A Better Understanding of Taxi Emissions in Shenzhen, China, Based on Floating Car Data

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ABSTRACT

Taxis are a major source of traffic emissions in Chinese urban areas because of their great number and long running time. However, studies on taxi emissions are absent in current literature because of the lack of data on taxis’ running information. This paper takes taxi emissions in Shenzhen, China, as a case study, where detailed taxi operation information is obtained from the floating car data (FCD). The taxi emissions are then estimated using an emission model where emission rates at each speed and acceleration category are obtained from CMEM (Comprehensive Modal Emission Model). The results show that, on average, taxis in Shenzhen annually emitted 682.9 tons of carbon monoxide (CO), 475.16 tons of hydrocarbon (HC), and 452.83 tons of nitrogen oxides (NOX), which accounts for around 4% of total CO, 5% of total HC, and 6% of total HC of all cars in Shenzhen. A great part (averagely over 57%) of these emissions is non-service emissions that are emitted during the time when taxis are cruising or idling for new passengers. Hourly non-serving emissions vary significantly depending on the time of day. They are much higher during the wee hours (12 am to 7 am) than at other times. Measures to save taxis’ cruising or idling time would thus be greatly effective for reducing taxi emissions, especially during the wee hours.

Key words: Floating Car Data, Traffic emission, CMEM Model, Taxi service
INTRODUCTION

Traffic emissions have been a major source of air pollution in urban areas all over the world (1, 2). Cities in China are no exception. For instance, mobile source emissions are responsible for approximately 78% of carbon monoxide (CO), 46% of nitrogen oxides (NOX), and 83% of hydrocarbons (HC) in Shanghai (3). In Beijing, traffic-related emissions account for 76% of CO, 94% of HC, and 92% of NOX during the heating seasons (April to August) and 68% of CO, 98% of HC and 85% of NOX during the non-heating seasons (November to March of next year) (4). Similarly, Shenzhen is now suffering severe transportation and environmental problems like other large cities in China, which is caused by the sharply increased vehicle population over recent years. It was reported that there are 1.4526 million vehicles in Shenzhen, with an average 870.9 vehicles per square kilometer, which is higher than that of other Chinese megacities, such as Beijing, Shanghai, and Guangzhou (5). Study by the Shenzhen Environmental Protection Bureau showed that 57.3% of NOx is a result of vehicle emissions in Shenzhen (6).

It has been determined that taxis contribute a considerable part of traffic emissions in most large cities. For example, it is estimated that, in Central London, 24% of particulate matter less than 10μm in diameter (PM10) and 12% of NOx in traffic emissions are come from taxis (7). Two reasons make taxis a significant source of traffic emissions:

First, there are a great number of taxis serving in large cities, which constitutes a significant segment of urban transportation (8-12). Take Hong Kong for an example, Taxis currently form about 25% of the overall traffic mix, serving approximately 10% of the total passenger transportation volume (8, 9, 13). In Beijing, taxis consisted of 19.36% of the road traffic flow during weekdays, and 23.17% on weekends (14-15). In the study by Gao and Kitirattragarn (2008), taxis are seen as an opportunity to mitigate the city’s air pollution in New York City as a great number of taxis (13,078 yellow taxis) are in service (16). In Shenzhen, taxis are also a significant component of the traffic fleet, which makes them a major air pollution source as in other cities. It is reported that there were 10,305 taxis in service in 2007 and that the number will continue to increase due to increased taxis demands. Therefore, analyzing taxi emissions is also important to the control and reduction of the traffic pollution of Shenzhen.

The second reason that makes taxis a significant source of traffic emissions is the high running time of taxis. As a high-end transportation mode that offers a 24-hour-a-day transportation service, a taxi runs more often in a day than other transportation modes such as a private car. The competition among taxi drivers leads them to usually work extended hours to make more profit (17). For example, in Stockholm, Sweden, a taxi driver works on average 10 hours a day (18). Thus, a taxi could emit several times more than a private car in a day. Full-time taxi drivers usually work one shift a day, which may last 8 to 12 hours (19-20). Moreover, another consequence of a longer running time is that it makes the taxi’s mechanical condition decline quickly, which makes its emissions greater.

Characteristic information of taxis’ emissions is essential for planners and decision makers to choose proper tools and measures to reduce taxi emissions. In this paper, we focus on the following questions, the answers to which could be used to aid to achieve the
goal of reductions in taxi emissions.

(1) What is the quantity of taxi emissions? Police makers have to know what kind of role taxis play in urban traffic emissions. Accordingly, they would know whether additional emissions reduction measures should be taken.

(2) What quantity of emissions is generated during the time when taxis are cruising or idling for new passengers? In general, a taxi’s emissions could be grouped into two categories according to the taxi’s running status: service emissions that are emitted while taxis are serving customers, and non-service emissions that are emitted while taxis are cruising to search or idling to wait for new passenger. Clearly, non-service emissions should be reduced, as they are emitted for nothing. Studies have shown that a taxi’s driver spends roughly 40% of the time on cruising empty or standing idle \((14, 22)\). During the period when there are fewer taxi requirements, the empty cruising time increases significantly as the probability of meeting a new customer becomes lower. Thus, the characteristic information of non-service is crucial to the reduction of taxi emissions.

(3) How do the hourly taxi emissions and its two components (service emissions and non-service emissions) vary? People’s travel behaviors differ at different times, which results in taxis’ rate of use differing between weekday and weekend, and, between day and night. Temporal variation information of taxi emissions is useful for further decision making, such as taking specific measures in special periods.

(4) How do traffic conditions influence taxi emissions? It has been noticed that traffic conditions are a major factor influencing vehicle emissions. Frequent stops and intense driving (vigorous accelerations and decelerations), caused by improper traffic design, roadway traffic, and tremendous increase of transportation vehicles, are additional reasons that automobile emission pollution in Shenzhen has worsened. The traffic flows on Shenzhen’s roads vary dramatically between road sections and present obvious bimodal distribution \((11)\). It is estimated that acceleration and deceleration modes contribute more than other driving modes (cruise and idle), which account for 66.7% of total travel time, 80.3% of traveling distance, and 74.6%-79.2% of vehicle emissions \((12)\). Thus, real-time road traffic condition information might be provided to taxi drivers to help determine their route choice.

Although taxis have been recognized as a major source of traffic emissions, research has yet get to be conducted analyzing taxi emissions based on our best knowledge. Lack of taxis’ running information data in detail might be one of the major reasons for the lack of research. In this study, characteristics of taxi emissions in Shenzhen are analyzed thanks to floating car data (FCD), which were collected by the equipped mobile devices of on-road vehicles \((23-25)\). In this paper, based on FCD, taxis running data, including each taxi’s position, instances speed, operation state, etc., are recorded at 30- second intervals by equipment installed in the taxis. Based on the emission rates from the CMEM model, taxi emissions are attained in detail.

The following of the paper includes four parts. The first part introduces the FCD used in this paper. The second part (i.e., methodology) gives details of the employed approach. The results are then analyzed in the third part. Lastly, conclusions are summarized in the final part.

**FLOATING CAR DATA**
Floating car data (FCD), obtained from the Shenzhen Urban Transport Simulation System (SUTSS) project, are collected by equipment (GPS and wireless communication interfaces) installed in taxicabs. Each taxicab reports its location, velocity, service status, directions, etc., to the central server at 30-second intervals, 24 hours a day. The data used in this study, consisting of 83,695,752 records, were collected from 05/01/2008 to 05/31/2008 by 3000 taxis. The fields of the dataset are described in Table 1.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Text</td>
<td>20080501</td>
<td>05/01/2008</td>
</tr>
<tr>
<td>Time</td>
<td>Text</td>
<td>200121</td>
<td>20:01:21</td>
</tr>
<tr>
<td>Taxi Firm ID</td>
<td>Text</td>
<td>H</td>
<td>The firm ID that this taxi belongs to</td>
</tr>
<tr>
<td>Taxi ID</td>
<td>Text</td>
<td>13816950512</td>
<td>The ID of this taxi</td>
</tr>
<tr>
<td>Longitude</td>
<td>Double</td>
<td>113.123456</td>
<td></td>
</tr>
<tr>
<td>Latitude</td>
<td>Double</td>
<td>22.123456</td>
<td></td>
</tr>
<tr>
<td>Instance Speed (km/h)</td>
<td>Integer</td>
<td>70</td>
<td>70 km/h</td>
</tr>
<tr>
<td>Direction</td>
<td>Integer</td>
<td>14</td>
<td>Angle to north Geographic pole</td>
</tr>
<tr>
<td>Service status</td>
<td>0 or 1</td>
<td>1</td>
<td>0= not serving customers, 1= serving</td>
</tr>
<tr>
<td>Data Availability</td>
<td>0 or 1</td>
<td>1</td>
<td>0= unavailable, 1= available</td>
</tr>
</tbody>
</table>

**METHODOLOGY**

Various traffic emission models have been developed to support the control and reduction of traffic pollution (26), which can be grouped into three levels: macroscopic, microscopic, and mesoscopic. At the macroscopic level (city level or state level), an overall traffic emissions inventory for air quality simulation is obtained. For instance, Yu et al. (2009) developed a macroscopic emission model for China on the basis of a combined use of real-world emission data collected in China and some supplementary modeling data from MOBILE (27). The impact of a regional simulation model on estimating vehicle emissions is examined in the study of Roden (2005), in which the TRANSIMS software and MOBILE6 emission inventory software are used (28). At the microscopic level, emissions are estimated based on the behaviors of the fleet on each road link or segment using macroscopic variables (such as link flows and link travel times). At the microscopic level, research focus on emissions from individual vehicles using second by second measurements, where microscopic traffic simulation models, capturing detailed vehicle trajectories (speeds and accelerations) and congestion effects, are combined with emission models (1, 29-30).

Since detailed taxi emission information is essential to the analysis of their characteristics, in this paper, a microscopic emission model, based on taxis’ running data collected using floating car technology (FCT) and emission rates from a microscopic modal emission model (CMEM), is developed. The emitted pollutant R (E_R) by a vehicle (taxi) in the timespan between time i and time j is defined using the following equation:
\[ E_R = q_R(s_{ij}, a_{ij}) \times VHT_{ij} \]  

(1)

Where: \(i\) and \(j\), measured in seconds, are the times of two adjacent records in FCD, respectively. \(s_{ij}\) and \(a_{ij}\) are the average speed (mph) and average acceleration (mph/sec) of taxi moving between time \(i\) and \(j\). \(q_R(s_{ij}, a_{ij})\) is the emission rate (gram/hour) for pollutant \(R\) for movement at average speed \(s_{ij}\) and average acceleration \(a_{ij}\). \(VHT_{ij}\) is the vehicle traveled hour between time \(i\) and \(j\).

Emission rates for each acceleration and speed category are obtained from CMEM (Comprehensive Modal Emission Model), as it provides the most detailed and best-tested estimates of hot-stabilized vehicle exhaust emissions at different speeds and accelerations (31). CMEM has been used in several case studies in China (II-12,32). As the emission rates depend on ambient temperature, the average temperature of August, 2008 in Shenzhen (28.3°C) is used.

Since \(i\) and \(j\) are measured in seconds, \(VHT_{ij}\) is calculated as follows:

\[ VHT_{ij} = (j - i)/3600 \]  

(2)

As acceleration is not included in FCD here, we made an assumption that a taxi accelerates or decelerates smoothly during the FCD recording intervals (an average of 30 seconds). Thus, average acceleration could be calculated using the following formula:

\[ a_{ij} = \frac{s_j - s_i}{j - i} \]  

(3)

Where, \(s_j\) and \(s_i\) are the instance speed (mile/s) at time \(j\) and \(i\).

RESULTS ANALYSIS AND DISCUSSION

Based on the FCD data and emission rates from the CMEM model, taxis’ running emissions in Shenzhen are calculated at 30-second intervals for one month (05/2008). Hourly and daily taxi emissions, both for weekends and weekdays, are then aggregated from the obtained emissions.

Characteristics of Taxis’ Travelling Time

Running time is one of the major explanatory factors for vehicle emissions. Therefore, the characteristics of taxis’ running time are analyzed first. In Shenzhen, two full-time taxi drivers operate one taxi and work swiftly every day. Thus, theoretically, a taxi can keep running 24 hours a day. Taxis run in two statuses: serving passengers and not serving passengers (cruising to search for or idling to wait for new passengers), which are represented by 1 and 0 in FCD, respectively. Accordingly, a taxi’s running time is divided into two categories: service time and non-service time. Table 2 summarizes taxis’ daily running time in Shenzhen. On average, a taxi in Shenzhen runs for 90.3% of the day on weekdays (21.67 hours) and 92% of the day on weekends (22.27 hours). But, only 35.0% on weekdays (7.57 hours) and 33.7% of running time on weekends (7.51 hours) is spent on serving passengers.

<table>
<thead>
<tr>
<th>TABLE 2 Summery of taxi’s running time in Shenzhen (Hour)</th>
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</thead>
</table>

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Taxis’ hourly running times for both weekdays and weekends are illustrated in Figure 1. Clearly, hourly running time does not change considerably from weekday to weekend. Moreover, there are no obvious differences of hourly running time at any given hour of the weekday and the weekend. However, the two categories of hourly running time (service running time and non-service running time) vary noticeably both on weekdays and on weekends. Generally, service running time is lower in the wee hours (12 am to 7 am) than at other time due to the relative lower taxi requirements during the wee hours and reaches the lowest point during 4 am-5 am both on weekday and weekends. Hourly non-service running time varies inversely since taxi drivers have to spend more time to search for new customers when taxis’ requirements are at a lower level. As shown in Figure 1, taxis spend a significant part (on average more than half) of time on their non-service activities, especially during the wee hours.

**FIGURE 1 Hourly taxi running time in Shenzhen**

**Daily Taxi Emissions**

Table 3 shows the summary of the daily emissions of a taxi in Shenzhen. Obviously, daily taxi emissions on weekends are slightly higher than that on weekdays, similar to the daily running time shown in Table 2. Annual taxi emissions in Shenzhen then could only be approximately aggregated because of the lack of data for the entire year and also because of the day-to-day temporal variations in a vehicle’s emissions caused by temporally varying factors, e.g., ambient temperature or people’s travel behaviors. Take CO, for example. The average daily CO emitted from a taxi is 1.52 grams. According to the report, with the addition of 2000 new taxis in 2008, the amount of taxis in Shenzhen reached 12,305. Thus, taxis emitted 682.9 tons of CO in 2008, which account for 4% of CO (170,000 tons) emitted by traffic overall. Therefore, taxis contribute a significant part to overall traffic emissions. Similarly, the estimated amount of HC and NOx that taxis emitted annually 2008 in Shenzhen are 475.16 tons and 452.83 tons, respectively.
TABLE 3 Daily taxi emissions in Shenzhen (gram/taxi/day)

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekday</td>
<td>1.500963086</td>
<td>0.104606832</td>
<td>0.093485678</td>
</tr>
<tr>
<td>Weekend day</td>
<td>1.569197903</td>
<td>0.108768176</td>
<td>0.09813402</td>
</tr>
<tr>
<td>Mean</td>
<td>1.520458748</td>
<td>0.105795786</td>
<td>0.094813783</td>
</tr>
</tbody>
</table>

Temporal Distribution of Daily Emissions

Similar to the classification of running time, in this study, taxi emissions are also grouped into two categories: service emissions and non-service emissions. From the point of view of environmental protection, non-serving taxi emissions should be avoided or reduced as much as possible, as taxis emit them without creating any benefit. As shown in Table 4, on average, only 42.91% of taxi emissions are emitted while taxis are serving passengers. Thus, 57.09% of taxi emissions are emitted without serving any useful purpose.

TABLE 4 Percentage of emission during serving passengers (%)

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekday</td>
<td>42.83</td>
<td>40.90</td>
<td>46.06</td>
<td>43.25</td>
</tr>
<tr>
<td>Weekend</td>
<td>41.67</td>
<td>39.75</td>
<td>44.88</td>
<td>42.10</td>
</tr>
<tr>
<td>Mean</td>
<td>42.46</td>
<td>40.57</td>
<td>45.71</td>
<td>42.91</td>
</tr>
</tbody>
</table>

Hourly Taxis Emissions

The variation of hourly emitted CO, HC, and NOx are illustrated in Figure 2-4. Compared to running time, illustrated in Figure 1, hourly taxi emissions and hourly running time show the same trend, confirming that taxi running time is a major factor for explaining taxi’s emissions. For example, during the wee hours, hourly taxi emissions are relatively lower than those at other periods both on weekday and weekend because of the relatively shorter hourly taxi running time during that period of the day.

FIGURE 2 Hourly emitted CO of a taxi in Shenzhen
Conclusions

In this paper, taxi emissions in Shenzhen are obtained by a microscopic emission model, based on the 30 seconds interval taxi running information obtained from floating car data and emission rates at each speed and acceleration category from CEME model. The results show that taxi emissions constitute a significant part of overall traffic emissions (around 4% of CO, for example) in Shenzhen. Although there is some variation in taxis’ hourly emissions, the two parts (service emissions and non-service emissions) vary significantly. In general, taxis’ hourly average emissions are at a lower level in the wee hours both on weekdays and on weekends, which could be explained by the lower level of taxi requirements during this period. Moreover, non-service emissions vary conversely with service emissions, indicating that taxi drivers have to spend more time to cruising for new customer during the periods when there is lower demand for taxis.

Our results shows that, overall, more than half of taxi emissions (57.09%) in Shenzhen are emitted from serving passengers, which should be avoided for protecting environment. Therefore, more advanced technologies, like a taxis guiding and dispatch system, could be helpful to reduce taxis emissions by shorting the taxis’ searching time for new passengers.

Reference


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