Hindawi
Journal of Advanced Transportation
Volume 2019, Article ID 6248796, 11 pages
https://doi.org/10.1155/2019/6248796

Research Article

Evaluating the Effects of One-Way Traffic Management on Different Vehicle Exhaust Emissions Using an Integrated Approach

Jieyu Fan, Kun Gao, Yingying Xing, and Jian Lu

College of Transportation Engineering, Tongji University, Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Shanghai, China

Correspondence should be addressed to Jian Lu; jianjohnlu@tongji.edu.cn

Received 28 June 2019; Revised 4 September 2019; Accepted 15 October 2019; Published 16 December 2019

Academic Editor: Francesco Galante

One-way traffic management is a recognized traffic organization to improve traffic efficiency and safety, but its effects on different traffic emissions remains unclear. This paper aims to investigate the impacts of one-way traffic management on three typical vehicle exhaust emissions including Carbonic Oxide (CO), Hydrocarbon Compounds (HC), and Nitrogen Oxides (NO_x) in a traffic system using an integrated approach. Field experiment was conducted to collect the vehicular emission data under different traffic conditions using the onboard portable emission measurement system. An instantaneous emission model (i.e., Vehicle Specific Power) is calibrated using the collected field emission data and is incorporated into the microscopic traffic simulation tool VISSIM for quantifying the emissions before and after one-way traffic management through simulation. Two scenarios based on real networks and traffic demands of peak hours in part areas of Shanghai are developed for simulation and evaluation. The results show that in the intersections, the emission rates of COHC, NO_x after one-way traffic management is significantly reduced by 20.46%, 21.29% and 21.06%, respectively. In the road sections, the emission rates of CO, HC, NO_x in the road sections decrease by 23.38% and 26.29%. The overall CO, HC, NO_x emissions in the studied network reduce by 21.34%, 22.29% and 23.77% separately due to one-way traffic management. The results provide insights into the derivative effects of one-way traffic management on traffic emissions in the intersections, road sections and network levels, and thus support scientific traffic management for promoting the sustainability of transport system.

1. Introduction

Environmental and energy issues derived from transportation emissions become increasingly severe and have attracted increasing attention from the transportation managers and practitioners in Chinese metropolis. The excessive emissions due to transportation have caused negative impacts on the air quality, public health, and climate [1]. It is reported the traffic pollutants including Carbonic Oxide (CO), Hydrocarbon Compounds (HC) and Nitrogen Oxides (NO_x), from 2016 to 2017, the CO, HC and NO_x emissions stemmed from transportation were 34.293, 42.20 and 57.78 million tons in China, respectively, which are not ignorable, in traffic emissions, the vehicles contribute 87.7% for CO emission, 84.1% for HC emission, and 92.5% for NO_x emission [2]. Compared with off-peak hours, fuel consumption during peak hours increased by 10%, and CO, HC and NO_x emissions from cars increased by 20% [3].

It is widely acknowledged that reducing traffic delays, the number of acceleration and deceleration events with stop-and-go traffic are beneficial for reducing vehicle emissions. Some studies have been conducted to address the influences of traffic management measurements on traffic emissions and to propose traffic operation methods that can reduce traffic emissions. Stemley [4] pointed out that in most urban traffic environments, one-way traffic could reduce conflict points and was beneficial for reducing the traffic delays and the occurrence of accidents. However, in some cases of one-way traffic networks, drivers must bypass the blocks to reach their destinations and might increase the travel distances. Nagurney [5] studied the relationship between travelers' route choice and emissions under various traffic demands and road network structures. They indicated that the rationality of the road network structure played an important role in reducing the traffic emission. Results showed that a reasonable road network configuration might increase travel distances but would not increase traffic emissions. On the contrary, the unreasonable road network structure may increase the overall emissions even although the travel demand was set to be smaller. Frey et al. [6] used portable instruments to collect the emission data of 20 vehicles of 4,000 km for investigating the key factors affecting vehicular emissions and to assess the impacts of coordinated traffic changes on traffic emissions. The results demonstrated that traffic coordination was one of the major factors affecting traffic emissions, and traffic design that led to increasing acceleration frequency would directly raise the traffic emissions. Coelho et al. [7] examined the relationship between emissions and vehicular dynamics and found that the traffic delays at intersections would boost the number of unexpected parking and thus result in increases in CO, HC and NO_x emissions by approximately 15%, 10% and 40%, respectively. They also indicated that more stops of vehicles would create more stops for the following cars and thus traffic control settings should consider the impacts of vehicle stops on traffic emissions. Moreover, Coelho et al. [8] quantified the impacts of urban single-lane roundabouts on traffic emissions. They reported that traffic emissions were correlated with speed and vehicle queue length when the roundabouts were congested. The accelerations and the number of collision points were strongly linked to the total emissions of CO, HC and NO_x at the intersections. Ahn et al. [9] employed the GPS data and micro-simulation tools to study the impact of route selections on the traffic emissions. The results showed that the high load operation of the vehicle engine was one of the main reasons for the increase in emissions and faster but longer routes did not always reduce emissions. Optimizing route selections and reducing emissions should be done simultaneously to ensure the multiple optimization objectives. Zegeye et al. [10] put forward a model-based traffic flow control approach for reducing both travel time and emissions in a traffic network. The control strategy was examined by simulation experiments and the results indicated that both reduction in emission and travel time could be achieved by properly defining the optimization of control strategy. However, they reported that the control strategy focusing on the reduction of travel time alone might not reduce the emissions simultaneously. Coelho et al. [11] used field measurements and traffic flow simulations to study the effects of stop-and-go behavior of vehicles in crowded traffic on traffic emission. The results showed that stopping led to a surge in CO and Carbon Dioxide (CO_2) emissions. Traffic disruption contributed to the largest proportion of traffic emission and account for more than 55% of CO emissions and more than 20% of total CO_2 emissions. Pandian et al. [12] established a traffic flow model including vehicle dynamics, road configurations and traffic flows to study the impacts of traffic characteristics on emissions. They pointed out that vehicle exhaust emissions near the traffic intersections largely depended on fleet speed, deceleration rates, queuing time in idle modes, red signal time, acceleration rates and queue length. These characteristics have cumulative effects on traffic pollutant emissions, but the most likely factors affecting the emission at intersections were not declared. Madireddy et al. [13] combined the emission model VERSIT with the microscopic traffic simulation tool Paramics to study the impact of vehicle speed control on traffic emissions and the effects of traffic signal coordination on traffic flow in the residential areas of Antwerp, Belgium. The results demonstrated that when the speed limit reduced from 50 km/h to 30 km/h, CO_2, and NO_x emissions reduced by 25%. Traffic signal coordination could promote traffic flow and reduced CO_2 and NO_x emissions by 10%. Nasir et al. [14] conducted vehicle exhaust pollutant emissions tests concerning HC, CO, CO_2, particulate matter (PM) and NO_x under traffic conditions of free-flow conditions, moderate congestion and severe congestion. They indicated that the shortest path was not the path with the least emissions. Traffic emission had a strong correlation with average speed, traffic congestion, stops and the fastest route. Chen et al. [15] used on-site detectors to record the vehicle's operating speed and estimated HC, CO and CO_2 emissions using a micro-emission model based on the vehicles' speed and trajectory. They explored the impacts of traffic conditions on vehicle activities and emissions and found that the emission trends of individual vehicles were basically consistent with the emission trends of traffic flows when the traffic flow was stable. Jamshidnejad et al. [16] used microscopic simulation software SUMO as a platform to investigate the relations between road congestions and traffic emissions. They proposed a common framework for integrating traffic flows and emissions models to generate mesoscopic integrated flow-emission models. Their empirical results showed that the mean and standard deviations for CO, HC and NO_x relative errors using the proposed model were less than 2% and 1.6%, respectively. Meneguzzer et al. [17] used experimental vehicles equipped with a portable emission measurement system to study the CO, CO_2 and NO_x emissions at the roundabouts and signal control intersections. The results show that the NO_x emissions at the roundabout were higher than the signal-controlled intersections, while CO_2 and CO emissions presented the opposite principles.

One-way traffic management is one of the useful strategies for alleviating the traffic pressure and reducing saturation in the single-direction of main roads [18]. Some studies have assessed the impacts of one-way traffic management on traffic network performances and indicate that it is beneficial for traffic network service capabilities and reducing conflict points [19]. Nevertheless, to our best knowledge, scarce studies have analyzed the potential effects of one-way traffic management on different vehicular exhaust emissions [20]. One-way traffic management somehow decreases the delays in saturated roads which is helpful for reducing emissions, but also forces vehicles to bypass and increases driving distances of some vehicles that may lead to more emissions. The quantitative evaluations regarding the overall effects of one-way traffic management on traffic network emissions are lacking. Moreover, microscopic emission models and traffic simulation tools are generally applied for traffic emission assessment [14], since it is often not feasible to evaluate the environmental effects of traffic management measures based on the trial-and-error field experiments. However, the majority of studies using the microscopic traffic simulation with instantaneous emission models in the assessment, did not calibrate and examine the emission models based on the real world emission data that consider vehicle dynamics and different vehicle standards in different regions [21]. This study stands in the wake of the literature to contribute to the state-of-art studies by investigating the influences of the typical one-way traffic management on different vehicle exhaust emissions (CO, HC, NO_x) in the urban traffic networks using an integrated method. The combination of microscope traffic simulation platform and an instantaneous emission model (Vehicle Specific Power) calibrated with field emission data in Chinese city contexts, is developed and employed for the assessment. The different exhaust emissions in the intersections, road segments and network levels before and after the implementations of one-way traffic management are compared to comprehensively understand the effects of one-way traffic management on different vehicle exhaust emissions.

The rest of this paper is structured as follows: Section 2 describes the field emission data collection, instantaneous emission model calibration process and the development of microscope traffic simulation. The analysis results are presented in Section 3. Lastly, Section 4 provides discussions and concluding remarks of the findings.

2. Methodology

2.1. Study Area and Emission Data Collection. It is crucial for traffic emission researches to develop reliable and trustful emission models. This study uses on-site emission measurement equipment to collect field emission data for constructing a specific instantaneous emission model in Chinese city contexts. The study area is "Fengxian" district located in the south of Shanghai, China. Figure 1 shows the roads in the study area. The speed limit in the area is 60 km/h. In the north, this area is bounded by the Nanting Highway, which is an urban main road with three lanes in each direction. In the south, the area is bounded by Jiangnan Road that is dual three-lane. The eastern part of the area is bounded by the Jianghai Road with two-way in each direction and parking spaces on some sections. The western boundary of the area is Cai Chang Road, with two lanes in each direction and parking spaces on the roadsides. The rest of the roads located inside the area are two-way lanes. The surrounding areas are all residential and commercial areas. The average speed of vehicles during the morning peak and evening peak hours in the studied area is only 20 km/h–30 km/h.

The experimental vehicles choose small vehicles, mainly including Volkswagen Long Yat, Harvard SUV and other household models according to our research goals. Their gasoline fuel emission standards are China National IV with an engine displacement of 1.6 l–2.0 l. The OBEAS-3000 Portable Emission Tester (PET) system is used to continuously monitor the instantaneous emission of HC, NO_x, CO, velocity and acceleration rates of the vehicles during experiments. The PET system is composed of a Siemens E-BOX PC gas analyzer, a vehicle parameter On-Board Diagnostic (OBD) instrument, Global Positioning System (GPS), power control units and a notebook computer for overall control and data recording. The dynamic

FIGURE 1: Testing area and the driving path. (Images are from google map.)

regimes including the accurate position, speed and acceleration of the experimental vehicle are obtained through the GPS system. The simultaneous vehicle exhaust emissions (CO, HC, NO_x) are detected by the OBEAS-3000 system. The OBEAS-3000 system has high sampling accuracy (every 0.1 s), but we accumulated and stored the overall data in every 1 s in actual process for the sake of reducing the variances of data. The final collected outputs contain diverse data like the amount of instantaneous exhaust emissions as well as corresponding vehicle dynamic characteristics (e.g., locations, speeds and accelerations). The testing setup of the data collection system is shown in Figure 2. Finally, 79032 observations of emission and vehicle dynamic data were obtained. Figure 3 shows the interface of the tail gas emission collection and record information.

2.2. Emission Model and Calibration. The Vehicle Specific Power (VSP) model is used as the instantaneous emission model in this study. VSP is the instantaneous power of a unit mass vehicle, in units of kW/t [22]. Vehicle transient emissions are closely related to values of VSP. VSP considers the wheel rotation resistance, the aerodynamic drag work, and the increased power required by overcoming the internal frictional resistance and the mechanical loss power of the drive train. Wyatt [23] provides detailed information about VSP model establishment. The VSP value is related to speed and accelerations and can be approximately expressed by the Equation (1).

$$\mathrm{VSP} = v \times (1.1a + g \times \mathrm{grade} + 0.132) + 0.000302v^3. \quad (1)$$

In the formula, v is velocity of vehicle. a is acceleration. grade is the road gradient. g is the acceleration of gravity, 9.81 m/s^2.

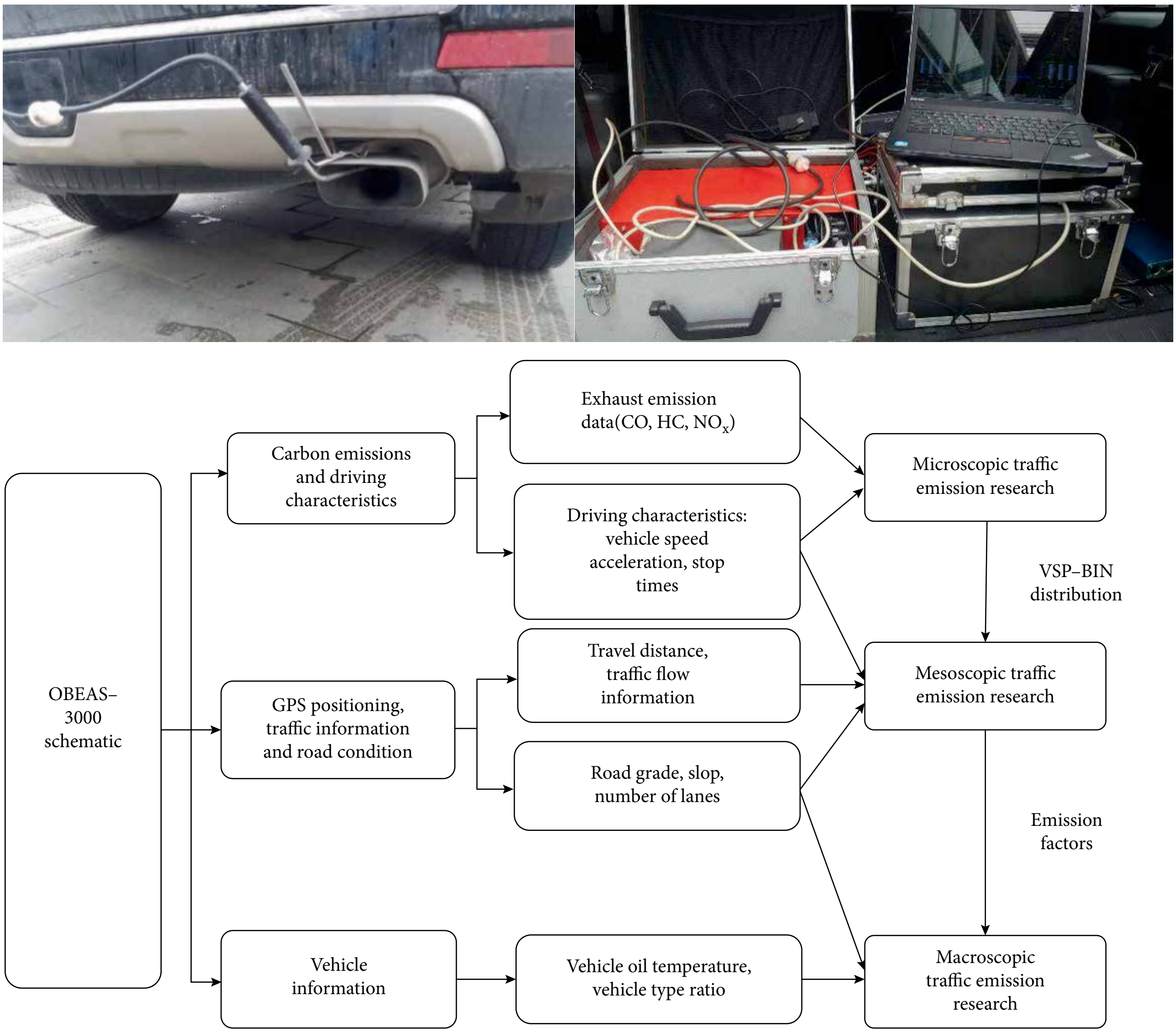


Figure 2: The experiments, emissions testing setup and schematic.

Figure 3: OBEAS-3000 application and data collection interface.

Specific power partitioning simplifies the computational process and highlights the differences in emission rates across different VSP intervals. Different studies used different numbers of intervals and specific power intervals. This study deduces the VSP internals based on the collected field data using the interval division principles proposed by Frey [24]. The internal definitions and process are as follows:

(1) The contribution rate of vehicular emissions is balanced in each VSP interval, and the emission sharing rate is the ratio of the emissions in each VSP interval to the total emissions.

(2) The difference of emission rates in different VSP internals should be obvious.

(3) Adjacent VSP values are assigned to the same or adjacent BIN intervals.

The statistical results of our empirical field data show that the VSP value in the range of [30,−30] covers 97.33% of the overall VSP values, which is over the 95% confidence levels of the empirical data. Therefore, the VSP interval range is set to [30,−30]. The frequencies of VSP intervals derived from our empirical emission data are shown in Table 1.

In order to accurately quantify the VSP-based emission rates by fully using the field emission data, we divide the VSP values by a step size of 2 kW/t to generate the BIN intervals VSP_{BIN_i}.

Table 1: Proportions of different VSP intervals.

VSP interval (kW/t)	Proportion
[−5, 5]	60.31%
[−10, 10]	67.93%
[−15, 15]	75.20%
[−20, 20]	88.46%
[−25, 25]	94.28%
[−30, 30]	97.33%

$$\forall \mathrm{VSP} \in \mathrm{VSP}_{\mathrm{BIN}_i} = \begin{cases} (-\infty, -30), \\ [2*n-2, 2*n],\ n=(-15,15), & n \in Z, \\ [30, +\infty]. \end{cases} \tag{2}$$

Taking advantages of the data collected by the field experiments, the calibrate the relationships between the $\mathrm{VSP}_{\mathrm{BIN}_i}$ and emission rates of different vehicle exhausts. The VSP values of the experimental vehicle at each second can be calculated using Equation (1) based on the recorded velocity and accelerations. Simultaneously, the corresponding emission rates of the vehicle exhausts were detected by OBEAS-3000 system, which can link the instantaneous emission rates with the VSP values. The emission rates of the same VSP interval were averaged to get a representative value of the emission rate in the VSP interval. The final calibrated results can be summarized in Table 2. The results construct the relationships among vehicle characteristics, VSP values and corresponding emission rates of different exhausts.

Table 2: VSP intervals and emission rates in a step of 2 kW/t.

Interval number	Range	CO (mg/s)	HC (mg/s)	NO_x (mg/s)
1	(−∞, −30)	4.25	0.62	0.36
2	[−30, −28)	5.59	0.51	0.18
3	[−28, −26)	5.21	0.65	0.07
4	[−26, −24)	5.19	0.72	0.13
5	[−24, −22)	5.54	0.54	0.07
6	[−22, −20)	4.45	0.88	0.17
7	[−20, −18)	5.67	0.59	0.20
8	[−18, −16)	5.45	0.57	0.18
9	[−16, −14)	4.56	0.85	0.14
10	[−14, −12)	5.14	0.46	0.16
11	[−12, −10)	4.23	0.53	0.05
12	[−10, −8)	6.22	0.95	0.24
13	[−8, −6)	3.74	0.49	0.10
14	[−6, −4)	3.94	0.69	0.06
15	[−4, −2)	3.13	0.53	0.12
16	[−2, 0)	3.31	0.59	0.08
17	[0, 2)	2.24	0.42	0.02
18	[2, 4)	3.56	0.65	0.07
19	[4, 6)	4.09	0.60	0.16
20	[6, 8)	4.67	0.71	0.09
21	[8, 10)	7.24	0.80	0.22
22	[10, 12)	3.90	0.56	0.14
23	[12, 14)	6.92	0.81	0.21
24	[14, 16)	7.82	0.84	0.10
25	[16, 18)	5.62	0.69	0.22
26	[18, 20)	8.96	0.82	0.41
27	[20, 22)	7.27	0.67	0.16
28	[22, 24)	7.68	0.75	0.30
29	[24, 26)	6.60	0.77	0.18
30	[26, 28)	9.29	0.85	0.38
31	[28, 30)	8.99	0.89	0.23
32	(30, +∞)	7.95	0.72	0.14

2.3. Scenarios Constructions. Two scenarios are established in the study. The baseline scenario is the original traffic networks with revealed traffic demand in the study area. Field demand survey was conducted to collect the actual road network geometry data (e.g. road length, slope, number of lanes, lane width, signal timing, properties of intersections and detailed traffic flow data) during the peak hours in the study area for reappearing the traffic conditions in simulation. Based on the collected data, the baseline scenario was established in the VISSIM [25] simulation platform.

The comparison scenario is the same traffic network and traffic demand after implementations of one-way traffic management. It is important to decide how the one-way traffic management should be implemented. The Synchro [26] traffic software was used to simulate the road network and determine which road should be changed to one-way on the basis of quantitative traffic analysis. Synchro can output the delay time and service level in the intersections. The simulated results are shown in Table 3. It can be found that several intersections including intersection 1, 11 and 12, had large traffic volume with ignorable traffic delays. According to the field traffic flow data in the study area, the one-way flow ratios of many road sections are larger than 1.2 in morning and evening peak hours as shown in Table 4. The design of the one-way traffic management needs to consider duality principle [27]. As per the principles of urban one-way traffic organization GAT_486-2004, road sections with a road width less than 10 m and a one-way flow ratio over 1.2, meet the requirements of one-way traffic management. The overall one-way traffic organization was determined depending on the traffic delays of intersections and the one-way flow ratios. Six roads in the area were changed to be one-way. The final one-way traffic management strategy is illustrated as Figure 4. The simulation results of Synchro show that the traffic performances of the studied network were obviously improved in terms of reducing the delay in intersections and travel time in the road segments. The corresponding scenario after one-way traffic management was established in the VISSIM simulation platform as well [28].

The VISSIM can output the detailed data including the speeds and accelerations of each vehicle during the simulation period. Based on the speeds and accelerations of vehicles, the instantaneous VSP of each vehicle can be calculated by Equation (1). Afterwards, the instantaneous emission rates of the three pollutant emissions (CO, HC, and NO_x) can be obtained based on the calibrated relationships between VSP and instantaneous emission rates in Table 2. The overall emissions in the road sections or in the intersections can be

Table 3: Traffic conditions of intersections simulated in Synchro.

Intersection number	Traffic flow (pcu/h)	Capacity utilization	Service level	Signal delay (s)
1	2532	65.1%	C	28.1
2	2290	73.5%	B	10.7
3	344	26.7%	A	-
4	632	33.6%	A	-
5	408	32.5%	A	-
6	676	35.4%	A	-
7	1036	52.5%	B	13.9
8	1172	56.5%	B	-
9	396	22.1%	A	-
10	580	32.7%	A	-
11	896	81.2%	C	30.6
12	2652	95.9%	C	22.9
13	592	24.2%	A	-
14	840	45.6%	A	-
15	284	28.1%	A	-
16	420	32.8%	A	-

Table 4: One-way traffic flow ratio of each road segment in peak hours.

Road section	Morning peak	Evening peak
1–3	1.20	1.80
2–4	1.60	1.36
3–5	0.80	1.26
4–6	0.46	1.26
5–7	0.76	1.25
6–8	2.06	1.24
7–9	1.21	0.85
8–10	1.38	1.58
9–11	1.46	1.69
10–12	1.20	0.70
11–13	1.81	0.43
12–14	1.44	0.26
13–15	1.27	1.69
14–16	2.62	0.78
3-4	1.40	1.20
5-6	0.86	1.22
9–10	1.00	1.46
13-14	1.63	1.41

obtained by accumulating the instantaneous emissions over time crossing through the intersections and road sections.

3. Result and Analysis

3.1. Influences on the Emissions in the Intersections. The emissions of the CO, HC and NO_x in the intersections, road sections and the whole studied network before and after the implementation of one-way traffic management are compared. The results about emissions in the intersections

Figure 4: One-way traffic management strategy.

are summarized in Table 5. The values in Table 5 are the average instantaneous emission rates of all vehicles crossing the intersections. The results show that the instantaneous CO emission rates of vehicles in the sixteen intersections after one-way traffic management are markedly reduced as compared to those without one-way traffic management. The decreasing ratio ranges from 6.88% to 66.9% and has a mean value of 20.46%. The instantaneous HC emission rates reduce 7.46–67.15% in different intersections and decrease by 21.29% on average after one-way traffic management. For the NO_x emission, the results indicate that the one-way traffic management cuts down the instantaneous NO_x emission rates in the intersections by 21.06% on average with a range of 7.47–66.89%. The results of statistical paired T-test show that the improvement of one-way traffic management on reducing the three pollutants are significant at the confidence level of 99%. The results demonstrate that the implement of one-traffic management is indeed beneficial for decreasing the three vehicle exhausts in the intersections. This may be ascribed to the fact that one-way traffic management can improve the average speed, alleviate the conflicts and reduce the delays in the intersections which are helpful in reducing exhaust emissions.

3.2. Influences on the Speed and Emissions in the Road Sections. On one hand, the implementation of one-way traffic may force the vehicles in the opposite directions to give up the shortest driving path and choose some other routes to bypass. Therefore, one-way traffic will inevitably increase the bypass distance of some vehicles, which would contribute to the increasing energy consumption and exhaust emissions during the road sections. On another hand, the implementation of

Table 5: Emission rate of three pollutants before and after one-way traffic management in intersections.

Intersection number	CO emission (mg/s)				HC emission (mg/s)				NO_x emission (mg/s)			
	Before	After	Difference	Relative difference	Before	After	Difference	Relative difference	Before	After	Difference	Relative difference
1	130.26	121.30	−8.96	−6.88%	5.89	5.15	−0.74	−12.56%	38.24	33.06	−5.18	−13.55%
2	117.81	102.94	−14.87	−12.62%	5.32	4.74	−0.58	−10.90%	34.58	30.80	−3.78	−10.93%
3	17.69	10.49	−7.20	−40.70%	0.80	0.47	−0.33	−41.25%	5.19	4.10	−1.09	−21.00%
4	32.51	13.37	−19.14	−58.87%	1.47	0.60	−0.87	−59.18%	9.545	3.92	−5.63	−58.98%
5	20.99	8.85	−12.14	−57.84%	0.95	0.42	−0.53	−55.79%	6.16	2.59	−3.57	−57.95%
6	34.77	17.69	−17.08	−49.12%	1.57	0.81	−0.76	−48.41%	10.21	5.19	−5.02	−49.17%
7	53.29	46.30	−6.99	−13.12%	2.41	2.09	−0.32	−13.28%	15.64	13.59	−2.05	−13.11%
8	60.29	48.15	−12.14	−20.14%	2.72	2.17	−0.55	−20.22%	17.7	14.13	−3.57	−20.17%
9	20.37	9.26	−11.11	−54.54%	0.92	0.41	−0.51	−55.43%	5.98	2.71	−3.27	−54.68%
10	29.83	12.75	−17.08	−57.26%	1.34	0.57	−0.77	−57.46%	8.75	3.74	−5.01	−57.26%
11	118.53	109.68	−8.85	−7.47%	5.36	4.96	−0.40	−7.46%	34.79	32.19	−2.6	−7.47%
12	136.43	122.85	−13.58	−9.95%	6.17	5.55	−0.62	−10.05%	40.05	36.06	−3.99	−9.96%
13	30.45	10.08	−20.37	−66.90%	1.37	0.45	−0.92	−67.15%	8.94	2.96	−5.98	−66.89%
14	43.21	39.92	−3.29	−7.61%	1.95	1.81	−0.15	−7.69%	12.68	11.71	−0.97	−7.65%
15	14.61	8.64	−5.97	−40.86%	0.66	0.39	−0.27	−40.91%	4.28	2.53	−1.75	−40.89%
16	21.61	19.70	−1.91	−8.84%	0.97	0.85	−0.12	−12.37%	6.34	5.22	−1.12	−17.67%
Mean values	55.17	43.87	−11.29	−20.46%	2.49	1.96	−0.53	−21.29%	16.19	12.78	−3.41	−21.06%
Paired t-value	8.179^{***}				8.499^{***}				8.136^{***}			

Note: The difference is equal to the emission after setting one-way traffic management subtracted by the emission before one-way traffic management. ***denotes significance in the 99% confidence level.

one-way traffic management enables vehicles on one-way lanes to travel in a single direction and reduces the interferences with the opposite vehicles for alleviating the conflicts, which is beneficial for increasing travel speed, travel stability of the vehicles and the operating efficiency of the entire road network. This aspect implies that one-way traffic management is helpful for reducing the exhaust emissions in road sections. The overall effects of one-way traffic management on emissions in the road segments need comprehensive evaluations.

The input traffic demands in the simulation scenarios before and after one-way traffic management are set to be the same. Based on the length and the traffic volumes in the road sections, the bypassing distance can be calculated as follows:

$$\Delta S = \sum_i \sum_i X_{ij} \cdot \Delta l_{ij} = \sum_i \sum_i X_{ij} \cdot \left(A_{ij} - B_{ij}\right). \quad (3)$$

In the formula, X is bypass traffic volume, Δl is bypass distance, A is travel bypassing distance after one-way traffic management, B is travel distance before one-way traffic management.

The length, the traffic volumes and the number of bypassing vehicles in each road section after one-way traffic management are shown in Table 6. The results show that the one-way traffic management leads to the detour of reverse traffic demands. The total number of bypassing vehicles is 1562 per hour after one-way traffic management. From the macroscopic analysis, the overall detour distance of the road network reaches 702.90 kilometers, and the average bypassing distance per vehicle is about 0.45 km. The average travel speeds in most road sections are improved after one-way traffic management as compared to original road network without one-way traffic management. The improved percentage of the travel speed is 20% on average ranging from 15.5% to 90.7%. It can be noted that the one-way traffic management considerably increases the average travel time of some road sections like Caichang Road (36.3%) and Jiaohang Road (90.7%).

The instantaneous emission rates of vehicles crossing the road sections before and after one-way traffic management are shown in Table 7. From the perspectives of all road sections, the CO, HC and NO_x emission rates decrease 22.19% from 902.14 mg/s to 701.96 mg/s, 23.38% from 40.98 mg/s to 31.40 mg/s, and 26.29% from 277.45 mg/s to 204.50 mg/s, respectively. There are some changes in the average speeds in the road sections and thus in the average travel times of road sections.

3.3. Regional Overall Emissions. The overall emission rates of the three vehicle exhausts in the study area including the intersections and road sections before and after the one-way traffic management are calculated and summarized in Table 8. After one-way traffic management, the overall CO emission rate in the study network decreases 21.34% from 1784.79 mg/s to 1403.93 mg/s, the overall HC emission rate reduce 22.29% from 80.85 mg/s to 62.83 mg/s and NO_x emission rate decreases 23.77% from 536.53 mg/s to 409.00 mg/s.

3.4. Emission Regression Analysis. The traffic discharge in the one-way traffic implementation area can reflect the impact of one-way traffic on urban traffic emissions. After one-way traffic management is implemented in the area, traffic

Table 6: Bypassing vehicles and speed in the road sections before and after one-way traffic management.

Road name	Road length (m)	Traffic flow after one-way traffic management (pcu/h)	Number of bypassing vehicles (pcu/h)	Average speed before one-way traffic management (km/h)	Average speed after one-way traffic management (km/h)	Increase ratio in velocity
Caichang Road	972	732	221	22.6	30.8	36.3%
Jiangai Road	1000	861	242	16.8	19.4	15.5%
Nanting Road	366	2693	0	15.3	16.9	10.4%
Yanjiang Road	354	823	259	22.4	28.2	25.9%
Xiulong Road	363	967	270	21.7	27.0	24.4%
Yuxiu Road	360	1528	0	19.6	20.1	2.5%
Jiaohang Road	363	775	249	17.2	32.8	90.7%
South Huancheng Road	365	2860	0	31.5	32.7	3.8%
Jianghaihe Road	363	1184	336	19.1	23.6	23.6%
Jiangnan Road	363	738	0	21.2	25.3	19.3%
Total bypassing distance of vehicles after one-way traffic (km)				702.90		
Average bypassing distance of each vehicle after one-way traffic (km)				0.45		

Table 7: Emissions in the road sections before and after one-way traffic management.

Emission index	Value	Difference	Relative difference
CO emission before one-way traffic (mg/s)	902.14	−200.18	−22.19%
CO emission after one-way traffic (mg/s)	701.96		
HC emission before one-way traffic (mg/s)	40.98	−9.58	−23.38%
HC emission after one-way traffic (mg/s)	31.40		
NO_x emission before one-way traffic (mg/s)	277.45	−72.95	−26.29%
NO_x emission after one-way traffic (mg/s)	204.50		

Note: the difference is equal to the emission after setting one-way traffic management subtracted by the emission before.

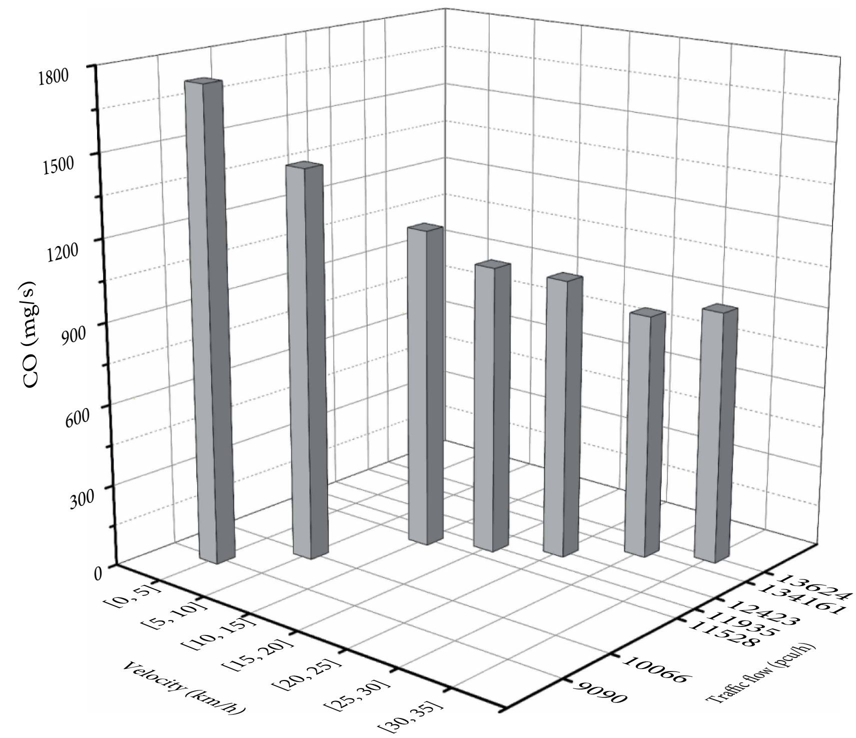
Table 8: Regional overall emissions before and after one-way traffic.

Emission index	Value	Difference	Relative difference
CO emission rate before one-way traffic (mg/s)	1784.79	−380.86	−21.34%
CO emission rate after one-way traffic (mg/s)	1403.93		
HC emission rate before one-way traffic (mg/s)	80.85	−18.02	−22.29%
HC emission rate after one-way traffic (mg/s)	62.83		
NO_x emission rate before one-way traffic (mg/s)	536.53	−127.53	−23.77%
NO_x emission rate after one-way traffic (mg/s)	409.00		

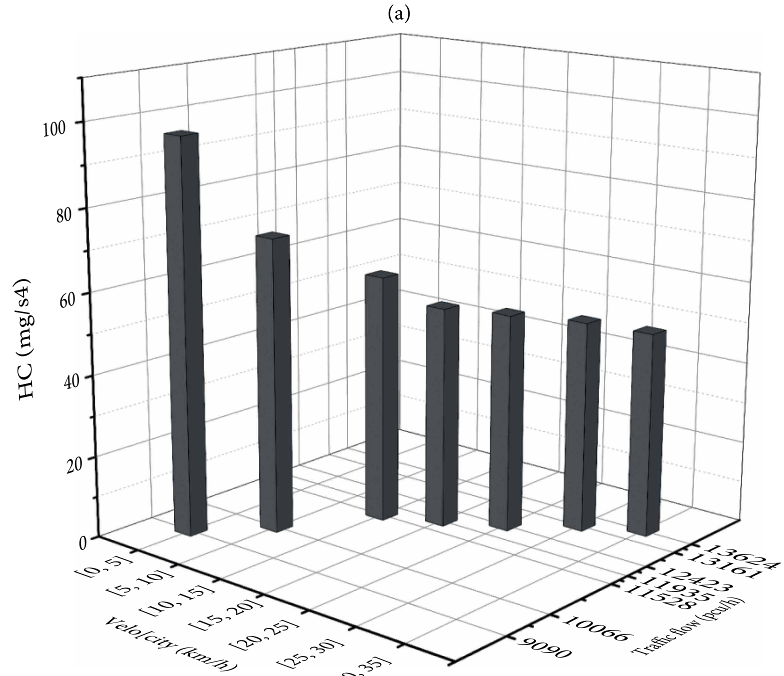
Note: the difference is equal to the emission after setting one-way traffic management subtracted by the emission before.

flow and vehicle velocity increase during peak hours, but emissions of CO, HC, and NO_x decrease. The relationships among traffic flow, velocity and emission rates is shown in Figure 5. Before the one-way traffic is implemented, the vehicle velocity in the area is less than 20 km/h, the CO maximum emission is more than 1650 mg/s, the HC maximum emission is more than 90 mg/s, the NO_x maximum emission is more than 550 mg/s. After the implementation of one-way traffic, the peak hourly velocity in the area is more than 30 km/h, and the traffic volume reaches a maximum of 13000 pcu/h, but the emissions decrease with the increasing of the vehicle speed.

Before the road design flow is reached, the traffic flow increases as the vehicle velocity increases, and the emissions decrease as the vehicle velocity increases. After reaching the road design flow, the vehicle velocity and traffic volume decrease, but the emissions increase. Through the analysis of the relationship between vehicle bypass distance, vehicle velocity, traffic flow and traffic emissions in Fengxian District, although one-way traffic causes a certain detour, it further improves the road capacity and increases the traffic volume in the area. It also increases the velocity of the vehicle, decreases traffic congestion and travel time. One-way traffic implementation has obvious effects on reducing emissions from urban transportation. It is of great significance to the implementation of Shanghai's energy-saving and low-emission transportation strategies.

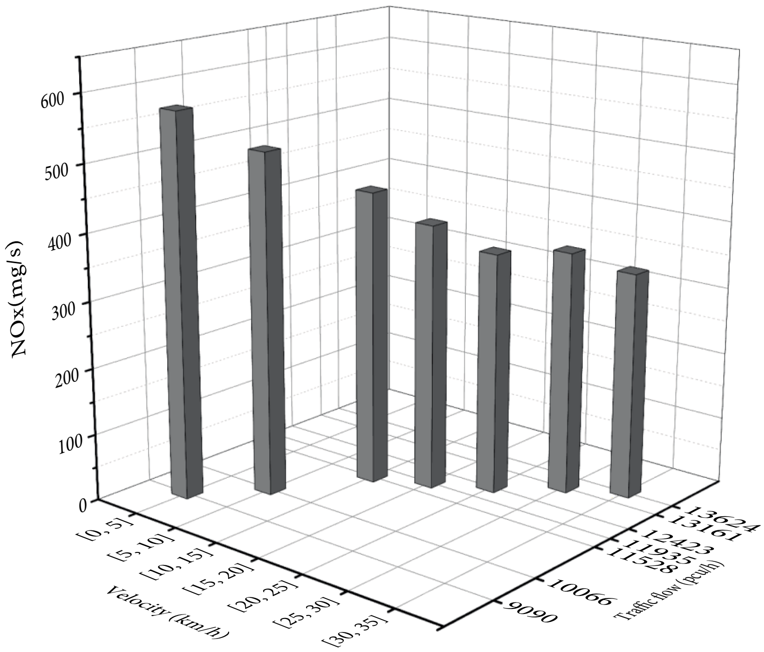


(a)



(b)

Figure 5: Continued.



(c)

Figure 5: Relationship among emissions, traffic flow and velocity. (a) CO emission analysis. (b) HC emission analysis. (c) NO_x emission analysis.

4. Conclusions

This study explores the influences of the typical one-way traffic management on different vehicle exhaust emissions (CO, HC and NO_x) using an integrated method. Two scenarios of a road network (i.e., before and after one-way traffic management) are established in the microscope traffic simulation platform VISSIM based on real road configurations and traffic demands in peak hours. An instantaneous emission model (Vehicle Specific Power) calibrated with field emission data in Chinese city contexts is employed to assess the instantaneous emissions of vehicles. The different exhaust emissions (CO, HC and NO_x) in the intersections, road segments and network levels before and after the implements of one-way traffic management are statistically compared for quantifying the effects of one-way traffic management on different vehicle exhaust emissions. The findings can be summarized as follows: (1) the CO, HC, NO_x emission rates in the intersections after one-way traffic management is significantly reduced by 20.46%, 21.29% and 21.06% as compared to those without one-way traffic management; (2) one-way traffic management decreases the CO, HC, NO_x emission rates in the road sections by 22.19%, 23.38% and 26.29%, respectively; (3) the overall emission rates of CO, HC and NO_x in the regional level decline by 21.34%, 22.29% and 23.77% due to one-way traffic management; (4) the implementation of one-way traffic management is beneficial for improving the travel speeds of vehicles in the road sections and reduce the overall emissions even though some vehicles have to detour. The results provide insights into the potential effects of one-way traffic management on traffic emission principles and contribute to the management concerning development of environment-friendly sustainable transport network.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The research was supported by National Natural Science Foundation of China, Project No. 71671127.

References

[1] A. Jamshidnejad, I. Papamichail, M. Papageorgiou, and B. De Schutter, “A mesoscopic integrated urban traffic flow-emission model,” *Transportation Research Part C: Emerging Technologies*, vol. 75, pp. 45–83, 2017.

[2] Z. Huang, C. Hao, and J. Wang, “Analysis of Vehicle Pollutant Emissions-Part II of China Motor Vehicle Environmental Management Annual Report (2017),” *Environmental Protection*, vol. 13, pp. 43–48, 2017.

[3] A. Choudhary and S. Gokhale, “Urban real-world driving traffic emissions during interruption and congestion,” *Transportation Research Part D: Transport and Environment*, vol. 43, pp. 59–70, 2016.

[4] J. J. Stemley, “One-way streets provide superior safety and convenience,” *Institute of Transportation Engineers Journal*, vol. 68, no. 8, pp. 47–50, 1998.

[5] A. Nagurney, "Congested urban transportation networks and emission paradoxes," *Transportation Research, Part D (Transport and Environment)*, vol. 5, no. 2, pp. 145–151, 2000.

[6] H. C. Frey, N. M. Rouphail, A. Unal, and J. D. Colyar, "Emission reduction through better traffic management: an empirical evaluation based upon on-road measurements," *North Carolina Department of Transportation*, 2001.

[7] M. C. Coelho, T. L. Farias, and N. M. Rouphail, "A methodology for modelling and measuring traffic and emission performance of speed control traffic signals," *Atmospheric Environment*, vol. 39, no. 13, pp. 2367–2376, 2005.

[8] M. C. Coelho, T. L. Farias, and N. M. Rouphail, "Effect of roundabout operations on pollutant emissions," *Transportation Research Part D: Transport and Environment*, vol. 11, no. 5, pp. 333–343, 2006.

[9] K. Ahn and H. Rakha, "The effects of route choice decisions on vehicle energy consumption and emissions," *Transportation Research Part D: Transport and Environment*, vol. 13, no. 3, pp. 151–167, 2008.

[10] S. K. Zegeye, B. De Schutter, H. Hellendoorn, and E. Breunesse, "Reduction of travel times and traffic emissions using model predictive control," *American Control Conference IEEE*, pp. 5392–5397, 2009.

[11] M. C. Coelho, T. L. Farias, and N. M. Rouphail, "A numerical tool for estimating pollutant emissions and vehicles performance in traffic interruptions on urban corridors," *International Journal of Sustainable Transportation*, vol. 3, no. 4, pp. 246–262, 2009.

[12] S. Pandian, S. Gokhale, and A. K. Ghoshal, "Evaluating effects of traffic and vehicle characteristics on vehicular emissions near traffic intersections," *Transportation Research Part D: Transport and Environment*, vol. 14, no. 3, pp. 180–196, 2009.

[13] M. Madireddy, B. De Coensel, A. Can et al., "Assessment of the impact of speed limit reduction and traffic signal coordination on vehicle emissions using an integrated approach," *Transportation Research Part D: Transport and Environment*, vol. 16, no. 7, pp. 504–508, 2011.

[14] M. K. Nasir, R. Md Noor, M. A. Kalam, and B. M. Masum, "Reduction of fuel consumption and exhaust pollutant using intelligent transport systems," *The Scientific World Journal*, vol. 2014, pp. 1–13, 2014.

[15] Z. Chen, C. Yang, and A. Chen, "Estimating fuel consumption and emissions based on reconstructed vehicle trajectories," *Journal of Advanced Transportation*, vol. 48, no. 6, pp. 627–641, 2014.

[16] A. Jamshidnejad, I. Papamichail, M. Papageorgiou, and B. De Schutter, "A mesoscopic integrated urban traffic flow-emission model," *Transportation Research Part C: Emerging Technologies*, vol. 75, pp. 45–83, 2017.

[17] C. Meneguzzer, M. Gastaldi, and R. Arboretti Giancristofaro, "Before-and-after field investigation of the effects on pollutant emissions of replacing a signal-controlled road intersection with a roundabout," *Journal of Advanced Transportation*, vol. 2018, pp. 1–15, 2018.

[18] F. Shi, E. Huang, Q. Chen, and Y. Wang, "Optimization of one-way traffic organization for urban microcirculation transportation network," *Journal of Transportation Systems Engineering and Information Technology*, vol. 9, no. 4, pp. 30–35, 2009.

[19] S. Floyd, "Connections with multiple congested gateways in packet-switched networks part 1: one-way traffic," *ACM SIGCOMM Computer Communication Review*, vol. 21, no. 5, pp. 30–47, 1991.

[20] S. Liu, H. Hellendoorn, and B. De Schutter, "Model predictive control for freeway networks based on multi-class traffic flow and emission models," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 2, pp. 306–320, 2016.

[21] T. Fontes, P. Fernandes, H. Rodrigues et al., "Are HOV/eco-lanes a sustainable option to reducing emissions in a medium-sized European city?" *Transportation Research Part A: Policy and Practice*, vol. 63, pp. 93–106, 2014.

[22] J. L. Jimenez-Palacios, "Understanding and quantifying motor vehicle emissions with vehicle specific power and TILDAS remote sensing," Massachusetts Institute of Technology, 1998.

[23] D. W. Wyatt, H. Li, and J. Tate, *Examining the Influence of Road Grade on Vehicle Specific Power (VSP) and Carbon Dioxide (CO_2) Emission Over a Real-World Driving Cycle*, SAE Technical Paper, Warrendale, PA, USA, 2013.

[24] H. C. Frey, N. M. Rouphail, and H. Zhai, "Speed-and facility-specific emission estimates for on-road light-duty vehicles on the basis of real-world speed profiles," *Transportation Research Record*, vol. 1987, no. 1, pp. 128–137, 2006.

[25] B. Park and J. D. Schneeberger, "Microscopic simulation model calibration and validation: case study of VISSIM simulation model for a coordinated actuated signal system," *Transportation Research Record*, vol. 1856, no. 1, pp. 185–192, 2003.

[26] B. S. Kerner and H. Rehborn, "Experimental properties of complexity in traffic flow," *Physical Review E*, vol. 53, no. 5, pp. R4275–R4278, 1996.

[27] S. B. Yu, Y. J. Hu, X. S. He, and S. W. Yang, "Single-line traffic lights wireless signal control device," *Applied Mechanics and Materials*, vol. 178, pp. 2721–2724, 2012.

[28] N. E. Lownes and R. B. Machemehl, "VISSIM: a multi-parameter sensitivity analysis," in *Proceedings of the 2006 Winter Simulation Conference*, IEEE, pp. 1406–1413, 2006.