Pollutant concentration profiles in vehicular road tunnels

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Abstract: - The objective of this study is to investigate the vehicle exhaust gaseous pollutant profiles in road tunnels using two sets of data, one from a field survey and one from routine fixed monitoring stations. Pollutant profiles are very useful in estimating vehicle emission factors. It is found that the pollutant concentration profiles can be developed by using the relative slope of the two sets of data. The angle between the two regression lines has a fix value and related strongly to the traffic volume.

Key-Words: - vehicle emission, CO, slope analysis, tunnel measurement

1 Introduction

Vehicular emission factors can be estimated using pollutant monitoring data obtained by the tunnel operators. However, the monitoring data were collected at a few fixed points well above ground in the tunnel. As the pollutant concentrations are only available at these monitoring points, i.e, discrete data, it is very difficult to apply certain popular statistical methods such as time series analysis to reasonable estimate the emission factors. Few points' measurement also leads to a problem of ignoring the variation of vehicle speed.

Despite the aforesaid, the tunnel operators have to collect data including air pollutant and traffic flow data in the management agreement. The fully use of tunnel data can help with long term monitoring of vehicle emissions. As such, this paper attempts to explore ways to convert the discrete data available at the fixed monitoring points to a continuous dataset along the entire tunnel length. To this end, it is logical to develop pollutant concentration profiles with a set of field data and calibrate the profiles with the monitoring data.

"Car flowing" and "car chasing" methods are adopted in the field data collection. An instrumented car is driven along the selected road tunnel. The instrumented car shall follow the front vehicle at a fixed distance in order to mimic the movement of the front vehicle. Kittelson et al. (2000) suggested "car chasing" technique can help with simulate more realistic traffic condition and pollutant concentration. Equipped with speed measurement instrument (such as micro-wave), the variation of traffic speed can be obtained. During "car chasing" experiment, gas pollutants were measured by portable gas analyzers.

2 Methodology

2.1 Sampling Location

The Lion Rock Tunnel in Hong Kong, a 1430m twin-bored toll tunnel, was opened to traffic in November 1967. It connects Sha Tin in the New Territories and Kowloon Tong in urban Kowloon Peninsula. It has two lanes in each direction, with toll booths located at Sha Tin end. The daily tunnel traffic volume is about 90 000 vehicles in 2005. Either north or south tube of LRT is closed for maintenance every weekday excluding public holidays from 1:30 am to 6:00 am. Traffic in both directions share one of the tunnels when the other undergoes maintenance works.

2.2 Data Collection

Field measurements were carried out in Lion Rock Tunnel between 9 and 15 January 2007. The traffic volume through the tunnel was manually counted for 15 min during every sampling hour by video system and student helpers. The speed of the instrumented vehicle was measured by a microwave speed meter and recorded second by second directly in a portable computer. The CO concentration was measured by a portable CO gas analyzer (Interscan Corporation, Series 4000). The detection range of this monitor is between 0 to 19.99 ppm, with resolution equals to 0.01 ppm. Before field work sampling, the instrument was calibrated by introducing a known concentration of CO gas and adjusting the span control to its proper level. The air outside of the car was sampled through a tube that stretched outside of the car through a window.

3 Results and discussion of field data

The average traffic volume in sampling period is shown in Table 1. The average traffic volume within sampling hour varied from 1994 veh/h to 2964 veh/h. Both tubes have relatively low average traffic volume in afternoon period for weekdays. For north tube, weekend sampling period do not have significant difference in traffic volume except morning period have recorded a 20% dropped. In south tube, the morning period and evening period have no significant change between weekday and weekend, but there is 17.7% increase in weekend afternoon period by compared to weekday.

The CO concentration inside the tunnel was measured in each survey trip, the average CO concentration from field work were used to compare with the data obtained by Tunnel Management Company. Tunnel Management Company obtained

Table 1: Average traffic volume in sampling period

To Shatin (North tube)						
	Weekday			Weekend		
	08:00-09:00	11:00-12:00	18:00-19:00	08:00-09:00	11:00-12:00	18:00-19:00
Sampling hour	5	5	5	1	1	2
Traffic volume (vehicles/h)	2553	2153	2746	1994	2089	2606
To Kowloon (South tube)						
Traffic volume (vehicles/h)	2964	2458	3023	2244	2354	2378

the pollutant concentration data for every 300m. The receptors were located at 10m above ground. The mean and range of hourly CO concentration of tunnel data and field data were plotted at figure one to three.

The average CO concentration obtained by field work varied from 0.14 ppm to 4.73 ppm. And the hourly average CO concentration obtained by Tunnel Management Company varied from 0.61 ppm to 7.82 ppm. As shown in above, the tunnel data always give a higher reading than remote field data. The variation of CO concentration in both tunnel data and field data has linear relation to the distance away from entry. One of the most common ways is to model CO concentration by linear regression, similar approach have been undertaken in tunnel data and field data. Linear regression model is used for modelling CO vs. location of receptors. For each trail of study, two regression lines are formed. The angle between two regression lines can be calculated by formula 1.

$$\tan\theta = \frac{m_1 - m_2}{1 + m_1 m_2} \qquad (1)$$

where $\theta =$ the angle between two regression line, $m_1, m_2 =$ the slope of tunnel regression and field regression respectively.

The average angle between two regression lines for the morning period and evening period were 22.6 degrees 21.6 degrees respectively. In afternoon period, the average angle between two regression lines was 30.2 degrees. The standard error of both three study period were not excess 2.8 degrees. Before further analysis can undertake, grouping of data were needed.

Chang and Rudy (1990) suggested ventilation rate was one of the major factors that affect pollutant concentrations. According to the tunnel management company, ventilation rate depends on traffic volume, eight units of fresh air supply fans and two units of exhaust air fans would be operated at high speed within the tunnel peak hour. Each unit of the supply / exhaust air fan has a volume flow rate of $47.2m^3/s$ and $80m^3/s$ respectively when operation at high speed.

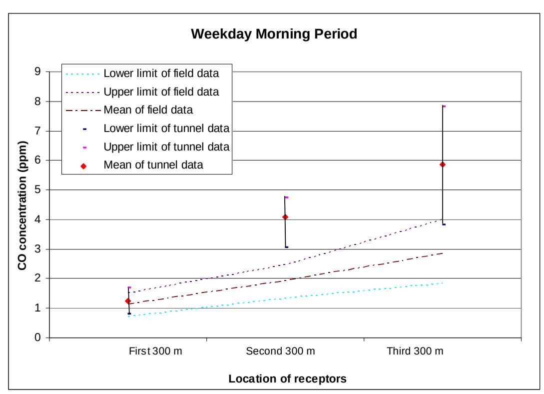


Fig 1. Variation of CO concentration in weekday morning period

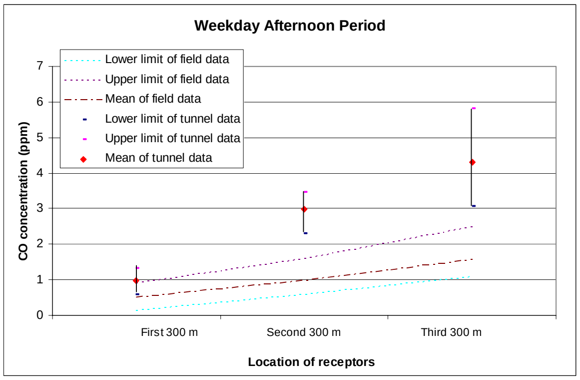


Fig 2. Variation of CO concentration in weekday afternoon period

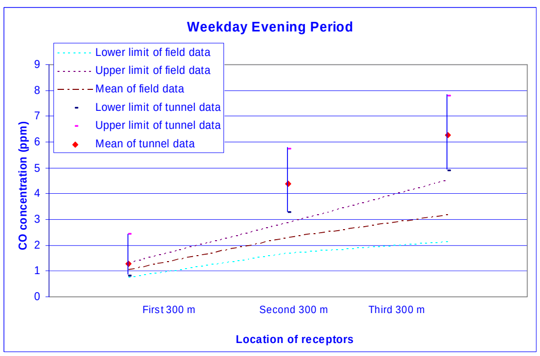


Fig 3. Variation of CO concentration in weekday evening period

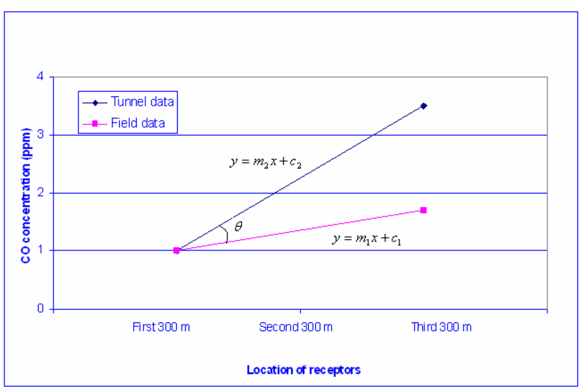


Fig 4. Angle between two regressions

Chan et al. (1996) suggested pollutant concentration is direct proportion to traffic volume, this may leads to significant relationship between the angle (θ) and traffic volume. Chaney (1978) suggested concentration of pollutants is highest in low speed. The remote receptor may beneficial by longer exposing time to obtain a higher concentration reading which leads to a smaller angle (θ). The hypothesis here is that the angle between two regression lines may be strongly influenced by the number of vehicles per hour. In order to test the hypothesis, cluster analysis is used. Cluster analysis should use for grouping objects of similar kind into respective categories and discovers structures in data. The angles (θ) were first allocated into two groups by traffic volume, for more than 2500 veh/hr will be classified as group one, otherwise group two. Then statistical software SPSS was used for separating the data into two main cluster groups by mean cluster analysis method, and the result shows in table 2. The table shows there are only two out of thirty were not follow the assumption, the final cluster centre for group one and group two is 21.86 and 29.90 respectively. As over 93.3% of data were allocated into the same group as hypothesis, there should have high correlation between the angles (θ) and traffic volume.

Table 2. Result of two main cluster groups

	Group1 (> 2500 veh/hr)	Group2 (< 2500 veh/hr)
By traffic flow	21	9
By Cluster method	19	11

4 Validation

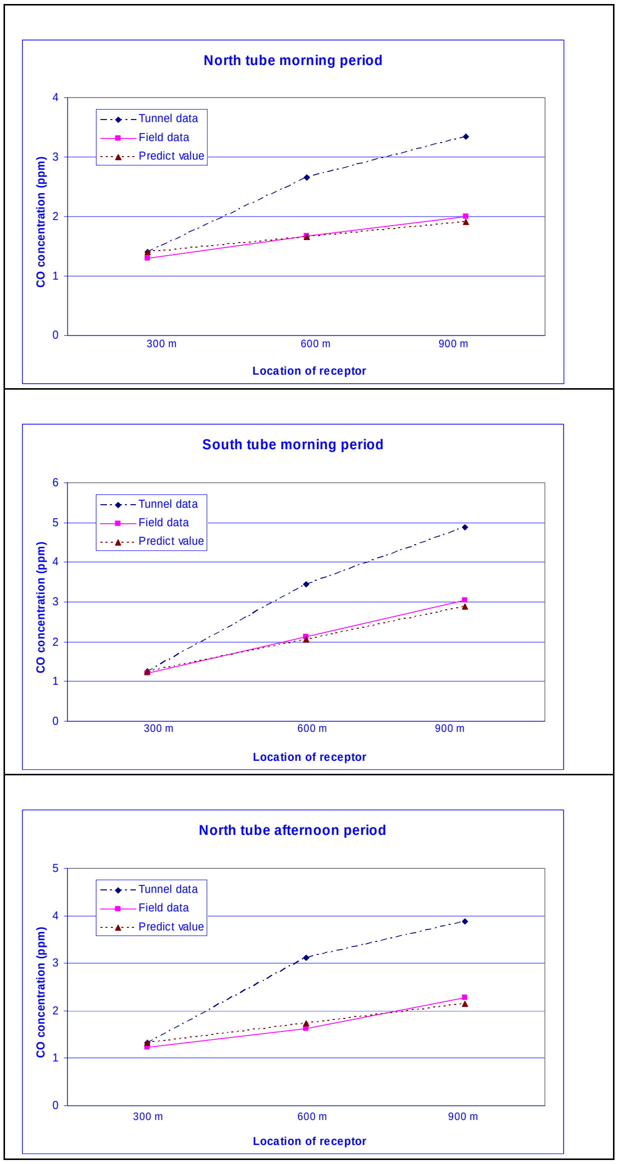
Cluster centre of each group should be used as the prediction angle between two regressions, fix ratio of each group can be simply calculated by tangent of angles. The fix ratio of group one and group two are 0.401 and 0.575 respectively. Tunnel data in 13th January, 2007 was used for testing the effeteness, the slope and traffic volume of tunnel data are listed in following table 3.

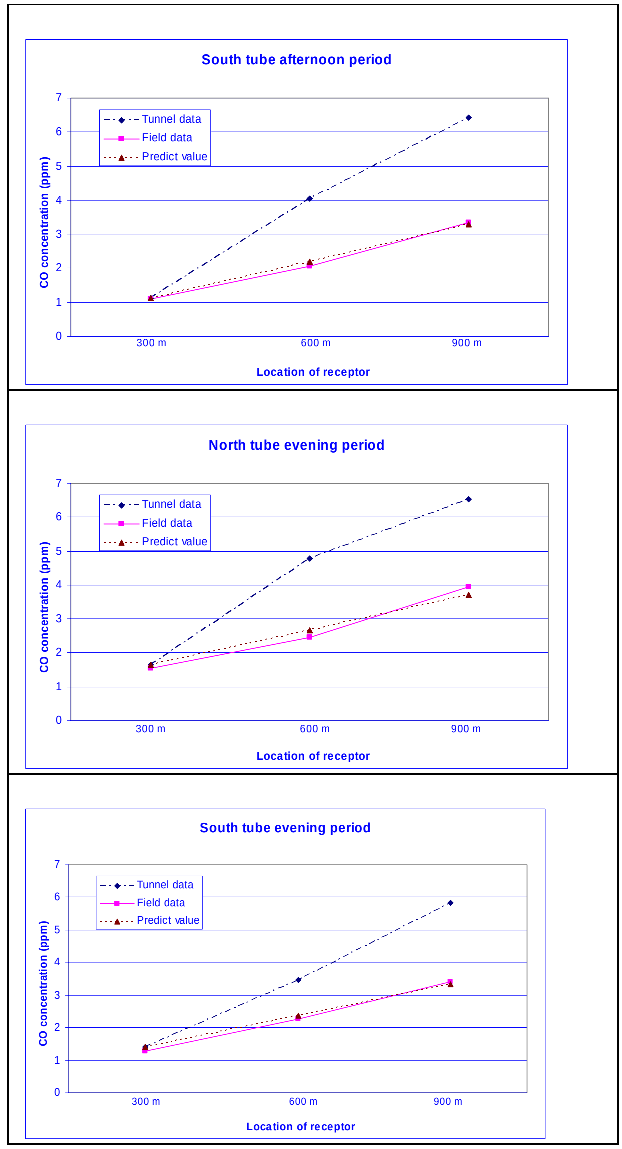
Table 3. The slope and traffic volume of tunnel data

		Slope	Traffic
Morning	North tube	0.9726	1994
	South tube	1.8192	2904
Afternoon	North tube	1.2714	2089
	South tube	2.6494	2873
Evening	North tube	2.4388	2845
	South	2.4124	3064

The slope of the estimate regression can be calculated by equation (1), the first point of tunnel data will be used with point-slope form for finding the liner equation of the estimate field trend. The estimated regression line was compared with the field measurement. Six cases were used for testing the effectiveness of method, the plots show that the estimated regression line is very close to the field measurement with no more than 9% difference. In both six cases, the estimated have a lower prediction value to the field measurement at the last point, the difference is between 1.35% and 5.83%.

Fig 5. Validation between simulation and field data of carbon monoxide





5 Measure error

The experiment suffers from random error, it consists of using portable CO gas analyzer for recording pollutant concentration. According to Clifford (1996), around 75% of total amount of pollution received from the car in front, the experiment result may affect by the type of vehicle which in front. For this reason, it is hard to state any firm conclusion of the fix angle between tunnel measurement and field measurement. In our case, cluster centre is being used for estimation. By reference to validation examples, I suggest the maximum estimate error is 10 percent.

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