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Measurements of roadside air pollution and traffic simulations

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Abstract

Air pollution levels at the roadside were measured and traffic flows were analyzed in order to determine the dynamic features of air pollutants. Moreover, a traffic simulator was used to simulate observed traffic flows and to evaluate proposed strategies. It was found that temperature-inversion above the road surface due to vehicle exhaust emissions might suppress the vertical dispersion of air pollutants in the early morning. It was also found that concentrations of air pollutants at the roadside near traffic lights had periodicity corresponding to the traffic signal cycle. But the phase of nitrogen dioxide concentration was different from that of suspended particulate matter. It was found that total traffic volume depended mainly on the number of small car, but level of air pollution along the roadside seemed to depend on mainly on the number of heavy-goods vehicles. A vehicle-actuated signal-control system that enables reduction of the air pollution level at the roadside is proposed.

1 Introduction

Urban air pollution due to road traffic is a serious problem [4]. Traffic congestion in urban area due to the increasing number of vehicles is the main cause of urban air pollution. Attempts have been made to reduce traffic congestion by building more roads, but new road construction has resulted in a larger volume of traffic. Thus, new road construction can have an undesirable effect on the environment. Is there an effective means for reducing urban air pollution caused by road traffic?

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Many countries have been adapted so-called Intelligent Transport Systems (ITS). The ITS are designed to improve the infrastructure of road networks, which could make safer and smoother traffic flow possible [1]. A strategy for using the ITS is vehicle-actuated signal-control, which requires real-time traffic information and real-time traffic signal control capability. However, possible environmental impacts of this microscopic strategy would not be detected by currently used networks for macroscopic monitoring of air pollution.

The objectives of this study were to reveal the dynamic features of air pollutants at the roadside and to develop a reliable method for evaluating tool for ITS-related strategies. For these purposes, we have been carrying out measurements of roadside air pollution, counting numbers of vehicles, and analyzing traffic signal patterns since 1997 in order to determine the microscopic behaviors of air pollutants in relation to traffic patterns. We have also used a traffic simulator to simulate observed traffic flows and to evaluate proposed strategies.

2 Measurements of the roadside air pollution

Measurements of air pollution at roadsides near traffic lights were carried out during winter, when concentrations of pollutants often exceed environmental standards. The weather in Kawasaki in winter is generally fair. Nocturnal radiation cooling induces temperature inversion near the ground, which suppresses the dispersion of air pollutants. Thus, in fair weather conditions, such as nitrogen oxides (NO_x) and suspended particulate matters (SPM) accumulate near the ground. Details of the measurements are shown in Table 1.

Table1. Dates and sites of measurements, items measured, and instruments used.

Date	Location	Traffic Obs.	Met. Obs.	NOx	CO2	SPM
01/26/97	Marukobashi, Kawasaki	x	x	x		
03/06/98	Hiyoshi, Yokohama	x	x	x	x	
12/01/99	Ikegami-Shincho, Kawasaki	x		x		
12/15/99	Ikegami-Shincho, Kawasaki	x	x	x	x	
10/26/00	Ikegami-Shincho, Kawasaki	x				
12/22/00	Ikegami-Shincho, Kawasaki	x	x	x	x	x
12/21/01	Ikegami-Shincho, Kawasaki	x	x	x	x	x

Weather Observation : Vaisala MAWS
NOx Measurement : Horiba APNA-360
CO2 sensor : Vaisala GMD20
SPM measurement : Shibata L20 and LD-3, ME pDR1200

Video cameras were used to record traffic counts and traffic signal patterns. Vehicles were classified into three types: small automobiles, heavy-goods vehicle, and motorcycles. Traffic counts were aggregated by vehicle type and vehicle movement at the intersection (i.e., turning left or turning right or proceeding in a straight line). Traffic signal patterns (each duration of red, yellow and green signal rights) were analyzed in order to simulate real conditions.

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As can be seen in Figure 1, the vertical temperature structure showed a maximum temperature at about 120 cm above the road surface when the weather was fair and calm. This temperature structure was different from the usual temperature inversion due to nocturnal radiation cooling that disappeared from the ground surface after sunrise. The temperature maximum at 120 cm above the road surface must be due to the exhaust gas emitted by vehicles. A temperature inversion above the road surface was observed after sunrise until 9:30 a.m. This temperature structure could affect the dispersion of air pollutants over the road.

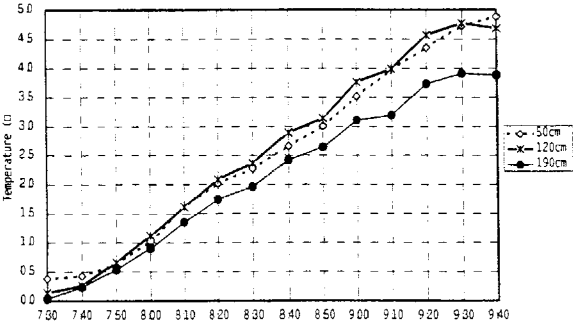

Figure 1. Changes in temperature and temperature (January 26, 1997 in Kawasaki).

Variations in NO_x concentration showed a similar periodicity to that of traffic signal cycle, as shown Figure 2. NO_x increased just after the traffic light turned red and then decreased after the light turned green. Local maximum and minimum NO_x levels were observed just before the traffic light changed from red and green, respectively, suggesting that appropriate signal control could reduce the NO_x concentration at the roadside.

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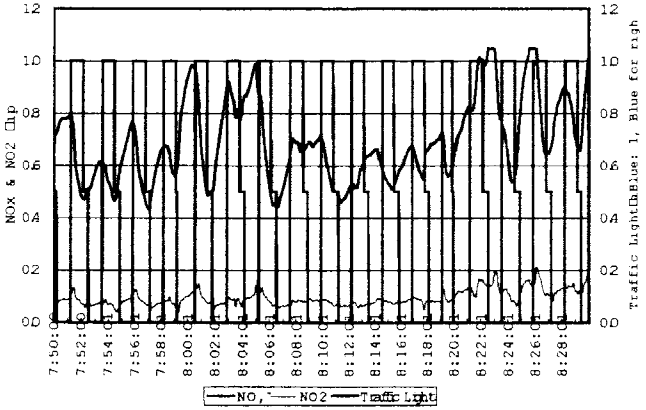

Figure 2. Measurement of NOx at the roadside near traffic lights (December 22, 2000 in Kawasaki).

Bulky and expensive equipment is needed for NO_x measurements. However, relatively small devices are needed to monitor the microscopic variation of NO_x concentration at the roadside. A carbon dioxide (CO_2) sensor is smaller and cheaper than an NO_x sensor. CO_2 emissions from engines are correlated with NO_x emissions. Both CO_2 and NO_x sensors were used, and the results were compared. As can be seen in Figure 3, variation in the concentration of CO_2 was similar to that in the concentration of NO_x. The CO_2 concentration can be used as an index of NO_x concentration. However, the periodicity of fluctuation in CO_2 was longer than that of NO_2. That might be due to the response time of the CO_2 sensor.

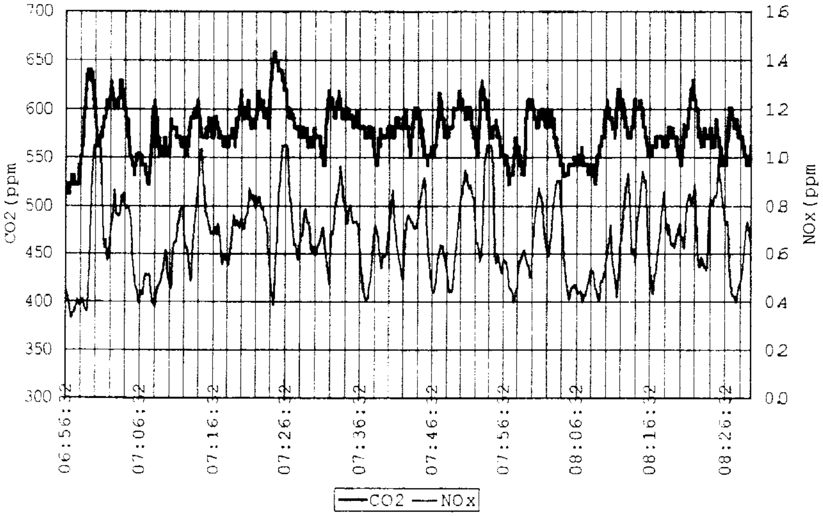

Figure 3. Comparison of CO2 and NOx variations (December 15, 1999 in Kawasaki).

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The concentrations of SPM were only measured on December 22, 2000 and July 12, 2001. The periodic change in SPM concentrations was similar to that of NO_2 concentrations as shown in Figure 4, but it was out of phase. The local maximum of SPM concentration was often observed when the traffic light was red and did not coincide with the NO_x maximum. Thus, the SPM concentration might be controlled not only by the exhaust emission from vehicles but also by other factors. Other factors might be friction between the tires and the road, the vehicle's movement, and wind. Based on the measurements, traffic simulation enabled NO_x emissions from vehicles to be calculated, but variation in SPM concentration at the roadside could not be simulated. Also, the simultaneous reduction of NO_x and SPM concentrations by means of traffic signal control would be difficult.

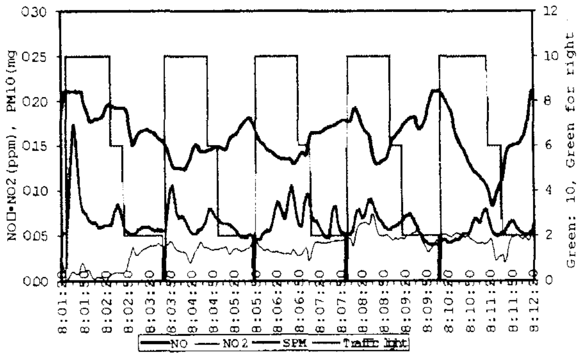

Figure 4. Measurements of SPM, NO_2 and Traffic signal pattern (July 12, 2001).

3 Computer simulations of roadside air pollution using a traffic simulation

The traffic simulator VISSIM, developed and sold by PTV in Germany, was used to simulate observed traffic flows and to evaluate the proposed signal control system. The VISSIM is a microscopic traffic simulator that enables simulation of each vehicle's movement and calculation of exhaust emission based on the vehicle's speed [3]. The VISSIM can compute any emissions from vehicles if the emission coefficients based on the vehicle's speed are provided. We used the VISSIM to analyze NO_x and SPM concentrations with respect to signal control system. The emission tables for NO_x and SPM were taken from research report by the Tokyo Metropolitan government [4]. After confirming the reliability of the simulation model, the effectiveness of several different signal control methods in reducing environmental impacts was investigated.

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Since computer simulation of traffic flow is a stochastic process, ten simulations were carried out using ten different random seeds for each case. Then ten results for each case were averaged in order to compare with different case. A screen image of the VISSIM traffic simulation is shown in Figure 5.

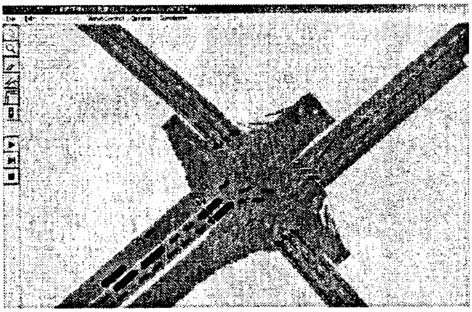

Figure 5. A screen image of VISSIM simulation of traffic at an intersection in Kawasaki.

The simulated traffic flow was compared with observed traffic flow, as shown in Figure 6. The correlation coefficient between them was 0.974. We therefore concluded that our traffic model could reproduce observed traffic flow and could be used to evaluate proposed traffic signal control systems.

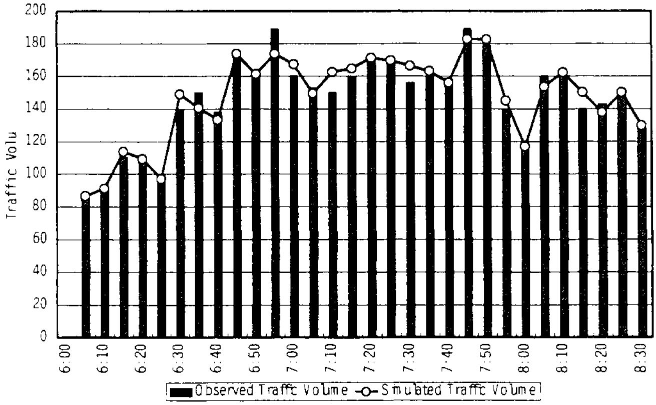

Figure 6. Simulated and observed traffic flow patterns on December 22, 2000.

4 Results and Discussion

The periodic fluctuations in NO_x and SPM concentrations observed at the roadside were reproduced by the VISSIM, as shown in Figure 7.

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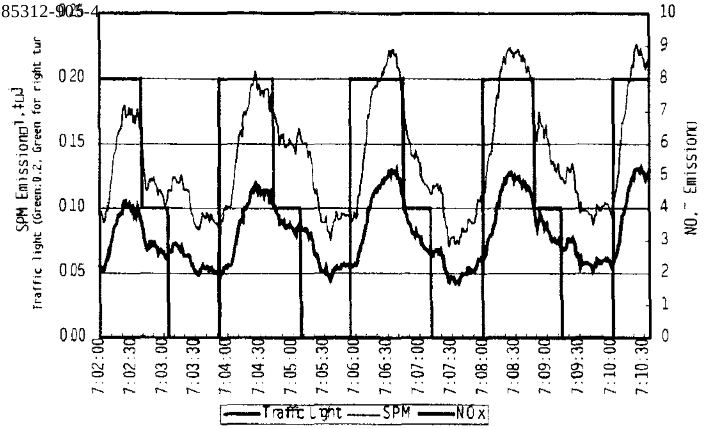

Figure 7. Simulated NO_x and SPM concentrations and Traffic signal pattern.

After the reliability of the model had been confirmed, several traffic signal-control methods were applied to the observed traffic flow. The Results showed that there was an appropriate signal cycle that would minimize the NO_x concentration under the observed traffic condition as shown in Figure 8. However, the best signal cycle depends on the traffic volume, whereas real signal control system uses a fixed traffic signal cycle. The fixed signal cycle observed was different from the signal cycle that had shown the minimum concentration in simulations. Therefore, we introduced vehicle-actuated signal-control to the simulations in order to minimize the environmental impact. The signal cycle was determined by the traffic volume, which was detected by a traffic counter set for each traffic lane. The results showed that the introduction of vehicle-actuated signal-control reduces NO_x concentration by 5% (Figure 8).

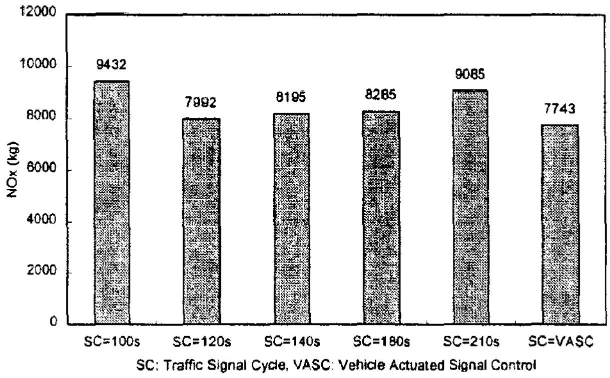

Figure 8. Reduction of the NOx concentration along the roadside.

The simulated SPM variations based on vehicle's speed were similar to the variations in NO_x (Figure 7). These results disagreed with observational data,

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which showed a phase difference between NO_x and SPM. We therefore tried to compute NO_x and SPM emissions based on acceleration, deceleration and velocity [2]. The results are shown in Figure 9.

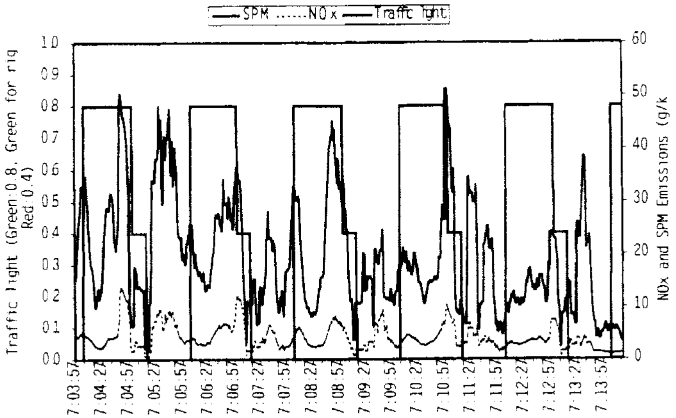

Figure 9. Calculations of NO_x and SPM concentrations based on acceleration, deceleration and speed of each vehicle.

5 Conclusions

We found followings through our measurements and traffic simulations:

(1) The temperature inversion above the road surface due to vehicle exhaust emissions might suppress the vertical dispersion of air pollutants in the winter morning.

(2) The concentrations of air pollutants at the roadside near traffic lights have periodicity corresponding to that of traffic signal cycle.

(3) The CO_2 concentration can be used as an index of NO_2 concentration.

(4) Utilization of the vehicle-actuated signal-control system enables reduction of the air pollution level at the roadside.

(5) A microscopic traffic-simulator is a useful tool for evaluating ITS features. However, a simple microscopic traffic simulator is not sufficient for estimating SPM concentration. Improvements in the traffic simulator and/or inclusion of a microscopic atmospheric model are needed for accurate estimation of SPM conditions.

Acknowledgments

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