7.1 Sources and types of air pollution from transport

Air pollution in China and India is rampant and transportation emissions contribute to a large proportion of the air pollution. This section will discuss air pollution from transportation emissions and analyze different types of emissions.

7.1.1 Air pollution and transportation emissions

7.1.1.1 China

China’s Environmental Protection Ministry published a report in November 2010 which showed that about a third of the 113 cities surveyed failed to meet national air standards in 2009. According to the World Bank, 16 of the world’s 20 cities with the worst air are in China (Facts and Details, 2016). According to Chinese government sources, about a fifth of urban Chinese breathe heavily polluted air; many places smell like high-sulfur coal and leaded gasoline. In addition, only a third of the 340 Chinese cities that are monitored meet China’s own pollution standards.

China’s smog-filled cities are ringed with heavy industry, metal smelters, and coal-fired power plants, all critical to keeping the fast-growing economy going even as they spew tons of carbon, metals, gases, and soot into the air. The air pollution and smog in Beijing and Shanghai are sometimes so bad that the airports are shut down because of poor visibility. The air quality in Beijing is 16 times worse than in New York City (Facts and Details, 2016). Sometimes one cannot even see buildings a few blocks away and blue sky is a rare sight.

Only 4% of Chinese breathe air considered safe by European Union (EU) standards, according to a World Bank study (Facts and Details, 2016). Air pollution is particularly bad in the rust belt areas of northeastern China. A study conducted by the World Health Organization (WHO) estimated that the amount of airborne suspended particulates in northern China is almost 20 times what WHO considers safe.

So, what are the main sources of China’s air pollutants, especially particulate matter (PM) 2.5? People from different areas of China might have different answers. In most of the rural areas,
especially in inland China, the energy and industry sectors, as well as wood cook stoves, dominate emissions. However, in urban areas, especially in megacities, transport is the major source of emissions and its share is growing due to urbanization and motorization (AQICN, 2016).

The evidence is still building, but it is already clear that road transport is a significant contributor to urban air pollution. Motor vehicles are estimated to emit about 15%–35% of local PM$_{2.5}$ in Chinese cities. In Beijing, this number is estimated to be 31%, 25% in Shanghai, 23% in Guangzhou, 31% in Shenzhen, 20% in Chengdu, 33% in Hangzhou, and 14% in Qingdao (AQICN, 2016). Vehicle emissions also account for 58% of the nitrogen oxides (NO$_x$) and 40% of volatile organic compounds (VOCs) in Beijing—both of which can have serious negative health effects.

### 7.1.1.2 India

India is the 7th largest country in the world with a 3.5 million km$^2$ territory and a population of 1.2 billion. As the 4th largest economy in the world, this country is fueled by large and growing trade and employment opportunities—almost all of which are powered by fossil fuels.

To match the great development of India’s economy, motor vehicle numbers grew 15.7% during 1991–2001, against a 2%–5% annual growth rate in Europe and America. The growing demand for transport leads to more air pollution and greenhouse gas (GHG) emissions. The increasing number of vehicles accounts for more than 30% of the ambient air quality in six Indian cities. Other major cities and secondary cities are also putting pressure on local infrastructure through a growing population. This inadequate infrastructure results in higher emission of local pollutants and GHGs. The transport sector in India consumed about 16.9% of total energy in 2005–2006 (Guttikunda and Jawahar, 2010).

According to the total emissions for 2010 along with sector contributions (Guttikunda and Calori, 2013), vehicle exhaust, road dust, and diffused domestic sources (with shares of 13%, 22%, and 12%, respectively) are at ground level and exacerbate exposure levels and exposure times for PM$_{10}$. For PM$_{2.5}$ and carbon monoxide (CO) emissions, researcher estimates suggest shares of 17% and 18% for vehicle exhaust. In the transport sector, freight movement via heavy-duty and light-duty trucks was the largest contributor. All the heavy-duty trucks are diesel operated and most of the light-duty trucks operate on compressed natural gas (CNG). For NO$_x$ emissions, vehicle exhaust remains the dominant source (53%) (Ramachandra and Shwetmala, 2009).

### 7.1.2 Sources of air pollution from the transport system

#### 7.1.2.1 China

##### 7.1.2.1.1 RAILWAY TRANSPORT

China’s railway transport is now mainly composed of electric and diesel locomotives. In 2012, the proportion of electric and diesel locomotives was 53.5% and 46.5%. In the case of known fuel consumption per ton-km for diesel locomotives and electric consumption per ton-km for electric locomotives, rail transport carbon emission factors can be calculated as Unit turnover fuel*Density of diesel*Carbon emission factor of diesel*46.5% + Unit turnover electricity carbon emission factors*53.5% (Li et al., 2015).

##### 7.1.2.1.2 ROAD TRANSPORT

Road transport energy consumption relates to freight cars on the road, energy structure, and loading rate, among other elements. Combined with Turnover Fuel Consumption of petrol and
diesel trucks given by China’s road transport energy consumption level standard, the road transport emissions factor can be calculated as “Unit turnover fuel*Density of gasoline (or diesel)*Carbon emission factor of gasoline”.

7.1.2.1.3 WATER TRANSPORT

Waterway transport includes sea transport and inland transport. Both consume diesel fuel similar to road transport. The waterway transport carbon emission factor is equal to Unit turnover*Diesel fuel density*Diesel emissions factor.

Vehicles contribute 22%–34% of PM$_{2.5}$ and 30% of NO$_x$ in the megacities of China, but these percentages are growing. Meanwhile, the energy consumption of different transport modes is quite different (Tian et al., 2014).

The Chinese freight transport sector has experienced rapid growth of GHG emissions, increasing from 163 million tons (MT) of carbon dioxide equivalent (CO$_{2e}$) in 2000 to 978 MT of CO$_{2e}$ in 2011. It is found that the GHG emissions of highway freight transport experienced an abnormal increase from 2007 to 2008 which resulted from the adjustment of China’s statistical standards, which led to an increase of highway freight turnover (Tian et al., 2014). It has been found that the adjusted trajectory of the total GHG emission from freight transport was decreased by modifying the values of highway freight turnover based on the ratio between the data in the pre-2007 and post-2008 periods. Even so, the trajectory of total GHG emission is divided into two obvious stages. First, the total GHG emission of the Chinese freight transport sector presented a slow growth trend during 2000–2007; then, it experienced a rapid increase during 2008–2011. From the perspective of the whole period (2000–2011), GHG emission from highway freight played a prominent role in the total GHG emission trajectory, followed by the emission from waterway freight. The GHG emissions from highway freight increased from 90 MT of CO$_{2e}$ in 2000 to 610 MT of CO$_{2e}$ in 2011, and the GHG emissions from water freight increased from 54 MT of CO$_{2e}$ in 2000 to 99 MT of CO$_{2e}$ in 2011. The proportions of the GHG emissions from these five transport modes, including railway, highway, waterway, aircraft, and oil pipeline, were 7.3%, 53.0%, 31.9%, 7.2%, and 0.6%, respectively, in 2000 and 2.4%, 82.9%, 11.3%, 3.0%, and 0.3% in 2011 (Tian et al., 2014).

The traffic sector has become one of the main sources of PM$_{2.5}$ in the atmosphere. In Beijing, 22% of PM$_{2.5}$ emissions come from vehicle emissions and the number is 25% in Shanghai (Earley, 2014). In addition, the PM$_{2.5}$ emissions that came from transportation could be divided into different vehicle types. For example, the heavy duty truck is the biggest contributor to traffic pollution emission at 61%. The large passenger vehicles are the second contributor at 18% (Earley, 2014).

7.1.2.2 India

According to the classification of transport systems, the source of air pollution from transport can be rail, aviation, shipping, and road transportation. Road, rail, and air are responsible for 80%, 13%, and 6% of the total emissions, respectively. Various energy sources used in this sector are coal, diesel, petroleum (gasoline), and electricity, which represent different sources from fuel.

Globalization and the government’s liberalization policies have spurred economic activities. Consequent to this policy change are increases in urbanization and concentrated economic activities in certain load centers resulting in higher mobility. This results in a rapid increase in the number of vehicles and traveling distances, thus a higher consumption of energy at an average annual rate of 2.9%. During the last two decades, the number of registered motor vehicles has increased dramatically from 5.4 million in 1980–1981 to 72.7 million in 2003–2004. Energy
consumption also varies with the mode of transport and public transport systems have the least average energy consumption per passenger kilometer. The urban population of India, which constitutes 28% of the total population, predominantly depends on road transport. Around 80% of passenger and 60% of freight movement depends on road transport. Traffic composition of six megacities of India (Delhi, Mumbai, Bangalore, Hyderabad, Chennai, and Kolkata) shows significant shifts from the share of slow-moving vehicles to fast-moving vehicles and public transport to private transport. Among the different types of motor vehicles, the percentage of two-wheelers has shown rapid growth (doubling every five years) and two-wheelers constitute 70% of the total motor vehicles of India. The total number of road vehicles in India as per the latest available statistics (March 2004) was 72.7 million. Indian railways play an important role in long-journey movement of both passengers and freight. In the last ten years, there has been a sharp increase in the number of passengers and goods movement and consequently fuel consumption. Current energy consumption in railways is around 5.1% of total transport energy, with about 77.5% from diesel and the balance from electricity. During 2004–2005, Indian civil aviation accounted for more than a 24% increase in the number of international and domestic flights, with a consequent increase of aviation fuel from 0.98 MT (1976–1977) to 6.2 MT in 2005–2006. The shipping sector has aided in the movement of about 18 MT of cargo (Badami, 2005).

Vehicular emissions account for about 60% of the GHGs from various activities in India. Considering the vehicle segment, the emission sources can be summarized as follows:

- Vehicles. With the available data, motor vehicles are the predominant sources for CO, hydrocarbons (HC), and NOx. Although these shares are lower than those of other sources, they are likely growing in Indian cities given the rapidly growing motor vehicle activities. Since the 1990s, Indian motor vehicle technology has been behind global practice, and the activities of motor vehicles cause higher pollution intensities.

- Fuel quality. Three important pollutants in poor fuel can have serious impacts on the environment and public health. Released lead forms PM10 and even low lead emission will cause neurological effects in children. Benzene is implicated in adult leukemia and lung cancer, but India did not control it until recently. Levels of sulfur, an important constituent in particulate emissions, were excessively high in Indian gasoline and diesel until the mid-1990s.

- Gasoline evaporation emission. There is no evaporating control on the fuel distribution system or on vehicles, except for cars produced after 1996. These facts, along with India’s high ambient temperatures, heighten the potential for evaporate emissions rich in reactive HC, which form ground-level ozone.

- Poor urban planning. Congestion has rapidly increased in Indian cities. This makes cars’ average speed low and causes more fuel consumption. Also, the lack of roads results in congestion and causes loss of time and productivity due to poor urban planning.

- Bad maintenance of roads and vehicles. One would expect good vehicle maintenance given the low labor and high fuel costs in India. However, many vehicle users maintain their vehicles only when absolutely unavoidable. Vehicle emission inspection regimes, such as in Delhi, have combined a decentralized test-repair system and no-load testing, which is technically flawed, open to corruption, and burdensome for users, who have circumvented or subverted the testing process.

- Fuel and lubricating oil adulteration. This adulteration has been enabled principally by the fact that kerosene, which is the poor person’s cooking fuel, has been heavily subsidized and is seven to ten times cheaper than gasoline. Diesel is of concern because it accounts for a significant share of petroleum product consumption and imports, and diesel exhaust contain particulates that are predominantly in the fine particulate range, as well as many toxic air contaminants.
Even so, there is no silver bullet to address all sources of transport-related emissions and one cannot have an impact on emission from transport using only one policy instrument. Rather an effective emissions control strategy must target reductions in multiple sources and pollutants.

In India, the phenomenon of two-wheeled motor (M2W) vehicles cannot be ignored. Motor vehicle ownership and activity are growing rapidly in India, causing impacts more adverse than in the Organization for Economic Cooperation and Development countries, despite much lower motorization levels. These impacts include rapidly growing congestion, air pollution, energy consumption, traffic accidents, noise, and transport wastes. The most easily affordable motorized mode of transport in India is an M2W vehicle, including scooters, motorcycles, and mopeds. M2W vehicles are accessible round-the-clock and offer reliable door-to-door service, require little parking space, can be parked securely inside the home, and can carry passengers as well as luggage. Although these vehicles contribute to congestion, they can be operated flexibly compared with other motorized modes because of their size and maneuverability. However, while most of the low-salary classes rely on bicycles for personal mobility, the middle classes, for whom cars are unaffordable, use buses occasionally and purchase M2W vehicles as soon as they can. In short, M2W vehicles provide mobility equal to that of cars at a fraction of the cost. Even as they provide affordable mobility to millions, M2W vehicles contribute significantly to transport impacts, accounting for nearly half the total gasoline consumption in India and high shares of urban air emissions and road fatalities, particularly on a passenger-kilometer basis.

7.1.3 Types of air pollution from the transport system

7.1.3.1 China

Air pollution levels are determined by the concentrations of a complex mixture of air pollutants. Currently, \( \text{SO}_2 \), \( \text{NO}_2 \), \( \text{CO} \), \( \text{O}_3 \), \( \text{PM}_{2.5} \), and \( \text{PM}_{10} \) are defined as the six criteria pollutants around the world in quantifying air pollution levels. The concentrations among the pollutants can differ by orders of magnitude, and their unit concentration health effects are significantly different as well. Therefore, it is difficult for the public to use the concentrations directly to characterize the levels of air pollution.

In 2013, the total amount of four pollutants for national motor vehicles was 45.709 MT. There were 34.397 MT of \( \text{CO} \), 4.312 MT of \( \text{HC} \), 6.406 MT of \( \text{NO}_x \), and 594,000 tons of \( \text{PM} \). Cars are major contributors of the emissions above. The total amount of \( \text{CO} \) and \( \text{HC} \) is more than 80%, and the total amount of \( \text{NO}_x \) and \( \text{PM} \) is more than 90% (Earley, 2014).

In 2013, the amount of \( \text{CO} \) for national motor vehicle emissions was 34.397 MT. Car emissions were 29.121 MT, accounting for 84.7%; low-speed vehicle emissions were 145,000 tons, accounting for 0.4%; and motorcycle emissions were 5.131 MT, accounting for 14.9% (Earley, 2014).

In 2013, the quantity of national motor vehicle \( \text{HC} \) emissions was 4,312 MT. Car emissions were 3.49 MT, accounting for 80.9%; low-speed vehicle emissions were 158,000 tons, accounting for 3.7%; and bikes discharged 664,000 tons, accounting for 15.4%.

In 2013, the quantity of national motor vehicle \( \text{NO}_x \) emissions was 6.406 MT. Car emissions were 5.887 MT, accounting for 91.9%; low-speed vehicle emissions were 419,000 tons, accounting for 6.5%; and motorcycle emissions were 100,000 tons, accounting for 1.6%.

In 2013, the volume of national motor vehicle \( \text{PM} \) emissions was 594,000 tons. Car emissions were 567,000 tons, accounting for 95.5% and low-speed vehicle emissions were 27,000 tons, accounting for 4.5% (MEP, China, 2014).
7.1.3.2 India

During 2003–2004, total transport emission of CO₂ was 258.10 Tg. CO₂ contributions in the road sector, aviation, railways, and shipping were 243.82 Tg (94.5%), 7.60 Tg (2.9%), 5.22 Tg (2%), and 1.45 Tg (0.6%), respectively. The road sector and aviation mainly contributed 3.03 Tg (53.3%) and 2.57 Tg (45.1%) of CO. Among all types (road, shipping, railways, and aviation) of transport, road and aviation were the major contributors of air pollution. Emissions from shipping and airways are generally not included in the national emission inventories because they occur mostly in international waters and air (Badami, 2005).

Taking only road transport into consideration, different types of vehicles contribute different shares of air pollution for different air pollutants. The emission inventory for 2010 (Guttikunda and Jawahar, 2012) due to road transport shows that many HCs, such as methane, contribute to global warming, as does black carbon, which is a major component of vehicular PM emissions. NOₓ and CO do not directly affect global warming, but both can react with other particles in the atmosphere and become global warming contributors. Controlling vehicular emissions of conventional pollutants will therefore have a positive impact in reducing GHG, even if this is not the primary intention of vehicular emissions controls. In other words, the emission inventory is developed for the following pollutants-particulates in two bins (PM₁₀, PM₂.₅), sulfur dioxide, NOₓ, CO, VOCs, black carbon, and organic carbon (Guttikunda and Jawahar, 2012).

7.2 Emission standards and the regulatory environment

Transportation emission problems mainly rely on solutions from government, so this section will introduce relevant policies, such as new vehicle standards, fuel quality standards, and new energy vehicles, in China and India. However, the two countries also adopted different approaches to managing transport-related emissions. In China, policymakers adopted special emission labeling policies and low emission zone programs, which we call the yellow label car. Also, in India, policymakers have had to confront problems caused by significant numbers of M2W vehicles. This section will introduce these differences.

7.2.1 New vehicle and engine emission standards

7.2.1.1 China

Emission standards, limits on the amount of pollutants released by or evaporated from new vehicles/engines over a pre-defined test cycle, are a crucial element of all vehicle emission control programs. Regarding the production of new vehicles, the “Air Pollution Law” prescribes that:

Motor-driven vehicles and vessels shall not be permitted to discharge atmospheric pollutants in excess of the emission standards. No unit or individual may manufacture, sell or import motor-driven vehicles and vessels that discharge atmospheric pollutants in excess of the emission standards.

The penalty for violating the law is that any unit or individual that:

manufactures, sells or imports motor-driven vehicles and vessels that discharge atmospheric pollutants in excess of emission standards shall be required by the department exercising the power of supervision and management according to the law to stop the illegal act; Illegal
gains, if any, will be confiscated, and a fine may be imposed equal to less than one time the illegal gains. The motor-driven vehicles and vessels that cannot meet the prescribed standards for pollutants emission shall be confiscated and destroyed.

Since the first set of emission standards for new motor vehicles was issued in 1983, Chinese emission standards have developed rapidly. By the end of 2009, China had almost established a complete emission standards system for new motor vehicles (MEP, China, 2010).

China implemented the China I emission standard nationwide in 2000. Then China II and China III emission standards were implemented in 2004 and 2007, respectively. In addition, Beijing and Shanghai have implemented China IV emission standards in advance. Along with the improvement of emission standards, pollutant emissions from individual vehicles have gradually reduced. For example, for a Class I light gasoline vehicle, from China I to China III, CO emissions dropped 44%, HC emissions dropped 70%, and oxides of nitrogen NOx emissions dropped 70% (MEP, China, 2010).

7.2.1.2 India

Emission standards are an essential element of all vehicle emission control programs. Vehicle emission standards evolve with fuel quality requirements, which enables advanced emission control technologies to be properly used and optimized. In India, the Air (Prevention and Control of Pollution) Act of 1981 established the right of the government to set vehicular emission standards. It should be noted that standards only limit the rate at which pollutants are emitted and not the total amount of pollutants released into the atmosphere.

For light-duty vehicles (LDVs), India first began to lower permissible vehicle emission limits following court rulings in the late 1980s and 1990s. After 2000, India adopted the European template for vehicle emission standards. Currently, new vehicles sold in 13 cities must meet Bharat IV (Euro 4-equivalent) standards, while the rest of the country mandates Bharat III standards (Automotive Research Association of India (ARAI), 2016).

For heavy-duty vehicles (HDVs), regulated pollutants are identical to those for LDVs. However, unlike the LDV standards, which are measured directly using chassis dynamometer testing (and have units of grams per kilometer), HDV emissions are certified in two cycles: the European Stationary Cycle (ESC) and the European Transient Cycle. Diesel-operated HDVs must pass both tests to be certified. HDVs operating on CNG do not have to undergo the ESC test. Engine emission limits are set in terms of grams per kilowatt hour. The timelines for adoption of HDV emission standards in India and other countries are different (ARAI, 2016). Indian cities that mandate Bharat IV LDV emission standards also do so for HDVs that operate only within their city limits, while the rest of India follows Bharat III.

For two- and three-wheelers, India introduced its first two- and three-wheeler emissions standards in 1991, with limits for CO and HC. Since then, other pollutants have been brought under regulation, and emission limits have been tightened. In the case of two- and three-wheelers, India does not follow the European model; the country has instead traditionally used the India Drive Cycle. India will likely fully switch to two-wheeler testing under the worldwide harmonized motorcycle test cycle in 2015 when Bharat IV standards are expected to be implemented.

One important difference between India’s approach and that of others in setting vehicle emission standards is that most other countries or regions do not form a committee to recommend a long-term road map for emission standards. This makes it difficult to predict what regulations will be in place well ahead of time.
7.2.2 Fuel quality standards

7.2.2.1 China

Fuel improvements can reduce pollutants from fuel combustion directly and, more importantly, enable the use of more effective exhaust after-treatment devices. Primarily following the European standards, China’s fuel standards have been gradually tightened since the late 1990s. Unleaded gasoline was introduced in the late 1990s and the sale of leaded gasoline was banned nationwide in 2000. The national limit on sulfur, the second most important element affecting vehicle emissions after lead, has been lowered from 1,500 ppm (parts-per-million) in 1999 to the current level of 150 ppm for gasoline and from up to 10,000 ppm to at most 2,000 ppm for diesel. A voluntary diesel sulfur limit of 500 ppm was already in effect and a mandatory limit of 350 ppm took effect in July 2011. Major cities like Beijing and Shanghai have adopted fuel standards limiting sulfur content in gasoline and diesel to within 50 ppm to enable early implementation of Euro 4 for passenger vehicles and Euro IV standards for medium- and heavy-duty vehicles (MEP, China, 2014).

Over the past decade, fuel standards in China, except for some major cities, have consistently lagged behind the fuel requirements corresponding to the vehicle emission standards (MEP, China, 2014). China stopped approval for China II heavy-duty diesel vehicles (HDDVs) on January 1, 2007, and for China II LDVs on July 1, 2007, nationwide, meaning that only HDDV and LDV prototypes meeting China III standards can be certified starting from these two dates. However, the China III gasoline standard was implemented in January 2010, two and a half years after China III LDV standards were implemented, and the China III diesel standard was not adopted nationwide until July 2011, four and a half years after the HDDV standard was tightened to China III. The lagged implementation of fuel standards (particularly the high diesel sulfur limits) has become a major roadblock to ratcheting down vehicle emission standards.

7.2.2.2 India

Fuel quality improvements directly reduce pollutants formed during combustion and enable the use of more effective exhaust after-treatment devices. Superior emission controls can be achieved only if fuel and vehicle standards are implemented in parallel and a compliance program is established to enforce both fuel and vehicle standards.

India fuel quality standards have been gradually tightened since the mid-1990s. Low-lead gasoline was introduced in 1994 in Delhi, Mumbai, Kolkata, and Chennai. On February 1, 2000, unleaded gasoline was mandated nationwide. After lead, the next most important factor in fuels is sulfur. The effect of sulfur content in fuel is particularly damaging to three types of after-treatment systems: diesel particulate filters, lean NOX traps (LNTs), and selective catalytic reduction (SCR). Sulfur in fuels also limits the efficiency of two important NOX control technologies: SCR and LNTs. However, limits of fuel sulfur in most of India are laxer than the limits in a handful of cities.

For gasoline standards, the properties that are the most relevant to vehicle emissions are sulfur content, volatility, benzene level, other aromatic hydrocarbons, olefins, and oxygenates. India’s current gasoline standards took effect on April 1, 2010. The new standards offer marked improvements from pre-2010 levels. Benzene limits were cut from 3% in cities previously governed by the Bharat III standard and 5% elsewhere to 1% nationwide. The aromatic content limit, which was unregulated under Bharat II, stands at 42% under Bharat III norms and 35% under Bharat IV. Olefins, which were also unregulated under Bharat II, now are restricted to 21% and 18% for regular unleaded and premium unleaded gasoline, respectively, under Bharat III and Bharat IV regulations.
For diesel fuel standards, India has reduced its diesel sulfur content from 10,000 ppm in most of the country in 1999 to a maximum of 350 ppm today. In 23 cities, the level has fallen to 50 ppm over the same period. A total of 63 cities (including those already subject to the 50 ppm sulfur limit) are scheduled to receive supplies of 50-ppm-sulfur diesel by 2015. Diesel fuel quality is perhaps more important in India than in other countries because of the increasing numbers of diesel LDVs in use over the past decade. This is at least partly attributable to government subsidies for diesel, considering the perceived importance of diesel in agriculture and goods transportation. The subsidies resulted in diesel being significantly cheaper (by about RS. 20, or 40%, per liter) than gasoline, despite the stepwise increases in diesel fuel prices, in January 2013. Naturally, this encourages the production and sale of diesel passenger vehicles.

In all, fuel quality standards have been designed and implemented in conjunction with vehicle emissions standards in India, which has allowed the benefits of emissions reduction policies to be realized. A problem remains, though, in that fuel sulfur limits in most of the country are laxer than the limits in a handful of cities. This means that vehicles designed to meet Bharat IV emissions standards, particularly diesel-powered vehicles, may have higher emissions than expected when and if they refuel in areas with higher fuel sulfur content.

### 7.2.3 Vehicle compliance and enforcement programs

#### 7.2.3.1 China

New vehicle emission standards can serve to protect air quality only if vehicular emissions are actually reduced when the vehicles are in normal use. To fully deliver the promise of environmental and health benefits from new vehicle standards, an effective vehicle compliance and enforcement program must be in place to ensure that emissions of new and in-use vehicles are effectively controlled.

China’s vehicle enforcement and compliance program consists of three main elements: (1) new vehicle type approval; (2) conformity of production (COP); and (3) Inspection and Maintenance (I/M) programs. The Ministry of Environmental Protection of the People’s Republic of China’s (MEP) compliance effort mainly focuses on new vehicle type approval and COP. Provincial and municipal environmental protection bureaus (EPBs) are charged with managing local I/M programs.

- **New vehicle type approval**
  - MEP has entrusted 23 laboratories nationwide to conduct emissions testing, of which 18 labs conduct testing for LDVs, HDVs and engines, agricultural vehicles, and non-road engines and five conduct motorcycle emissions testing. These labs are mainly used for type approval testing, but some also conduct testing for COP.
  - Type approval reports are submitted to the vehicle emission control center (VECC) for review, but all reports submitted to date are passing reports, meaning that laboratories are not required to provide any report / data on vehicles or engines tested that do not pass the certification requirements. Therefore, MEP/VECC does not receive information and data on failed certification tests. The only rejections of type approval reports that have occurred to date are for minor and obvious problems, such as a manufacturer not providing the correct application materials.

- **Conformity of production**
  - Every year MEP commissions VECC to conduct a number of random COP tests. Results of the COP tests are summarized in a report submitted to the MEP. Some of
the COP tests are conducted by selecting and testing vehicles right off the assembly line and some are performed on vehicles purchased on the market.

- In 2008, VECC conducted random COP testing at 11 auto manufacturers, and mass products of 13 vehicle models were inspected (including both LDV and HDV). Of the 13 models, two were directly judged as out of compliance because essential parts/accessories used in mass production were inconsistent with those reported in the certification application. Of the 11 manufacturing facilities inspected, the quality of inspection equipment of three production lines did not meet the requirements.

- In-use compliance testing and recall

  - Currently, MEP requires vehicle manufacturers to submit an in-use compliance plan and annual report but, because of the lack of supply of compatible fuel, MEP has not selected and verified any of the in-use compliance plans and reports. However, the city of Beijing has started an in-use testing program focused on passenger vehicles. In March 2009, the Beijing Environmental Protection Bureau (BEPB) launched a random in-use testing program for China III and IV passenger vehicles with cumulated mileage of no more than 100,000 km. So far, 60 vehicles have been tested. In addition to the in-use testing conducted by BEPB, BEPB released a notice on in-use testing on June 3, 2010, requiring manufacturers to conduct in-use testing of any engine/vehicle model selling more than 500 units/year in Beijing.

- I/M program

  - Under the Air Pollution Prevention and Control Law, I/M programs are managed by provincial- and municipality-level EPBs. Maintenance and repair centers are managed by the provincial transportation management authorities.

  - MEP establishes test procedures for loaded and unloaded I/M tests and specifies emission limits for unloaded tests. Local governments are required to adopt the MEP I/M test procedures and limits (if an unloaded test is used); regions suffering from severe air pollution are recommended to use the loaded test for I/M testing, and the local EPBs need to set the emissions limits according to the local situation. An MEP notice released in December 2010 mandates that each I/M testing department submit city EPBs in an annual work report with a description of the test facility and emission problems identified. City EPBs will then prepare and submit an I/M inspection and management report to provincial EPBs for transmission to MEP.

7.2.3.2 India

Government authority to regulate motor vehicle emissions in India was first established by the Air (Prevention and Control of Pollution) Act, 1981, and the Environment (Protection) Act, 1986. The former vested powers in the individual states to regulate and enforce broad environmental standards, while the latter gave most of the same powers to the central government. The Motor Vehicles Act, 1989, then fixed vehicular emission standards and authorized the central government and state governments to regulate and enforce them. At this time, it is ultimately the Ministry of Road Transport and Highways (MORTH) that is responsible for enforcing compliance with India’s vehicular emission standards. However, it is difficult to coordinate and enforce. Therefore, the 2003 Auto Fuel Policy Committee recommended the creation of a single agency responsible for all vehicle emissions and related fuel quality issues.
India’s vehicle enforcement and compliance program also consists of three main elements: (1) new vehicle type approval; (2) COP; and (3) I/M programs.

In India, in-use and “pollution under check” (PUC) programs remain less effective than type approval and COP programs. India’s PUC program has other problems as well. While the difficulty remains with the decentralized infrastructure and lack of well-defined guidelines, the greatest problem may be lax standards. Another problem with the PUC program is the low visibility for proof of compliance. In contrast with in-use vehicle emissions compliance, new vehicle enforcement has had some success in India. Vehicle manufacturers now offer warranties on emissions.

7.2.4 Emission labeling and low emission zone programs

In China, the concept of vehicle emission labels dates back to 1999, when Beijing first introduced yellow stickers for vehicles that do not meet China I emission standards. Following that, a number of provinces and major cities implemented environmental labels for motor vehicles, with a unique design for each region. During the past decade, the emissions labels were mainly used to facilitate the traffic restriction program for high-polluting vehicles. In 2009, MEP published a rule to standardize the design of vehicle emission labels in China, which allows the harmonization of traffic restriction programs across regions. At the same time, MEP and other state agencies initiated a subsidy program to encourage early scrappage of yellow-sticker vehicles, aiming to phase out some 18 million yellow-sticker vehicles by 2015. These efforts turned out to be very successful in quickly replacing the heavy polluters with clean vehicles. Beijing, for example, eliminated 97,000 yellow-sticker vehicles, or 27% of its total yellow-sticker vehicles, by October 2009.

China’s vehicle emission labeling program aims to phase out the most polluting vehicles. Of the 64 million motor vehicles operating in China today, 18 million, or 28%, are pre-China I gasoline vehicles or pre-China III diesel vehicles without particle control equipment (diesel oxidation catalysts or PM filters). These vehicles emit 75% of total exhaust emissions from all vehicles. In the most congested cities, the large numbers of high emission vehicles contribute to severe local air quality problems. During the last decade, large metropolitan areas, such as Beijing, Shenzhen, Shanghai, and Guangzhou, have introduced vehicle emission labels and traffic restriction programs. A number of midsize cities have followed suit.

In July 2009, MEP announced a new normalized labeling system nationwide. The requirements for issuing the two types of labels (four-wheels and Motorcycles/Scooters) meet different standards (MEP, China, 2014). Vehicles receiving green labels include all spark ignition engine four-wheelers that meet or exceed the China I emission standard, compression ignition engine four-wheelers that meet or exceed the China III emission standard, and motorcycles or motor scooters that meet or exceed the China III emission standard. Vehicles that do not meet these minimum requirements (but still meet their corresponding emission standards) receive yellow labels. Vehicles that fail to meet their corresponding emission standards cannot be granted a label (MEP, China, 2014).

7.2.5 Fuel efficiency and GHG programs

7.2.5.1 China

China introduced its first national fuel consumption standards for new passenger vehicles (M1 category under the European classification) in 2005. Three years later, as the second stage, the
standards were made about 10% more stringent. In August 2009, China proposed a further strengthening of the Phase III standard (MEP, China, 2014).

Unlike the corporate average fuel economy or vehicle GHG emissions standards adopted in other parts of the world, the first two phases of the Chinese standards were per-vehicle certificate standards. Under that type of system, a new vehicle model must meet the minimum fuel consumption requirement for its weight class before it can enter the market. Such a compliance scheme, though useful to phase out vehicles with outdated technologies at an early stage, does not encourage manufacturers to adopt state-of-the-art fuel efficiency technologies over time. In the proposed Phase III regulation, China is considering a combined per-vehicle certificate standard and corporate average standard system. So far, a detailed implementation plan has not been released.

Phase I and Phase II standards helped improve the fuel efficiency of new passenger cars from 9.1 L/100 km in 2002 to 8.1 L/100 km in 2008. According to the China Automotive Technology and Research Center, the proposed Phase III standards could reduce the fleet-average fuel consumption of the new car fleet to 7L/100 km when fully implemented in 2015. This represents a 13% improvement in fleet-wide fuel efficiency by 2015, or a 1.8% annual gain over the period. According to the comparison of the world’s LDV fuel efficiency (GHG) regulations (MEP, China, 2010). China’s new target ranks 4th after Japan, the EU, and South Korea in terms of regulatory stringency. Note that such ranking does not correct for the differences in average vehicle weight in various markets. Generally speaking, the heavier a vehicle, the more fuel will be consumed.

7.2.5.2 India

To deliver on the promise of environmental and health benefits from new vehicle standards, an effective vehicle compliance and enforcement program must be in place to ensure that regulations for new and in-use vehicles are effectively implemented.

India, too, has recently started a process to set national fuel consumption standards. Vehicle efficiency policies include fuel economy standards, measured by distance traveled per unit of fuel, or fuel consumption standards, measured by amount of fuel used for a given distance of travel. GHG emission standards may narrowly refer to carbon dioxide emissions directly from combustion or to a suite of GHGs emitted from an operating vehicle or its accessories.

The transportation sector is currently the second-largest contributor of GHG emissions in the country, after power generation. India can adopt many strategies with respect to the transportation sector to mitigate GHG emissions. Establishing national fuel economy standards for vehicles is one such strategy. India is currently developing its first-ever fuel economy standards for passenger vehicles. The new regulations envision a continuous reduction in fuel consumption over a ten-year period. They will be implemented according to a corporate average fuel consumption model, meaning that there will not be a set of standards for each vehicle produced but rather weighted fleet-average standards for each manufacturer. LDV fuel economy regulations are expected to be implemented first, to be followed by rules for HDVs and two- and three-wheelers. There is much potential to improve the efficiency of India’s two- and three-wheeler fleet. However, the country still does not have two- and three-wheeler fuel economy or fuel consumption standards. India debuted a fuel economy label for new cars sold in fiscal year 2011–2012. Apart from displaying the combined fuel economy of the vehicles, the label ranks fuel efficiency by a five-star system. India also has another fuel economy label that the Society of Indian Automobile Manufacturers issued. This label is not mandatory, and it is not available for each car. This label can be obtained from a car dealership, which classifies the vehicles according to weight.
7.2.6 Alternative fuels and new energy vehicle policies

7.2.6.1 China

Alternative fuels for vehicles refer to the replacements for conventional fuels such as diesel and gasoline. With the rapidly growing vehicle population and limited oil supplies, many governments around the world have sought to promote non-petroleum and often home-grown fuels as suitable alternatives.

- Methanol vehicles
  - Though theoretically methanol can be made from any organic material, it is most commonly produced from coal and natural gas for cost reasons. Methanol is currently used in dedicated vehicles or blended at a range of ratios with gasoline (most commonly M5 to M85). In California, when methanol fuel was promoted during the 1990s, methanol vehicles mainly used M85 with 15% gasoline. In China, most so-called methanol vehicles to date have been normal gasoline engine vehicles that use M15 as the motor fuel. Methanol vehicles may reduce certain regulated air pollutants and the potential air quality benefits from using methanol remains one of the key drivers for promoting its use. An M85 pilot program in California from 1980 to 1990 showed that manufacturers could produce M85 that met California’s Low Emission Vehicle Standards, with non-methane organic gas emissions less than 0.125 g/mile, reduce NOx and CO emissions, especially from heavy-duty engines, dramatically reduce PMs compared with traditional gasoline vehicles, and almost eliminate all air toxins except formaldehyde. However, there are several barriers to the use of methanol as a motor fuel. Combustion of methanol emits a great deal of toxic formaldehyde, which is classified as a carcinogen by the WHO’s International Agency for Research on Cancer.

- Natural gas vehicles
  - Most of China’s natural gas resources and fields are located in its southwest provinces (Sichuan, Xinjiang, etc.). In the mid-1990s, the Ministry of Science and Technology announced the Clean Air Action Plan to promote alternative fuel vehicles in major Chinese cities. Since then, China has promoted natural gas vehicles (NGVs) in a number of southwest cities, where there is a significant price premium for gasoline compared to natural gas (natural gas price is about 40%–50% that of gasoline). At the beginning of the 21st century, enabled by the East Gas Line Project, natural gas became a commonly available energy source for eastern cities like Shanghai and Beijing, which also laid the ground for developing NGVs in these regions. By the end of 2008, NGVs were being promoted in 80 cities, with more than 170,000 NGVs and more than 500 CNG refueling stations nationwide, while Sichuan province still maintained the largest CNG fleet in China. Chongqing city (a municipality neighboring Sichuan province) had 50,000–60,000 CNG vehicles by 2009; of those, about 10,000 were dual-fuel CNG taxi cars and 7,000–8,000 were dedicated CNG buses. The city had about 70 CNG refueling stations to serve CNG vehicles.

- Ethanol vehicles
  - China is now the third largest producer of bio-ethanol with an annual production of 1.63 Mt in 2006. The main feedstock of bio-ethanol in China is aged grain stock, cassava, and sweet potato. Ethanol-capable vehicles in China mainly run on E10.
In 2001, the central government established the first ever ethanol program in China with the intention of reducing aged corn stocks in China. Four grain-based ethanol plants were approved in Northern China with production of 350 million gallons of ethanol a year. The central government provided the four ethanol plants with a subsidy similar to the US corn ethanol subsidy. Ethanol is blended into gasoline at 10K by volume in ten provinces. Recognizing the limitation of grain-based ethanol in China, in 2008, the central government decided to promote non-grain-based ethanol production, while allowing the four grain-based ethanol plants to continue their operation. The government policy of encouraging non-grain-based ethanol resulted in a large cassava ethanol plant in Guangxi Province, now in operation, and another one under construction. Furthermore, several small-scale pilot cellulosic ethanol plants have been developed in China.

• New energy vehicles

In China, four vehicle types are considered new energy vehicles, including conventional hybrid vehicles, plug-in hybrid vehicles (PHEV), hydrogen fuel cell electric vehicles (FCEV), and battery electric vehicles (BEV).

Although the initial efforts to develop electric vehicles (EVs) in China date back to the early 1990s, they were not a focus of the auto industry’s strategy until early this century. In 2001 (the beginning of the tenth Five-Year Plan), China included for the first time various EV research and development (R&D) projects as a key component in the National High-tech Development Plan (usually called the 863 Program). Since then, the government established a so-called “Three Transverses” (i.e., Fuel Cell Vehicles, Hybrid Electric Vehicles, and Pure Electric Vehicles) and “Three Longitudes” (i.e., Multi-Energy Powertrain System, Drive Motor, and Power Battery) strategy and a massive amount of investment began to flow into EV development. A total of 2 billion RMB was invested in alternative vehicle R&D including EVs by the end of 2008. In the following five-year period (2006–2010), the Chinese government reinforced the EV R&D activities and also started to explore initial paths for commercialization. The sales of new energy vehicles in China were growing from 2011 to 2016 (CNELC, 2016).

The first attempt at wide and public application of EVs was the demonstration of the new energy vehicle fleet deployed for the 2008 Summer Olympic Games in Beijing. During the Games, 595 new energy vehicles—mainly battery, fuel cell, and hybrid electric vehicles—operated for 3.7 million kilometers and conveyed 4.4 million passengers. Premier Keqiang Li chaired a State Council Executive meeting on September 29, 2015, and decided to launch a new wave of decentralization reforms, build equity norms to facilitate the business environment, speed up rainwater storage and smooth deployment of reasonable utilization of sponge city (a city where almost every raindrop is captured, controlled and reused), effect the development of new energy cars, and promote structural adjustment in domestic demand expansion. The hybrid electrical vehicle (HEV) has been widely applied in megacities as a supplement of EV. HEVs could improve fuel economy and emissions performance, but they also suffer from most in-car electronics (ICE)-related problems (Feng et al., 2010).

7.2.6.2 India

Delhi has been at the forefront in introducing CNG HDVs in India. Other cities have also followed Delhi’s lead in switching their bus fleets to CNG. In addition to buses, many LDVs use
CNG as a fuel, particularly taxis and auto rickshaws. In the 2010–2011 fiscal year, more than 80,000 new CNG vehicles were sold, representing 2.7% of total passenger vehicle sales in India. In India, however, ultra-low-sulfur diesel is not scheduled to be introduced in the near future. This means that CNG vehicles, especially buses, will remain key to controlling air pollution in many cities.

Passenger cars with liquefied petroleum gas (LPG) as a fuel have been gaining popularity in India. The advantage of LPG is its lower price relative to gasoline. In 2010–2011, only 1.5% of all passenger vehicle sales were LPG dual-fuel vehicles. Given the cheaper cost of CNG, it seems likely that CNG will have higher demand than LPG in the future.

Biofuels include both ethanol and biodiesel. The former is often blended with gasoline, or it can be used as an alternative to gasoline in appropriate vehicles. The latter serves the same purpose with diesel. Most of the ethanol produced in India uses sugarcane molasses as a feedstock. India is working to expand the country’s ethanol production capability and increase the use of ethanol as a fuel. However, the country is experiencing difficulties in increasing production of biodiesel, which is mostly extracted from animal fat and waste oil.

India has taken steps over the last few years to promote EVs, mainly in the form of subsidies. Apart from the subsidies, India has reduced the excise duty on EVs from 8% to 4%, and various states have added their own incentives.

### Standards and regulations for two-wheeled motors in India

Given the role of M2W vehicles in transport emissions, emission standards have been made particularly stringent and have been tightened particularly rapidly for these vehicles. The durability of catalytic converters (and emissions durability, generally) is particularly challenging for M2W vehicles, partly because of the high “engine-out” emissions and temperatures.

That the Indian M2W vehicle industry has responded to the challenges posed by increasingly stringent emission standards, while greatly expanding its offering of vehicle types and models, shows that this industry has come a long way in just a decade. This transformation in innovation and quality may be attributed to various factors, including regulatory pressures in response to concerns over urban air pollution; rising urban incomes, accelerating demand, and growing user expectations in terms of performance, reliability, and fuel economy; fierce competition and technology collaborations in response to these factors; and growing global market opportunities. Indian M2W vehicles are not only low cost but they also meet the most stringent emission standards and offer superior fuel economy, which is increasingly important as gasoline prices rise.

### Emission and air quality evaluation models

Facing the serious problem of air pollution, both countries have undertaken a series of research projects in related fields. This section will introduce the air quality models, the emission models, and traffic simulation technology, etc., in China and India.

#### Techniques of emission data collection

#### Chassis dynamometer

An ORIENT chassis dynamometer (ARAI, 2016) is an integrated assembly, thanks to up-to-date technology, with mechanics/electronics sub-systems and software. All functions provide the
capability to simulate actual road loads while the vehicle tested remains in a safe stationary condition. In addition, the testing would enable operators to connect test instruments and diagnostic equipment to monitor and tune up a vehicle’s engine for specific performance. This technology is widely used in China and India.

The direct current machine and alternative current machine chassis dynamometers are used for complete road simulation as well as measurement of vehicle emission, constant speed fuel consumption, and vehicle performance. These dynamometers are suitable to test vehicles as per the Indian, European Economic Community (EEC), and The US Environmental Protection Agency (EPA) emission regulations.

The constant volume sampler (CVS) and dilution tunnels are suitable for emission measurement of two-wheelers, three-wheelers, and four-wheeler passenger cars, as well as light commercial vehicles as per the Indian, EEC, and EPA emission regulations. These tunnels are especially used to measure particulates in diesel vehicles.

The world-class analyzers are used to measure different constituents of the automotive exhaust gases, such as HC, CO, carbon dioxide, and oxides of nitrogen from diesel, gasoline, LPG, and CNG vehicles. Non-methane HC from CNG vehicles can also be measured. The latest generation analyzer is based on the dirty/clean line concept for distinguishing between clean and dirty engines during emission measurement.

During the measurement of PM for heavy commercial vehicle applications, the secondary dilution tunnel and the existing CVS with an 18” diameter dilution tunnel is used to keep the temperature of diluted gas below 52.7°C.

7.3.1.2 Remote sensing

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus is in contrast to on-site observation. A vehicle with remote sensing devices is shown in Figure 7.1. Remote sensing is a sub-field of geography. Now, remote sensing is used in transportation as a technique of emissions data collection in China and India.

![Figure 7.1: Remote sensing used in transportation](image)

*Source: BJTU, China, 2014.*
In Hangzhou, China, researchers used on-road remote sensing to measure the real-world emissions of CO, HC, and nitrogen oxide at five sites. Remote sensing measurements helped them obtain more accurate emissions data (Guo et al., 2007).

China’s national government and Beijing city authorities have adopted additional control measures to reduce the negative impact of vehicle emissions on Beijing’s air quality. In-use emissions from light-duty gasoline vehicles were investigated at five sites in Beijing with remote sensing instrumentation (Zhou, Fu and Cheng, 2007).

7.3.1.3 PEMS

A portable emissions measurement system (PEMS), as shown in Figure 7.2, is essentially a lightweight laboratory that is used to test and/or assess mobile source emissions (i.e., cars, trucks, buses, construction equipment, generators, trains, cranes) for the purposes of compliance, regulation, or decision-making. PEMS are also applied in China.

In Shanghai, China, PEMS was used to measure the on-road emissions, as shown in Figure 7.3, from trucks to estimate the accuracy of the vehicle emission factors calculated by the International Vehicle Emission (IVE) model (Wang et al., 2008). Also in China, many universities and research organizations like Beijing Jiaotong University are using PEMS to characterize the emissions of the growing vehicle fleet (Yu, 2011).

7.3.1.4 SHED

The Sealed Housing for Evaporative Determination (SHED) is used to measure evaporative emissions from the gasoline four-wheeled vehicles as per the Indian, Economic Commission for Europe (ECE), (EURO III & IV), EPA, and California Air Resources Board (CARB)

![Figure 7.2 PEMS is used to assess mobile source emissions in China](Source: BJTU, China, 2014.)
regulations (ARAI, 2016). SHED can also be used to measure evaporative emission from gasoline two- and three-wheeled vehicles as per CARB regulations.

### 7.3.1.5 Engine dynamometer test facilities

The engine dynamometers are used to conduct the power and emission test on diesel/CNG engines as per the Central Motor Vehicles Rules (CMVR), EEC, and EPA regulations (ARAI, 2016).

The Raw Exhaust Gas Analysis System for diesel and CNG engines equipment provides the facility to measure different constituents in raw exhaust gases, such as HC, CO, carbon dioxide, oxides of nitrogen, and oxygen from engines. The Mini Dilution Tunnel (partial flow dilution, total sampling) AVL Austria Model – SPC472 (2 Nos.) is suitable to measure particulates from diesel engines as per national and international standards, such as EEC 91/542, ISO 8178, and ECE R-49.

The engine intake air conditioning unit supplies air at reference atmospheric conditions (temperature, pressure, and humidity) to the engine intake as per regulations, such as CMVR, EEC 91 / 542, ECE R 49, and ISO 8178. In engine test automation systems, all the equipment in the engine test cell such as dynamometer, dynamic fuel consumption meter, fuel and coolant conditioning unit, smoke meter, combustion air handling unit, raw exhaust gas analysis system, and particulate measurement unit have been interfaced with the host computer. With an automation system, it is possible to conduct the power, smoke (steady and transient), and emission measurement tests (steady state) in AUTO mode with the final result calculation and report generation.

### 7.3.1.6 Nano particle measurement facilities

The Measurement of Nano Particle Emission of Automobiles setup has features useful for both export homologation/certification and research and development on engines and vehicles. The
facility can be used for measurement of regulated pollutants and nano particles in terms of size, number, and surface area (MEP, China, 2010).

To ensure accuracy of weighing filter paper and particulates, the weighing chamber must meet narrow band atmospheric conditions, as required (MEP, China, 2010).

In addition, researchers in India use a questionnaire to collect data from road users or they obtain emission data from ARAI and emission factors from the Central Pollution Control Board (CPCB). ARAI is a cooperative industrial research association of the automotive industry and Ministry of Industry, Government of India. The institute has been set up by the Indian vehicle and automotive ancillary manufacturers and the Ministry of Industry as a cooperative industrial research body to provide services to the industry in the fields of applied research and product development in automotive engineering. Thus, it can provide authoritative data about automotive emissions using advanced techniques like chassis dynamometers (Wikipedia: ARAI., 2016).

CPCB is a statutory organization under the Ministry of Environment and Forests. The board conducts environmental assessment and research. It is responsible for maintaining national standards under a variety of environmental laws, in consultation with zonal offices and tribal and local governments. It has a monitoring function for air quality and maintains the related quality data. The agency also works with industries and all levels of government in a wide variety of voluntary pollution prevention programs and energy conservation efforts. Thus, this board releases authoritative data of national emission factors (Wikipedia: ARAI., 2016).

7.3.2 Modeling of transport activities for emission estimation

7.3.2.1 Macroscopic modeling of transport activities

The land-use/transport interaction model (LUTI) is considered an important tool for modeling urban spatial development processes. Using the LUTI concept and taking economic and transport activities as an entry point, an urban activity spatial evolution model (UASEM) can be developed and the implementation of this model can be discussed in detail. UASEM includes a number of sub-models, such as an Activity Transition Model that predicts the amount of activities, an Estate Development Model that predicts the floor space of buildings, a Transport Model that evaluates transport accessibility, and an Activity Location Model that predicts the spatial distribution of socioeconomic activities (Niu et al., 2015).

The Secure Cross-border Transport Model is also being used in China; this model promotes effective management of cross-border vehicles/goods with modern technologies, which provide more tools for controls of cross-border transport (Li, 2012).

7.3.2.2 Mesoscopic modeling of transport activities

According to recent studies, the fleet model to estimated age-distributed on-road vehicle population can be formulated as follows.

\[ V_{c,a}(t) = V_{c,0}(t-a) \times S_{uc,a} \]  

(7.1)

where, \( V_{c,a}(t) \) is the vehicle population in year \( t \) of vehicle category \( c \) and age \( a \), \( V_{c,0}(t-a) \) is the population of new vehicles sold (i.e., age 0) in year \( t-a \) and \( S_{uc,a} \) is the survival fraction applicable to the given vehicle category and age. For a given vehicle type, survival fraction \( sup \) for age “\( a' \)” is calculated as the ratio of survival rate \( S_u \) for age “\( a \)” to that for age 0.
Vehicle survival was modeled with a logistic function, as is shown in the following. A data-driven approach involving long-term vehicle-registration data, vehicle sales, and age distribution of vehicles at a specific point in time (2004) was used to determine survival function parameters.

\[
S_u(a) = \frac{1}{1 + e^{-a(1 - \frac{L_{50}}{a})}}
\]  

(7.2)

Here, survival rate \( S_u(a) \) is a function of vehicles of age “a” while shape factor “a” relates to the onset of significant vehicle retirement and “\( L_{50} \)” is the age by which 50% of vehicles have been retired. Function parameters \( a \) and \( L_{50} \) were varied over a range of possible values to find an optimum solution, which gave the best least-squares fit between modeled and calculated survival rates. Data enabling such calculation were available for two- and four-wheelers and light duty diesel vehicles (LDDVs). For three-wheeled vehicles, \( L_{50} \) and \( a \) were assumed to be the same as for two-wheelers on the basis of similar service lives and in the absence of other information. The survival-function parameters for HDDVs were taken in the absence of other information. For two-wheelers, three-wheelers, four-wheelers, LDDVs and HDDVs, \( a \) is \(-2.9^a, -2.9^b, -5.2^a, -2.1^a \) and \(-4.5^c \) respectively, \( L_{50} \) is \(10.1^a, 10.1^b, 19.8^a, 8.5^a, 13.0^c \) respectively. The estimated survival-function parameters for the vehicle categories are used to construct the survival-fraction curves and calculate the age distributions of on-road populations from long-term sales data and the estimated survival characteristics (Pandey and Venkataraman, 2014).

Vehicle activity was obtained from survey data available for two-, three-, and four-wheeled vehicles and assumed from the literature for LDDVs and HDDVs. A framework evaluated the difference between estimated fuel use and top-down reported consumption at the national level to identify parameters that require alternate estimation methods. The literature provided the vehicle activity estimates for LDDVs and HDDVs. Survey-based data were available for HDDVs (buses and trucks), but expert judgment was provided for LDDVs, which are primarily used for goods transport (Guttikunda and Jawahar, 2012).

Another important model in transport activity is traffic forecasting activities. The general one is a four-stage model. The four-stage model consists of trip generation, trip distribution, modal split, and traffic assignment. Trip attraction models have the same purpose as trip production models. The trip distribution and modal split phases were carried out jointly using doubly constrained gravity models. The activities of Indian cities are based on the models developed based on any of the methodologies.

A discussion gives an overview of the determinants of travel behavior of individuals in Indian cities. The travel demand models currently employed in India are limited in analyzing the impacts on travel demand. Moreover, they are incapable of analyzing many of the sustainable transportation policies for the reasons mentioned earlier in this study. However, activity-based travel demand modeling can handle many of these situations. Moreover, it is capable of analyzing the impacts of the communication revolution and land use changes on travel behavior (Guttikunda and Jawahar, 2012).

### 7.3.2.3 Microscopic modeling of transport activities

The development of new fuel consumption and emission models creates the need to characterize traffic conditions by using Vehicle Specific Power (VSP) distribution. The researcher uses large samples of floating car data (FCD) collected from the expressways in Beijing to associate the VSP...
distributions with various average travel speeds. After a comprehensive analysis, regular patterns are found between the VSP distribution and the average travel speed. The mean of the VSP distribution is the VSP value when cruising at the average travel speed, and the standard deviation can be expressed as a power function of the average travel speed. Based on these findings, a mathematical model for developing the VSP distributions is derived by using the average travel speed. Finally, a comparative analysis between the estimated and actual fuel consumption demonstrates that the VSP distributions developed by the proposed model apply for the estimation of fuel consumptions (Song, Yu and Tu, 2012, Zhai et al., 2016). Examples of speed specific VSP distributions are illustrated in Figure 7.4.

Figure 7.4  VSP distributions on expressways

Source: Zhai et al., 2016.
7.3.3 Macroscopic emission model and its applications

A macroscopic emission model is selected to generate emission factors and develop emission inventories at national and/or regional levels. State-of-the-practice macroscopic emission models include EMIT, COPERT, the Motor Vehicle Emission Simulator (MOVES), MOBILE, and the latest version MOBILE6.2. In contrast to the development in US and Europe, China still does not have its own emission models, so it must adopt modified versions of US or European-based emission models to provide a short-term solution. The US EPA developed the Mobile Source Emission Factor Model (MOBILE), a computer program that estimates emission factors for gasoline- and diesel-fueled highway motor vehicles. The MOBILE emission model was developed based on laboratory dynamometer driving tests for vehicles. The two different versions of MOBILE, MOBILE5 and MOBILE6, differ significantly in their input requirements and output structures.

7.3.3.1 MOBILE6 and COPERT

Wang et al. collected real-world emission factors on mini-buses and compared them with the corresponding emission factors generated by MOBILE6. This comparison indicated that the prediction results from MOBILE6 were much higher than real-world values. Liu adjusted the primary input parameters of MOBILE6 according to Chinese conditions and calibrated the model based on the emission data collected from the real-world traffic network. Xie et al. used the COPERT III model to calculate Chinese vehicle emission factors by adjusting the required parameters based on actual vehicle characteristics in China. This study compared the emission factors produced from COPERT III and MOBILE and indicated that the emission forecasting by the COPERT III model is better in China (Yu et al., 2009a).

7.3.3.2 CRRI

The CRRI method, which is proposed for a road network for the prediction of emissions from automobiles, is as follows:

\[ E_i = \sum_j (Veh_j \cdot D_j \cdot e_{ij}) \]

where, \( E_i \) is total emissions of pollutant \( i \) (g/day); \( Veh_j \) is the number of vehicles of type \( j \); \( D_j \) is distance traveled by vehicle type \( j \); \( e_{ij} \) is the emission factor for pollutant \( i \) for vehicle type \( j \) (g/km). CPCB 2000 emission factors are used in this method (Aguilar-Armendariz and Martinez-Garcia, 2015). The models above belong to the on-road transport macroscopic emission model.

7.3.3.3 AEDT

Only a few studies have reported aviation-emission factors for PM that apply to landing and takeoff (LTO) and cruise operations. This work used particulate emission indexes, calculated by the Aviation Environmental Design Tool’s (AEDT’s) emission module. These indexes are based on the results of ground-level and on-site emission tests published in the literature. Emission factors used in AEDT’s 2004 inventory represent LTO emissions, while indexes for the 2006 inventory are consistent with cruise emissions (Pandey and Venkataraman, 2014).
7.3.4 Microscopic emission model and its applications

Microscopic emission models are important to quantify vehicle emissions and evaluate the energy-saving effect of traffic management measures.

7.3.4.1 CMEM and EMIT

In China, researchers have used the CMEM traffic emission model to evaluate the emission improvement from ramp metering. Ramp metering is an effective way to alleviate freeway congestion. It also makes some contributions to increase traffic flow, improve operational efficiency, and reduce traffic accidents. Using the collected data, several microscopic emission models, including CMEM, VT-Micro, EMIT, and POLY, were evaluated and compared through calibration and validation procedures. Non-linear optimization methods were applied for calibration of the CMEM and EMIT models. The CMEM model was selected for the emission estimation for ramp metering (Gao et al., 2013).

7.3.4.2 MOVES

Based on the analysis of modeling principle and input parameters of the MOVES model, the localized method is proposed to obtain the input parameters. Then, the MOVES model based on default emission rates and measured emission rates is used to evaluate the effect of emission reductions of Electronic Toll Collections (ETC) strategy. The modeled emissions are compared with real world emissions (Yue et al., 2013).

7.3.4.3 IVE

The IVE model, developed by the International Sustainable Systems Research Center, was employed to simulate the vehicle emission factors for 22 cities in China (Huo et al., 2011). Wang et al. applied the IVE model to estimate vehicle emissions in Shanghai. In this research, many essential data such as vehicle technical levels were collected and used as local input parameters for the IVE model.

The IVE model was jointly developed by the International Sustainable Systems Research Center and the University of California at Riverside through funding from the US EPA. This model calculates vehicular emissions at macro, meso, and micro scales. The IVE model can be used to estimate emission for local, global, and toxic pollutants for 1990 through 2050. It can estimate emissions from more than 700 different types of technologies with different combinations of fuel and after-treatment technologies. It accounts separately for start emissions and running emissions. It also further considers changes in emission rates over time due to fleet turnover, diurnal emissions, and hot-soak emissions, running losses, and refueling emissions. Base emission rates depend on vehicle technology, air/fuel ratios, engine sizes, and fuel types. It uses VSP and engine stress to capture the impact of driving behavior more accurately. VSP is estimated using speed, acceleration, and grade. The IVE model estimates emission rates using the following equation by adjusting for different correction factors. The general inputs to the model are fleet characteristics, vehicle activity, driving patterns, fuel quality, and temperature based on local conditions (Davis et al., 2005).

An application used in Chennai, India, in 2005 shows that the estimated emissions from motor vehicles were 431, 119, 46, 7, and 4575 tons/day, respectively, for CO, VOC, NOx, PM, and CO2. About 19% of emissions are from start emissions. The results illustrate the estimated travel
demand and source of emissions from different vehicle classes. Local pollutants are of immediate concern for urban air quality since they have significant impacts on health. Temporal distribution of emissions is required to quantify the health impacts of mobile source emissions in a city. Previous studies have quantified the temporal distribution based on traffic intensity and assumed the same for all pollutants. However, the distribution varies based on many factors such as road geometry, traffic characteristics, and weather conditions. In addition, the IVE model shows the estimated daily temporal variation for different pollutants. One can see that starts emissions are high during the morning peak hours (Nesamani, 2010).

Another application in India is to estimate the emissions of criteria pollutants by utilizing a dataset available from field observations at different traffic intersections in Delhi. Thus, vehicular emissions, based on dynamic emission factors, have been estimated for 2003–2012, which are comparable to the monitored concentrations at different locations in Delhi. Note that the total emissions of CO, NOx, and PM10 increased by 45.63%, 68.88%, and 17.92%, respectively, up to 2012 and the emissions of NOx and PM10 grew continuously with an annual average growth rate of 5.4% and 1.7%, respectively. The same dynamic emission factors have also been used in the IVE model to calculate emissions of criteria pollutants for all types of vehicular sources over 2003–2012 in Delhi. Analysis of the results shows that two-wheelers and cars are the biggest contributors of emissions of criteria pollutants (Mishra and Goyal, 2014).

7.3.5 Traffic simulation and emission evaluation

In China, researchers intended to develop an integrated microscopic traffic-emission simulation platform by using the microscopic traffic simulation model, VISSIM,1 and the modal emission model, CMEM. A sub-network selected from the Haidian district of Beijing was used to build a traffic simulation network, in which traffic and emission conditions were subsequently evaluated. First, the relationship between the instantaneous emission/fuel consumption rate and the instantaneous speed/acceleration was analyzed. Then, the emissions for a variety of vehicle types in the network were calculated. Finally, it evaluated the impact of two alternative traffic control and management strategies using the developed platform (Chen and Yu, 2007).

In China, someone argued that the integration model, combining traffic simulation and vehicle emissions, can be used to calculate the instantaneous emission rates of different vehicles and total vehicle emissions at roundabouts. By contrasting the exhaust emission results between no signal control and signal control in such areas at rush hour, one can conclude that the optimized signal control strategy can effectively reduce the regional vehicle emissions. The proposed approach has been submitted to a simulation and experiment that involves an environmental assessment in Satellite Square, a roundabout in a medium-sized city located in China (Wang et al., 2013).

In Beijing, China, researchers have presented a method to evaluate the estimation accuracy of emissions based on the best explanatory parameter of energy consumption and VSP distribution and conducted a study on the applicability of microscopic traffic simulation models in vehicle emissions estimation (Zhang, 2011).

In China, researchers aim to assess the effects of different transit signal priority scenarios on vehicles emissions in the entire network. Their research analyzes the effects of different transit signal priority scenarios on vehicle emissions from three aspects: emission characteristics from time perspective, emission characteristics from space perspective, and total emissions. The results will provide the basis for traffic operators when they develop environmentally friendly strategies for transit signal priorities (Liu, 2012).

Relying on real-time network traffic detection and traffic simulation technology, an advanced and comprehensive laboratory for intelligent transport system (ITS) applications is in the works in
Shenzhen. It will be integrated with a true testing area in the city, where it will be engaged to improve the quality of not only real traffic movement but also the whole traffic system from planning to administration (Duan, Wang and Zeng, 2000).

SYNCHRO™ is transportation operational analysis software for modeling and optimizing traffic signal timing. It implements the Intersection Capacity Utilization (ICU) 2003 method for determining intersection capacity. This method compares the current demand to the ultimate capacity of intersections. SYNCHRO estimates emissions based on fuel consumption and utilizes various vehicle and fleet characteristics such as cruise speed, total signal delay, vehicle miles travelled, and total stops per vehicle. Based on inputs of traffic volume, optimal signal timing can be obtained. From this analysis, it is also possible to obtain average delay, number of stops, and fuel consumption, as well as estimates of CO, NOx, and VOC emissions. The analysis from SYNCHRO provides information on the v/c ratio, delay, intersection capacity utilization, intersection LOS (level of service), and ICU LOS.

Research conducted in India with the data collected from an intersection of Kolkata shows that the emission inventories developed using the MOBILE, Central Road Research Institute (CRRI), and SYNCHRO methods are comparable to that of the heavy vehicle simulator (HVS) method. MOBILE yielded the closest estimate of emissions compared to the others. Emission estimation from MOBILE resulted in a 20% overestimation and the results from the CRRI method overestimated more than half of the HVS estimates. On the other hand, SYNCHRO underestimated emissions compared to HVS. Hence, for modeling purposes, MOBILE is used. Here it is worth mentioning that HVS provides concentrations rather than direct emissions (Aguilar-Armendariz and Martinez-Garcia, 2015).

### 7.3.6 Air quality model and its applications

Based on the process of atmospheric physics and chemistry, the air quality model is a mathematical tool to reproduce the process of the pollutant’s transportation, reaction, or degradation in the air, applying atmospheric principles and mathematical methods to stimulate the quality of air from both horizontal and vertical directions on a large scale. It is a significant technique to analyze evolution rules, intrinsic principles, and original sources of air pollution and to establish the quantified relationship between emission reduction and improvement of air quality.

The Pollutants in the Atmosphere and their Transport over Hong Kong (PATH) modeling system was set up in 2000 and has since provided useful information on the various aspects of air pollution in and around Hong Kong. The system has also been enhanced to make short-term forecasts of air quality. Further upgrades of the system to meet new challenges are continuing (Fung, 2010).

The statistical response surface methodology is successfully applied for a Community Multi-scale Air Quality (CMAQ) analysis of ozone sensitivity studies. Prediction performance has been demonstrated through cross-validation, out-of-sample validation, and isolated validation. Sample methods and key parameters, including the maximum numbers of variables, involved in statistical interpolation and training samples have been tested and selected through computational experiments.

A modified two-dimensional Euler Ian air quality model was used to simulate both the gaseous and particulate pollutant concentrations during October 21–24, 2004, in the Pearl River Delta region of China. The most significant improvement to the model is the added capability to predict the secondary organic aerosol (SOA) concentrations because of the inclusion of the SOA formation chemistry (Cheng et al., 2007).

According to the topography data, surface data, and upper data from MM5 of a gas plant, the AERMOD and CALPUFF³ models are used to forecast the atmospheric environmental impact of a gas plant located in a complex mountainous area (Yu et al., 2009b).
Based on the local emission inventory, the models-3/CMAQ model combined with the weather research and forecasting model was used to simulate the spatial distribution of air pollutants in Hangzhou city in May 2010. Comparisons of the three major species with observed data from five local stations were conducted to evaluate the performance of this air quality model. Results showed that the CMAQ model can accurately predict the tendency of the three major pollutants (NO$_2$, SO$_2$ and PM$_{10}$) and the simulation deviations are in a reasonable range (Wu et al., 2014).

Concentrations of PM$_{2.5}$ in January, April, July, and October 2012 were simulated by the models-3/CMAQ in Chengdu – Chongqing Economic Zone (Sichuan). The comparison of the simulated results, made by the aerosol optical depth distribution of monitoring data and remote sensing inversion, indicated that this system had a good simulation performance on PM$_{2.5}$ (Li et al., 2013).

In 2001, Prateek Sharma and Mukesh Khare, who are in Guru Gobind Singh Indrapratha University and India Institute of Technology, reviewed the modeling of vehicular exhausts. The review included modeling studies in the domain, primarily, of analytical model performance evaluation, but comparative assessment studies were also discussed. Furthermore, the studies conducted to model vehicular exhaust emissions (VEEs) at urban road intersections and urban street canyons were also reviewed. They divided those models into analytical models, numerical models, and statistical models. Air quality models can provide significant insight into the impact of vehicular sources of air pollution on the urban air quality (Sharma and Khare, 2001).

In 2012, Saratha K. Guttikunda and Puja Jawahar, who are in the Division of Atmospheric Sciences and Urban Emissions in New Delhi, introduced an air quality model called SIM-air. Results from SIM-air were published in *Atmospheric Environment*. The SIM-air (“Simple Interactive Models for better AIR quality”) family of tools has been developed to use the available information to support integrated urban air quality management. The modules are designed to estimate emissions and to simulate the interactions among emissions, pollution dispersion, impacts, and management options. These tools and supporting documentation are distributed for free. All the databases, calculations, and interfaces are maintained in spreadsheets for easy access. For the analysis of emissions inventory and health impacts, a database of emission factors and concentration-response functions is included in the tools, which can be adjusted with specific data from cities.

The emissions inventory is maintained on a geographic information system (GIS)-based platform to spatially segregate emissions for further use in atmospheric modeling. The researchers used GIS data interfaced with Google Earth to map roads (including information on bus stops, bus depots, traffic signals, and landmarks). For the transport sector, they used grid-based population density and vehicle density surveys conducted by MORTH (New Delhi) to distribute emissions on feeder, arterial, and main roads. As a result, according to CPCB, low-lying sources like road dust and vehicle exhaust were identified as major sources. Interestingly, among other sources, LPG was identified as a key contributor to PM$_{2.5}$ in residential areas, which no other studies have reported. In the case of vehicle exhausts, the highest density of emissions was observed along the major roads, due to large heavy-duty truck emissions, and the emissions inside the main district areas are linked to the density of the feeder roads in each grid. A combination of vehicle, road, industrial, and population density is used to assign weights for congestion emissions.

The Atmospheric Transport Modeling System—a meso-scale three-layer forward trajectory Lagrangian Puff transport dispersion model—is used to estimate PM concentrations. The multiple layers allow the model to differentiate the contributions of near-ground diffused area sources, like transport and domestic combustion emissions. The model has flexible temporal and spatial resolution and can run for periods ranging from one month to a year and from regional to urban scales. This system is used to estimate PM emission in six cities in India under the SIM-air model (Guttikunda and Jawahar, 2012).
According to research from the Indian Institute of Technology, two well-known regulatory models, namely, AERMOD (07026) and ADMS-Urban (2.2), are applied in India (Mohan et al., 2011). An attempt is made here to undertake performance evaluation of these models for a tropical city such as Delhi, India, which is a well-known megacity of the world. The models have been applied to estimate ambient PM concentrations for the years 2000 and 2004 over seven sites in Delhi. Concentrations have been estimated for the winter season in both years as the low temperature and low-speed wind conditions in this season make it most significant from an air pollution point of view. Both the models tend toward under-prediction and estimated values by both models agree with the observed concentrations within a factor of two.

7.4 Advanced transport strategies to reduce emissions

To reduce emissions, advanced transport strategies are used. Travel demand management strategies are widely used in China and India. In addition, traffic control and management optimization like public transportation system strategies and analysis of emissions in intersection congestion have typical application in both countries. Also, advanced techniques like GIS and hybrid energy vehicles are expected to be widely applied in developing countries.

7.4.1 Travel demand management strategies

Travel demand management is the application of strategies and policies to reduce travel demand (specifically that of single-occupancy private vehicles) or to redistribute this demand in space or time.

7.4.1.1 Reduction of VKT through transit-oriented development

Chennai has relatively high population densities and traditionally has mixed use transport. However, the average trip length has increased from 4km to 11km mainly due to urban sprawl over the last four decades. In 1970, Chennai city was about 80 km². This increased to 174 km² in 2006. The population density has an inverse correlation with the distance from the central business district. It is a matter of fact that as one moves out of the core city, a mixture of land uses and isolated developments, reflecting characteristics of urban sprawl, is widely prevalent. This is due to a lack of integrated planning. Settlements in the urban fringe heavily depend on the mother city. Hence, transportation demand increases significantly. Furthermore, total daily person-trips in Chennai are projected to increase from 10.6 to 20.8 million in the next two decades. Therefore, the Chennai Metropolitan Development Authority (CMDA) plans to intensify development along transit corridors through increased floor space index (FSI) and relaxed parking regulations. A study by L&T Ramboll has recommended increasing the FSI from 1.5 to 2.0 on both sides of the corridor to improve the patronage of the mass rapid transit system (MRTS). Higher urban density can significantly reduce vehicle kilometers travelled (VKT) and increase the share of transit use. Currently, the MRTS carries only about 76,000 commuters per day and this is only one ninth of the projected share of patronage. This may change once the third and fourth phases of the MRTS corridor are completed and integrated with other public transits.

7.4.1.2 Reduction of VKT through traffic demand management

The modal shift from private vehicles to public transportation can significantly reduce VKT. Chennai city has 3,000 buses that cater to four million passenger trips per day. The city has four
rail corridors with a combined length of about 140km that accommodate about 0.7 million trips per day. The modal split of public and personal transports (share of modes) has been about 35% and 65%. However, the Second Master Plan has ambitiously proposed to increase the share of public transport from 35% to 70% by 2026 with a sub-modal split of 60% and 40% for bus and rail. This could be possible only through radical and far-reaching decisions. Traffic management in Chennai focuses on traffic strategy management such as one-way streets and turning restrictions, and traffic control devices completely ignore traffic demand management (TDM). The underlying principle of TDM is to restrain extravagant use of low-occupancy private cars and two-wheelers. The techniques can include parking control, tolls, road pricing, motorist traffic restraints, and staggering of office and school hours. The MRTS, the first one in the country, was extended to about 20km in 2007 in Chennai and fleet strength of the manual toll collection (MTC) was substantially augmented for the first time in 30 years. A further expansion, through Jawaharlal Nehru National Urban Renewal Mission funding, is under consideration. However, mere promotion of public transport is inadequate to shift commuters to public transport from personal transport. Simultaneous disincentives for private vehicle use are required to achieve increased ridership. Therefore, adoption of TDM techniques is a crucial emission control strategy (Nesamani, 2010).

7.4.1.3 Road congestion pricing strategies
The rapid urban motorization has brought increasingly worsened traffic congestion problems, which, at the same time, has increased the pollution of vehicle emissions in the environment. In response to these challenges, Beijing has proposed research on road congestion pricing strategies based on vehicle emissions. This effort is intended not only to alleviate congestion by deploying road congestion pricing, but also to make vehicle users bear the external cost of the effect of emissions on health by considering the emission factors in the pricing scheme (Wu, 2013).

7.4.1.4 Shifting peak demand and restricting car usage
Hangzhou implemented travel demand management measures by shifting peak demand and restricting car usage. Researchers analyzed the changes in urban transportation performance and the feedback of citizens according to real-time monitoring and dynamic evaluation results for half a year. Finally, they concluded that these measures are widely supported by citizens and proved to be very successful (Tan et al., 2012).

7.4.1.5 Prioritizing public transit
In Shanghai, researchers analyzed the implementation effects of transit priority and the balance strategy on travel demand and supply. Facing future urbanization development, the need to pay more attention to the gap in roadway infrastructure development, balanced construction and management, and coordination of supply and demand strategy is discussed (Xue and Gu, 2012).

7.4.1.6 Park-and-ride
Park-and-ride is an important treatment for urban travel demand management. Park-and-ride lots are typically located at the outer edges of activity centers with transit networks and transit centers, which intercept car travelers to the center, lead travelers to transfer to a high-occupancy vehicle mode, optimize trip mode frameworks, save energy sources, and improve environment quality.
Based on analysis of the urban park-and-ride system, the planning theory was applied to Beijing’s project. First, the goals and objectives of Beijing’s project were determined. Then, based on the background data of total urban characteristics, traffic demand characteristics, traffic facilities characteristics, and traffic development policies of Beijing’s park-and-ride application were analyzed by classifying the park-and-ride lots (Yin, 2005).

### 7.4.2 Optimization of traffic control and management

The goal of traffic control is to maintain efficient operations. Traffic is also managed by restrictions on demand and by pricing. The purpose of demand management is to tailor the pattern of demand to match an efficiently (or inefficiently) controlled supply of transportation service (Kurzhanskiy and Varaiya, 2015).

In China, Tongji Advanced Traffic Control and Management System (TJATCMS) (Yang, Yuan and Lin, 2005) takes development of the ITS and the characteristics of urban roadway traffic in China into account and aggregates many advanced state-of-the-art detection technologies. TJATCMS explores the concept of coordinated control for intersection groups and develops the corresponding traffic control model and algorithm independently. Based on these studies, TJATCMS develops its control logic structure and control software structure using an object-oriented software design method. The control strategies and algorithms are tested in a practical network running with more than 20% improvements in the average link cruise speed.

Due to the fact that the design, installation, and operation of the freeway traffic control and management systems in China are separated, there are issues on the efficiency improvement. According to the characteristics that high technology is utilized in the freeway traffic control and management system, a new operational mode that is the integration of design, installation, and operation was proposed (Wu, 2002) to improve the system efficiency.

The integrated system frame of a real-time adaptive traffic control system called the China Urban Traffic Real-time Adaptive Control and Management System (CUTRACMS) is developed. Based on the demand analysis, the logic structure, physical structure, and mathematic model and algorithms are constructed (Yang, Zeng and Hang, 2001).

Effectively controlling mixed traffic flow at signalized intersections is a key to traffic management in China. Bicycle and pedestrian arrival and departure characteristics at signalized intersection are analyzed using a statistical method based on traffic investigation. Bicycle and pedestrian arrival models at intersections are developed. The departure saturation flow, departure speed for bicycle, and speed for pedestrian are calibrated (Qu, Zhou and Wang, 2004).

The intervals between phases of roundabout traffic are transformed into three parts: inter-green intervals between left turns, straights in the same phase, and straights in the next phase. A calculation method for the inter-green interval is put forward based on the potential conflict pot and starting wave in the intersection. It is applied to the Lianban intersection in Xiamen. The result of the study is important to improve the efficiency and safety of roundabouts (Ma, Yang and Zeng, 2007).

In India, traffic flow models are the mathematical description of the complex traffic flow system for characterizing and predicting the behavior of traffic. The models for traffic flow can generally be grouped as microscopic and macroscopic based on the level of detail with which they attempt to describe traffic behavior. Studies reported from India are mainly microscopic in nature. The associated model is based on those using the law of conservation of vehicles and dynamic speed formula with a linear traffic stream model developed for the traffic under study. Density and aggregate space-mean speed are considered as the state variables of interest in this model. The Kalman filter estimation scheme for traffic density was corroborated using the field values.
The full state feedback controller based on state estimation is designed for the given dynamic system and checked for response characteristics. The observer uses the Kalman filter and the values of the state variables, namely, density and speed, from the closed loop system were plotted for every instant of time and checked for performance (Zhang, 2011).

7.4.3 Applications and practices for emission reduction

7.4.3.1 Dynamic emission estimations by using real-time traffic data

A VSP-based model was used to estimate the emission impact of traffic flows over dual-loop monitoring stations in highways. An innovative algorithm was developed to generate traffic volume, vehicle composition, and operating mode distribution from the dual-loop data. Those parameters were used as contributing variables in the VSP-based emission model and their accuracy was tested using video-based ground truth data (Liu et al., 2012).

In China, researchers have presented a road segment-based emission model (ROSE) for transportation GHG emissions estimation. The objective is to provide a framework for quickly estimating traffic-related GHG emissions and analyzing their spatiotemporal distribution and variation based on real-time traffic data. The model uses a combination of ITS technology, GIS technology, and the IVE model. In the ROSE model, the ITS’ FCD and loop detector data are used as the model input. GIS-based dynamic emission data is shown in Figure 7.5, where the IVE model is used to provide microscopic vehicle emission rates and GIS is used not only as a database exchanger, but also as a computation and visualization tool in the ROSE model (Song, 2009). Meanwhile, the GIS-based emission estimations are applied in China as shown in Figure 7.6.

In India, the researchers investigated six cities and utilized a GIS-based model to estimate the level of air quality. The researchers developed the emissions inventory on a GIS platform to spatially disaggregate the emissions for further use in atmospheric dispersion modeling. For the transport sector, they used vehicle density surveys conducted by the Central Road Research Institute, New Delhi (CRRI) to distribute emissions on feeder, arterial, and main roads.

According to Guttikunda and Calori (2013), the study domain covered Delhi and its satellite cities, also including two ring roads, main roads including highways, brick kilns, power plants, and some points of interest. The monitoring data came from the continuous air monitoring stations operated by CPCB and the Delhi Pollution Control Committee. The studies take vehicle exhaust, road dust, and air traffic into consideration as multi-pollutant emission inventory.

The emissions inventory was maintained on a GIS-based platform to spatially segregate emissions for further use in atmospheric modeling. GIS data interfaced with Google Earth were used to map roads (including information on bus stops, bus depots, traffic signals, and landmarks). For the transport sector, grid-based population density and vehicle density surveys conducted by MORTH (New Delhi) were used to distribute emissions on feeder, arterial, and main roads. As a result, according to CPCB, low-lying sources like road dust and vehicle exhausts were identified as major sources. Interestingly, among other sources, LPG was identified as a key contributor to PM2.5 in residential areas, which no other studies have reported. In the case of vehicle exhausts, the highest density of emissions was observed along the major roads due to large heavy-duty truck emissions, and the emissions inside the main district areas were linked to the density of the feeder roads in each grid. A combination of vehicle, road, industrial, and population density was used to assign weights for congestion emissions.

The model used the ASIF methodology to calculate vehicle exhaust emissions. In this method, total travel activity (A) and modal shares (S) describe how much people travel by mode (in vehicle-km traveled per day), modal energy intensity (I) represents energy use per kilometer, and
Figure 7.5 GIS-based dynamic emission data
Source: Song, 2009.
the emission factor (F) is the emitted mass per vehicle-km traveled. The average vehicle-km traveled and average trip lengths by mode are estimated from passenger travel surveys conducted in 30 big, medium-sized, and small cities in India. Annual average vehicle-km traveled is estimated for passenger cars, multi-utility vehicles, taxis, and three-wheelers, public transport buses, and HDVs and LDVs. The age mix of on-road vehicles is calculated using data from the PUC program, under which all passenger and para-transit vehicles are required to undergo emission tests and receive an I/M certificate. In 2010, before the Commonwealth Games, the public transport fleet was upgraded with newer CNG buses. Planners did not utilize the emission rate results from PUC tests, as they are based on free acceleration tests conducted along the roadside for compliance and do not include a full driving cycle. They used emission factors for the Indian vehicle fleet from CPCB and integrated with DIESEL and GAINS.

The sectors and regions need further pollution control measures. Pollution is an externality (a public bad) that cannot be addressed without concerted action from the city and national authorities.

7.4.3.2 Emission impact analysis for public transportation system
(bus exclusive lanes, transit signal priority, etc.)

Guangzhou, China, undertook a bus rapid transit emissions impact analysis. When the city of Guangzhou opened its new 22.5-kilometer Bus Rapid Transit (BRT) corridor in 2010, it aimed to cut congestion on one of the city’s busiest roads, Zhongshan Avenue, and to improve the efficiency of the city’s bus system. This analysis showed that the system had succeeded in doing
that and more. The Guangzhou BRT demonstrated the viability of metro-scale BRT in China. The system is a model of highly cost-effective urban transport that should be employed as more Chinese cities pursue local and global environmental sustainability (Hughes and Zhu, 2011).

In Beijing, researchers estimated emission factors for gasoline, diesel, and CNG buses meeting different emission control standards. A bus emission inventory was developed based on these emission factors. The bus emissions were compared with the one before the CNG bus fleet was introduced. The results showed that the CO₂ equivalent of greenhouse gas emissions of Beijing buses in 2007 was 2.4% higher than the scenario without CNG buses (Zhou et al., 2010).

An impact of transit signal priority (TSP) on the emission is analyzed in Beijing. In the Basic scenario, only BRT vehicles run in the bus lane. In Scenario 1, 21 TSP devices are implemented at the intersections. In Scenario 2-1, three conventional bus lines are allowed into the bus lane. In Scenario 2-2, four conventional bus lines are allowed into the bus lane. In Scenario 2-3, five conventional bus lines are allowed into the bus lane. In Scenario 3, the queue jumps lanes with advanced stop bars implemented (Liu, 2012).

The implementation of TSP can decrease the emissions of BRT and conventional buses, but increase the emissions of cars. The total emissions of CO₂, NOₓ, HC, and CO change by 0.5%, –1.8%, –3.4%, and 1.7% (Liu, 2012).

In India, three questions about transit are discussed. The first is that since cleaner transit vehicles can contribute to important air pollutant and CO₂ reductions, which fuel type is the best? The second addresses which is the best fuel and technology to reduce emissions in a specific location. The third question concerning which bus is best also goes beyond simply choosing a cleaner fuel to understand the context of government and transit agency policies that affect fleet decisions. How fleets are operated and procured, publicly or privately, and the amount of subsidy supporting transit has an impact on the likelihood of changing to renewable fuels.

The goal of this analysis is to find a range of emissions resulting from different fuel and technology combinations and understand which factors contribute to lowering emissions. One key idea is that some fuel types can meet emissions standards for individual pollutants without advanced technologies. To meet emissions standards for all pollutants, emissions-reducing technologies are needed. Another idea is that not all buses’ on-road emissions meet the emissions standards; therefore, it is important to continue to review in-use emissions, not just standard testing procedures. Also, decisions weighing the trade-offs between reducing local air pollution and reducing CO₂ emissions may be made most appropriately at the local or national level depending on current air quality issues as well as GHG reduction targets.

### 7.4.3.3 Evaluation of ETC/Signal coordination

For the same system, there are different evaluation demands in different application hierarchies. Accordingly, different evaluation strategies and methods must be applied. First, the demands of ETC evaluation in each hierarchy were analyzed. Next, what should be evaluated was determined. Furthermore, fuel consumption and CO₂ emissions for ETC and MTC lanes were analyzed and the corresponding evaluation framework established (Ding et al., 2004). The comparison of the speed and the energy consumption index comparison of ETC and MTC are shown in Figures 7.7 and 7.8.

### 7.4.3.4 Emission implications of converting two-way to one-way streets

The emission of CO, NOₓ, and HC is reduced after implementing a one-way drive strategy, by 33.54%, 35.92%, and 34.23%, respectively. With the smooth condition of the traffic...
flow, the running state of vehicles has been dramatically improved, including boosting rotate speed, burning more efficiently, and lifting the air–fuel ratio to nearly an ideal value so that the emission of CO, HC, and NOx has dropped significantly (Cui, 2009).

Figure 7.7  The comparison of the speed of MTC and ETC
Source: Song, Yu and Zhang, 2008.

Figure 7.8  The energy consumption index comparison of ETC and MTC
Source: Song, Yu and Zhang, 2008.
7.4.3.5 Comparative studies of emissions for hybrid vs. gasoline vehicles

The Chinese government adopted a plan in 2009 to turn the country into one of the leaders of all-electric and hybrid vehicles by 2012. The government’s intention was to create a world-leading industry that produced jobs and exports and to reduce urban pollution and the country’s oil dependence. However, a study (Green and Gerard, 2009) found that even though local air pollution would be reduced by replacing a gasoline car with a similar-size electric car, it would reduce GHG emissions by only 19% versus gas vehicles, as China uses coal for 75% of its electricity production.

Prius is a hybrid car and Yuanjian is a gasoline car. According to the observation of road traffic, the 2.5 km long Shangbu Road was congested during the evening peak, and the 6.8 km long Binhe Road was not congested at noon, both of which times were selected as congested versus non-congested roads for the analysis. The emission factors on those roads were analyzed by matching the emission data to the road map on a GIS platform. A study (Song and Yu, 2007) found that the emissions of Yuanjian on the congested road were as large as 1.45–2.38 times those on the non-congested road. On the other hand, the NOx and HC emissions of Prius on the congested road were even less than those on the non-congested road. On the congested road, all the emission factors of Prius were three-fourths less than those of Yuanjian. In addition, the calculated fuel consumption of Prius on the congested and non-congested roads was 55.1% and 87.4% of those of Yuanjian. This demonstrated that Prius had advantages in both fuel economy and emission reduction on congested roads.

In India, based on the pressing challenges with growth in vehicle sales and energy security facing the country, the central government released the National Electric Mobility Mission Plan (NEMMP) which establishes a pathway for the widespread deployment of hybrids, plug-in hybrids, and EVs in India. The rapid deployment of plug-in hybrids and fully electric vehicles (collectively called plug-in vehicles, PEVs) called for in the NEMMP places significant demands on an already strained electricity grid in India. A detailed vehicle powertrain model is used to estimate electrical consumption for four types of vehicles. Five drive cycles are chosen based on Indian driving conditions, including a New Delhi cycle, Pune cycle, the modified Indian drive cycle, and an Indian urban and Indian highway cycle.

There are significant concerns with the impact that EV charging will have on an already strained Indian electricity grid. Vehicle size has the greatest impact on per km electrical consumption, followed by driving characteristics. Ancillary components have a significant impact on electrical consumption, with per km electrical consumption increasing linearly with greater ancillary component loads. The slope of increasing electrical consumption is larger for lower speed driving conditions (i.e., in cities), but is not sensitive to vehicle type. Per km electrical consumption also increases linearly with increasing vehicle mass. The slope of increase is fairly consistent across different driving conditions and vehicle types. Per km electrical consumption decreases linearly with greater motor operating efficiency; however, the slope of this decrease is highly sensitive to vehicle size (Saxena, Gopal and Phadke, 2014).

Other research argues that battery-powered cars and hydrogen–fuel-cell buses are alternative technologies to significantly reduce local and global pollutants. However, the cost of such technologies is not affordable for most road users in India. In developed countries like the US, these technologies are at demonstration stages and mass production is not expected until after 2025–2030 due to performance limitations and safety requirements (Walsh et al., 2007). In Chennai, the Department of Transport has introduced about 5,000 LPG-based three-wheelers to promote alternative-fuel vehicles (CMDA, 2007). Such technologies can be adopted in ecologically sensitive areas in a limited way (Nesamani, 2010).
7.4.3.6 Impact of traffic congestion on vehicle emissions

Traffic congestion not only affects the normal travel of residents, but also creates rising social costs. Serious congestion substantially increases residents’ travel time, thus increasing travel costs. Serious congestion also results in an increased risk of motor vehicle acceleration, deceleration, and engine idling. Based on the sustainable development and environment-friendly transportation concept, congestion and emission must simultaneously consider the road network with mixed equilibrium behavior of user equilibrium, system optimal, and Cournot-Nash.

On account of the enormous quantity of vehicles in the 5th ring expressway in Beijing, the traffic flow volume is larger, the velocity is slower, and the delay time is greater than in other areas, the combination of which is responsible for the most severe congestion in Beijing. That is why this area is highly representational for this issue. According to the study (Yu, Tang and Yuan, 2011), conducting the stimulation of this area by DYNASMART (DYNamic Network Assignment-Simulation Model for Advanced Road Telematics), we can obtain the vehicle emission data in varied congested situations, which represents the sum of CO, HC, and NOx. It is obvious that emission volume rises with higher levels of congestion.

Figure 7.9 describes the hourly pollutant emission data in various congested situations in Beijing. It is apparent that the emission in a smooth level is 50% of the emission in a less-smooth level, which is caused by the change in traffic volume and emission factors. The explanation is that the velocity in smooth situations is higher than in less-smooth situations and the traffic volume in smooth situations is less than in less-smooth situations, so that the former emission factor is smaller than the latter one. This indicates that the level of congestion is pretty influential for the emission volume. However, considering the travel time’s drastic increase, the comprehensive result is that hourly emission volume boosts with the lifting of the congestion level. Therefore, one practical strategy to cut down the emission volume is to control the level of traffic congestion (Yu, Tang and Yuan, 2011).

The traffic index is set for traffic space scope, duration, and severity of integrated numerical, traffic management, and traffic participants. With the traffic index, the traffic state of regional road networks can be determined. Therefore, effective measures can be used to reduce the occurrence of congestion.

![Figure 7.9 The different traffic congestion hourly pollutant emissions](image)

*Source: Yu, Tang and Yuan, 2011.*
The traffic index can help reveal whether residents’ travel time, for example, is 30 minutes to commute to work, so when the road network experiences moderate congestion, travel time can be adjusted to accommodate the delay (Traffic Performance Index – Baike.com, 2016).

- 0 ~ 2, Smooth: Residents can smoothly reach their destination.
- 2 ~ 4, Basic flow: Residents’ travel takes an average of 0.2 to 0.5 times longer than in open time.
- 4 ~ 6, Mild congestion: Residents’ average travel cost is 0.5 to 0.8 times more than in open time.
- 6 ~ 8, Moderate congestion: Residents’ travel takes an average of 0.8 to 1.1 times longer than in open time.
- 8 ~ 10, Severe congestion: Residents’ travel takes an average of 1.1 times longer than in smooth conditions over time.

The emission factor grows with the increase in the traffic performance index (TPI). When the TPI changes from 2 to 8, the emission factor increases steadily (Li et al., 2016). When the TPI is (0.6, 2] or [8, 9.4], the emission factor grows rapidly. As shown in Figure 7.10, by fitting the function relationship between the CO₂ emission factor and the TPI, the reliability index is greater than 0.97, which means it is rational.

**Figure 7.10** Based on the distribution regularity of traffic index of CO₂ emissions factor

*Source: Li et al., 2016.*
7.5 Summary

To provide effective emission control strategies in Asia, this chapter took China and India as study countries to discuss how transportation emissions contribute to the air pollution as well as the implementation of relevant policies. Sources and types of air pollution from the transportation sector were introduced first. Emission standards and the regulatory environment, related to new vehicle standards, fuel quality standards, and new energy vehicles were analyzed. Emission and air quality evaluation models and their applications were summarized. Advanced transport strategies to reduce emissions including travel demand management and traffic control and management optimization strategies were also analyzed for these two countries. The demand side strategies adopted in China and India have the added benefits of controlling not one—but several—pollutants simultaneously and thus would seemingly be preferable from a policymaker’s point of view. They nonetheless are not easy to implement for every country in Asia, suggesting that greater future research is needed on the gap between an approach to regulating demand that promises emissions reductions and the disappointing results that these approaches produce under different circumstances. The follow up research on bridging the transport modeling and policy were recommended in the near future.

Notes


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ADMS-Urban for Total Suspended Particulate Matter Concentrations in Megacity Delhi. Aerosol and 
Air Quality Research, 11, pp. 883–894.

Total Environment, 408, pp. 1800–1811.


Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>AEDT</td>
<td>Aviation Environmental Design Tool</td>
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<tr>
<td>BEPB</td>
<td>The Beijing Environmental Protection Bureau</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicles</td>
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<td>CARB</td>
<td>California Air Resources Board</td>
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<tr>
<td>CMAQ</td>
<td>Community Multi-Scale Air Quality</td>
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<td>CMVR</td>
<td>The Central Motor Vehicles Rules</td>
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<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
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<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
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<td>COP</td>
<td>Conformity of Production</td>
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<tr>
<td>CPCB</td>
<td>Central Pollution Control Board</td>
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<tr>
<td>CVS</td>
<td>Constant Volume Sampler</td>
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<tr>
<td>ECE</td>
<td>Economic Commission for Europe</td>
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<td>EEC</td>
<td>European Economic Community</td>
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<td>EPA</td>
<td>Environmental Protection Agency</td>
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<td>EPB</td>
<td>Environmental Protection Bureau</td>
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<tr>
<td>ESC</td>
<td>The European Stationary Cycle</td>
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<tr>
<td>ETC</td>
<td>Electronic Toll Collections</td>
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<td>FCD</td>
<td>Floating Car Data</td>
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<td>FCEV</td>
<td>Fuel Cell Electric Vehicles</td>
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<td>FSI</td>
<td>Floor Space Index</td>
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<td>GHG</td>
<td>Greenhouse Gas</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<td>HC</td>
<td>Hydrocarbons</td>
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<tr>
<td>HEV</td>
<td>Hybrid Vehicle</td>
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<tr>
<td>HDDV</td>
<td>Heavy-Duty Diesel Vehicle</td>
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<tr>
<td>HDV</td>
<td>Heavy-Duty Vehicle</td>
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<tr>
<td>ICU</td>
<td>Intersection Capacity Utilization</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>I/M</td>
<td>Inspection and Maintenance</td>
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<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
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<tr>
<td>IVE</td>
<td>The International Vehicle Emission</td>
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<td>LDV</td>
<td>Light-Duty Vehicles</td>
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<tr>
<td>LNT</td>
<td>Lean NOₓ Traps</td>
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<tr>
<td>LOS</td>
<td>Level of Service</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<td>LUTI</td>
<td>The Land-Use/Transport Interaction Model</td>
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<td>M2W</td>
<td>Two-Wheeled Motor</td>
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<tr>
<td>MEP</td>
<td>Ministry of Environmental Protection of the People’s Republic of China</td>
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<tr>
<td>MOBILE</td>
<td>The Mobile Source Emission Factor Model</td>
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<tr>
<td>MoEF</td>
<td>The Ministry of Environment and Forests</td>
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<tr>
<td>MORTH</td>
<td>The Ministry of Road Transport and Highways</td>
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<tr>
<td>MOVES</td>
<td>Motor Vehicle Emission Simulator</td>
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<td>MRTS</td>
<td>The Mass Rapid Transit System</td>
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<td>MT</td>
<td>Million Tons</td>
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<td>MTC</td>
<td>Manual Toll Collection</td>
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<td>NEMMP</td>
<td>The National Electric Mobility Mission Plan</td>
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<td>NGV</td>
<td>Natural Gas Vehicle</td>
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<td>NOₓ</td>
<td>Nitrogen Oxides</td>
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<td>PATH</td>
<td>Pollutants in the Atmosphere and their Transport over Hong Kong</td>
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<td>PEMS</td>
<td>Portable Emissions Measurement System</td>
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<td>PEV</td>
<td>Plug-in Vehicle</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Vehicles</td>
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<td>PM</td>
<td>Particulate Matter</td>
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<td>PUC</td>
<td>“Pollution under Check”</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>ROSE</td>
<td>Road Segment-Based Emissions</td>
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<td>SCR</td>
<td>Selective Catalytic Reduction</td>
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<td>SHED</td>
<td>Sealed Housing for Evaporative Determination</td>
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<tr>
<td>SOA</td>
<td>Secondary Organic Aerosol</td>
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<td>TDM</td>
<td>Traffic Demand Management</td>
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<td>TJATCMS</td>
<td>Tongji Advanced Traffic Control and Management System</td>
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<td>TPI</td>
<td>The Traffic Performance Index</td>
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<td>UASEM</td>
<td>Urban Activity Spatial Evolution Model</td>
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<tr>
<td>VECC</td>
<td>Vehicle Emission Control Center</td>
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<tr>
<td>VKT</td>
<td>Vehicle Kilometers Travelled</td>
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<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
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<tr>
<td>VSP</td>
<td>Vehicle Specific Power</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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