

Research on Reducing Auto Exhaust Nitrogen Compounds (NOx) Through Control of Traffic Flow

(Measures for realizing a traffic pollution reduction system)

Tomoko Okada (Koito Industries, Ltd)

100, Maeda-cho, Totsuka-ku Yokohama-shi, KANAGAWA 244 JAPAN

TEL:+81 45-826-6783 FAX:+81 45-826-4591 E-mail:okada-t@sys.koito-ind.co.jp

Takashi Yoshiura (Koito Industries, Ltd)

100, Maeda-cho, Totsuka-ku Yokohama-shi, KANAGAWA 244 JAPAN

TEL:+81 45-826-6783 FAX:+81 45-826-4591 E-mail:yoshiura-t@sys.koito-ind.co.jp

Kohei Takeuchi (Universal Traffic Management Society of Japan)

Airman's Building 7th Floor No.6, Ichigaya-Tamachi 2cho-me

Shinjuku-ku, TOKYO 162 JAPAN

TEL:+81 3-3235-6520 FAX:+81 3-3235-6522

Yutaka Shibuya (National Police Agency)

2-1-2, Kasumigaseki Chiyoda-ku, TOKYO 100 JAPAN

TEL:+81 3-3581-0141 FAX:+81 3-3593-2375

INTRODUCTION

The environment protection management systems (EPMS) is a system for measuring the various quantities of pollution produced by road traffic (emissions, noise, vibration), reducing them with various means such as traffic flow control, the provision of traffic information, and route guidance for individual vehicles, maintaining the health of roadside residents and pedestrians who are exposed to automobile exhaust emissions, and protecting the environment. Traffic pollution, having relatively little effect that would bring pronounced direct physical harm as corporate emission pollution does, has been overlooked because it was buried amid a vortex of corporate emission pollution. Interest in traffic pollution has increased rapidly over the past quarter century, and environmental lawsuits have been filed in some locations, such as Ushigome Yanagi-cho in Tokyo. But today's economy is highly dependent on automobile traffic, making it difficult to greatly reduce overall traffic volume by such means of traffic regulations. Diligent research is going on to reduce pollutants, noise, and vibration by the installation and improvement of desulfurization equipment, more-advanced engines, and newly constructed highways, but much time and cost will be needed until these efforts bear fruit. Thus the National Police Agency has come up with environment protection management systems (EPMS) as one of the subsystems that make up universal traffic management systems (UTMS), and it has been actively working on their research and development since 1994.

BACKGROUND OF THE RESEARCH

Basic research on EPMS began in fiscal 1994, and study of the basic theory was completed by the first half of fiscal 1996, leading to basic demonstration experiment in the city of Shizuoka in Shizuoka Prefecture in the last half of fiscal 1996. In fiscal 1994 a correlation analysis was made of the pollution and traffic variables in Tokyo, and a study was made of pollution investigation data by the Tokyo Environmental Preservation Bureau and the National Research Institute of Police Science. But no effective correlation was found between traffic variables and the pollution measurement data of the national and regional governments. In fiscal 1995, noting the control of total traffic volume due mainly to the traffic regulations in effect while the APEC summit was being held in Osaka, an investigation was made of the pollution values at general pollution measuring

stations within the district where the total traffic volume was controlled, but no reduction in pollution values was found. As a result of re-analysis of the relevant conditions and repeated research with organizations that constantly take measurements, it became clear that the generally collected air pollution data encompasses a range of effect that is far broader than the size of a city, taking in an area as big as a square 200-300 km on each side, and affected by topography and weather on a nationwide scale. It is also clear that important factors locally include local topography, local winds, local air pressure distribution, sunlight, and temperature distribution. While viewing these factors as important background data, we reached the conclusion that it is essential to measure vehicle emissions near its source, immediately before it is diffused in the atmosphere. As a result of the above research over a period of two years, the concepts concerning the nature of traffic pollution control were summarized as follows.

- (1) The control of traffic pollution concerning air pollutants is greatly affected by many relevant factors, especially meteorological conditions such as wind speed and direction and the air temperature. With regard to data from general pollution measuring stations in particular, it is essential to take fully into account the diffusion, dilution, and convection of air pollutants released along highways, as well as effects from other regions.
- (2) It is thus impossible to facilely discuss control merely in terms of simple traffic patterns or pollution data from general pollution measuring stations alone.
- (3) General concepts must be considered, including control methods that take into account both local pollution quantities and overall pollution quantities.
- (4) It is important to measure the concentration of air pollutants as closely as possible to the road in order to exclude other factors, and to establish more clearly the correlation between traffic variables and the concentration of air pollutants.

DEMONSTRATION EXPERIMENT

The research goal set for fiscal 1996 was to establish the basis for EPMS control by determining, by theoretical values, the traffic conditions associated with changes in such traffic variables as fluctuations in traffic volume and vehicle speed and the frequency of starting and stopping, and their correlation with the concentration of nitrogen oxides (NOx) measured at the roadside and elsewhere, and by verifying this through demonstration experiment.

STUDY OF THEORETICAL VALUES

We attempted an analysis of theoretical values concerning the correlation between traffic conditions and the concentration of air pollutants by devising formulas for deriving the relationship between vehicle travel speed and the vehicle emissions and for deriving the exhaust coefficient per unit time, as well as a simple model for vehicle travel.

- (1) A roughly proportional relationship obtains between increases and decreases in the assumed measured quantity of pollution and increases and decreases in traffic volume.
- (2) The conclusion was reached that if limit values for traffic volume are assumed and realistic values are assigned for travel speed and distance between vehicles, the quantity of pollution, per measured unit volume and measured unit time, will be reduced the most by a condition of constant speed in the neighborhood of 40-50 km/hr.

The above desktop study led to the expectation that the roadside concentration of air pollutants would be reduced by reducing traffic volume by such means as synchronizing traffic signals and encouraging drivers to take detours, and by reducing the frequency of vehicle stops and starts even if there is no change in the traffic volume.

DEMONSTRATION EXPERIMENT

Demonstration tests were carried out within the city of Shizuoka in Shizuoka Prefecture over a total of four weeks, consisting of two weeks each in December 1996 and January 1997.

PURPOSE

- (1) The theory will be demonstrated that "the amount of pollution at the roadside will be reduced if deliberate signal control is done and vehicles are made to travel within a fixed range of speed, or by reducing the number of times vehicles stop and start."
- (2) The basic field data needed for making EPMS practical will be collected. Previous research showed that an EPMS can be constructed more specifically by doing analysis concerning the correlation between pollution data and traffic flow as affected by such factors as the weather and the discrepancy between where pollution is generated and where it is measured, concerning the correlation between variables whose relevant positional relationship has not been clearly quantified, and concerning the interrelationship between factors.

LOCATION OF THE EXPERIMENT

For the location for conducting the experiment, the Egawa-cho intersection in the city of Shizuoka in Shizuoka Prefecture located in the central part of the main island of Honshu was chosen, and the southbound direction of the IkawakoMiyuki route, which is a major regional route, was chosen as the section on which to carry out the study. There are many reasons for this choice, the main ones being as follows.

- (1) The measured values of the main air pollutants that are factors in traffic pollution in the city of Shizuoka (NO_x, CO, SPM, etc.) are near the environmental standard values, showing no extreme upper-limit or lower-limit values.
- (2) The wind speed in the city of Shizuoka is generally low throughout the year, and there are no pronounced seasonal winds during any of the four seasons.
- (3) The IkawakoMiyuki route is a bus route, and it is easy to ascertain the proportion of buses, which are large diesel vehicles, along this route and how they are operated. And because medium- and large-size trucks that are designated diesel vehicles make up only a tiny proportion of the traffic, it is easy to obtain a rough idea of the quantity of gasoline vehicles.
- (4) The Egawa-cho intersection is a major intersection in the city of Shizuoka and is relatively well equipped with infrastructure on the part of the traffic control center, which makes it easy to collect the various data.(5) The Egawa-cho intersection is subject to rush-hour traffic mornings and evenings, but during the daytime and at night it is judged to have traffic whose traffic flow can be controlled.

As listed below, five NO_x pollution detectors and anemoscopes and anemometers were set up along a 600-m stretch of the IkawakoMiyuki route, from Egawa-cho to the Naka-cho intersection (see the map in Figure 1).

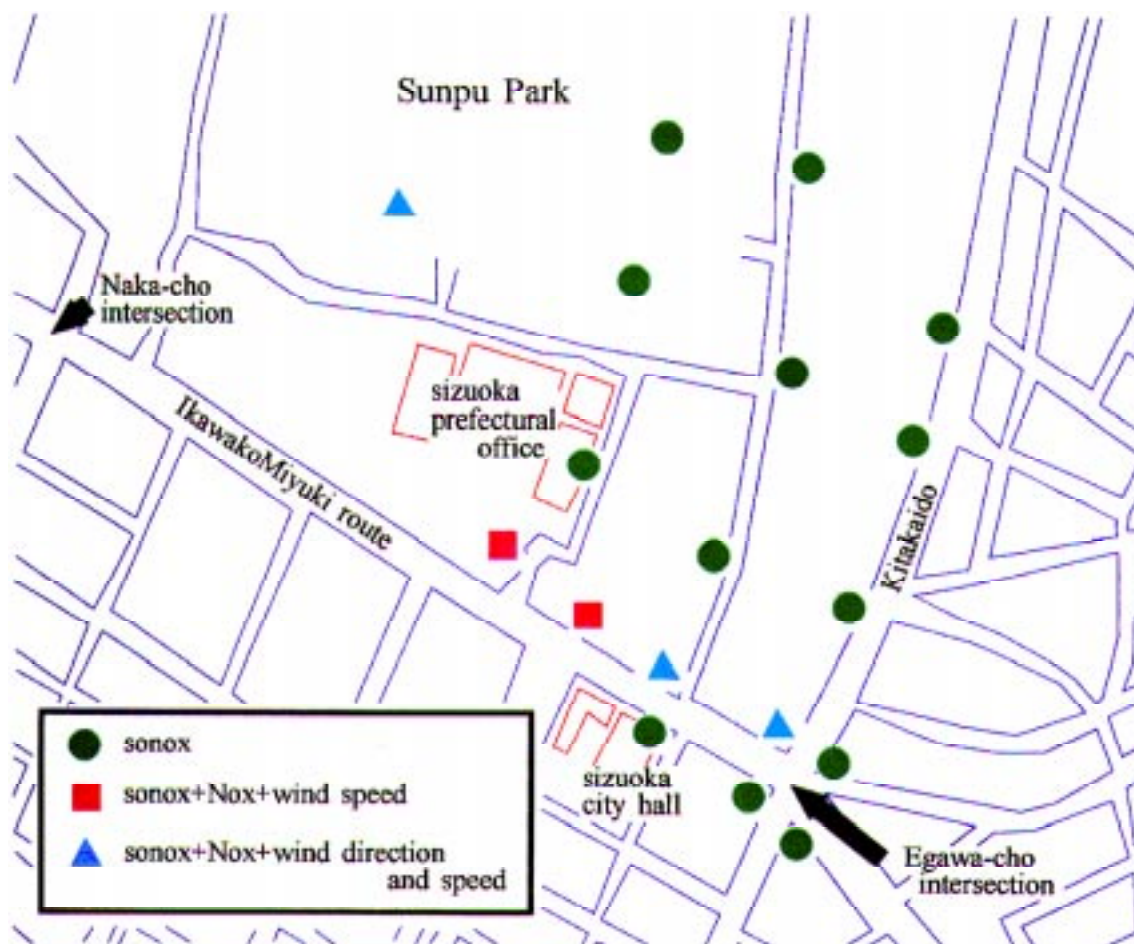


Figure 1 Disposal map of Nox detector, Wind direction and speed, SONOX

SELECTION OF THE DETECTORS

The APNA360, manufactured by Horiba, Ltd., was used as the device for measuring nitrogen oxides. This detector operates by the chemiluminescence method and has the advantages of a fast reaction time and the ability to measure with scaling from 0 up to 0.1/0.2/0.5/1 ppm. A hot-wire anemometer can measure very small wind speeds but cannot measure strong winds, while a three-cup anemometer can measure strong winds but not gentle breezes; because of this complementarity, different types of anemometers were used depending on the location.

TYPE AND CONTENT OF THE COLLECTED DATA

- (1) Roadside pollution quantities (NO_x/NO₂/NO)
 - (a) Analog chart recording, digital recording
 - (b) The nature of the digital recording is 10-minute-value collection for December (the 10-minute value is the cumulative average value of the 1-minute values) and 1-minute-value collection for January.

- (2) Traffic volume, proportion of total, speed (digital recording every 10 minutes)
- (3) Roadside wind speed and direction (analog chart and digital recording)
- (4) Shizuoka City background data (six locations)
 - (a) Collection classified by the items NO_x, SPM, CO, HC, O_x, SO₂
 - (b) 1-hour value, daily maximum, daily minimum, daily average
- (5) Shizuoka regional meteorological observatory data

Wind direction and speed (1-minute value); intensity and quantity of precipitation (January 24 only); air temperature, dew point, and humidity (1-hour value, 10-minute value); weather, cloudiness, and sunlight (1-hour value, 10-minute value); ground weather map, high-altitude weather map (850 hpa, 700 hpa, 500 hpa, 300 hpa)
- (6) SONOX (18 locations) (1-day-average data, measured over four days in December)
- (7) Bus operation data (measured over 14 days in December)
- (8) Taxi traffic volume (measured over three days in December)
- (9) Number of vehicles in Shizuoka City, classified by type (data collected by the Land Transport Bureau)
- (10) Visual roadside observation data, fixed-point observation data

METHOD

Pollution measurements were taken continuously for a two-week period in December and for a two-week period in January. The EPMS signal control system described below was carried out in the area of the study during specified hours on specified days, and measurements were taken for comparison with ordinary traffic control.

- (1) Inflow limitations (Efforts are made to narrow the southbound split of Naka-cho on the upstream side and reduce the number of southbound vehicles that arrive at Egawa-cho.)
- (2) Complete priority offset (Southbound vehicles starting from Naka-cho proceed non-stop to Egawa-cho without encountering a traffic jam.)
- (3) Complete reversal offset (Southbound vehicles that start from Naka-cho stop for a long period each time at the intersection in front of the prefectural government office and at the Egawa-cho intersection.)
- (4) Successive stop-and-go offset (Southbound vehicles that start from Naka-cho stop for a short time at the intersection in front of the prefectural government office and at the Egawa-cho intersection, then resume their movement.)
- (5) Inflow limitations/complete priority offset (Control that allows southbound vehicles between Naka-cho and Egawa-cho to travel smoothly.)
- (6) Complete reversal/successive stop-and-go offset (Control that impedes the travel of southbound vehicles between Naka-cho and Egawa-cho.)

RESULTS

Analysis of the experimental data, from the total of four weeks done in December and January, yielded the following results when half the data was analyzed one month after control changes were made at arbitrary times at which the traffic volume is considered roughly constant.

- (1) A clear direct-proportion time-series correlation was found between traffic volume and NO_x concentration during almost all time-of-day periods, including the morning and evening rush hours, and at almost all measurement locations. The followup delay in measurement with respect to the time series was generally no more than 30 seconds to 1 minute.

- (2) It was found that when the traffic volume is roughly the same, if the relationship between vehicle travel speed and NOx concentration is compared, there is a region of travel speed in which the NOx concentration is reduced. Also, it was revealed that under the same conditions, the NOx concentration is reduced by reducing the frequency of stops and starts.

Figure 2 shows how the NOx value and traffic volume vary with the time of day, and Figure 3 shows how the NOx value varies with the roadside speed.

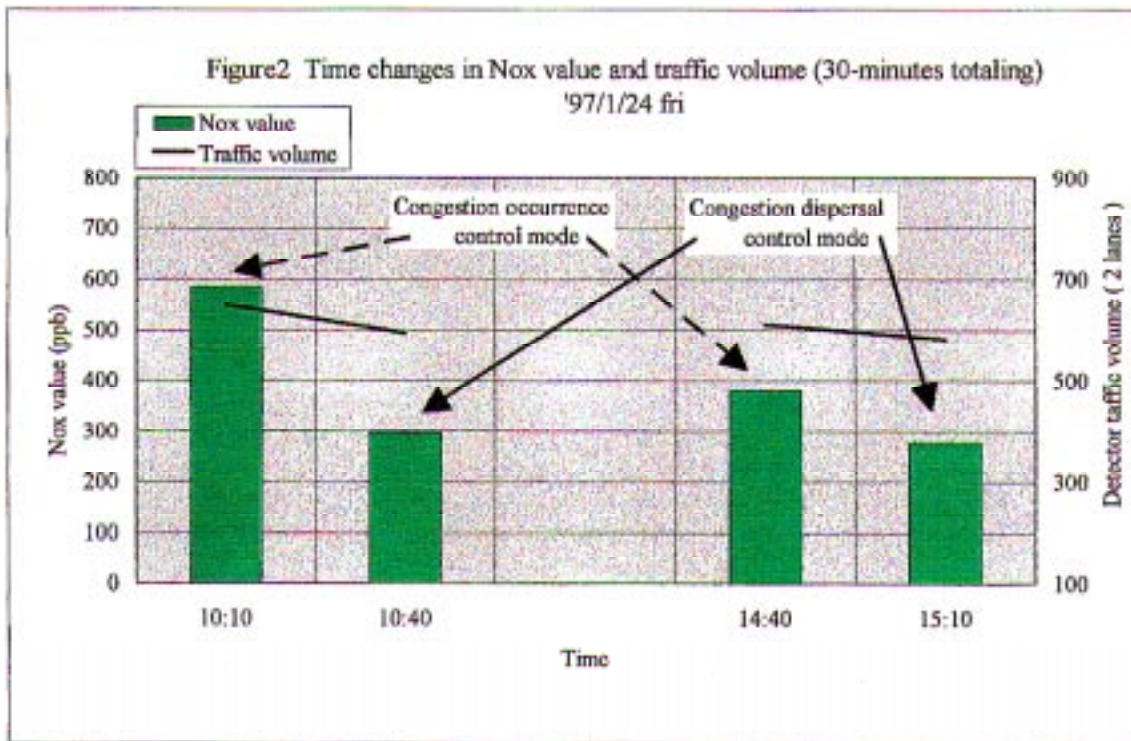


Figure 2 Time changes in Nox value and traffic volume (30-minutes totaling)

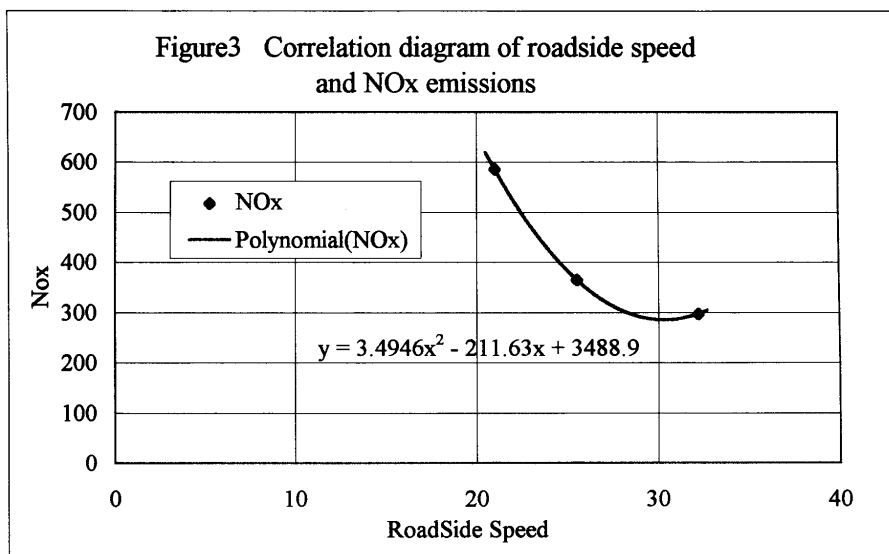


Figure 3 Correlation diagram of roadside speed and Nox emissions

As seen in Figure 2, successive stop-and-go offset is begun at 10:10, and complete priority offset is begun at 10:40. During complete priority offset, a group of vehicles travels at a speed of 30-40 km/hr. During this time the traffic volume is reduced by only about 50 vehicles, but the NOx emissions at the roadside is reduced by nearly 300 ppm. The NOx emissions was reduced as the vehicle speed approaches 40 km/hr, even though almost no change in traffic volume is seen. This fact suggests that it is clear that there exists a vehicle speed range that reduces NOx emissions the most. At the same time, data collected in this experiment shows that the amount of NOx emissions is greatest under conditions of repeated stop-and-go driving.

- (3) The NOx value measured at a location about 30 m perpendicularly distant from the roadside was about half what the value is at the roadside itself, which is similar to the results of reports based on, for example, a paper stating that the concentration is reduced in inverse proportion to the square of the distance from the roadside. It was also found that the NOx concentration is greatly affected by dispersion according to the direction and speed of the wind.

Figure 4 shows the measured values of the NOx concentration in three dimensions according to SONOX.

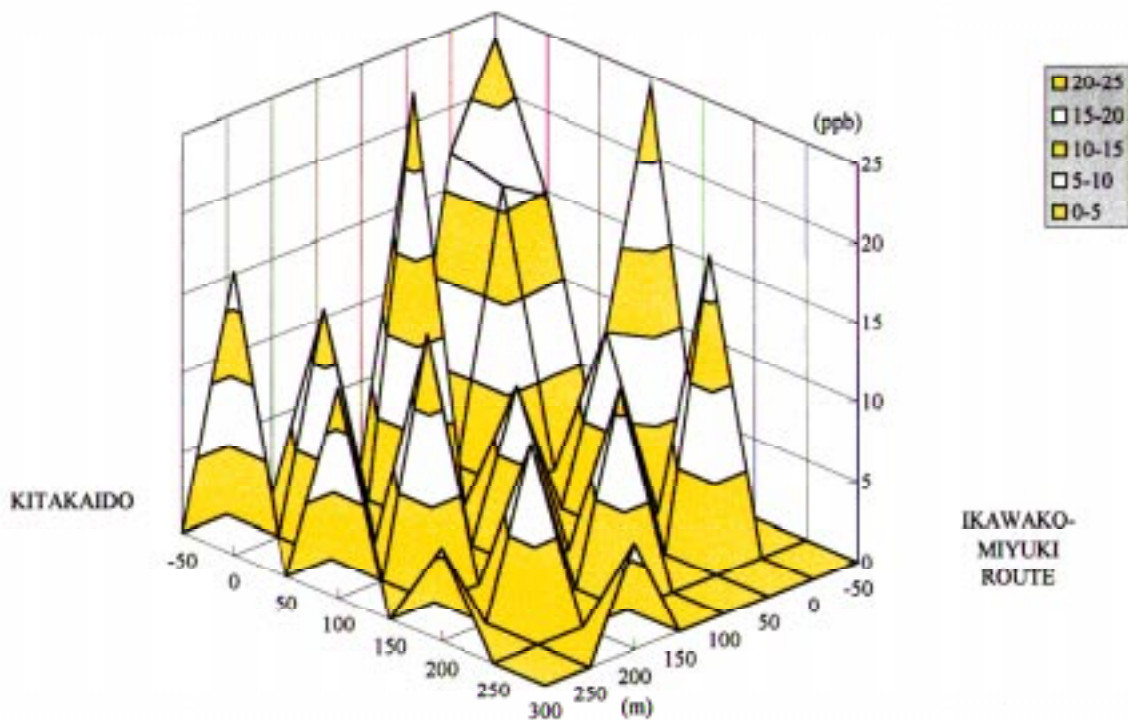


Figure 4 diffusion of the Nox concentration by SONOX

- (4) It was found that when the average wind speed locally exceeds 3-4 m/s, the effect of dispersion by the natural wind gradually appears and the correlation tends to begin to collapse.

CONCLUSIONS OBTAINED FROM THE RESULTS

- (1) If the speed value of a group of vehicles can be deliberately controlled, by means of signal control by the traffic control center, so as to remain within a fixed travel speed range, a system can be built that reduces the amount of vehicle emissions pollution along the route. But it is recognized that it is necessary to control the system's control execution and suspension in several stages, according to the relative amount of pollution of the entire region along the route (the background pollution quantity).
- (2) Exhaust emissions from the flow of traffic passing are found to have a clear effect up to about 30 m from the roadside. Therefore the realization of an EPMS can reduce the exposure of roadside residents and pedestrians to emission pollution, thereby contributing to the public's quality of life.

FUTURE DEVELOPMENTS

With the data collected in fiscal 1996, in fiscal 1997 we plan to use various analysis techniques to elucidate the correlation between various factors and to pursue the quantification that will be needed to build an EPMS. And beginning in fiscal 1997 we plan to successively carry out the same quantification for other major air pollutants besides NOx.