AIR POLLUTION FROM MOTOR VEHICLES A MATHEMATICAL MODEL ANALYSIS: CASE STUDY IN IPOH CITY,PERAK, MALAYSIA.

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Abstract: Carbon Monoxide and Sulfur Dioxides concentrations and traffic volume data were collected at several locations in Ipoh City in the state of Perak in Malaysia. The sites were categorised into an enclosed area and an open area and at each site different vehicles driving mode were considered. A mathematical models based for pollutant concentration were developed using the least square method. Results from these studies indicate that the maximum concentration of pollutant is higher in an enclosed surrounding for all driving modes compared to an open surrounding similar traffic volume. The relationships derived between traffics flows and pollutants concentrations indicate that the adopted approach to forecast pollutant levels from traffic counts is workable for Malaysian situation.

Key words: Motor Vehicle, Air Pollution, Carbon Monoxide, Sulfur Dioxide, and Mathematical Model.

1. INTRODUCTION

1.1 Urban air quality and traffic.

Atmospheric pollutants are responsible for both acute and chronic effects on human health (WHO, 2000). Air pollution is a major environmental health problem, affecting developed and developing countries in the world. Increasing amounts of potentially harmful gases and particles are being emitted into the atmosphere at a global scale, damaging the human health and the environment. Motor vehicle emission has been recognized as one of the major sources of air pollution, particularly in highly urbanized areas. The main traffic-related pollutants are carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons, lesser amounts of particulate matter and sulfur oxides. Based on 1992 study by the Japan International Cooperation Agency (1993), it was concluded that the air pollution problem in Kuala Lumpur is relatively serious when compared with accepted air quality standards. The annual and daily readings for CO, Ozone and PM_{10} have exceeded the standard. Unfortunately follow-up studies in 1994 continued to shows serious problem, and motor vehicles were again found to be the main source of air pollution (Walsh et al., 1997).

Studies around the world have indicated that carbon monoxide is the most abundant pollutant per annum with practically 70% of all carbon monoxide gas produced solely by motor transport vehicles (Kiely, 1997). According to Davis and Cornwell in 1998, carbon monoxide is a colorless, odorless, tasteless and non-irritating gas but can be lethal to human beings within minutes at high concentrations exceeding 12,800 parts per million (ppm).

On the other hand, sulfur dioxide is a colorless gas with irritating smell. Sulfur oxides are formed when fossil fuel containing sulfur is burned. These oxides contribute to acid rain and to the formation of secondary particles. The amount of sulfur emitted is indirectly proportion to the amount of sulfur in the fuel especially from diesel fuel. Exhaust fumes from automobiles also produce sulfur oxides, which is the major source of sulfuric acid and the major form of acid deposition. Recent study carried out in Europe showed that the diesel emissions contain sulfur in particulate and gaseous form, which mean by reducing sulfur in diesel fuel it will lower the particulates.

In urban environments and especially in those areas where population and traffic density are relatively high, human exposure to hazardous substances is expected to be significantly increased. This is often the case near busy traffic points in city center, where urban situation may contribute to the creation of poor air dispersion conditions giving rise to contamination hotspots (Sotiris *et al.,* 2003).

According to the report from the 2000 Annual Report of the Road Transport Department of Malaysia, the number of registered road vehicles has increased from more than 6.8 million in 1995 to over 10.5 million in June 2001, representing a 53% increase. The composition of road vehicle fleet is 51% motorcycles, 32% cars, 7% vans and the remainder are buses, heavy goods vehicles and others. Petrol-fuel vehicles accounted about 92% of all road vehicles while the remaining 8% is diesel operated. Table 1 shows the summary of the number of vehicles registered and the total pollutants emitted from the motor source for the year 1997 to the year 2000.

Table 1 : Total vehicles registration and pollutants from the motor vehicle source in Malaysia for the year 1997 to 2000.

Year	1997	1998	1999	2000
Total registration of vehicles	8.5 mil	8.9 mil	9.9 mil	10.6 mil
Carbon Monoxide (tonne metric)	1.9 mil	2.0 mil	1.9 mil	2.3 mil
Nitrogen Oxide (tonne metric)	224,000	237,000	268,000	302.678
Hydrocarbon (tonne metric)	101,000	111,000	120,000	141,097
Sulfur Dioxide (tonne metric)	36,000	38,000	no info	40,126
Particles (tonne metric)	16,000	17,000	17,480	19,277

Source: Malaysia Environmental Quality Report, 1997-2000, Department of Environmental Malaysia.

1.2 Air Quality Modelling.

Air quality modeling is very important as it helps to predict the impact of any proposed project on air environment. It is also an important tool and play a crucial role in the attempt to protect air quality. Modelling tools are needed to predict roadside air quality and to analyse travel behaviour strategies to mitigate possible negative impacts. For instance, Barth *et al.*, (1999) and others in US are developing modal emission models that can estimate emissions from microscopic traffic conditions. However, most of air dispersion modelling work is focused on large-scale industrial pollution sources. Recent efforts with respect to vehicle emissions include the work by Moseholm et al. in 1996, who conducted a sample technique for sheltered intersections and Matzoros (1992a) and Matzoros (1992b) who analysed emissions for traffic control strategies at intersections using queuing theory and traffic simulation

The concentration of pollutants emitted from vehicles exhausts will depends on the driving mode (Maccarrone, 1986). In general, as the average speed increases, emissions increase for NO_X and decrease for CO and HC. Hickman (1976) indicates that the CO concentration was found to be higher at locations, which has access to an elevated ring road, and a set of traffic lights compared to other location with a free flow of traffic. The reason is that vehicles spend a longer time near junctions due to queuing and the acceleration and deceleration phase they go through are more polluting than steady speed cruising. Phase periods of idling mode increases emissions of all pollutants (Zellner and Mousiopoulos, 1986).

Pollutant concentrations were found to be considerably higher at intersections and even much higher where streets are under elevated expressway. Based on studies carried out by Claggett *et al.* (1991) they have observed that pollution concentrations are higher near traffic junctions, where queuing occurs, than at the intermediate links. The results show that CO concentration may be substantially higher at signalised intersections of an arterial street than when near freeways even with two to three times higher traffic volumes. They have also shown that CO concentrations measured in the queue zone at the intersections can be attributed to the high rate of CO emissions from idling engines of vehicles stopping during red traffic signal cycle and reduced dispersion due to lack of traffic generate turbulence. This is because vehicles spend longer periods of time near junctions while queuing, decelerating or accelerating which generate more pollutants than during the steady cruise.

The nature of surrounding buildings has found to be influencing the traffic pollutants (Hickman, 1973). The buildings and structures effects to the pollutant concentration was discussed by many others like Hassan *et al.,* (1998a, 1998b) and Hongchang *et al.,* (2001). Study by Hongchang Zhou *et al.,* (2001) gave some input on how the concentration level of pollutant is difficult to predict due to complex dispersion processes near high-rise buildings. The impact of air pollution on urban environments has become an important research issues, leading to numerous modeling studies related to the influence of buildings and other urban structures on pollutant accumulation and dissipation pattern (Sotiris *et al.,* 2003).

1.3 Transport and Environment studies in Malaysia.

In Malaysia, an increasing effort is being devoted to understanding traffic characteristics, emission trend and emission dispersion. Muhammad Awang *et al.,* (1988) compared the level of pollutant in urban areas in Kuala Lumpur. The report indicated that the maximum concentration level of CO at almost all urban streets exceeds the safety limit for urban people, which of 10 ppm/8 hr or 40 ppm/hr. Base on a study to estimate pollutants from moving vehicles by Khairani(1993), shows that Carbon Monoxides is the highest pollution, follow by Nitrogen Oxides, Hydrocarbon, Particles and Sulfur Dioxides. Other studies have also made observations of the air quality in urban areas such as Wong Wei Hoong (1992), Rosmini Mohd Salleh (1993) and S.T. Koo(2001).

More efforts are being devoted by Sharifah Rofashida (2001) and Noor Zaitun *et al.,* (2001) to establish the mathematical models between gas emission and the traffic situation at different sites. Analysis of Carbon Monoxide data for different locations showed significant differences between characteristic of vehicle operation (idling, accelerating and cruising)at an enclosed and an open surrounding (Noor Zaitun *et al.,* 2002; Noor Zaitun *et al.,* 2003). The differences can be attributed to a combination of factors. The situation at intersections and in enclosed sites would contribute more to the pollution level as compared to the cruising zone. The high CO concentration measured at the closed intersection situation can be attributed to a high rate of CO emissions from idling engines of vehicles and even much higher where streets are surrounded by the buildings.

This paper reports on a study in Ipoh City of air pollution concentration at different vehicles mode which represent an open and enclosed surrounding. Our goal is to develop a mathematical model between the pollutants and traffic flow by using the least square method and to suit Malaysian conditions.

1.4 Objectives

This study will focus on analyzing Carbon Monoxide (CO) and Sulfur Dioxide (SO_2) gas concentration in relation to traffic flow at an open and closed surrounding and also on approaches to traffic light junctions. The objectives are:

a) To provide an air pollutions and traffic data information collected on approaches to urban intersections.

b) To create relationship models between the pollutants and traffic.

2. METHODOLOGY

2.1 Site Location.

Table 2 summarizes the site location and details of the data collected in this study. The measurements of pollutants and traffic data were made at an arterial intersection in Ipoh City Center. A sampling site criteria given by Harrison et al., (1986) was been used as a basis to determine the differences type of locations. A general rule adopted was that the top of obstructions such as buildings should subtend less than 30^0 angle with the horizontal at the sampling site. If the top of the building subtends more than 30^0 angle, the location was considered an enclosed zone while an open zone location was a location where the angle to the top of the building is less than 30^0.

Table 2: Summary of Site Location and Data Description.

Road	Distance from the traffic light junction	Mode of vehicle	CO Data	SO_2 Data
Perhentian Int.	0 m	Idling Enclosed	Available	Available
Gopeng Int.	0 m	Idling Opened	Available	Available
S.Yusof Road	30 m ahead	Acceleration Enclosed	Available	Not available
Gopeng Road	30 m ahead	Acceleration Opened	Available	Not available
Lahat Road.	More than 200 m	Cruising Enclosed	Available	Not available
P. Puteh Rd.	More than 200 m	Cruising Opened	Available	Not available

2.2 Variables

The variables used for the modeling were gaseous pollutant concentration which are carbon monoxide (CO) and sulfur dioxide (SO_2) in parts per million unit (ppm). The second parameter is the traffic volume in passenger car unit (pcu).

2.3 Measurement of the pollutant gaseous.

The emissions produced from vehicles at ambient was measured using a portable equipment called Multiwarn II Draeger. This is a real time monitoring equipment, which gives continuous reading which is then downloaded to a computer, which in turn is being used for analysis by the Gas Vision software. Sensors to detect the gaseous in the ambient is part of the equipment. The sensitivity of the sensors is in the range of 0 to 1000 ppm for CO and 0 to 100 ppm for SO_2. Before sampling is taken, the instrument will undergo the fresh air calibration process.

During the process of data collection, the equipment was located at the height of 1.5 meter from the ground and approximately 1.5 meter from the kerb side of the road. Measurement of average concentration carbon monoxide formula was based an the following:

$$\text{Average Concentration} = \frac{1}{\Delta t}\int c\,dt \quad (1)$$

c = concentration of carbon monoxide gas according to the real time monitoring.
t = time of measurement
(Source: Noel De Nevers, 2000).

2.4 Measurement of traffic volume and the pollutants.

Traffic vehicle composition was counted manually. Hand tally counter was used to help enumerators to manually count the traffic. Data was collected based on one hour and 15 minutes interval. This process was carried out for different distances from the stop line along the approach road. Traffic data was collected simultaneously with the measurement of pollutants.

Due to the mixed traffic composition in Malaysia, it is necessary to relate the capacity effect of various vehicle types to conventional passenger car and was been done using the equivalent passenger car unit (pcu). PCU values are employed as a device to convert a traffic stream composed of a mix vehicles types into an equivalent traffic stream composed of exclusively passenger cars (Asri et al., 1993). The vehicle classification according to Malaysian Standard is summarized in table 3 below.

Table 3: Vehicle classification in passenger car unit (pcu)

Types of vehicles (pcu/hr)	Passenger Car	Light Van / Two axle lorry	Heavy vehicle	Bus	Motorcycle
	1.0	1.75	2.25	2.25	0.33

Source : Malaysian Design Standard (Road), JKR 13/87.

3. RESULTS

3.1 Statistical Discussion for the pollutants.

The raw data obtained from this study was analysed using comprehensive statistical software known as *SPSS Base 9.0*. The average CO and SO_2 concentrations values measured are summarized in Table 4. From The results, the highest concentration for both types of pollutants was recorded for the idling during mode in enclosed zone, which was in Perhentian Road.

Table 4: Pollutants analyses at different driving mode.

DRIVING MODE	Idling Zone		Acceleration Zone		Cruising Zone	
	Perhentian Int. (Enclosed)	Gopeng Int. (Opened)	S. Yusuf Rd. (Enclosed)	Gopeng Rd. (Opened)	Lahat Road (Enclosed)	Pasir Puteh Rd. (Opened)
Max.CO (ppm/hr)	24.83	12.33	8.71	2.19	6.68	6.8
Mean CO (ppm/hr)	12.95	7.8	6.78	1.30	4.49	2.57
Max. SO_2 (ppm/hr)	0.99	0.73	NA	NA	NA	NA
Mean SO_2 (ppm/hr)	0.52	0.36	NA	NA	NA	AN
Max. Traffic volume (pcu/hr)	2510	2493	2629	1940	2203	1952
Mean. Traffic volume (pcu/hr)	1734	1907	2258	1705	1752	1567

Note : NA ; Data not available.

The results also indicate that the lowest CO concentration was recorded at an open area for all driving modes. The significant differences between an open and an enclosed surrounding at all driving modes show that the buildings surrounding the location have influence on the concentration of CO. In details, at the enclosed area of an idling zone, the average concentration of CO was found to be more than double times higher than at an open space for the same zone even with approximately similar traffic flow. This indicates that the high traffic volume and the buildings along Perhentian Intersection may give higher impact on the level of pollutant compared to Gopeng Intersection, which is in an open space. The maximum concentration of CO at the cruising region of an enclosed and open area, which are at Lahat Road and Pasir Puteh Road, are about equal to a similar hourly average traffic passenger car unit. It can therefore be safely concluded that the concentration of CO is lower at the cruising zone and higher at the intersections. The descriptive statistics analyses obtained from this study also shows that the degree of scatter representing dispersion in the study was high at an intersection compared to the open cruising section. The differences of statistical results at the three open space areas seem to indicate that there are other factors affecting the levels of pollutant.

The SO_2 concentrations obtained from the analysis indicate the significant differences in pollutant levels between the enclosed and an open surroundings. Higher SO_2 at the enclosed background indicate that the buildings along the road give impact of the trend of the pollutant. The impact of the high volume of diesel vehicles passing through this location has increased the SO_2 level in this area and may possibly be another influencing factor.

3.2 General relationship between pollutants and traffic volume.

Although inferences of the general effect of the traffic flow can be drawn from simple inspection of the data, quantification of the relationship between the various parameters provides a more detailed description of the variation in pollutant concentrations at this site.

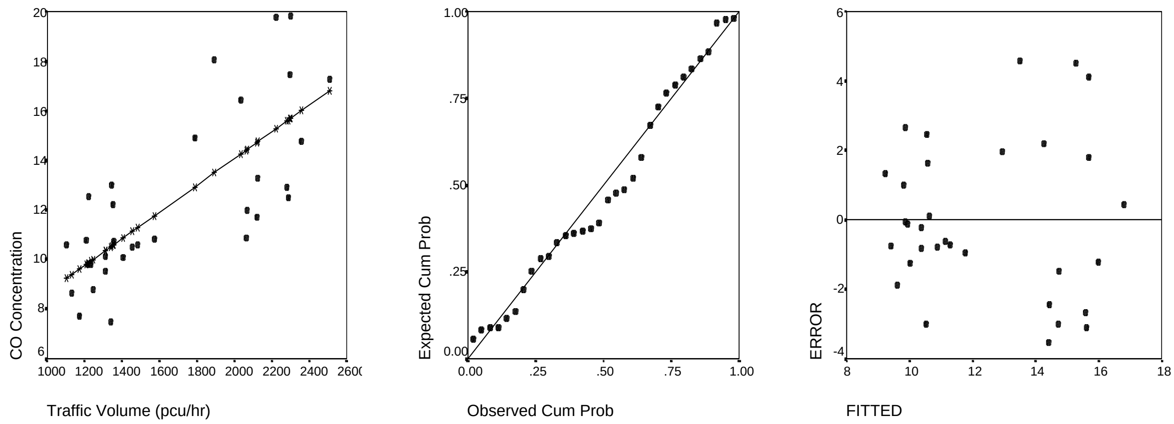
The linear regression analysis has been used to analyze the relationship between two variables. The method of least square has been used as a tool to estimate the relationship between the traffic volume and to predict values of the pollutant. For least squares estimation to yield reliable estimates of β_o and β_1 , the following must be true about error **(ε).** The random disturbance are normal with zero mean, homogeneous and independent. In order to use the estimates for consequential decisions, there was a need to further check that the estimates are unbiased and otherwise reliable. The least squares method will yield unbiased, consistent, and efficient estimates when certain conditions are true. Therefore, examination using residual technique to differentiate between our estimated regression line and the observed y value was done.

3.3 Traffic Volume and Carbon Monoxide Mathematical Model.

Figure 1a to Figure 6a show the scatter plot and the regression line or curve obtained from the regressions analyses between CO concentration (parts per millions) and traffic volume (passenger car unit).

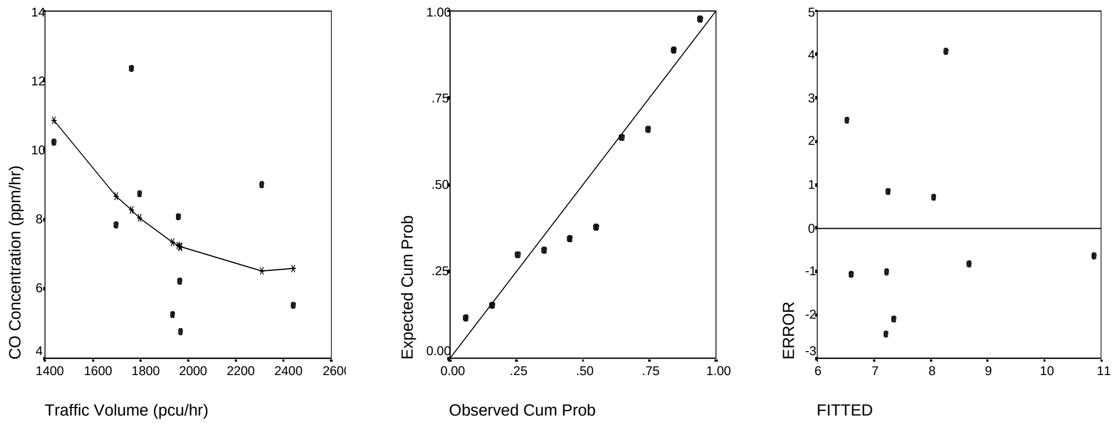
Table 5 summarizes the regression result of this study. The best values of R^2 (coefficient of determination) of this study is 0.71 which is for an opened acceleration area. This shows that the goodness of fit of the line obtained from the analysis is accepted since the R^2 values are above 5. While the weak relationship for an closed acceleration and opened intersection area shows that there are other factors influence the CO concentration. The equations obtained from the analysis are also given and can be used to predict CO concentration at the other locations.

The residual analyses are shown in Figure 1b and 1c to Figure 6b and 6c respectively.



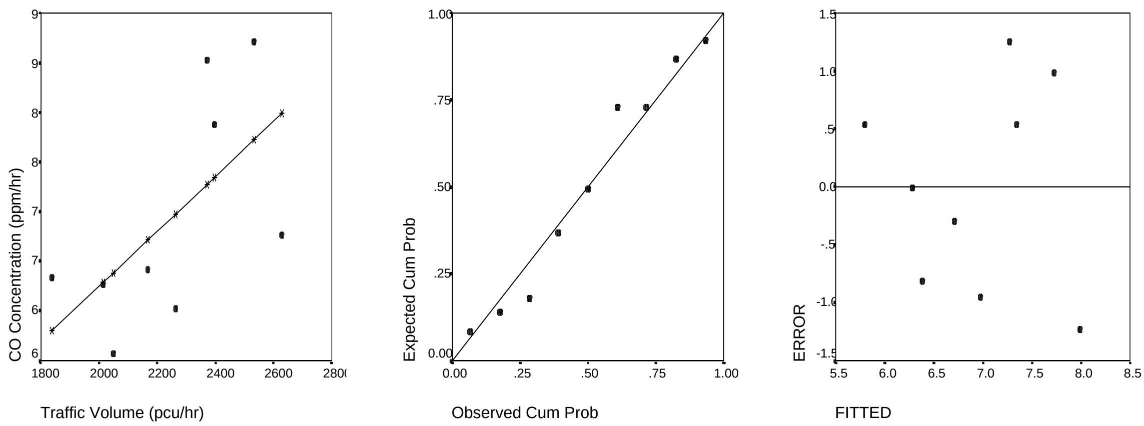
(a) (b) (c)

Figure 1: Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Idling Mode in an enclosed area a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



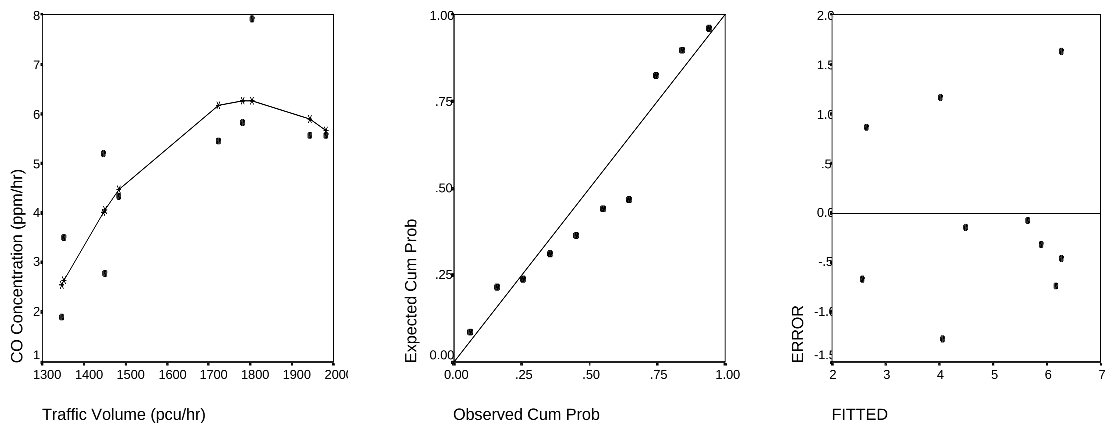
(a) (b) (c)

Figure 2 : Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Idling Mode in an opened area. a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



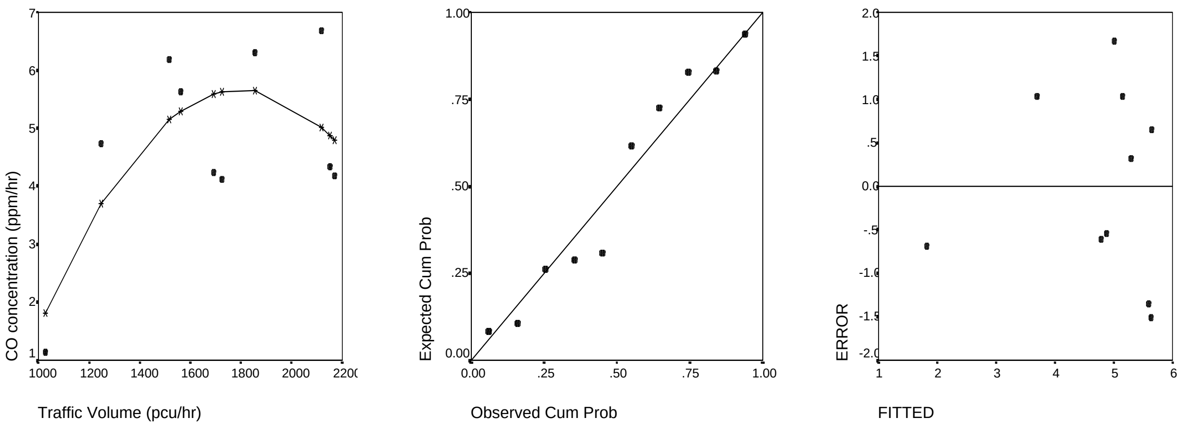
(a) (b) (c)

Figure 3: Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Acceleration Mode in an enclosed area. a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



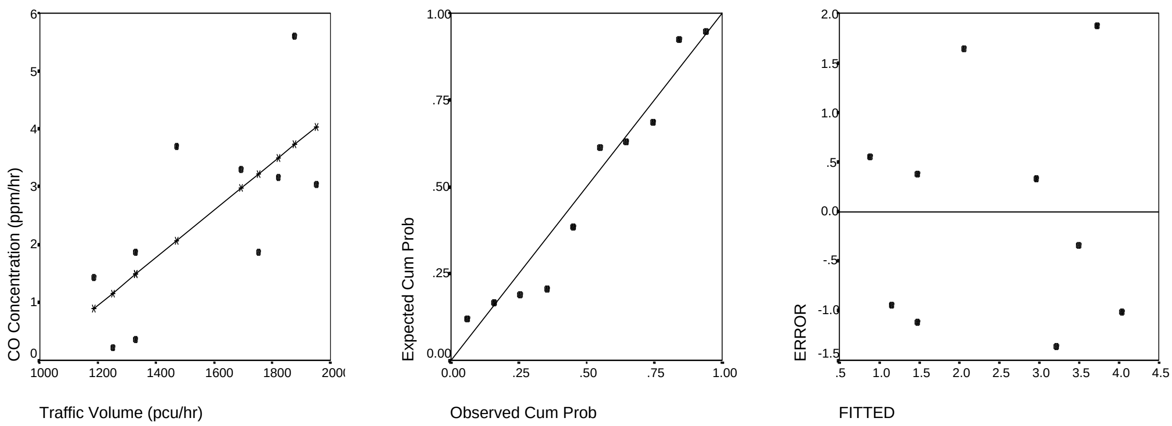
(a) (b) (c)

Figure 4: Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Acceleration Mode in an opened area. a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



(a) (b) (c)

Figure 5: Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Cruising Mode Closed in an enclosed area. a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



(a) (b) (c)

Figure 6: Relationship between CO concentration (ppm/hr) and traffic volume (pcu/hr) for the Cruising Mode in an opened area. a) Scatter plot for observed CO and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.

Table 5: Regression analysis for Carbon Monoxide model results.

Sites	R	R^2	Equations
Closed Intersection	0.74	0.55	$CO= 5.4 \times 10^{-3}T + 3.13$
Open Intersection	0.53	0.30	$CO=-0.026T +5.56T^2 + 36.44$
Closed Acceleration	0.63	0.40	$CO=0.03\ T + 0.70$
Open Acceleration	0.84	0.71	$CO=0.065\ T - 1.81 \times 10^{-5}T^2 -52.43$
Closed Cruise	0.73	0.53	$CO=0.023\ T - 6.44 \times 10^{-6}T^2 - 15.22$
Open Cruise	0.71	0.50	$CO=0.004\ T - 4.0$

Keywords: CO : Carbon Monoxide concentration, hour average,(ppm)
T : Traffic flow (passenger car unit) per hour

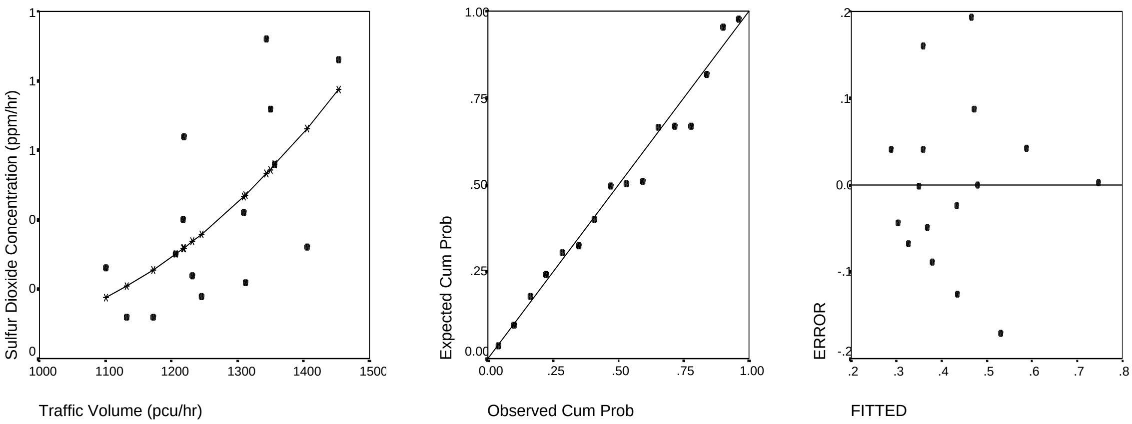
3.4 Traffic Volume and Sulfur Dioxide Mathematical Model.

Figure 7a to Figure 8a show the scatter plot between SO_2 concentration in parts per millions and traffic volume in passenger car unit. According to the regression, differences of traffic volume are approximately between of the variation in SO_2 concentration at the two locations. Table 6 summarizes the regression results of this study. The Quadratic equations obtained from the analyses are also given and can be used to predict the SO_2 concentration since the R^2 of the model shows more than 5. The residual analyses are shown in Figure 7b and 7c to Figure 8b and 8c respectively.

Table 6: Regression analysis for Sulfur Dioxide model results.

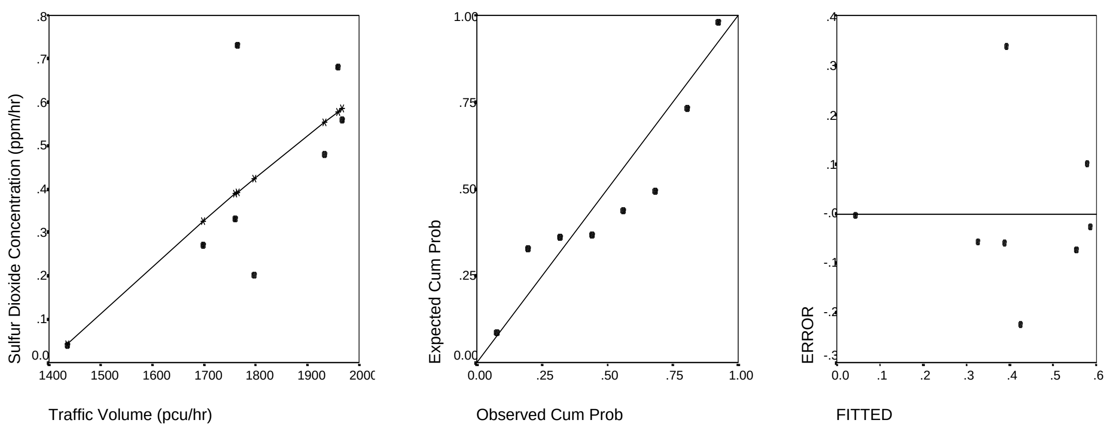
Sites	R	R^2	Equations
Closed Intersection	0.77	0.60	$CO = -0.002\,T + 1.0 \times 10^{-6}T^2 + 1.03$
Open Intersection	0.74	0.54	$CO = 0.002\,T - 2\times10^{-7}T^2 - 2.0$

Keywords: CO : Sulfur Dioxide concentration, hourly average,(ppm)
T : Traffic flow (passenger car unit) per hour



(a) (b) (c)

Figure 7: Relationship between SO_2 concentration (ppm/hr) and traffic volume (pcu/hr) for the Idling Mode in an enclosed area. a) Scatter plot for observed SO_2 and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.



(a) (b) (c)

Figure 8: Relationship between SO_2 concentration (ppm/hr) and traffic volume (pcu/hr) for the Idling Mode in an opened area. a) Scatter plot for observed SO_2 and Traffic Volume. b) Normal P-P Plot of Regression Analysis. c) Scatter plot of the estimated values.

3.5 Applicability of the model.

The effort to understand the behavior and characteristics of pollutant emission due to traffic promises many opportunities to integrate environmental issues with transport planning. Supporting the sustainable transport agenda, the models will become handy transport planning tools. The models, linking pollutant emission to traffic models allow environmental impact analysis to be undertaken, once traffic flow is forecast using the conventional demand models.

In the case provided by this paper, subsequent to the demand models predicting traffic movements at intersections, transport analyst and planner will now be able to have a feel on the environmental impact it will also bring. No doubt, that this is not something new, but to date such modeling for Malaysia has not been possible. Therefore, this work will allow at least for demand models developed elsewhere to be calibrated to Malaysian conditions including for the environmental impact module. This work shall also lead towards integrating environmental concerns with the intelligent transport system.

4. CONCLUSION

Analysis of the carbon monoxide and sulfur dioxide data for the different locations showed significant differences between characteristic of vehicle operation (idling, accelerating and cruising) at an enclosed and an open surrounding. The differences can be attributed to a combination of factors. The situation at intersections and in enclosed sites would contribute more to the pollution level as compared to the cruising zone. The high CO concentration measured at the closed intersection situation can be attributed to a high rate of CO emission from idling engines of vehicles and even much higher where streets are sheltered by surrounding buildings. The high level of SO_2 at the curbside are probably much greater than that of an equal quantity from a utility stack or industrial boiler, since motor vehicle exhaust is emitted close to ground level near roads, buildings and at people's breathing height. High concentration occurred when traffic volumes were moderate to heavy. However it was also observed that the large volume of traffic using the road created a great deal of local air turbulence and it was likely that this air turbulence movement was a major factor in causing dispersion over the relatively short distances considered in this study.

Improvement to the study would be to consider more elaborate treatment of traffic flow and queuing, to include meteorological factors and to study the relation of tailpipe emissions to the air pollution. The study on the fuel consumption also might be useful in order to reduce the pollutant. Since the pollutant level is significantly related to the meteorology factor, subsequent work will investigate how wind factors influence air pollution at these sites.

These suggestions and suggestive enhancements require better understanding of traffic behaviour, emissions trend and dispersion process. A bigger challenge, though, will be the collection of more data and funding. As a developing country it is wise to carefully plan infrastructure investment plans and to adopt increasingly severe rules for vehicles movement, traffic management and traffic air quality assessment. To facilitate these actions, it is urgent that data and similar models that are relevant to cities within the country be developed.

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