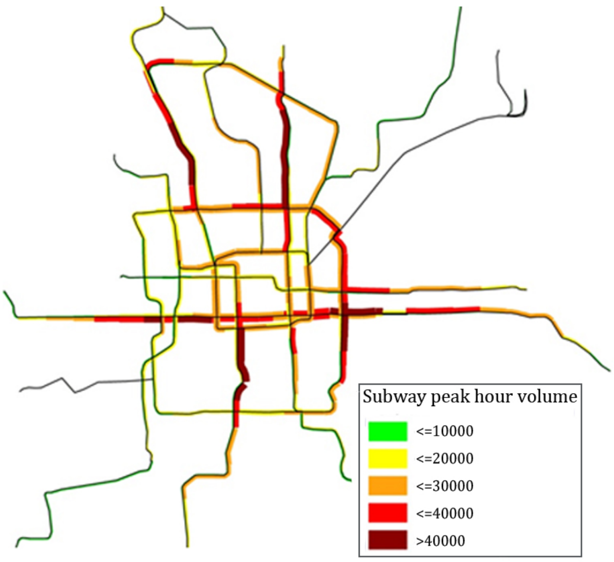

Fig.6 Morning peak volume of Beijing subway

2.1.3. New traffic demand caused by internet service innovation

With the fast development of online shopping, the number of E-consumers increases rapidly. At present, there are more than 350 million E-consumers in China[14], which equals to 25% of the total population of China. These E-consumers spent $ 450 billion on online shopping in 2014[15], which equaled to 10% of the total retail sales in China. Package delivery demand was generated together with the huge number of online purchase. There were 14 billion packages delivered in 2014, which was nearly 4 times of the number in 2011 (see Fig.7). In big cities such as Beijing, Shanghai, and Guangzhou, more than 65% of the residents are E-consumers[16].

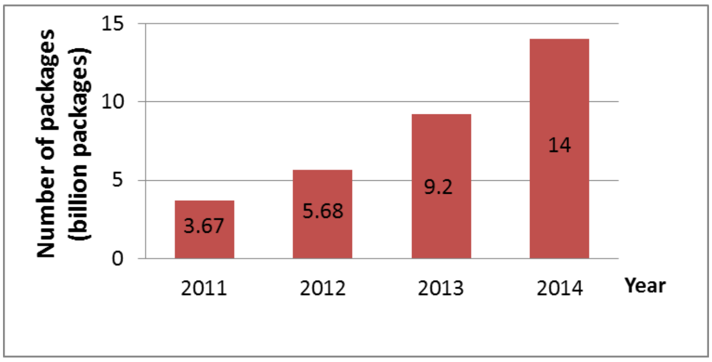

Fig.7 Package number growth in China

One characteristics of package production is that the package number always increases sharply during holidays and special festivals. For example, there were 215,600,000 packages produced within 24 hours on the "11.11" Online Shopping Festival. This festival was innovated by Alibaba, and the "11.11" was just a holiday for singles (where "1" represents "singles", and four "1" represents "singles all together") at the beginning. However, since the promotions on "11.11" are not restricted to singles, couples would purchase online as well. In 2014, up to $ 9.2 billion was spent on that day[17]. This number is about nine times as that of the online shopping on Thanksgiving Day in 2014 throughout the US.

Meanwhile, groupon apps and relevant services have been widely promoted in China. These apps broadcast real-time on-sale promotions of entertainments such as food service, shopping malls, parks, movies, etc. Such services have also been stimulating the growth of travelling for entertainments in recent years.

2.2. Limited resource

By 2013, the total length of urban roads in Beijing reached 6295 km, including 269 km of urban express ways, 953 km of arterial roads, 614 km of secondary roads, and 4459 km of branch roads[18]. However, the fast developing road network still cannot meet the dramatically growing travel demand which is produced by the fast growing number of private cars. By 2014, the private car ownership in Beijing has reached 4.2 million.

2.2.1. Limited parking facility

Parking demand has been increasing fast during the past few years. The development of parking service cannot meet the parking demand. The conflict between huge parking demand and limited parking space leads to parking chaos as well as high price parking. For example, in 2014, the average price for parking lots of condos was $ 100,000 in Beijing and $110,000 in Guangzhou[19,20]. However, purchasing a private car only cost about $ 10,000, which is only one-tenth of the price of a parking lot. The result is most people would like to purchase a car however park it wherever free. The parking chaos has already caused congestion and high fuel consumption because of vehicles' long-time cruising for parking space.

2.2.2. Fast expanding congestion

Fast speed motorization also results in the fast expansion of congestion. At the beginning, congestion only happened in city center, while in recent years, the congestion has spread from city center to suburbs. Furthermore, the lasting time of morning-peek and evening-peek has also been extended. The traffic condition becomes vulnerable and even a weather variation would significantly impact the road network. Large-scale congestion happens frequently during rainy or snowy work days[21].

3. Solutions

3.1. Traffic monitoring system

Considering of the heavy congestion, new measures on traffic monitoring was proposed by Beijing Transportation Research Center (BTRC). The Floating-Car Data Collection System was developed for traffic status monitoring and traffic condition study. This system receives real-time data produced by 67,000 taxis which are equipped with GPS devices. More than 90% of the road network in Beijing during peak hours is covered by the system. Based on these floating-car data, real-time traffic condition is calculated and presented.

The Traffic Congestion Index (TCI)[22] is developed and proposed by BTRC based on the Floating-Car Data Collection System to address regularities in traffic operation. TCI defines five congestion levels (from 0-10P）, which are heavy congestion, moderate congestion, light congestion, smooth traffic and free flow. By analyzing TCI, congestion can be described in five dimensions which are intensity, duration, coverage, frequency and reliability. The TCI over time could help better understand the congestion trend of road network. For example, the traffic congestion trend in workday during peak hours from 2007 to 2014 is shown in Fig. 8[23]. It could be observed that Beijing is at the smooth-traffic level under effective traffic measures. In addition, TCI could also be used to compare the difference of road network congestion levels by years. The comparison among 2012, 2013 and 2014 (Fig.9) shows that it is less congested in February of 2013 and November of 2014 than those of the same months in the other years.

Furthermore, congestions have been forecasted and spread on Radios and through newspapers to affect public travel modes and to avoid more serious congestion in advance.

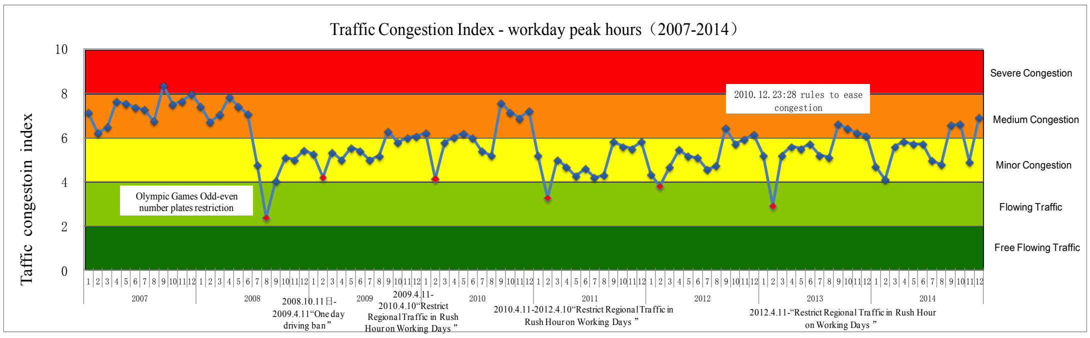

Fig.8 Traffic congestion index trend over years

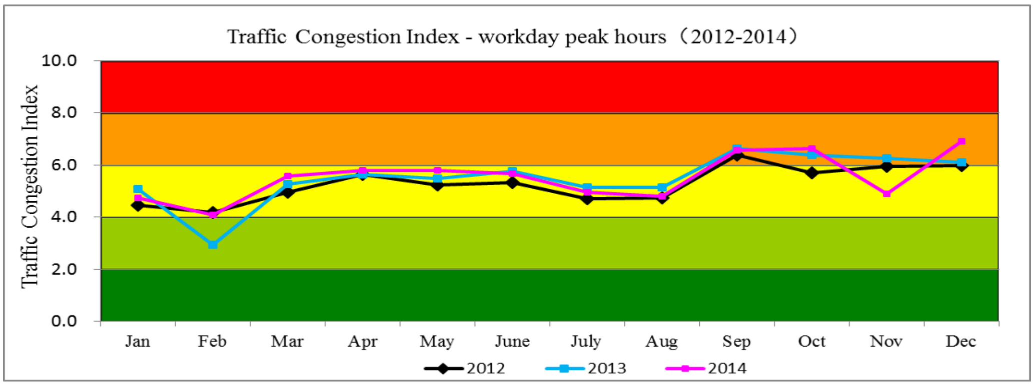

Fig.9 Traffic congestion index trend comparison

3.2. Public transport monitoring system

According to the household survey conducted in Beijing, nearly 50% travelers would prefer public transport as their major travel mode (Fig.10). There are totally 18 railway lines and 527km railways in Beijing. The average daily times-of-travel is 8.78 million, and the highest daily times-of-travel for subways could be 11.06 million. There are 813 bus lines running 23,592 buses, and the average daily times-of-travel for buses are 13.2 million[24].

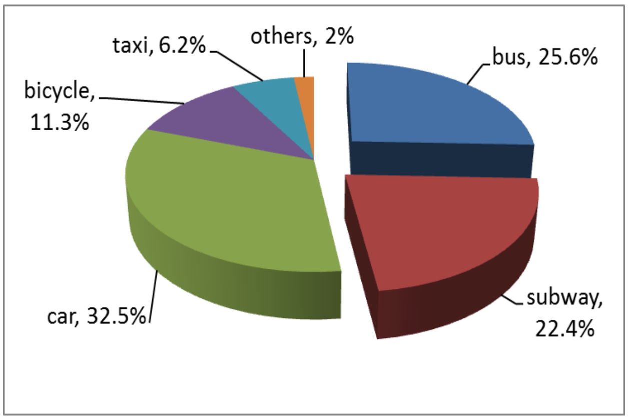

Fig.10 Proportion of travel mode[12]

In order to monitor such travel behavior, the data from electronic payment systems were used and a real-time public transport monitoring system was developed in 2006. This system has been collecting IC card tolling data since May 2006. About 17 million records are collected every day. To sum up, about 50 billion records have been collected over the past 9 years. These IC card data are used to monitor public transport operation and to help the Beijing government and the traffic management agencies make improvements. For example, the government would operate real-time monitoring on public transport. (Fig.11).

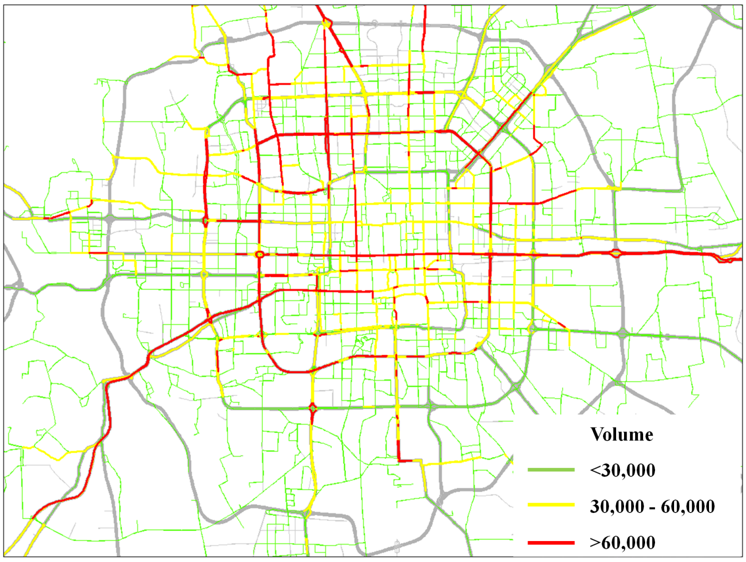

Fig.11 Real-time travel volume monitoring

4. Future prospect of applying driverless cars in Beijing

4.1. Population distribution

In metropolitans, bus stops and subway stations could be kilometers away from home/work for travelers because of the large scale of road network. It may cost the commuters quite a while walking from home/work to the nearest bus/subway stations. There are 21.14 million residents living in 16,410 km^2 in Beijing[18]. Inside the Sixth-Ring-Road, the density of residents is 24,000 residents/km^2 in urban area, 8,090 persons/km^2 in Suburb area, however only 1,067 residents/km^2 in rural area (Fig.12).

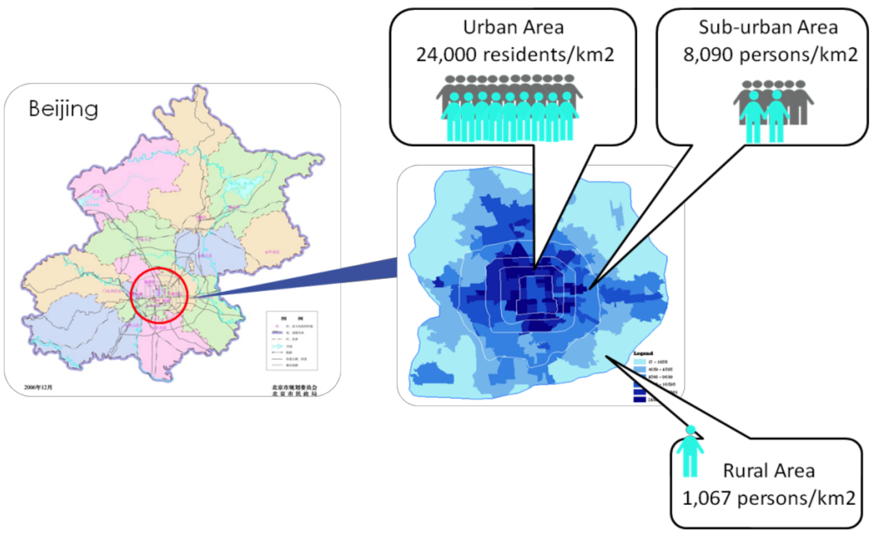

Fig.12 Population distribution inside Sixth-Ring-Road of Beijing

The huge scale of city area and the unbalanced population distribution leads to the high volume and long distance commuting travel in Beijing. There are up to 48 million trips every day and the average travel distance is about 10.6 km (excluding the travel distance of walking).

4.2. Time saving for public transport

According to the fourth comprehensive transport survey of Beijing in 2010[3], the average travel time for door-to-door trips could be summarized as Fig. 13. For the commuters who use public transport, the average travel time on bus or on train is about 42.6 minutes, the average door-station-door travel time is about 15 minutes and the average time waiting and transferring time is about 8.6 minutes.

Door-to-station and station-to-door travel takes about one fourth of the total travel time for each public transport traveler. While analyzing the three parts of travel, the on-bus/on-train travel time and the waiting and transferring time could not be saved. But driverless cars could possibly help save the time from doors to stations and from stations to doors.

According to the survey, the average door-station-door travel distance is about 1.2 km, the average walking speed is about 1.2-1.3 m/s, and the average travel speed of a Google car is about 12 m/s which is about ten times of the average walking speed in China. Therefore, if the door-station-door walking is replaced by driverless car traveling, the saved travel time will be equal to:

Saved time per trip = current door-station-door travel time - average travel time of driverless cars

= 15min – 1.2km/12m/s = 15min – 1.7min = 13.3min (1)

And as shown in Fig. 10, nearly 50% travelers would choose public transport for travelling, which means, the travel time of about 24 million trips would be potentially saved. The time saved by driverless cars could be 5,320,000 hours every day:

$$Total\ saved\ time = 24{,}000{,}000 trips/day \times 13.3/60 hrs/trip = 5{,}320{,}000 hrs/day \quad (2)$$

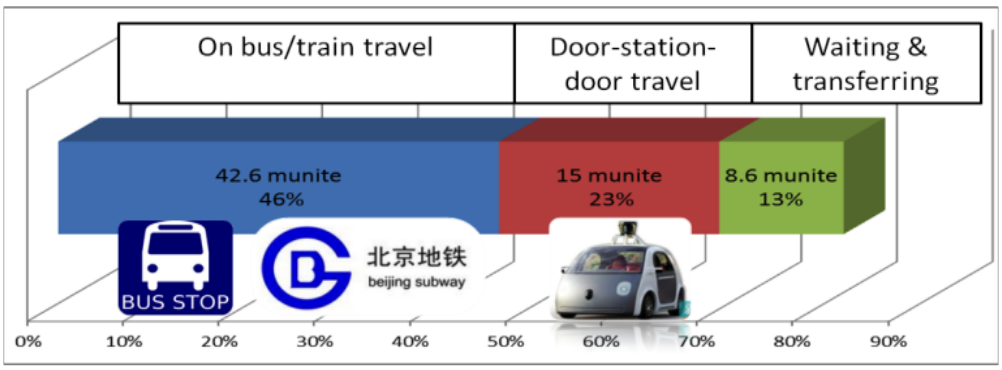

Fig.13 Door-to-door travel chain

4.3. Short distance trips replaced by driverless cars

At the same time, short-distance travel still plays an important role in Beijing. Survey shows that, there are 5.6 million vehicles producing 17 million automobile trips every day. Define that a trip less than 5 km is a short trip, the proportion of short-trip travel in the vehicle trips are 44% (Fig.14). Furthermore, 61% trips of the total trips are urban-to-urban trips. Due to the limited parking resource in urban areas, all these urban-to-urban short-trip travels could potentially be replaced by driverless cars so that driverless cars would drive to its next customer (passenger) and the "drivers" (former customer) will not bother parking anymore.

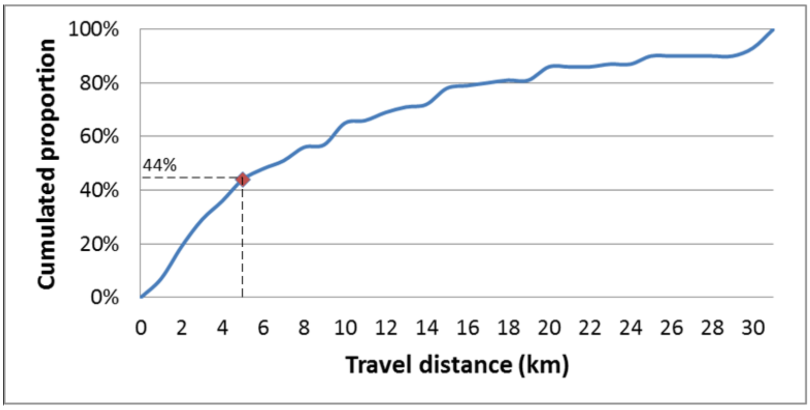

Fig.14 Cumulated proportion of vehicle travel distance

4.4. Parking recourse released by driverless cars

Driverless cars apply car sharing strategy which allows them to pick up a next nearby passenger after dropping its current passenger to his/her destination. After sending all its passengers to their destinations, a driverless car would find an out-of-city-center place to park. By this way, parking resources in city center will be saved. There are totally 5.6 million vehicles in Beijing[24], assuming that each vehicle requires about 30 m^2 to park, then the total area saved because of applying driverless cars could be calculated as (3),

$$released\ area = 5,610,000 \times 30\,m^2 = 168\ km^2 \quad (3)$$

where, the saved parking area equals to the total area inside the Third- Ring-Road, where is the most severely congested area in Beijing (Fig.15). The average annual Traffic Congestion Index (TCI) for the area inside the Third-Ring-Road in 2014 was 7.4 (Medium congestion level), whereas the average annual TCI for the whole road network of Beijing was only 5.5 (minor congestion)[25]. Such congestion is caused by high traffic volume as well as limited parking facilities. Therefore, by applying driverless cars, most road-side parking facilities would be released for moving traffic and the traffic pressure in central area might be partially remitted.

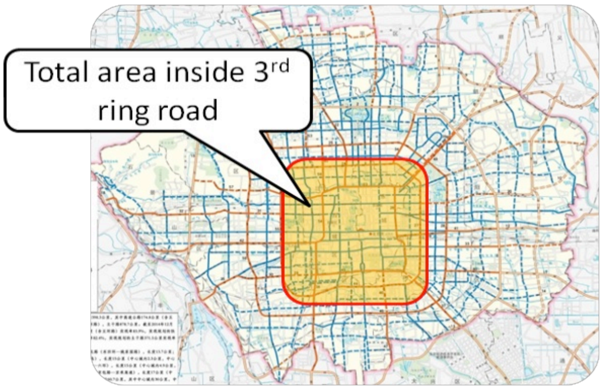

Fig.15 Total area inside 3rd ring road of Beijing

4.5. Labor resource released by driverless cars

Because of the high dense population and the huge demand on commuting travel, buses and trains will still be the major carrier of urban passengers. Driverless cars could potentially take the role of existing taxis, buses, and logistics in the future.

4.5.1. Taxis and buses

Currently, there are 65,700 taxis and up to 100,000 employees working on the taxi business[26]. With the development of internet innovation, new "taxi service" such as Uber and Car Drops (innovated by Alibaba) has made the actual number of taxi employees to increase about 40,000. At the same time, there are 23,592 buses with 100,000 employees working on public transport service and 80,000 employees working on the management of 6,448 commercial parking lots[26]. Along with the widespread of driverless cars, a big number of labor force could be released. For example, drivers will not be needed for taxis and buses, and most parking lot managers will be replaced by several network monitoring manager and maybe some technical support engineers. To sum up, it is estimated that the driverless cars will help release up to 320,000 labor force in Beijing.

4.5.2. Logistics

As shown in Chapter 2.3, the number of E-consumers has been increasing fast in China. As a consequence, new express companies have been set up. By the year 2014, there are totally 8,000 express companies with about 1 billion employees in China[27]. SF-Express is the biggest express company in China, it has 290,000 employees and 12,000 freight vehicles. When driverless cars are widely used, it can be foresee that most of the labor force could be released.

Meanwhile, while looking at the package deliveries from sub-storages to doors, most of them are made by tricycles (see Fig. 16). Such deliveries could be replaced by driverless Google cars and drones during off-peak hours. It is highly possible that not only more parking places will be saved but also more efficient delivery will be implemented if driverless cars are put in use.

Fig. 16 Tricycles for sub-storage-to-door delivery

4.6. Challenges for putting driverless cars in use

The development of driverless cars in China has been challenging for two reasons. Firstly, the mixed-traffic condition would greatly affect the operation of driverless cars. Hundreds of pedestrians and cyclists may wait at an intersection every cycle, and the traveler behavior could be much more unpredictable than that of the US. Thus, the route planning system and the pedestrian avoidance system need to be robust. Secondly, the road network of Beijing is complex. For example, within the 1,088 km^2 central city area, there are at least four levels of automobile roads, including urban express ways, arterial roads, secondary roads and branch roads. Up to 71% of these automobile roads are branch roads, and about one-fifth of these branch roads are Hutong roads (about 1000km). Since the width of most Hutong roads is less than 4 meters, it will be very difficult for the traffic traveling through. Furthermore, there are more than 4,200 roadway junctions, 1,555 ramps[18] , 276 interchanges (grade separation for urban express ways) and up to 2,800 signal-controlled intersections in central city area[28]. With no doubt the complex road network in central area will greatly impact the operation of driverless cars.

5. Summary

Since the 21th century, cities like Beijing have been expanding quickly along with the fast speed urbanization in China. The fast increasing number of residents has led to fast motorization and has resulted in a series of traffic problems such as congestion, parking space shortage, low efficiency package delivery, etc. On the other hand, with the fast development of information technology and control science, the development of driverless cars has stepped to its widely testing period. This paper tries to look at the future usage of driverless cars in Beijing.

While looking at the fast development of Chinese cities like Beijing, travelling comfort has become a new travel demand. The fast growing number of vehicles has caused serious traffic problems and congestion has become a popular “city flue”. Beijing Transportation Research Center (BTRC) together with Beijing Municipal Commission of Transport has been making great efforts on easing the traffic pressure, alleviating traffic congestion and improving traffic operation efficiency. A traffic monitoring system was developed applying floating-car data. The Traffic Congestion Index (TCI) was developed and has been used to evaluate the level of transportation service in many cities. The data from electronic payment systems were used to develop a real-time public transport monitoring system. This system has been used to monitor public transport operation and to help the Beijing government and traffic management agencies make improvements.

Because that the demand on commuting travel is huge and more than half of the travels are urban-to-urban travels, mass transit system is still an exclusive choice for commuters. However, driverless cars could potentially help change the inconvenient travels between doors and stations. Along with the widely usage of driverless cars, totally 5,320,000 hours could be saved every day. Since driverless cars could drive to suburbs by itself when it is not employed, parking space in central area would be saved. At last, the labor force of drivers and couriers could be saved.

In the future, our study will emphasis more on further evaluating the potential impact of driverless cars on the existing transportation system of Beijing, which involves analyzing the development demand of driverless cars, evaluating the potential impact on taxi service, freight transportation and public transport systems, proposing short-term and long-term objectives as well as preparing deployment strategies. A bigger picture of the future transportation system in Beijing will be painted describing the future road network, parking facilities, signal control strategies, etc.

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