CENTER FOR AUTOMOTIVE RESEARCH

Challenges and Opportunities for Developing Sustainable Transportation Systems in Beijing

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ABSTRACT

With an increasing population and expanding economy, China has emerged as an important world power. In recent decades, China's urban population has grown exponentially, with a corresponding increase in the personal wealth of citizens. The capital city of Beijing exemplifies the rapid development of urban China. The city is now home to over twenty-million people and is expected to continue gaining residents. This growth also drives unprecedented challenges for urban policy and city management.

The two primary challenges for managing large Chinese cities are mobility and air pollution. Traffic congestion and air pollution in Beijing have become two critical issues that are attracting worldwide attention. These issues are inter-related, as transportation modes often create exhaust composed of polluting gases and airborne particulates. These challenges have been exacerbated by increasing automobile usage in Beijing, which is up from 5% of trips in 1986, to 34% in 2010.

Addressing such challenges requires detailed knowledge of multiple factors, including trends in urban development, existing transportation and air quality conditions, planning practices, and societal context. This report provides the background information needed to inform a systems-based approach to develop solutions for the challenges of mobility and air quality in Beijing. Initiated by the University of Michigan's Sustainable Mobility and Accessibility Research and Transformation (SMART) initiative under a grant from the Alcoa Foundation and undertaken in partnership with the Center for Automotive Research (CAR), this research aims to help catalyze effective and targeted solutions for Beijing and other cities in China.

INTRODUCTION

Urban mobility and air pollution have become the most significant development challenges in Chinese cities, including Beijing, the capital city of China. Both the Chinese central government and Beijing Municipal government have spent a tremendous amount of resources on congestion relief and air quality improvement, but the magnitude of the issue has often outweighed their efforts. As with many other cities in China, the dramatic growth in the number of motor vehicles in Beijing is often considered one of the major causes of urban mobility and air pollution. Many other factors need to be considered, however, including the city's status as the capital of China, the concentration of central government agencies in the downtown area, its special traffic operation and management needs, its population growth, land use issues, and the industrial development in surrounding provinces. These factors are interconnected and often complicate the mobility and air pollution issues in Beijing.

The University of Michigan's Sustainable Mobility and Accessibility Research and Transformation (SMART) initiative received a grant from the Alcoa Foundation to develop research and practical solutions needed to address the challenges of sustainable transportation in the Detroit and Beijing regions. The project is meant to iterate and inform research and implementation of New Mobility systems in both regions by advancing and accelerating the uptake of multi-modal, IT-enabled, door-to-door, sustainable transportation systems and related innovation and economic development. SMART works around the world to address such challenges and conditions. It focuses in three key areas that are often not addressed. First it offers new conceptual frameworks related to taking a systems-based, multi-modal, multi-technology, and multi-stakeholder approach (as opposed to single solution) to transforming transportation in cities. Second it works to advance innovation, economic development, job creation, and cost savings related to New Mobility by working with private sector partners – both big business and small and medium enterprises and startups. Third, it explores psychological and cultural underpinnings of transportation and the narratives that drive our relationship to our transportation choices.

To facilitate these tasks, SMART and the Center for Automotive Research developed this background paper with a focus on the trends of urban development, existing transportation and air quality conditions, planning practices, and challenges and opportunities in Beijing. We hope that the background information presented in this paper will provide context for future research on consumer preferences and travel behavior in Beijing and eventually catalyze effective and targeted solutions for Beijing and other cities in China.

DEVELOPMENT AND TRANSPORTATION TRENDS

Many factors affect the nature of transportation systems. Economic and population growth is generally associated with increased demand for transportation and, in particular, road vehicles. Understanding these growth trends is important because it has implications for policy decisions.

Population

Beijing is one of the fastest growing cities in China. Its population hit 20.7 million in 2012, of which more than 7.7 million persons, or 37 percent of the total, were migrants from other parts of China. Figure 1 shows a steady increase in Beijing population from 2000 to 2012. A recent forecast estimated that the number of people living in the Chinese capital could balloon to 27.7 million by 2020, even though the city had planned to keep its population below 18 million (1).

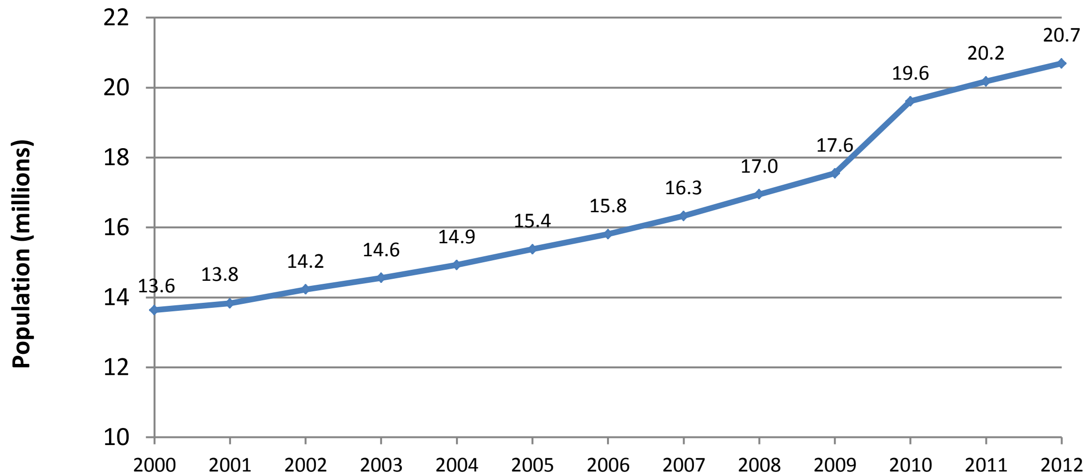

FIGURE 1 Population growth in Beijing (2000 – 2012).
Source: (2)

Economic Growth

The city's population is growing fast and so is its economy. The Gross Domestic Product (GDP) of Beijing has grown about 10% annually during the past five years, and its per capita GDP has increased 808% from $1,520 in 1995 to $13,797 in 2012 (see Figure 2).

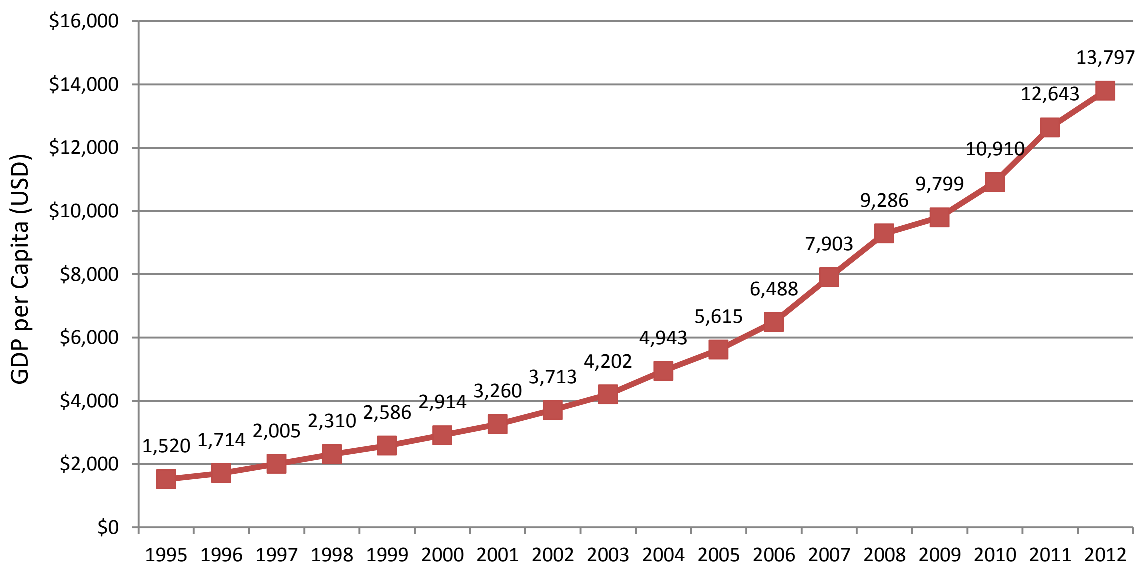

FIGURE 2 GDP per capita in Beijing (1995 – 2012).
Source: (2)

Motor Vehicle Population

China’s large population and increasing household income has made it the world’s largest vehicle market. In 2000, China produced and sold approximately two million motor vehicles. In 2010, a decade later, production and sales had both risen to more than 18 million units (3).

Automakers in China plan to dramatically increase production capacity over the next several years, resulting in a total national production capacity of 35 to 40 million units annually (4).

The automotive market in Beijing has effectively doubled in size from 2005 to 2012, increasing challenges of excessive energy consumption, air pollution, and traffic congestion. During the same time period, the number of passenger light vehicles in operation increased more than 200% from 1.3 million to 4.1 million (see Figure 3). The vehicle ownership rate in Beijing (228 vehicles per 1,000 people) is much higher than national average (52 vehicles per 1,000 people), and it is even higher than the world average (128 vehicles per 1,000 people).

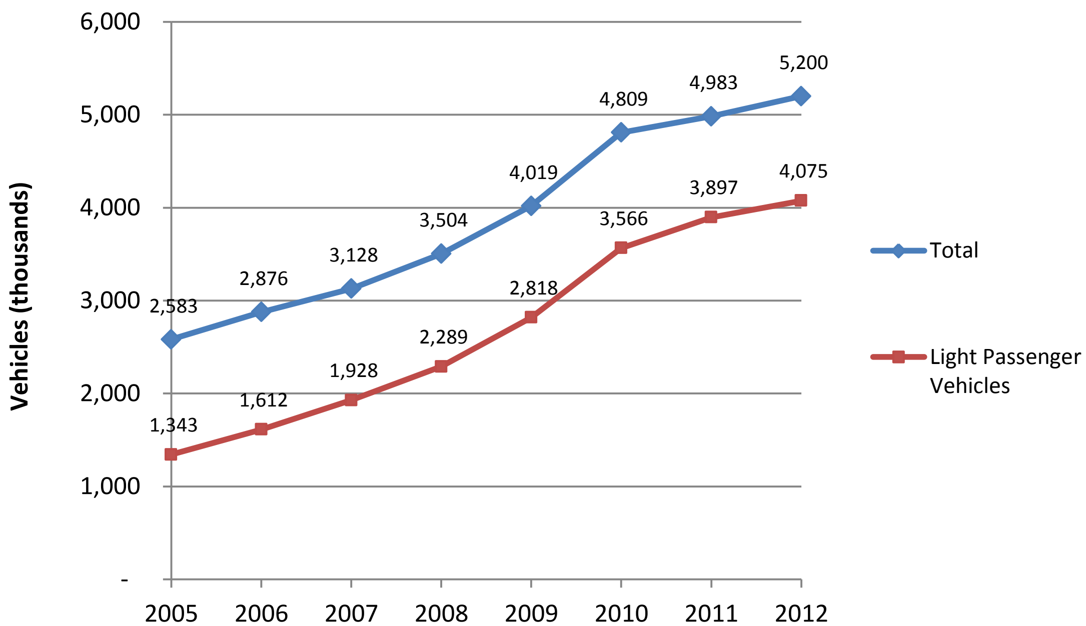

FIGURE 3 Growth of motor vehicle operation in Beijing (2005 – 2012).
Source: (2)

Mode of Transportation

With the growth in the vehicle population, Beijing also has experienced a significant decline in bicycle trips. As shown in Figure 4, Beijing has seen a drastic decrease in the number of trips taken by bicycle – from 63% in 1986 to 16% in 2010, and a corresponding increase in number of trips taken by automobile – from 5% in 1986 to more than a third in 2010. From 2007-2010, however, the number of trips taken by automobile remained generally flat. This is interesting considering that the number of vehicles in Beijing has increased significantly over this time. Over this same period, the number of trips taken by subway increased about 5%.

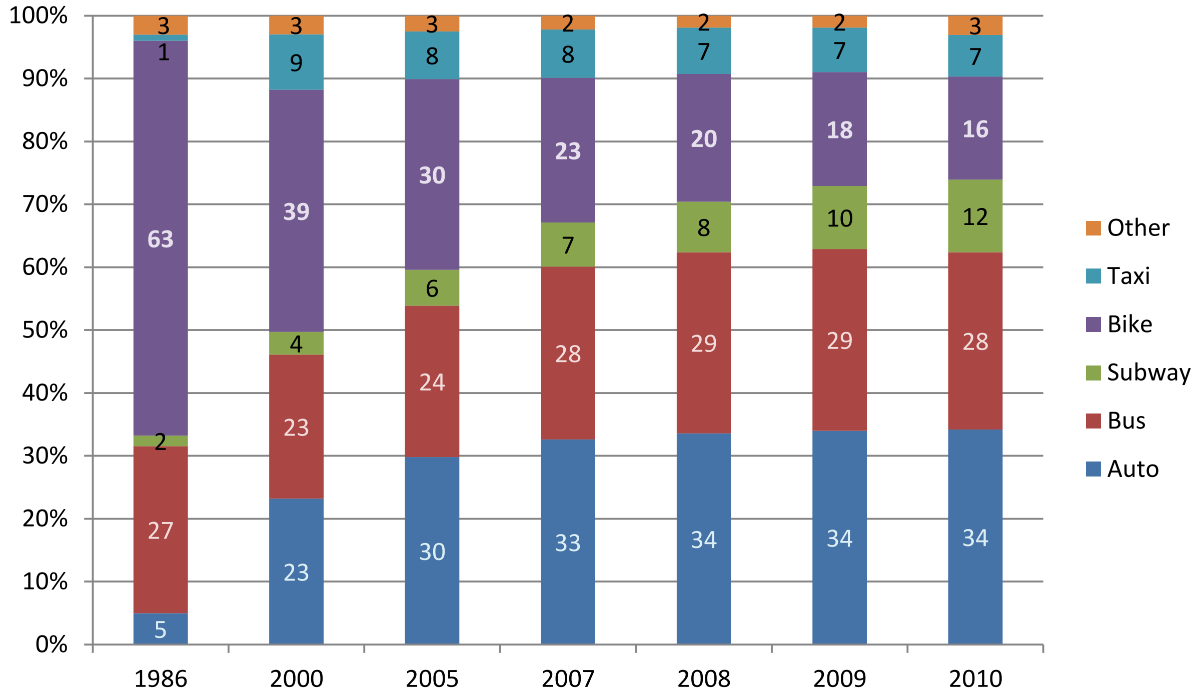

FIGURE 4 Mode of transportation in Beijing (all trips).
Source: (5)

NEGATIVE EFFECTS OF DEVELOPMENT AND GROWTH

In addition to affecting local levels of safety, congestion, and pollution, the high growth of road vehicle use has important implications for transportation management and environmental policy. This section discusses current congestion and air quality conditions in Beijing.

Traffic Congestion and Travel Time

Due to the rapid increase of middle class and vehicle population, Beijing's traffic congestion has finally reached the tipping point. People in China always associate Beijing with the "capital of traffic congestion" (首堵). During the morning and evening peak hours, there are more than 100 kilometers of urban streets experiencing medium or severe congestion within the 5th ring road. Average weekday congested time also increased from 55 minutes in 2011 to 70 minutes in 2012. The government departments have been taking measures to solve the problem, but a 2013 online survey conducted by Beijing Transportation Research Center (BTRC) shows that three-quarters of respondents are pessimistic about the traffic conditions (6).

The relative concentration of trip departure time is an important factor that contributed to traffic congestion condition in Beijing. For example, 21% of daily trips by all modes occurred between 7:00 a.m. and 8:00 a.m. Another 17% occurred during the afternoon peak hour (5:00 p.m. to 6:00 p.m.). Encouraging flexible work and scheduling practices, including telecommuting, should be considered when developing congestion relief measures.

Travel time and speed are important factors when people choose their mode of transportation. Like many other places around the world, public transit in Beijing does not have advantages in this regard, where the average morning commute times for bus riders, subway users, and auto drivers are 60 minutes, 73 minutes, and 32 minutes, respectively. Bus riders have about the same commuting distance as the automobile drivers, but their travel time could be 70% to 80% longer (see Table 1).

TABLE 1 Travel Time by Mode of Transportation during Peak Hours

	Travel Distance (km)		Travel Time (minutes)		Travel Speed (km/h)	
Mode	AM Peak	PM Peak	AM Peak	PM Peak	AM Peak	PM Peak
Bus	9.6	9.6	60.7	66.4	9.5	8.7
Rail/ Subway	16.9	15.8	73.1	74.8	13.87	12.65
Auto	9.2	9.4	32.9	38.9	16.83	14.57
Taxi	7.1	7.2	33.2	39.4	12.85	11.01
Bike	3.2	3.3	20.6	22.1	9.31	8.87
Motor Bike	4.5	4.8	22.1	23.9	12.25	11.94
Walk	1.5	1.5	16.8	17.3	5.32	5.33

Source: (5)

Air Quality

The widely-reported air pollution in eastern China through January 2013 was unprecedented in scale, covering 2.4 million square kilometers (1/4th of China), including Beijing, Tianjin, and other 15 provinces, and affecting more than 700 million people or 52% of China's population. Unlike the issues related to smog in Los Angeles and London which have occurred in the last century, air pollution in Beijing is more complicated since many pollutants originate from industrial and power plants located in surrounding provinces, and therefore air quality management requires coordinated regional efforts.

The preliminary study by the China Academy of Sciences indicates that emissions from motor vehicles contributed about 25% of the PM2.5 in Beijing (7). More comprehensive studies that investigate the finer spatial-temporal and seasonal characteristics of smog and PM2.5 and their causes are not available. Within the transportation sector, emissions by mode of transportation (e.g., auto, air, rail, and bus) are not well understood either. So far, the policy responses to the smog are limited to the 30% reduction in government vehicle use during smog days and the roll out of higher gas standards - the new National Standard V, which is similar to Euro V, with a sulfur content no more than 10 ppm – that will become compulsory by the end of 2017, and the National Standard IV for diesel mandated by the end of 2014.

Systematic review or quantitative analysis of air quality trends in Beijing and other cities in China is critical but hardly seen. The availability of data began to change after the U.S. Embassy in Beijing started publishing air quality readings on Twitter in October 2011. The readings include hourly PM2.5 concentration and air quality index (AQI) using U.S. Environmental Protection Agency (EPA) guidelines. For example, each AQI category corresponds to a different level of health concern. The six levels of health concern and what they mean are:

- "Good" AQI is 0 - 50. Air quality is considered satisfactory.
- "Moderate" AQI is 51 - 100. Air quality is acceptable.
- "Unhealthy for Sensitive Groups" AQI is 101 - 150.
- "Unhealthy" AQI is 151 - 200.
- "Very Unhealthy" AQI is 201 - 300.
- "Hazardous" AQI greater than 300.

This section summarizes the temporal characteristics and seasonal variations of PM2.5 concentration and AQI in Beijing using the U.S. Embassy's hourly air quality data. There are several implications of the analysis. First, it provides one of the most comprehensive analyses of PM2.5 concentration and air quality condition in Beijing from January 2012 to June 2013. Even though the analysis is limited to data collected from one single location, it is still meaningful as a proxy for general conditions in Beijing and as one method to observing seasonal trends in air quality. Second, the study results will become the benchmark for future research and trend analysis in Beijing when more data become available.

The preliminary analysis shows that the monthly average AQI are at unhealthy levels throughout the year in 2012 and 2013, with the highest level of 264 in January 2013 and a noticeable dip to 112 in September 2012 (Figure 5). A similar trend is found with PM2.5 readings, with the highest level of 199 in January 2013 and the lowest level of 60 in September 2012 (Figure 6). According U.S. EPA standards, it is unsafe if PM2.5 is above 35 (24-hour averaging). The World Health Organization's safety level is 25.

Table 2 presents the percentage of six AQI categories by month and annual average. It shows that 12% of the time in January and December of 2012, the AQI was greater than 300 or hazardous. Annually, 69% of the time the air quality is unhealthy or worse in 2012 (101 or above). In other words, only 31% of the time the air quality is "good" or "moderate". For the first six months of 2013, the "good" or "moderate" air quality time decreased to 24%. Notably in January 2013, 37% of AQI readings were classified as hazardous.

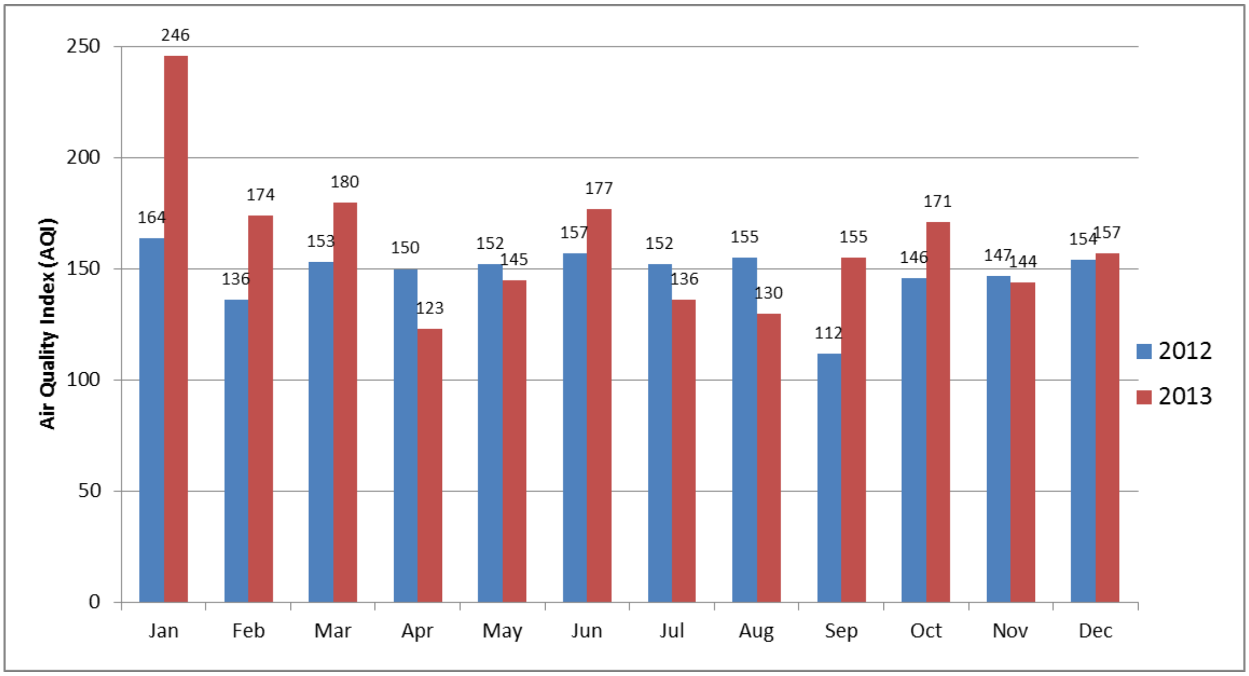

FIGURE 5 Monthly average of Air Quality Index (AQI)
Data Source: (8)

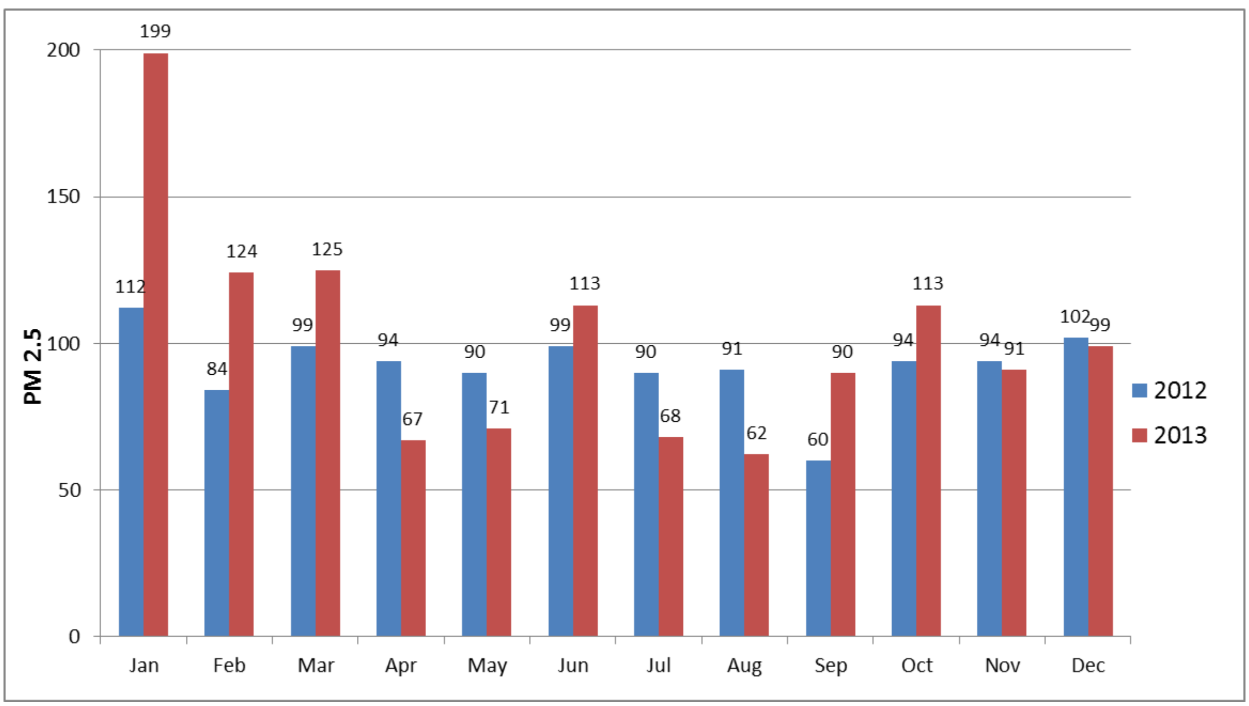

FIGURE 6 Monthly average of PM2.5
Data Source: (8)

TABLE 2 Distribution of AQI Categories by Month, January 2012 thru June 2013

Month	0-50	51-100	101-150	151-200	201-300	300+	Total
Jan 2012	11%	26%	13%	25%	12%	12%	100%
Feb 2012	20%	20%	12%	29%	14%	5%	100%
Mar 2012	14%	19%	11%	33%	15%	8%	100%
Apr 2012	13%	16%	19%	27%	22%	3%	100%
May 2012	6%	12%	18%	51%	11%	2%	100%
Jun 2012	13%	7%	19%	39%	20%	2%	100%
Jul 2012	4%	19%	18%	41%	17%	0%	100%
Aug 2012	5%	10%	25%	45%	14%	2%	100%
Sep 2012	25%	20%	17%	30%	7%	0%	100%
Oct 2012	22%	15%	16%	24%	15%	9%	100%
Nov 2012	17%	20%	13%	27%	18%	6%	100%
Dec 2012	17%	19%	12%	25%	15%	12%	100%
2012 Average	**14%**	**17%**	**16%**	**33%**	**15%**	**5%**	**100%**
Jan 2013	4%	15%	11%	19%	14%	37%	100%
Feb 2013	18%	15%	10%	23%	20%	15%	100%
Mar 2013	13%	9%	10%	37%	22%	10%	100%
Apr 2013	22%	18%	21%	28%	11%	1%	100%
May 2013	2%	17%	19%	59%	3%	0%	100%
Jun 2013	0%	12%	12%	48%	25%	3%	100%
2013 Average	**10%**	**14%**	**14%**	**36%**	**16%**	**11%**	**100%**

Data Source: (8)

The data show that air pollution tends to peak late night to early morning and to be lower in midafternoon. In other words, air quality in the nighttime is usually worse than during day time. One possibility for this is that weather conditions (e.g., wind direction) could transmit more pollutants from other regions to Beijing during the night. Inversion layers that trap pollutants are also likely responsible for the increased air pollution in Beijing during the evening.

TRANSPORTATION PLANNING AND POLICY TOOLS

Increasing population size, household incomes, and vehicle ownership rates have made China the world's largest vehicle market. Absent mitigating policies, the number of vehicles on the road will continue to increase considerably, intensifying the already severe issues stemming from the rapid adoption of motor vehicles in urban areas. Among these vehicle-related problems are high levels of collision-related mortality and injury, road congestion, oil consumption, air pollution, and greenhouse gas emissions.

China may be able to avoid many of the transportation problems that have been experienced in Western countries by "leapfrogging" ahead of them and adopting advanced transportation approaches and technologies. The concept of leapfrogging is used in the context of sustainable development to describe the opportunity for developing countries to accelerate development by skipping inferior technologies—which may be more inefficient, costly, or polluting—and instead move directly towards using more advanced technologies.

As Chinese cities continue to expand and prosper, they have the opportunity to use policy and planning tools to direct development of their transportation systems. Beijing has an opportunity to use such tools to reduce or prevent some of the worst side-effects of transportation sector growth and even improve safety and environmental conditions. These tools include the use of regulations, deployment of sustainable modes and integrated mobility approaches, deployment of intelligent transportation systems (ITS), and the use of alternative fuel vehicles (of all types).

Regulations

The city has experimented with numerous regulatory policies aimed at mitigating the negative consequences from the city's transportation system. These policies include implementing European emissions standards, an annual inspection and maintenance program, fuel quality improvements, scrappage incentives, vehicle retrofit programs, environmental labeling of vehicles, vehicle purchase incentives, and driving restrictions (9).

Registration Limitations

Major Chinese cities, such as Beijing, Guangzhou, Guiyang, and Shanghai, have already introduced license plate quotas or auctions to limit the growth of private vehicle ownership (10). Beijing's stringent quota, which was enacted in December 2010 in response to traffic congestion, effectively imposed a 70 percent reduction in annual vehicle sales within the city (11). Now new registrations are limited to 20,000 a month or 240,000 units a year. New license plates are randomly assigned to applicants through a lottery program.

Driving Limitations

Beijing has also used other transportation demand management regulations, such as its temporary odd-even license plate policy enacted in July 2008 for the Summer Olympics. The odd-even policy allowed vehicles to drive only on alternating days depending on the last digit of their license plate. After the Olympics, Beijing instituted a permanent, but less stringent, policy which forbade vehicles from driving on public roads for one day of the week based on license plate numbers (9). The effect of the regulation is that one fifth of the city's vehicles are not allowed on the roads from 7:00 a.m. to 8:00 p.m. each weekday.

Intelligent Transportation Systems (ITS) Technology

Intelligent transportation systems use a combination of electronics, telecommunications, and information technologies used to improve efficiency and safety of transportation. Example ITS applications include traffic monitoring, public transportation coordination, emergency management, traveler information, advanced vehicle safety, commercial vehicle operations, and electronic payment systems. Some of these applications are already in use today, while other applications are still in research and development stages or just beginning to be implemented (12).

Due to its large population, political and economic significance, and congestion issues, Beijing was already implementing ITS solutions before it was announced as the host of the 2008 Olympic Games. After the announcement, the Ministry of Science and Technology increased efforts by designating Beijing as an ITS demonstration city (13). Several different ITS technologies have since been deployed in Beijing, including traffic management, traffic information, and electronic payment systems (14). Beijing has also been involved in pilot testing more advanced projects, such as Star Wings and New Traffic Information System Model Project, which involve data collection using connected vehicle systems.

Real-Time Traffic Monitoring
The Beijing Transportation Information Center and Nissan developed *Star Wings*, a navigation system that is designed to reduce congestion and decrease travel times. Using probe data collected from 10,000 taxis, the system aggregates real-time traffic information that is then transmitted to vehicles to plan the fastest route and avoid congested areas. Research suggests it can reduce travel time by 16 to 20 percent (15).

ITS for Public and Multi-Modal Transportation
Connectivity and system efficiency can also enable smarter and more seamless multi-modal transportation systems. Applications for mobile devices can provide transportation system users with real time data from vehicles and help them plan their trips. For instance, information on bus locations and estimated arrival times can help passengers choose faster routes or better plan the timing of all transport activities. Applications can also be used to help travelers plan efficient cross-modal trips (which may involve many types of transportation, such as buses, trains, taxis, bicycles, and walking) using real time traffic information. While passengers are on buses and trains or while they are waiting at stops, built-in electronic displays can be used to provide real-time information to all passengers, even those without mobile device applications. With access to more information about public transportation systems, travelers will be able to use these systems more efficiently and effectively.

Electronic fare payment can also support seamless multi-modal travel. There are several cab-calling applications for mobile devices that are available in Beijing. As of March 2013, the popular application, "Didi Taxi," is in use by more than 600,000 users and 12,000 taxi drivers, nearly one fifth of Beijing's approximately 66,000 taxis. The application launched just five months earlier in September 2012 with just 200 test cabs and a few hundred users (16). The application records the users current location and destination then sends this information to taxi drivers who can respond to the request. The application allows users to bid an extra amount above the metered fare for the taxi, a feature that can be used during high traffic periods to more quickly secure a taxi. Bids typically range from $1-5.

Deployment of Sustainable Modes and Integrated Mobility Approaches

Sustainable Multi-Modal Systems Implementation (Developing the "New Mobility Grid")
In December, 2012, over 60 government leaders from the City of Beijing participated in a SMART-led session focused on multi-mode, multi-technology system implementation. This is an innovative and regionally customized approach SMART has developed based on its work in over 20 global cities to optimize multiple sustainable solutions (including those mentioned in this paper) to serve the transport user from door to door as well as to increase urban livability (including air quality and congestion), innovation, and regional economic development. The approach is outlined in "Connecting and Transforming the Future of Transportation" (17).

Alternative Fuel Vehicles
In June 2012, China established a goal of having 500,000 "new energy vehicles" in operation by 2015 and 5 million in operation by 2020. The term new energy vehicle refers to a vehicle that uses alternative fuel technologies; such vehicles include hybrid electric vehicles, battery electric vehicles, hydrogen fuel cell vehicles, or natural gas vehicles. Beijing has set its own target of having 50,000 electric or hybrid vehicles in Beijing by 2015 (18). The total will include 30,000

private vehicles, 8,000 buses, 10,000 taxis, and 2,000 vehicles used for other purposes. The Chinese central government and several Chinese cities have used government procurement programs, purchase or registration subsidies, quotas, and tax exemptions to support the adoption of alternative fuel vehicles.

Incentives for New Energy Vehicles
From 2010 to 2012, the Chinese central government provided subsidies for the purchase alternative fuel vehicles, and recently government officials have made statements suggesting that new subsidies for alternative fuel vehicles will be enacted for the next three years (19). As previously mentioned, the cities of Beijing, Guangzhou, Guiyang, and Shanghai have set license plate quotas, limiting the number of new vehicles that could be registered in those cities each year. As an incentive to drive alternative fuel vehicles, some of these cities have created special exceptions to these laws. Guangzhou, for instance, has dedicated ten percent of its 120,000 license plate quota to AFVs, including all-electric autos, plug-in hybrids, and hybrid vehicles (20). Buyers of alternative fuel vehicles in Guangzhou will also qualify for 10,000 yuan in subsidies from the government. In the first half of 2013, Beijing will announce preferential policies for electric vehicles: electric car buyers will be able to register their vehicles without entering the city license plate lottery and would be eligible for a subsidy of up to 120,000 yuan (21).

Infrastructure Deployment
Lack of refueling infrastructure is seen as a major barrier to the adoption of alternative fuel vehicles globally. In most markets, gasoline and diesel fuel are widely available, with many refueling stations available to provide fuel to vehicles. Consumers who are considering purchasing alternative fuel vehicles may be dissuaded if they do not think there will be adequate refueling capacity to serve their vehicle or if they will be required to drastically change their driving habits while using such vehicles (e.g., driving shorter trips, taking longer to refuel, or needing to plan trips around refueling station locations).

Further complicating matters, creating new infrastructure to power alternative fuel vehicles is expensive, and fuel providers may be reluctant to invest in public infrastructure if there are not enough vehicles to purchase fuel from them. These conditions can lead to “chicken or egg” problems where neither consumers nor suppliers want to invest in a new technology because of uncertainty about the behavior of the other group (10). Much of the initial investment in refueling infrastructure will come from national and local governments as well as fleet owners who build their own centralized refueling stations. While initial deployment of infrastructure may be limited, ITS solutions, such as mobile device applications similar to the one offered by ChargePoint in the United States (22), can help drivers of alternative fuel vehicles locate nearby stations when they need to refuel their vehicle.

Electric Bicycles
While China has struggled to meet deployment targets for electric vehicles despite strong government support, one form of electric mobility, the electric bicycle, has seen broad adoption. According to a recent report form Navigant Research, 90 percent of all electric bicycles sold worldwide through 2020 will be in China (23). While electric cars have seen local and national support for adoption, some cities have already banned electric bicycles or are considering enacting a ban due to concerns about accidents and congestion (24).

Emerging Vehicle Technologies
In 2010 the General Motors EN-V concept was displayed at the Shanghai Expo (25). The vehicle was jointly designed by General Motors and Shanghai Automotive Industry Corporation (SAIC). The EN-V can be driven normally, or using an automated driving mode, in which the vehicle uses sensors and computing power to direct itself to the desired destination. The EN-V can also park itself and be summoned from its parking space using a mobile device.

CONCLUSIONS

Urban mobility and air pollution has become one of the most significant development challenges in Chinese cities, including in the capital city of Beijing. This paper focuses on urban development trends, existing transportation conditions, current and emerging planning practices, and transportation challenges and opportunities in Beijing. The transportation system and air pollution are related to each other and many additional factors. Investigating solutions will require a systems-based, multi-modal, multi-technology, multi-stakeholder approach. Challenges to be addressed by future research include the following:

- Identifying and quantifying sources of air pollution
- Developing modeling tools to assess relationship between transportation systems and air pollution using more accurate and relevant datasets
- Identifying current and potential public policy effects on mobility
- Identifying and forecasting megatrends such as future population growth and transportation mode choice
- Identifying and forecasting adoption of new systems approaches and technological advancements that may affect the relationship between transportation and air pollution.

Beijing continues to undergo “growing pains” as the size of its population; economy, developed space, and motor vehicle fleet continue to climb. The Chinese central government and the city of Beijing have created initiatives to reduce the negative consequences of the city’s transportation system, but the magnitude of the issues has often outweighed their efforts. Transportation innovation, planning, and policy tools present the possibility of improved transportation system performance and mitigation of its negative effects. SMART works directly with urban and transportation leaders around the world to learn, synthesize, and introduce new systems-based innovation and implementation approaches, engaging all sectors including major corporations, small entrepreneurs, non-governmental organizations, and government at all levels and across the full range of related sectors and functions. More recently SMART has begun to work with local citizens, as well. By doing this, SMART aims to offer a sufficiently robust platform for tackling the growing challenge of increasing safety and efficiency, while reducing traffic congestion and improving air quality and quality of life in Beijing.

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