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COMMUTERS' EXPOSURE TO PARTICULATE MATTER AND CARBON MONOXIDE IN HANOI: A PILOT STUDY

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Abtract

In October 2006, We conducted a pilot study to get preliminary estimates of personal exposures to particulate matter (PM10) and carbon monoxide (CO) while traveling on three major roads in Hanoi (Giai Phong, Truong Chinh, Pham Van Dong). We also investigated the effect of the few factors, such as mode of transport, route, rush-hour, and air-conditioning on the exposure levels. Investigators carried lightweight portable real-time measurement devices while traveling on buses, cars, mobiles and walking.

The mean value of all PM10 concentrations was found to be 455 $\mu g/m^3$, with 580 $\mu g/m^3$ on measured on mobiles, 495$\mu g/m^3$ on while walling, 408 $\mu g/m^3$ in cars and 262 $\mu g/m^3$ in buses (By TCVN 2005 for PM10 is 150 $\mu g/m^3$ for 24-hour means, by WHO is 50 $\mu g/m^3$) .

The mean value of all CO concentrations was 15.7 ppm, with 18.6 ppm measured on mobiles, 18.5 ppm in cars, 11.5 ppm in buses and 8.5 ppm while walking (By TCVN 2005 for CO is 10000 $\mu g/m^3$ for 8-hour means, by WHO is 50 ppm for 30-minute means)

In the cars, switching on the air-conditioner was found to significantly reduce PM10 levels by 62%, but had no effect on CO levels.

1. Introduction

In Hanoi the vehicle population is expected to continue to grow rapidly in coming years as the overall economy continues to advance. The city's vehicle fleet is projected to grow at an annual rate of 8.5% between 2000 and 2010. In 2006 there were only 150,000 four wheelers in Hanoi compared with 1.7 million motorcycles and a rather smaller number of bicycles. Motorcycles account for about 70% of all vehicular trips and bicycles about 20%. Without improvements in public transit, the number of motorcycles is projected to grow at an annual rate of 13% to 15% and reach over 2.0 million units by 2010. The average vehicle speed in the urban area is from 18 – 32 km/h

Traffic volumes on the city's major routes have reached 1,800 to 3,600 units per hour. Hanoi's narrow roads and numerous intersections were not designed to handle the traffic volumes. Therefore, the vehicles are obliged to idle or change frequently their speed causing chaotic traffic flow and many accidents. Motorcycles account for a much higher percentage of total vehicular flow than automobiles, and the peak transportation flow occurs in different times of the day: 7:00 to 8:00 a.m. and 5:00 to 6:00 p.m.

Hanoi's motored vehicle fleet includes a high percentage of old cars and trucks emitting harmful air pollutants. In the transportation sector, gasoline-burning cars, trucks and motorcycles are major sources of carbon monoxide (CO), and hydrocarbons (HCs). Diesel buses and trucks are the main sources of sulfur dioxide (SO2) and nitrogen oxides (NOx). Both diesel and gasoline vehicles emit suspended particulate matter (SPM) and PM10.

The roads and streets surfaces contribute to high ambient dust concentrations, often above the allowable limit due to them being repaired, rehabilitated and newly constructed. At the traffic intersections, concentrations of air pollutants exceed Vietnam standards (TCVN) of ambient air quality. In 2006, hourly concentrations for three periods (morning, noon and afternoon) were reported for five traffic intersections, namely, Nga Tu So, Cau Giay, Nga Tu Vong, Chuong Duong Bridge as well as the ancient city area. The data indicated that hourly levels of SPM ranged from 0.4-1.5 mg/m3 exceeding the Vietnamese standard of 0.3 mg/ m3. The daily average CO level ranges from 2.0 to 6.5 mg/m3, compared to the TCVN standard of 5 mg/m3.

Air pollution is concentrated along traffic thoroughfares where people live and work. Fine particles are responsible for cases of respiratory disease and premature death every year. Most particle pollution originates from combustion operations and from vehicles. These particles are so small that they can bypass respiratory defenses and lodge deep in the lungs, worsening lung diseases such as asthma, and increasing the risk of heart attack and premature death. Air pollution from emissions interferes with the development and function of the central nervous system, as well as the cardiovascular and reproductive systems. The least mobile populations – the poor, the young and the elderly suffer particularly.

Roadside Monitoring Survey

To address the need for better information on roadside air quality, CEETIA using a mobile monitoring station, measured roadside air pollutant concentrations on Giai Phong road, a major traffic artery in Hanoi, during two-week periods in both November 2004 and June 2005. The study found that daily average concentrations of several air pollutants (PM10, SO2, NO2, CO and O3) were higher at the mobile monitoring station than at CEETIA's fixed-site station monitor in near road residential area.

Studies of human exposure are needed to quantify the impact of air pollution on public health. However, quantifying that impact in urban areas is difficult and challenging, because large numbers of people may be exposed to relatively low levels over long periods of time. Such exposures result in rare health problems that are difficult to value or even attribute to air pollution. On the other hand, a substantial number of people can be exposed to relatively high levels of air pollution for short periods of time due to the nature of their daily activities or occupations. Hence, it becomes important to measure air pollutant exposures as people perform their daily activities.

The aim of our study was to get an estimate of the range of concentration of major pollutants (PM10 and CO) under different circumstances and to investigate the impact of a few factors (types of road, and with differential modes of transport: Bus, Car, Mobike, Walking) on pollutant concentration levels. A survey of the literature on commuters' exposure to air pollution in developed countries points to knowledge gaps related to aspects that are unique to Asia, such as high use of 2-wheelers and very heterogenous composition of traffic on most types of roads. Therefore, our study has an emphasis on users of 2-wheelers.

2. Methods

We conducted the pilot survey (in October 2006) on three arterial roads that had been earlier identified as some of 3 major 'hot-spots' of Hanoi – Truong Chinh, Giai Phong and Pham Van Dong roads and Tran Hung Dao road. Giai Phong, Pham Van Dong roads are very broad and in sections have wide medians as well. In contrast, though Truong Chinh has high traffic volumes, in many sections it is narrow with mulit-story buildings very close to the road. We compared the conditions on these roads with those on a distributor road (chosen arbitrarily), which was supposed to have much less traffic - Tran Hung Dao. On two of these roads are located official air quality monitoring stations of the Hanoi network. These are CEETIA's station on Giai Phong road and Four modes of transportation were considered – buses, cars, mobikes, and walking. Most buses plying on the major routes are modern, air-conditioned and run on diesel. We used CEETIA's official car, with an air-conditioner, on all days of the study. Mobikes personally owned by some of the investigators were used in the study.

Prior to the first day of monitoring we had identified on each road two pairs of bus-stops. The distance between the bus stops, on one side of the road, was approximately 4 – 5 km. We identified the corresponding bus stops on the other side of the road as well. A previous survey had shown that average trip distances traveled by bus users and motorcyclists were 6.5 km and 5.2 km respectively (TDSI 2005). The routes chosen were mostly straight without sharp turns. That is, the investigators remained on a single road throughout the monitoring. The monitoring scheme was as follows. First during the rush-hour period, two investigators boarded a bus at the pre-identified starting point and switched on the samplers. At the same time two investigators traveled alongside the bus in the car (with the air-conditioner on). The investigators in the bus got off the bus at the end point, switched off the monitors and crossed over to the other side of the road and waited for the bus traveling in that direction. The investigators in the car too, switched off the monitors and turned the car around. The monitoring was then repeated in that direction when a bus came along. Immediately after this, the investigators who were earlier on the bus, got on to mobikes and switched on the monitors, riding between the two bus stops. The investigators in the car followed them, monitoring as earlier, but this time with the air-conditioner switched off. The two groups then conducted a monitoring run on the other side of the road as well. Finally, the investigators in the car left the car and conducted monitoring while walking between the bus stops. The investigators on the mobikes also did a new monitoring run in both directions. Thus, we have twice the number of samples for mobikes and cars as compared to buses and pedestrians. Currently, mobikes have 71% of the modal share of transport. Though the share of cars is just 3%, the automobile population is growing rapidly at 10% per year. Based on these facts we felt that having larger samples for mobikes and cars was justifiable.

On two days, we also monitored PM10 and CO levels in road-side cafes (which are very common in Hanoi) in between the in-vehicle monitoring sessions. These cafes were located on Giai Phong and Pham Van Dong roads.

Investigators carried personal lightweight monitors while traveling. For CO measurements we used a portable electrochemical monitor, the Model T15n instrument from Langan Products, Inc. This instrument has many features that make it ideal for field surveys. The monitor measures and records CO concentrations to the nearest 0.055 ppm over a range of 1 to 200 ppm. Besides CO, the instrument can also measure temperature. It has a storage capacity of 43,000 CO samples and a minimum sampling frequency of 1 second. Stored data in the monitor can be downloaded to a personal computer for statistical analysis. Batteries supply operating power for several months of continuous use. The Langan monitor has been used in studies by Jantunen et al. (1998) and Flachsbart et al. (2004b). The instruments were calibrated in Honolulu, USA at the East-West Center in late September 2006 by zeroing them under clean conditions and using a span gas of 60 ppm (manufactured by Calgaz LLC, Cambridge, USA). In Hanoi, the instruments were zeroed every morning in a clean environment using an air tight tedlar bag fitted with a HEPA filter.

To measure PM10 we used a nephelometer, which measures the intensity of light scattered by airborne particles passing through their sensing chamber, manufactured by Thermo Inc., model PDR -1000. The intensity of the light is linearly proportional to the concentration of the particles in the chamber. This passive monitor measures mass concentrations of dust, smoke, mists and fumes, ranging in size from 0.1 – 10 μm. The instrument estimates mass concentrations ranging from 0.001 to 400 $mg.m^{-3}$. This instrument's performance has been widely studied under different operating conditions (Liu, Malaysia, etc.). The monitors were less than a year old and had been factory-calibrated. In Hanoi, the instruments were zeroed every morning in a clean environment using an air tight tedlar bag fitted with a HEPA filter.

Data quality control and assurance procedures included studying the correlations among similar monitors by collocating them during special sampling sessions. We observed that the correlation coefficient, r, ranged from 0.841 to 0.988 for the PM10 monitors and from 0.997 to 0.999 for the CO monitors.

In addition to PM10 and CO we also measured temperature and relative humidity using the HOBO U10 data logger (made by Onset Computer Corporation). Extreme weather conditions are known to affect the performance of both these types of instruments. Outliers in the data, if any, could potentially be due to extreme weather conditions.

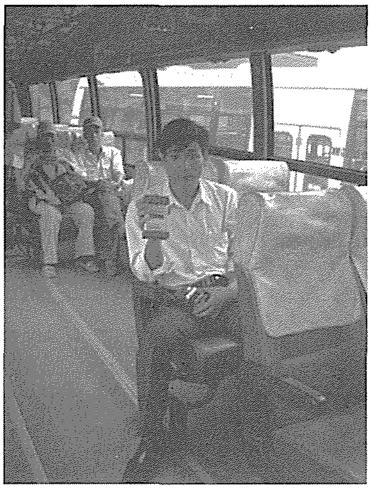

Figure 1. Monitoring in a bus

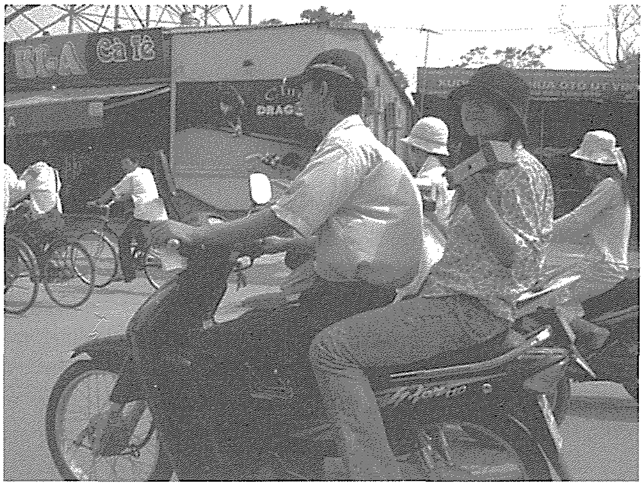

Figure 2. Monitoring on a mobike

The sampling frequency for all the instruments described above was set to 12 seconds. The CO and HOBO monitors were set to begin logging continuously from early morning and at the end of the day the data were downloaded as a single file for each of these instruments. The datalogger was then cleared. On the other hand, PM10 monitors were switched on for every sample and switched off at the end of the sample run. Thus, each sample was stored in a different file identified by a unique tag by the monitors' internal software. Investigators manually recorded the tag number for each sample on a data sheet. The PM10 monitors had sufficient memory to accomodate all the data. So there was no need to erase the internal memory every day. All the monitors' internal clocks had been synchronized with a singe laptop's clock, on which the downloading softwares had been loaded. The PM10 monitor's data file indicated the true start and end times for a single sample. The corresponding sections from the downloaded CO and HOBO files were copied and pasted into a single Excel worksheet that had been exported from the PM10 datalogger. We did the statistical analysis using SPSS (version 12).

3. Results and discussion

The mean value of PM10 concentration was found to be 455 $\mu g.\ m^{-3}$ (the new World Health Organization guideline for PM10 is 50 $\mu g.m^{-3}$ for 24-hour means), with 580 $\mu g.\ m^{-3}$ measured on mobikes, 495 $\mu g.\ m^{-3}$ while walking, 408 $\mu g.\ m^{-3}$ in cars and 262 $\mu g.\ m^{-3}$ in buses. The mean value of CO was 15.7 ppm, with 18.6 ppm measured in mobikes, 18.5 ppm in cars, 11.5 ppm in buses and 8.5 ppm while walking (Table 1) (the World Health Organization guideline for CO is 10 ppm for 8-hour means and 50 ppm for 30 minute means). The variability of levels for CO was much higher than for PM10, judging by the coefficient of variation and geometric standard deviation indicators.

Though particulate matter is increasingly being considered as the most important air pollutant of concern in Asia, there are not many studies that have looked at the exposures of 2-wheeler users to particulate matter. A study in New Delhi, India showed much higher levels of PM5 for car users (2860 $\mu g.\ m^{-3}$) as compared to our study (Saksena et al 2006). It is known that at the time when this study was conducted in Delhi, the ambient air pollution was much worse than in Hanoi. Even for bus users the Delhi study observed higher PM5 levels (800 $\mu g.\ m^{-3}$). However, for car users the results were similar (370 μg. m^{-3}). But it is also possible that the differences in results could be partly due to the differences in sampling methods. The Delhi study used the more traditional and accurate gravimetric method, while in our study we used nephelometers.

Other studies in developing countries have reported the following range of PM10 values - Cars: 65 – 140 μg. m^{-3}; Bus: 125-184 μg. m^{-3}; and subway: 55-78 μg. m^{-3} (Chan, Lau, Lee, et al. 2002; Chan, Lau, Zou, et al. 2002; Zhao, Wang, He, et al. 2004; Chau, Tu, Chan, et al. 2002).

Figures 3 and 4 indicate the variation in data across the four modes of transport through box-plots. For both pollutants cars showed the highest variability. This could be because in this survey cars were operated in two modes – with and without air-conditioning. Many studies conducted in USA and Europe that primarily measured gaseous pollutants indicated that car users experience higher concentrations than pedestrians. In our survey we observed the same pattern for CO but not for PM10. The reason for this could be that in the spatial scale of interest here, vehicles are the only source of CO, whereas PM10 could have other sources, such as re-suspended dust near the curb.

As Figure 5 shows, PM10 levels were lowest on the road with least traffic (Tran Hung Dao) as compared to the three hot-spot roads. But on this road, CO levels were the second highest among the four roads considered (Figure 6). Though Tran Hung Dao road has comparatively lower traffic flows, it is much narrower than the other roads and has multi-story buildings very near the curb. We speculate that such a geometry may not be allowing CO to disperse rapidly, thus leading to a build of concentrations. The road also has many trees, which, we speculate, in the case of PM10 may be suppressing PM10 levels. The effect of trees on gaseous pollutants such as CO is less pronounced.

Rush-hour levels for PM10 and CO were found to be higher than during non-rush hour periods (Figures 7 and 8). But the differences were statistically significant (Table 2) only for walkers (CO and PM10), car users (only for CO) and bus users (only for CO). Judging by the exposures of walkers it may be said that the general ambient air pollution levels are higher during rush-hour traffic, but for those right on the road, the patterns are more complicated.

In cars, switching on the air-conditioner was found to significantly reduce PM10 levels, but had no effect on CO levels. In cars, mean PM10 levels with the air-conditioner on were 595 μg. m^{-3}. Without the air-conditioning and with all windows rolled down the mean PM10 levels were 222 μg m^{-3} (t-test results: $t = 7.13$, $p < 0.001$). This corresponds to a removal efficiency of 62%. A t-test indicated that the levels of PM10 in the air-conditioned car were very similar to those in the air-conditioned buses (262 μg m^{-3}). The differential effect of air-conditioning on PM10 and CO is understandable because the filters in cars are designed only to remove larger particles and not gases from the cabin air-stream.

Correlations between PM10 and CO were generally very weak (Table 3). In unshielded modes of transport, such as mobikes, and walking, the correlations were slightly higher. We are unable to unexplain the negative correlation observed in buses. These results imply that though CO is easier to measure, it cannot be used as a reliable surrogate indicator for PM10 under such conditions.

One of the roads (Pham Van Dong road) has a regular official air quality monitoring station operated by CENMA. Though at this station normally all major pollutants are monitored, during this period their PM10 monitor was under repair. On this road the average CO level measured while traveling was 6 ppm, while that measured by the roof-top station was much lower - 1.5 ppm (as measured by their NDIR instrument). Traditional ambient air quality monitoring networks provide very useful assessments of broad trends and patterns, and in some cases may provide fairly reliable estimates of relative risks to human health. But as this study seems to indicate data from ambient air quality monitoring stations can grossly underestimate absolute risks to air pollution.

Table 4 shows pollutant levels measured in two roadside cafes. Monitoring was done in the cafes for approximately half an hour on two consecutive days. The PM10 levels are unexpectedly high –

higher than concentrations measured in most modes of transport. In one of the cafes CO levels were also very high, comparable to what we measured in buses.

4. Conclusions

The survey has clearly provided evidence of the extremely high levels of pollution experienced by commuters, thereby justifying the need for a larger and more comprehensive assessment of the exposures and the factors that influence exposures. The survey also highlights the need to consider comprehensive assessments of exposures within buildings, such as cafes and shops, which are very near the road. Future studies that build on this one need to focus on the following issues:

- Measure exposures of actual commuters, including cyclists
- Develop objective criterion for selection of roads and routes to be monitored
- Examine in greater detail the intra-day temporal patterns, including assessing the situation during the afternoon rush-hour period
- Develop stringent and comprehensive protocols for data downloading and management because real-time devices, such as the ones used in this study tend to generate huge databases.
- All of the above have to be preceded by improving project-specific methods to measure particulate matter. There are far less uncertainties associated with CO instrumentation.

Table 1. Descriptive statistics of PM10 and CO concentration across modes of transport

	PM10 (μg m^{-3})					CO (ppm)				
	Bus	Car	Mobike	Walking	All	Bus	Car	Mobike	Walking	All
N	16	32	32	16	96	16	32	32	16	96
Mean	262	408	580	495	455	11.5	18.5	18.6	8.5	15.7
CV (%)	45	59	34	38	50	72	66	47	83	66
GM	242	343	547	460	397	9.2	15.7	16.3	5.1	1.88
GSD	1.46	2.07	1.38	1.32	1.56	2.61	1.65	1.46	2.65	1.88

CV = coefficient of variation, GM = geometric mean, GSD = geometric standard deviation

Table 2: t-test results for testing the difference in concentration between rush hour and non-rush sessions

Mode	Pollutant	t	df	Sig. (2-tailed)	Mean Difference
Bus	PM10	.929	14	.369	.05464686
	CO	2.355	14	.034	8.554952
Car	PM10	1.532	30	.136	.12665699
	CO	2.098	30	.044	8.541732
Mobike	PM10	1.050	30	.302	.07370385
	CO	.907	30	.372	2.787932
Walking	PM10	3.193	14	.007	.23330476
	CO	1.859	14	.084	6.075624

Table 3. Correlation between PM10 and CO concentrations across modes of transport

Mode	Pearson correlation, r
Bus	-0.238
Car	0.252
Mobike	0.455*
Walking	0.817*
All	0.335*

* Correlation is significant at the 0.01 level (2-tailed)

Table 4. PM10 and CO levels in roadside cafes

Statistic	PM10 (μg m-3)		CO (ppm)	
	Giai Phong road	Pham Van Dong road	Giai Phong road	Pham Van Dong road
n	148	127	148	127
Mean	404	617	3.2	11.3
Coefficient of variation (%)	18	32	75	8
Geometric mean	400	591	2.8	11.3
Geometric standard deviation	1.14	1.53	1.5	1.09

N refers to the number of 12-second intervals logged during sampling

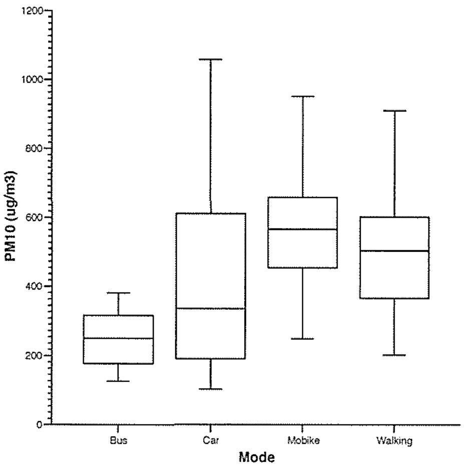

Figure 3. Box plot of PM10 concentration across modes of transport

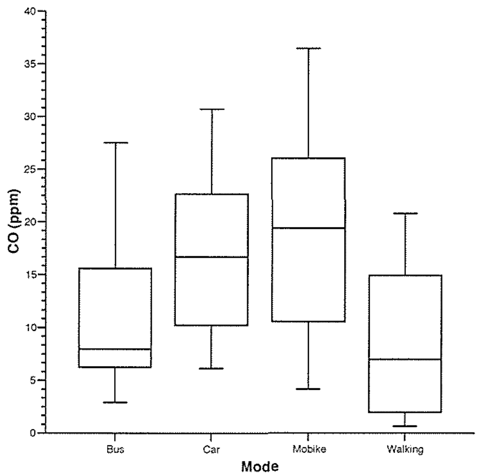

Figure 4. Box plot of CO concentration across modes of transport

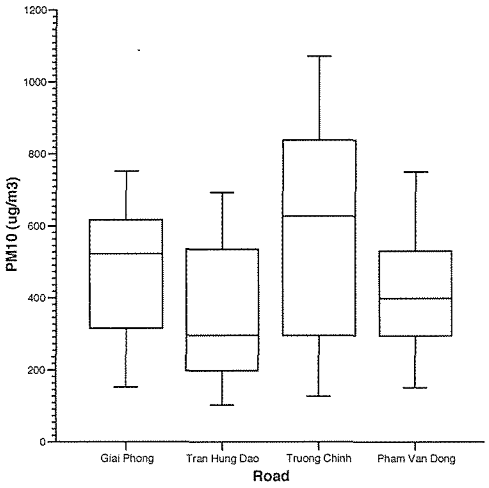

Figure 5. Box plot of PM10 concentration across roads

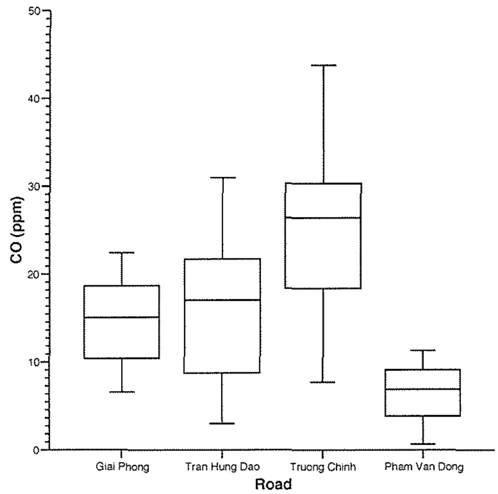

Figure 6. Box plot of CO concentration across roads

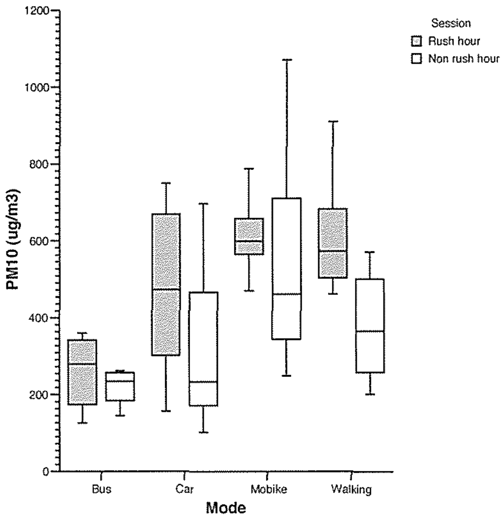

Figure 7. Effect of rush-hour on PM10 concentration

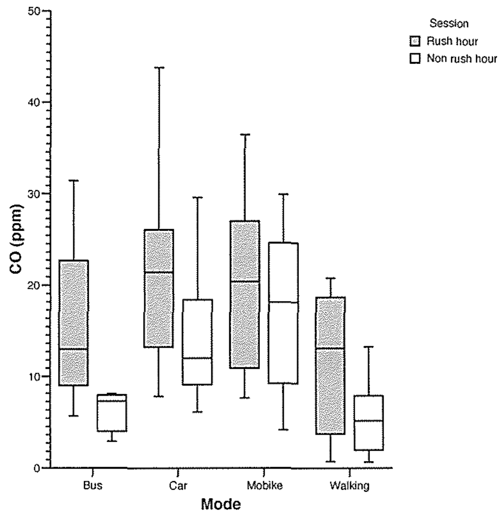

Figure 8. Effect of rush-hour on CO concentration

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