Micro Traffic Simulation Approach to the Evaluation of Vehicle Emmissions on One-way vs. Two-way Streets: A Case Study in Houston Downtown

By

Jinghui Wang, Graduate Research Assistant
Department of Transportation Studies, Texas Southern University
3100 Cleburne Avenue, Houston, Texas 77004
Phone: (713) 313-7532, Fax: (713) 313-1856,
Email: alex88.jhwang@gmail.com, wangj@tsu.edu

Lei Yu, Ph.D., P.E. (Corresponding Author)
Professor of Texas Southern University
Yangtze River Scholar of Beijing Jiaotong University
Department of Transportation Studies, Texas Southern University
3100 Cleburne Avenue, Houston, Texas 77004
Phone: (713) 313-7007, Fax: (713) 313-1856, E-mail: yu_lx@tsu.edu

and

Fengxiang Qiao, Ph.D., Associate Professor
Department of Transportation Studies, Texas Southern University
3100 Cleburne Avenue, Houston, Texas 77004
Phone: (713) 313-1915; Fax: (713) 313-1856; E-mail: Qiao_FG@TSU.EDU

Submitted for Presentation at the 92nd Transportation Research Board Annual Meeting and
Publication in the Transportation Research Record
Washington D.C., January, 2013

Date of Submission: July 31, 2012

Word Count: 5112 (Text) + 250*2(Table) + 250*7 (Figure) = 7362
ABSTRACT

Vehicles that run on one-way or two-way streets may generate totally different emissions. One-way streets can reduce the amount of conflicts between vehicles going to different directions, but sometimes create circuitous routes which may increase Vehicle Miles Traveled (VMT) and travel times, thus may increase emissions. Two-way streets can avoid circuitous routes, but create slower traffic due to the existence of more moving conflicts between vehicles, which may lead to increased stop, acceleration-and-deceleration activities, thus may also increase emissions but at a different degree. Further, regularities of such emission increases may be different for peak vs. non-peak hours. This paper intends to evaluate vehicle emissions for one-way and two-way streets for peak vs. non-peak hours to investigate which street configuration produces relatively lower emissions, attempting to help traffic engineers decide whether a conversion between one-way and two-way streets contributes to the improvement of air quality. The micro-traffic simulation model—VISSIM—is utilized to output the second-by-second speed and acceleration data for the purpose of emission estimation. The operating mode binning approach is used to calculate emission factors, and differences of generated emissions are adopted as the measure of effectiveness. The analysis shows that the two-way street network produces lower emissions, thus can better improve the air quality during non-peak hours. However, such improvement will be weakened during peak hours. Further, emissions from the two-way street network may eventually exceed those from the one-way street network when the traffic demand increases to certain level.

KEY WORDS

Vehicle emissions; One-way Streets, Two-way Streets; Traffic Simulation; VISSIM; Non-peak hour, Peak hour; Portable Emissions Measurement Systems (PEMS)
INTRODUCTION

In the United States, the construction of one-way streets can be traced back to 1950’s when freeways were proliferated. Freeways opened the door for downtown workers to move farther from their place of work. As downtown workers moved out of the downtowns to suburban, the mode balance on downtown roadways that had been prevalent for many years began to shift toward facilitating the speedy entrance and exodus of commuters (1). In this case, downtown streets began to be converted to one-way streets to make the traffic move faster into the city in the morning and out in the afternoon. In 1990’s, with the resurgence of downtowns, many people returned to downtown as residents or workers (1). To make downtowns safer and friendlier for all modes of travel, a rebalancing of downtown roadways was required. In this context, one-way streets began to be converted back to two-way streets again.

Vehicles that run on one-way or two-way streets may generate totally different emissions. On one hand, despite the notion that one-way streets can avoid the amount of conflicts between vehicles, they sometimes force additional turning movements at intersections caused by motorists who have to travel “out-of-direction” to reach their destinations, which results in a system-wide increase in Vehicle Miles Traveled (VMT) and travel times, thus may produce increased emissions. On the other hand, slower traffic and the existence of more moving conflicts between vehicles on two-way streets may lead to an increase of emissions. Since on-road vehicle emissions have become a major contributor to the urban air pollution problem (2), when designing the converting between one-way and two-way streets, it is important to consider vehicle emissions. However, few existing studies have conducted a comprehensive quantitative evaluation of vehicle emissions when such converting is considered. Wadewalker et al. (1) provided a comparative evaluation of one-way vs. two-way streets by a combination of measures: capacity, VMT, recirculation, turning movements, average speed, pedestrian issues, concluding, even though without considering emissions, that one-way street networks are more contributable to creating a livable and safe community. The technical report of Clifton Forge in Virginia (3) provided two alternatives for converting from one-way to two-way streets by comparing the capacity of streets. Baco (4) investigated the average speed, capacity, total travel time, pedestrian safety, travel distance and visibility of one-way vs. two-way streets and created alternatives of converting downtown streets from one-way to two-way streets. Meng et al. (5) evaluated impacts of converting from two-way street networks back to one-way street networks on such variables.
as average speed, vehicle delay, vehicle-hours travel, and VMT, suggesting that higher average speed and lesser average delay were observed in a one-way street network. Eisele et al. (6) raised the guidance of the frontage road converted from two-way to one-way street networks through investigating impacts of such converting on safety. Stemley (7) analyzed both of advantages and disadvantages of one-way street networks in a qualitative level, indicating, though higher VMT and vehicle emissions, that one-way street networks should not be converted back to two-way street networks due to the higher capacity and safety on one-way streets. Hart (8) proposed a different point: some of the downtown’ streets should be converted back to two-way streets due to the resulting lower VMT, less confusing to motorists and improved access to properties on two-way streets. Despite the above numerous studies, however, the consideration of the converting between one-way and two-way streets was heavily restricted to parameters of the capacity, speed, safety, delay, VMT and economic impacts; while few studies evaluated its impact on vehicle emissions in a quantitative level. In this context, in order to make the converting between one-way and two-way street networks environmentally optimal, it is important to investigate which street network practically produces relatively lower emissions. In addition, impacts of one-way vs. two-way streets on emissions appear to have distinct features under diverse demand levels. Therefore, the impact analysis should be conducted for both peak and non-peak hours which represent different demand scenarios.

In recent studies of vehicle emissions, the Vehicle Specific Power (VSP) (9) (10) (11) has been proved to be a most effective parameter to estimate vehicle emissions because of its direct physical interpretation of and strong statistical relationship with vehicle emissions. The VSP value is calculated by the following equation (11):

$$VSP = v \cdot (1.1 \cdot a + 9.81 \cdot grade(\%) + 0.132) + 0.000302 \cdot v^3$$

(1)

where $v$ is the vehicle speed in the unit of $m/s$, $a$ is the acceleration in the unit of $m/s^2$, and $grade$ (%) is the vehicle vertical rise divided by the slope length, which can be assumed to be zero where the terrain is flat. Since the Houston downtown is a flat area, the $grade$ is assumed to be zero in this paper. Then, the VSP equation can be simplified as follows:

$$VSP = v \cdot (1.1 \cdot a + 0.132) + 0.000302 \cdot v^3$$

(2)
According to the equation, the second-by-second speed and acceleration data are the two major factors, which determine values of the VSP. Consequently, the instantaneous speed and acceleration data are used for the VSP-based emission estimation.

For the purpose of comparative analysis, emissions from both one-way and two-way street networks should be estimated. In reality, however, simply for this study, it is impossible to convert a one-way street network to a two-way street network to collect the real world emission data or the instantaneous speed and acceleration data of the two-way street network, and vice versa. In this paper, the study is conducted on a simulated platform. Due to the limitation of collecting real-world data in some cases, the micro-traffic simulation has been widely accepted as an effective approach to provide the traffic activity data for estimating vehicle emissions. Examples of such simulation models include VISSIM, CORSIM, INTEGRATION, and PARAMICS. In this study, VISSIM (version 5.30) is used to build the one-way and two-way street networks respectively. The VISSIM has been widely and successfully applied by many researchers to provide vehicle activity data for the estimation of emissions. Chen et al. (12) evaluated the impacts of traffic control strategies on vehicle emissions by establishing the simulated platform that integrated VISSIM with the Comprehensive Modal Emission Model (CMEM). By integrating the vehicle activity data provided by VISSIM and the emission data collected by PEMS, Zhang and Chen (13) compared vehicle emissions of coordinated vs. non-coordinated signal control strategies, indicating that the coordinated signal control can effectively reduce vehicle emissions. Stevanovic et al. (14) optimized the signal timing aiming at the minimum fuel consumption and vehicle emissions by linking VISSIM, CMEM and VISGAOST (an optimization program that optimizes signal timings of traffic controllers based on their performance in VISSIM microscopic simulation). Park et al. (15) estimated roadside vehicle emissions by combining the VISSIM with the MODEM emission model. Stathopoulos et al. (16) compared vehicular emissions of two proposed scenarios for improving traffic flows by using VISSIM and CMEM data. In view of the wide application of VISSIM in providing the vehicle activity data for the emission estimation, authors selected this model in this paper.

The primary objective of this paper is to evaluate vehicle emissions on one-way vs. two-way streets for peak vs. non-peak hours using the VISSIM simulation model. To this end, the real-world second-by-second speed data and the traffic volume data are collected to calibrate the VISSIM model. The operating mode binning approach provided by the Motor Vehicle Emission
Simulator (MOVES) (9) is utilized to calculate emissions by combining the instantaneous speed
& acceleration data produced by VISSIM with emission data collected by Portable Emissions
Measurement Systems (PEMS) in Houston.

METHODOLOGY

For the purpose of a comparative analysis, four emissions are evaluated: carbon dioxide (CO₂),
carbon monoxide (CO), hydrocarbon (HC), and nitric oxide (NOₓ). Two VISSIM networks, one-
way vs. two-way street networks, are established based on a real world study area selected in the
city of Houston. Both peak and non-peak hours are investigated.

Data Collection and Preparation

Three sources of data are needed in this study. The first is the emission data collected by the
PEMS in Houston; the second one is the traffic volume and the second-by-second speed data
collected in Houston downtown area which are used to calibrate the VISSIM model; and the last
one is the instantaneous speed and acceleration data output from VISSIM. The data of the first
source have been stored in the PEMS database established at Texas Southern University. In this
section, the collection of the second and the third sources of data are introduced.

Collection and Preparation of Real-world Volume and Speed Data

Both traffic volume data and instantaneous speed data were collected on May 30th, 2012. The
test area was defined in Houston downtown marked with the dark blue arrows, as shown in
Figure 1. There are 24 intersections in this network with a total distance of 2.1 miles (12
entrances and 11 exits). All of roadways are one-way streets. Existing signals are coordinated,
and each of signals has two phases.
The volume data collection was conducted from 12:30pm to 06:30pm. At each intersection, there was one trained student recording signal scenarios of the intersection and counting the number of vehicles for each traffic movement. The number of vehicles was recorded every 15 minutes. The average network flow rates of each 15 minutes were statistically calculated by summing up the 15-mins flow rate at each intersection, resulting in Figure 2. It is found from Figure 2 that the hourly flow rate reached the highest level at 04:30pm - 05:30pm and stayed in the lowest level during 01:30pm – 02:30pm. Consequently, 04:30pm - 05:30pm and 01:30pm – 02:30pm are used as the peak and non-peak hours respectively in this paper. In addition, flow rates of entering the network from each entrance were calculated as well based on the collected volume data to be used as the trip generated at each origin that is to be used for creating O-D demand programs in the section of Data Preparation of Simulated Vehicle Activities.
For the speed data collection, one person drove a car equipped with a Global Position System (GPS) device along the routes marked with red and green arrows, starting from Chenevert St @ Leeland Ave. (marked with five-pointed star). The test was conducted for 20 rounds from 2:15pm to 6:15pm. For each round, the test car ran along the red route and the green route once respectively. A total of 14,618 records of second-by-second speed data were collected. The collected speed data for non-peak and peak hours were extracted and grouped into 7 bins from 0 km/h to 70 km/h respectively (there are no samples for speed higher than 70 km/h). The spacing of each speed bin was 10 km/h. Then, the speed distribution can be derived for the calibration of VISSIM.

Data Preparation of Simulated Vehicle Activities
In this section, a one-way street network and a two-way street network were respectively established in VISSIM in order to produce simulated second-by-second speed and acceleration data for the estimation of the instantaneous VSP and operating mode distributions. The real world study area (shown in Figure 1) was used for developing simulation scenarios.

Before generating the instantaneous speed and acceleration data, the VISSIM model should be calibrated by using the field data collected in Houston downtown to ensure the accuracy of the simulation. The desired speed distribution, the driving behavior and fleet composition were calibrated. The calibration process was based on parameters of the average
flow rate at each intersection and the instantaneous speed distribution. It should be stated that, instead of the average speed, the instantaneous speed is selected as the benchmark of the calibration in this paper because it is strongly related to vehicle emissions. All relative errors between simulated intersection flow rates and real-world flow rates were found lower than 10%, and all absolute errors of the speed frequency in each speed bin were less than 5% for both peak and non-peak hours. After the calibration, VISSIM parameters for the desired speed distribution were from 20 km/h to 60km/h with two immediate points of 0.28 at 40 km/h and 0.70 at 50 km/h for the non-peak hour, and from 20 km/h to 60 km/h with two immediate points of 0.36 at 40 km/h and 0.88 at 50 km/h for the peak hour. Both the maximum acceleration and deceleration were set to 3.5 m/s$^2$ and -3.0 m/s$^2$; the desired acceleration distribution applied a curve with the maximum of 3.5 m/s$^2$. The desired deceleration was -2.8 m/s$^2$ with upper and lower boundaries of -2.5 m/s$^2$ and -3.0 m/s$^2$. The maximum deceleration for cooperative breaking was set to -3.0 m/s$^2$; the safety distance reduction factor was 0.6; the maximum looking ahead distance was 150 m, and the headway time (CC1) was set to 1.9s.

In order to obtain the instantaneous speed and acceleration data for both peak and non-peak hours, two different scenarios were created, as shown in the follows:

1. Non-peak one-way street scenario vs. non-peak two-way street scenario; and
2. Peak one-way street scenario vs. peak two-way street scenario.

In the well-calibrated one-way street model, there are 12 entrances through which vehicles can enter the network and 11 exits by which vehicles depart from the network. Consequently, two O-D demand programs (peak vs. non-peak), each of which had 12 origins and 11 destinations, were developed. In the peak-hour scenario, the peak-hour (04:30pm - 05:30pm) flow rates at each entrance were input into the VISSIM model, serving as peak-hour trips generated at each origin; while the non-peak hour (01:30pm – 02:30pm) flow rates were used as non-peak trips generated. Routes from each origin to destinations were determined by the VISSIM. Signal scenarios at each intersection in simulated networks are the same as ones collected from the real world test. Further, to obtain the instantaneous speed and acceleration data for the two-way street network, the two-way street network was established in the VISSIM based on the well-calibrated one-way street network by converting all of one-way streets into two-way streets. To eliminate impacts of signals and demand levels on estimated results of emissions, signal scenarios and O-D demand programs adopted by the two-way street model
were the same as those by the one-way street model for both peak and the non-peak scenarios. In addition, parameters of the speed (m/s) and the acceleration (m/s$^2$) were selected in the Vehicle Record command of the database output. Both peak and non-peak scenarios were simulated to produce sufficient data outputs. Each scenario was run for 1 hour. A total of 1,048,576 seconds of the speed and acceleration data were collected for both one-way and two-way street networks respectively in each simulated scenario. Instantaneous VSPs for each scenario were then calculated using Equation (2). Upon this point, operating mode distributions were obtained based on the MOVES operating mode binning approach (9), as shown in Figure 3.

![Non-Peak Hour](image)

(a) Non-Peak Scenario
Estimation of Vehicle Emissions

Vehicle emissions in a traffic network are equal to the product of emission factors and the VMT in each operating mode bin (Operating Mode Distribution). Therefore, before estimating vehicle emissions, average emission factors should be derived in advance. A set of emission rates (g/s or mg/s) in the PEMS database at Texas Southern University was used to derive emission factors. Since all of streets in the study area of this paper are local streets, only the data collected in local areas are needed. A total of 59,924 records of emission rates were extracted from a total of 163,437 records, eliminating the data collected on freeways. By using selected emission rates and the second-by-second speed data, average emission factors of CO₂ (g/mile), HC (mg/mile), CO (mg/mile), and NOₓ (mg/mile) were calculated for each operating mode bin based on the MOVES operating mode binning standard, resulting in Table 1. Combining the data in Table 1 with the simulated operating mode distributions in Figure 3, emission factors and total emissions of each scenario were estimated, resulting in Table 2 in which simulated VMTs are listed as well.
TABLE 1 Emission Factors in Each Operating Mode Bin based on the Data Collected by PEMS

<table>
<thead>
<tr>
<th>Operating Mode Bin ID</th>
<th>Average Emission Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO(_2) (g/mile)</td>
</tr>
<tr>
<td>0</td>
<td>659.66</td>
</tr>
<tr>
<td>1</td>
<td>1,642.95</td>
</tr>
<tr>
<td>11</td>
<td>409.39</td>
</tr>
<tr>
<td>12</td>
<td>867.65</td>
</tr>
<tr>
<td>13</td>
<td>802.03</td>
</tr>
<tr>
<td>14</td>
<td>758.32</td>
</tr>
<tr>
<td>15</td>
<td>769.92</td>
</tr>
<tr>
<td>16</td>
<td>827.57</td>
</tr>
<tr>
<td>21</td>
<td>125.90</td>
</tr>
<tr>
<td>22</td>
<td>172.38</td>
</tr>
<tr>
<td>23</td>
<td>203.42</td>
</tr>
<tr>
<td>24</td>
<td>322.46</td>
</tr>
<tr>
<td>25</td>
<td>387.30</td>
</tr>
<tr>
<td>27</td>
<td>508.01</td>
</tr>
<tr>
<td>28</td>
<td>611.25</td>
</tr>
<tr>
<td>29</td>
<td>592.53</td>
</tr>
<tr>
<td>30</td>
<td>376.58</td>
</tr>
<tr>
<td>33</td>
<td>NaN</td>
</tr>
<tr>
<td>35</td>
<td>NaN</td>
</tr>
<tr>
<td>37</td>
<td>NaN</td>
</tr>
<tr>
<td>38</td>
<td>NaN</td>
</tr>
<tr>
<td>39</td>
<td>NaN</td>
</tr>
<tr>
<td>40</td>
<td>NaN</td>
</tr>
</tbody>
</table>
## TABLE 2 Emission Factors, VMTs and Total Emissions of Each Scenario

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Case</th>
<th>CO\textsubscript{2} (g/mile)</th>
<th>CO (mg/mile)</th>
<th>HC (mg/mile)</th>
<th>NO\textsubscript{x} (mg/mile)</th>
<th>VMTs (mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Non-peak</td>
<td>one-way</td>
<td>750.27</td>
<td>736.91</td>
<td>230.65</td>
<td>456.58</td>
<td>1,524.26</td>
</tr>
<tr>
<td></td>
<td>two-way</td>
<td>750.80</td>
<td>737.30</td>
<td>243.27</td>
<td>472.01</td>
<td>1,349.67</td>
</tr>
<tr>
<td>2 peak</td>
<td>one-way</td>
<td>796.67</td>
<td>792.33</td>
<td>257.08</td>
<td>493.43</td>
<td>3,239.12</td>
</tr>
<tr>
<td></td>
<td>two-way</td>
<td>826.51</td>
<td>806.60</td>
<td>284.93</td>
<td>528.05</td>
<td>2,938.97</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Case</th>
<th>CO\textsubscript{2} (g)</th>
<th>CO (mg)</th>
<th>HC (mg)</th>
<th>NO\textsubscript{x} (mg)</th>
<th>VMTs (mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Non-peak</td>
<td>one-way</td>
<td>1,143,600.00</td>
<td>1,123,234.00</td>
<td>351,566.00</td>
<td>695,944.50</td>
<td>1,524.26</td>
</tr>
<tr>
<td></td>
<td>two-way</td>
<td>1,013,332.00</td>
<td>995,111.30</td>
<td>328,336.50</td>
<td>637,053.80</td>
<td>1,349.67</td>
</tr>
<tr>
<td>2 peak</td>
<td>one-way</td>
<td>2,580,494.00</td>
<td>2,566,451.00</td>
<td>832,708.00</td>
<td>1,598,271.00</td>
<td>3,239.12</td>
</tr>
<tr>
<td></td>
<td>two-way</td>
<td>2,429,091.00</td>
<td>2,370,588.00</td>
<td>837,395.20</td>
<td>1,551,930.00</td>
<td>2,938.97</td>
</tr>
</tbody>
</table>

### COMPARATIVE ANALYSIS OF VEHICLE EMISSIONS

To compare emissions of one-way vs. two-way street networks, differences of emissions between these two networks are calculated for both emission factors and total emissions, using the following Equations (3) and (4):

\[
\text{Differences of emission factors}\% = \frac{\text{emission factors of one way} - \text{emission factors of two way}}{\text{emission factors of two way}} \times 100\%
\]  

\[
\text{Differences of total emissions}\% = \frac{\text{total emissions of one way} - \text{total emissions of two way}}{\text{total emissions of two way}} \times 100\%
\]

By using Equation (3), the frequency of differences of emission factors for each scenario can be calculated, as shown in Figure 4. It is shown that emission factors of the two-way street network are higher than those of the one-way street network, especially during the peak hour. That is because two-way streets have narrower streets in one direction and more conflicts at intersections which lead to higher delays and more stop times on two-way street networks. Such disadvantage of the two-way street network becomes worse during the peak hour.
FIGURE 4 Differences of Emission Factors between One-way vs. the Two-way Street Networks

For total emissions, Table 2 provides a general description of the aggregation of four emissions for peak vs. non-peak scenarios respectively. It is found that higher emissions are produced by the one-way street network in most cases.

For a better comparative analysis, the differences of total emissions are calculated by using Equation (4), resulting in Figure 5 in which the x-coordinate represents the species of emissions, while the y-coordinate represents the frequency of differences. As shown in Figure 5, emissions of the one-way street network are higher than those of the two-way street network when values of the frequency are positive, while lower when values are negative. It is illustrated that the one-way street network generates higher total emissions than does the two-way street network, except for the case of HC during the peak hour. In addition, values of the frequency are smaller during the peak hour than those during the non-peak hour, which indicates that differences of total emissions between one-way and two-way street networks are becoming smaller during the transition from the non-peak to the peak hours. That is because emissions of the two-way street network increase faster than those of the one-way street network when transiting from the non-peak hour to the peak hour due to the slower traffic and the significant increase of conflicting points at intersections in the two-way street network. Further, the total hydrocarbon (HC) emission has even become higher in the two-way street network than in the
one-way street network during the peak hour. Consequently, with the increase of traffic demand, emissions of the two-way street network become increasingly close to the ones generated by the one-way street network. As such, the improvement of the two-way network to the air quality will be weakened when the traffic demand increases.

![Figure 5: Differences of Total Emissions between the One-way vs. Two-way Street Networks](image)

### DISCUSSIONS

After the above analysis, there is a question regarding whether emissions of the two-way network will eventually exceed those of the one-way street network when the traffic demand increases to a certain level. To answer this question, additional two scenarios were created by increasing the peak-hour traffic demand at each origin by 10 and 20 percents respectively. Differences of emissions as well as emission factors for these two scenarios were calculated, resulting in Figure 6.

In Figure 6, bars represent total emissions and scattered points represent emission factors, and 10% up and 20% up represent the 10% and 20% increase of the peak-hour traffic demand. In Figure 6, emissions of the one-way network are higher than those of the two-way network when values of the difference are positive, while lower when values of the difference are negative. It is indicated
that emission factors are always higher in the two-way network than in the one-way network. For total emissions, values of the difference become negative when the peak-hour traffic demand is increased by 10%. In other words, emissions of the two-way street network become higher than those of the one-way network. However, when the demand is increased by 20%, values of the difference for CO\(_2\) and CO become positive again and, for HC and NO\(_x\), approach to 0 from the negative side, which means that emissions of the one-way street network increase faster than those of the two-way street network when the traffic demand continues to increase over a limit. That is because the two-way street network becomes over congested when the traffic demand increases from 10% to 20%, which leads to the increase of idling activities and the decrease of VMTs per unit time, resulting in Figure 7. As shown in Figure 7, VMTs of the one-way street network increase with the growth of the traffic, while VMTs of the two-way street network decrease, though more vehicles enter the network, when the traffic demand increases from 10% to 20%. In this context, differences of VMTs between the one-way and two-way street networks become bigger with the increase of the traffic demand. Consequently, the two-way street network, though with higher emission factors, produces lower total emissions per unit time when the traffic becomes over-congested.

![Figure 6 Differences of Total Emissions and Emission Factors between One-way vs. Two-way Street Networks for Three Peak Scenarios](image-url)
CONCLUSIONS

Based on the second-by-second speed and acceleration data provided by the VISSIM simulation, VSP and operating mode distributions were calculated to estimate vehicle emissions of one-way vs. two-way street networks. Both emission factors and total emissions were evaluated during peak vs. non-peak hours. Further, peak-hour traffic demands were increased by 10% and 20% respectively to examine whether emissions of the two-way network will eventually exceed those of the one-way network with the continued increase of traffic demands. To better understand impacts of one-way vs. two-way street networks on vehicle emissions, differences of emissions were calculated. Several conclusions can be drawn from the analysis:

1. Emission factors of the two-way street network are always higher than those of the one-way street network, especially during peak hours.

2. The two-way street network produces less total emissions than does the one-way street network during non-peak hours, thus may better improve the air quality. However, such improvement will be weakened and even completely disappear during the transition from non-peak to peak hours. In other words, emissions of the two-way street network will
eventually exceed those of the one-way network with the continued increase of traffic demands.

3. If the two-way network becomes over-congested when converting from the one-way network, emissions of the two-way street network per unit time will be overtaken by those of the one-way network due to the decrease of VMTs per unit time in the two-way network.

Findings of this paper provide better understanding about the air quality implications of the converting between one-way and two-way street networks. To further the study in this paper, it is recommended that the following research be conducted in the future:

1. More study areas from different cities be selected for a further evaluation and a comparison with observations in this study.
2. Heavy duty vehicles be studied in a real world network.

ACKNOWLEDGEMENTS

This research is supported in part by the National Science Foundation (NSF) under grant #1137732, the United States Department of Transportation (USDOT) under grant #DTRT12GUTC17, the Natural Science Foundation of China (NSFC) # 71273024 and 51208033, the National Basic Research Program of China (No. 2012CB725403), and the National High-tech R&D Program (863 Program No. 2011AA110302). The authors acknowledge all the personnel who either provided the technical supports or helped on data collection. The contents of this paper reflect views of authors, who are responsible for the facts and the accuracy of the data presented.

REFERENCES

2. Tao, F., Q. Shi, and L. Yu. Evaluation of Effectiveness of Coordinated Signal Control on Reducing Vehicle Emissions during Peak Hours Vs Non-peak Hours. In *Transportation


