

Spatial Patterns of CO Vehicular Pollutant in Macao Peninsula

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Abstract:

This paper describes a new approach to assess high-resolution Carbon Dioxide (CO) distribution for the peninsula of Macao Special Administrative Region (S.A.R.). Firstly, two widely used vehicular pollution models, namely Danish Operational Street Pollution Model (OSPM) and United States intersection vehicular pollution model (CAL3QHC), were applied to evaluate the roadside CO concentration from vehicular emission. It was found that the OSPM was more suitable in this region. Therefore, the OSPM was adopted to simulate such pollutants in front of each building block in the Macao peninsula. Geographic Information System (GIS) was utilized to run all model cases and store the model results automatically. The spatial pattern of CO distribution in all the main streets of Macao peninsula was found and the influence of traffic loading was shown by a spatial comparison of the CO concentration and traffic loading.

1 Introduction

Carbon Monoxide (CO) of a city is usually reported from data collected by fixed monitoring stations located at various functional areas such as industrial, residential and roadside areas; and both urban and suburban zones. This may be suitable for simple geographic conditions where dispersion is simple. However, in urban area such as the peninsula of Macao Special Administrative Region (S.A.R.), one roadside monitoring station is insufficient to represent the whole functional area because of the variation of the height of buildings, traffic loading, etc.

A new approach was therefore proposed to access this CO ambient concentration in front of each building block in the main streets of the Macao peninsula by using modeling technique. Firstly, two widely used mathematical dispersion models, namely Danish Operational Street Pollution Model (OSPM) and United States intersection vehicular pollution model (CAL3QHC), were applied to evaluate the roadside CO. In comparison with the CAL3QHC, the OSPM was found to be more suitable for this region. Therefore, the OSPM was adopted in this paper to estimate CO vehicular pollutants. To represent the whole functional area well, hundreds of roadside receptors located in front of each building block in the main streets would require to be monitored. Hence, an automatic technique was preferred. In this paper, the OSPM was integrated with the Geographic Information System (GIS) to model all cases automatically. The spatial pattern of CO concentration in all the main streets of Macao peninsula was found. Finally, traffic loading influence on the CO concentration was analysed spatially under the GIS platform.

In Section 2, the OSPM and the CAL3QHC were introduced and the corresponding theoretical background was given. These two models were tested for identifying their applicability in the Macao peninsula. In Section 3.1, the method of integrating the OSPM with the GIS is proposed; in Section 3.2, the results of CO distribution are shown and discussed. Conclusions are outlined in Section 4.

2 Evaluation of Dispersion Models

2.1 The CAL3QHC and the OSPM

Two main factors of street level vehicular pollutants in Macao peninsula are the idle emission from vehicles (related to the traffic jam condition happened frequently at busy hours) and the street canyon dispersion condition (related to the spatial geometry of streets and buildings). The Macao

peninsula is one of the highest traffic density cities in the world. Idle emission from vehicles is hence typical in this region. Idle emission is important since it is much larger than free flow emission. Street canyon condition, which prevents the ventilation of vehicular emission, is typical also. Therefore, two vehicular pollution models focused on each condition were chosen for evaluation. They were the CAL3QHC model -- an intersection vehicular pollution model (United States Environmental Protection Agency (U.S. EPA), 1995) and the -- the Operational Street Model --OSPM (Berkowicz et al, 1995a, b), a street canyon vehicular pollution model.

The CAL3QHC was chosen since it had the best performance among eight intersection models (U.S. EPA, 1995). It is a versatile dispersion model to predict carbon monoxide or other inert pollutant concentrations from motor vehicles at intersections near highway and arterial streets. The model includes the CALINE3 line source dispersion model (Paul, 1979) and a traffic algorithm for estimating vehicular queue lengths at signalized intersections. The CAL3QHC is then applicable to estimate air pollution during traffic jam conditions in the Macao peninsula.

The Danish OSPM model is widely used in Europe. It is based on similar principles as the CPB-model by Yamartino and Wiegand (1986). Vehicular pollutants inside a street canyon are calculated using a combination of a plume model for direct contribution and a box model for the recirculation portion. Parameters of flow and dispersion conditions are deduced from extensive analysis of experimental data and model testing (Berkowicz et al, 1995a, b). Comparison of the two models are given according to Berkowicz et al. (1995a, b), Paul (1979) and US EPA (1995).

The spatial data requirement for air pollution modeling is important since it indicates the modeling and output resolution. Geometry of all intersection lanes are required in the CAL3QHC as it estimates the pollutant at the intersection. A series of receptors can be placed along the kerbs. As the dispersion estimation bases on the flat surface geographical environment, only a user specified surface roughness coefficient is used. It ranges from 0.03cm to 370cm, representing smooth surface to residential apartment conditions. Since the OSPM focuses on estimating a single urban canyon street, two receptors are located to represent the condition of windward side and leeward side. The input requirement for determining the street canyon parameters includes the heights and locations of nearby buildings as well as the direction of the street. The OSPM required more spatial data and hence, as shown in later sections, proved to be more reliable than the CAL3QHC for the urban situation of the Macao peninsula.

2.2 Theoretical Analysis of the CAL3QHC and the OSPM Models

The CAL3QHC separates emissions into two parts: the emission from free flow condition during the green signal and the queue condition during red signal. The emission factor for the free flow is user specified. By the approaching traffic flow, the growing of the queue lane is estimated and the emission is calculated by a specified idle emission factor, which is much larger than the classical free flow emission factor. Estimation is then carried on under the approach condition and the Under-Saturated/Over-Saturated Conditions. The OSPM does not require the idle emission because the queue lane concept is not applicable here. However, the hourly average speed of the vehicle is required and the corresponding emission variation for each type of vehicles can then be adjusted.

The CALINE3 (Paul, 1979) is the dispersion component of the CAL3QHC. It estimates vehicular emission as a "line source" which disperses in a Gaussian distribution. The horizontal dispersion parameter at 3 meters away from the highway is:

$$\sigma_{z1} = (1.8 + 0.11 \times TR) \times (ATIM/30)^{0.2} \quad (1)$$

where $ATIM$ = averaging time; TR (residence time) = W_2/U ; W_2 = highway half width; and U = wind speed:

$$\sigma_{y1} = AY1 \times (ATIM/3)^{0.2} \times (Z0/3)^{0.07} \quad (at\ 3m) \quad (2)$$

$$\sigma_{Y10} = AY2 \times (ATIM/3)^{0.2} \times (Z0/3)^{0.07} \quad (at\ 10km) \quad (3)$$

$$\sigma_{Z10} = AZ \times (ATIM/3)^{0.2} \times (Z0/3)^{0.07} \quad (at\ 10km) \quad (4)$$

$AY1$ and $AY2$ are σ_y at 3m and 10 km; AZ is σ_z at 10km. Finally, σ_y and σ_z can be obtained in Pasquill power curve approximation between 3m and 10 km.

The OSPM uses a simplified parameterization of flow and dispersion conditions in a street canyon. Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the re-circulating part of the pollutants in the street as,

$$C_{st} = C_d + C_r \quad (5)$$

where C_{st} is the total concentration; C_d is the direct gauss plume dispersion by traffic emission; C_r is the re-circulating part of the pollutants in the street. For direct gauss plume dispersion, concentration from the line source is

$$dC_d = \sqrt{\frac{2}{\pi}} \frac{dQ}{u_b \sigma_z(x)} \quad (6)$$

where u_b is the wind speed at the street level; $\sigma_z(x)$ is the vertical dispersion parameter at a downwind distance x as,

$$\sigma_w = \sqrt{(\alpha u_b)^2 + \sigma_{w0}^2} \quad (7)$$

$$\sigma_z(x) = \sigma_w \frac{x}{u_b} + h_0 \quad (8)$$

σ_w is the vertical turbulent velocity fluctuation; α is a constant; σ_{w0} is the traffic created turbulence; h_0 is the initial dispersion in the wakes of the vehicles. C_d can then be calculated by integrating along the wind path. C_r is modeled by a simple box model. The inflow rate per unit length is as follows:

$$Q_{inf\ low} = \frac{Q}{W} L_1 \quad (9)$$

$$Q_{outflow} = C_r (\sigma_{wt} L_2 + u_t L_3 + u_b L_4) \quad (10)$$

where L_1 is the width of the recirculation zone; L_2, L_3, L_4 are related to the canyon geometry; σ_{wt}, u_t, u_b are the velocities at the top, upper half of the side edge and lower half of the side edge. As the inflow rate is equal to the outflow rate, C_r can be obtained.

2.3 Experimental Evaluation

An air pollution monitoring station in Rua de Campo (Figure 1) was chosen as experimental site representing roadside situation in commercial/residential areas. This is a typical heavy traffic lane with flow up to 4000 vehicles per busy hour and is 35 degree clockwise from the North. The station locates inside Calçada do Poco, about 10 meters northwest to Rua de Campo at 2 meters above ground level.

One-year Carbon Monoxide (CO) monitoring data from Aug. 1999 to Aug. 2000, excluding non-working days, were used to evaluate the dispersion models the CAL3QHC and the OSPM. Two comparison charts were constructed in Figure 2 and Figure 3: the x-axis represented the monitor

data obtained from the station and the y-axis represented the modeled values by the CAL3QHC and the OSPM respectively.

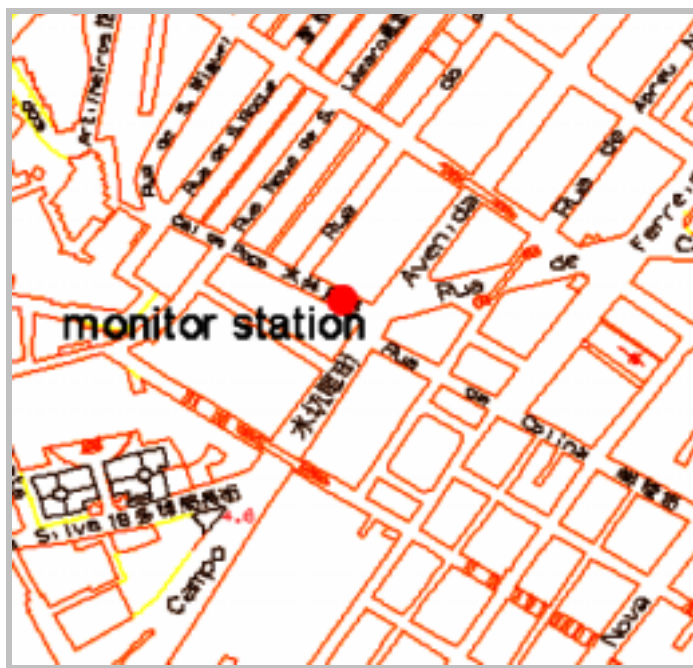


Figure 1 The experimental site for roadside condition at Rua do Camps of Macao

Figure 2 shows that the distribution of the points mostly located under the diagnose line. This pattern indicated a lower model values obtained in general, especially for the zone of high concentration monitoring data. The correlation coefficient of the model values by the CAL3QHC and monitoring data from the station was 0.46. On the other hand, the OSPM model values were distributed symmetrically of the diagonal wherever in the zones of low monitoring data or the high monitoring data as shown in Figure 3. An acceptable correlation coefficient of 0.63 between the OSPM model values and station monitoring data was obtained. The results showed that choosing the correct atmospheric dispersion type was more important than the detail traffic simulation for the urban situation of Macao peninsula and hence the OSPM was chosen.

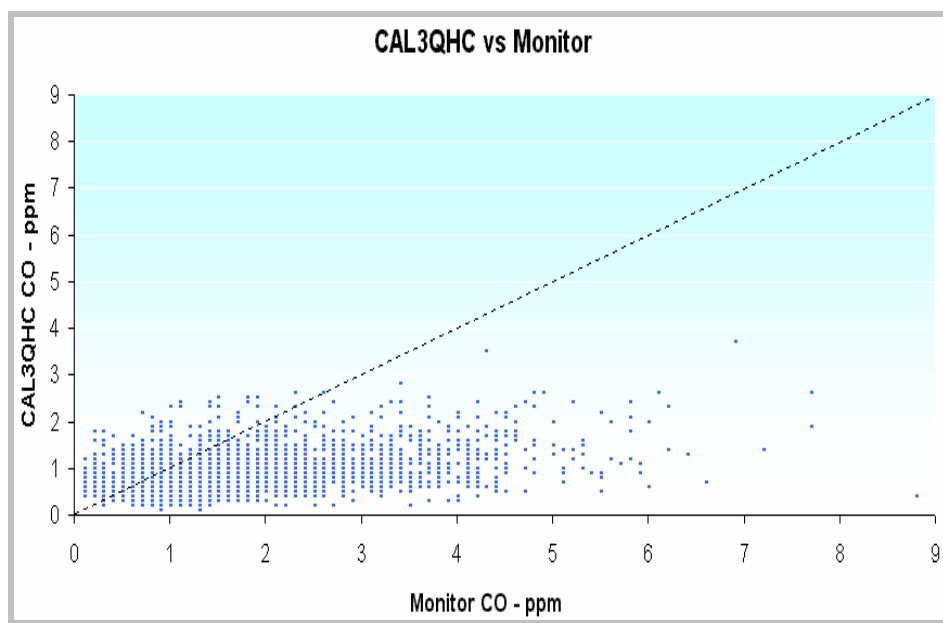


Figure 2 One year monitor vs. model pollutants the Cal3QHC

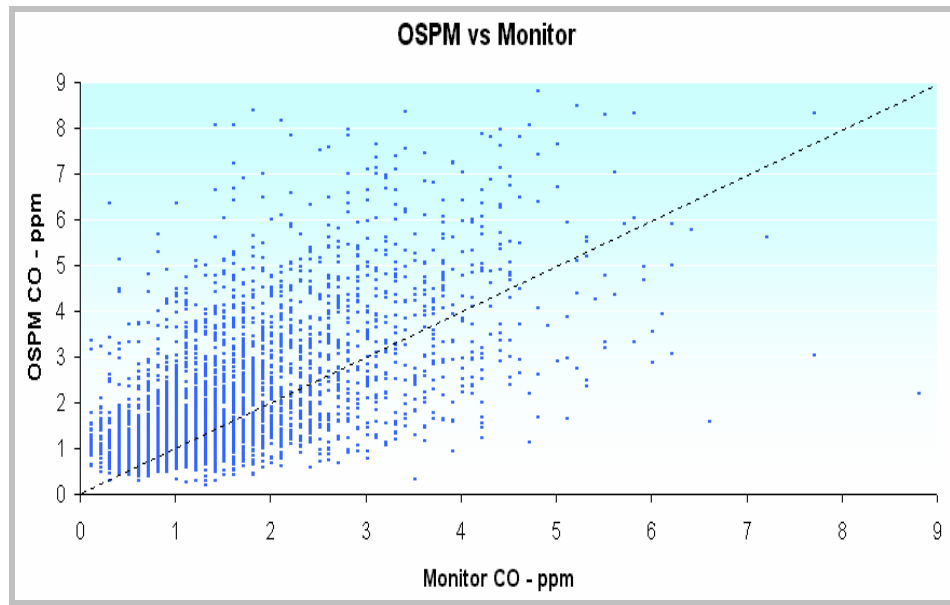


Figure 3 One year monitor vs. model pollutants the OSPM

3 Spatial Patterns of CO Vehicular Pollutants

3.1 Conceptual Framework for the OSPM/GIS Connection

Modelling all cases within this region manually was time-consuming and human-error-inducing. GIS was then utilized successfully to overcome such problem according to the proposed idea of solving the same problem by *Jensen S. S. (1998)*. This concept was then applied in Macao S.A.R. to access the spatial distribution of vehicular pollutant.

The research to access the spatial distribution of vehicular pollutant by applying this concept in Macao S.A.R. was started at the end of 1998 and ArcView with Avenue program was used then. The framework of connection allowed programs within GIS to produce the necessary information for the input file of exterior model. ArcView GIS then executed user written internal program in order to obtain a properly spaced input file and then exterior model could be executed. The exterior model output was then imported back into GIS for spatial analysis.

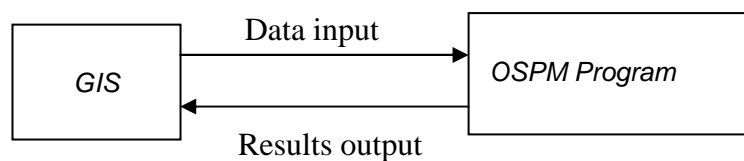


Figure 4 Process of integration the OSPM into GIS

Through out the integration, Avenue was used for programming within ArcView in order to:

- a) extract the spatial data from the base map of Macau peninsula within ArcView (such as building height and location, road width and direction etc. required by the OSPM;
- b) generate spatial input files according to the format requirement of the OSPM;
- c) control the execution of the OSPM in each model case;
- d) store the OSPM result in corresponding object in ArcView as a coverage.

3.2 Result and Analysis of CO Distribution

CO Distribution Classified by the Chinese National Air Quality Standard

A typical meteorological condition during summer time in Macao (south wind direction, 15 km/hr wind speed) was chosen for examining the general air quality distribution at busy hours. Hourly CO concentrations were modelled and classified according to the Chinese National Ambient Air Quality Standards GB3095-96. This standard is classified according to three types of functional area: Type I area includes sightseeing area, environmental protection area and other special protection area; Type II area includes residential area, commercial, industrial, and rural areas.; Type III area includes special industrial area. Type I, II and III function areas should meet the requirements of Class I, II, and III air quality correspondingly (Table 1).



Figure 5 Modeled CO distribution (the values of 1/3, 2/3 and 3/3 of class I Chinese National Air Quality Standard requirements are displayed as white, gray and black dots respectively)

Table 1: Chinese National Ambient Air Quality Standard GB3095-96

Pollutants	Concentration mg/m ³			
	Period	Class I	Class II	Class III
CO	Hourly	10.0	10.0	20.0

As the tourist industry is an exclusive economic sector in Macao, fulfilling Class I is the ultimate goal. All the modeled CO concentrations in front of each building block in busy street were then classified according to the range of Class I air quality standards for the assessment of air quality. Results showed that all the receptors had modeled CO concentrations under the Class I requirements. Therefore, in figure 5, the concentrations fallen within 1/3, 2/3 to 3/3 of Class I requirements were represented by three classes of circle symbols with graduate colors from white to black. The distribution of CO showed that half of the locations exceeded 1/3 of the Class I CO requirement. The several highest polluted receptors with dark color were located.

CO Distribution Compare with Traffic Loading Distribution

Traffic loading dominates the CO emission intensity of automobile. The higher of traffic loading, the more CO pollutants emit by automobile. In order to find how this factor influencing the CO

distribution, a preliminary analysis was done under the spatial display capability of the GIS. In Figure 4, amounts of total traffic flows at busy hour were displayed by the heights of the gray 3D-strips over the streets. Levels of CO concentrations were shown by the heights of white 3D-columns.

This figure showed that in general, a higher concentration of CO was modeled when the traffic loading was high also. An apparent case was shown in the two linked streets aligned the same direction from the most southwest to the most northwest direction of Figure 4. The southwest street section is Rua doAlmirante Sergio (approaching to the Templo de A-Ma from the street Avenida de Almeida Ribeiro) and the northwest street section is Rua de Visconde Paco de Arcos (approaching the north district from the street Avenida de Almeida Ribeiro). Large differences of traffic loading were shown between the two streets sections because most of the traffic flow did not extend straightly to Templo de A-Ma but turned southeast to central district at the intersection of the street Avenida de Almeida Ribeiro. At the same time, large differences of CO concentration were shown between them as well. Such behavior was consistence in merely all the main streets with high traffic loading around the peninsula.

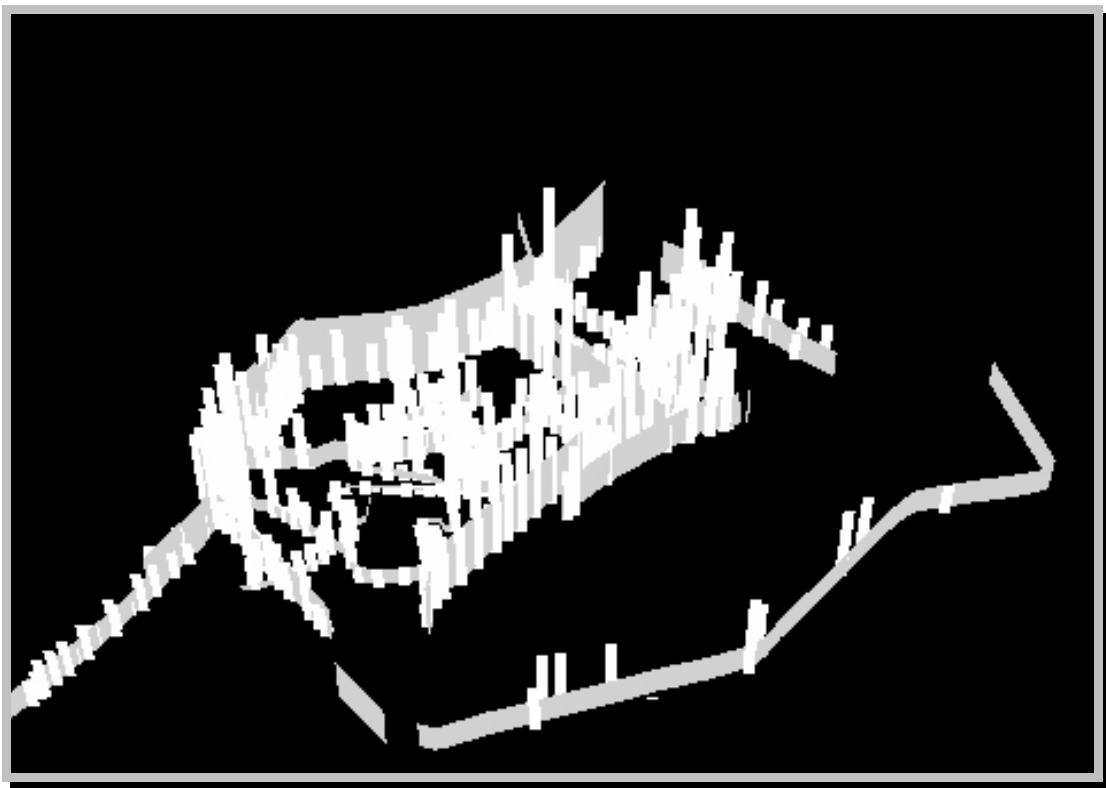


Figure 4 CO concentration vs. total traffic volume at busy hours. CO represented by the height of white 3D-column and total traffic loading represented by the height of gray 3D-strip

4 Conclusions

The OSPM model concerning street canyon dispersion was evaluated to be more reliable than the CAL3QHC model with Gaussian simulation for the Macao peninsula. Roadside concentrations of CO vehicular pollutant in front of each building block of Macao peninsula were then be found under the successful integration of the OSPM into ArcView GIS. Although results showed that all the receptors had modeled CO concentrations under the Chinese National Air Quality Class I requirements for the preliminary model condition, government should pay attention to those several locations with CO concentration within 2/3 to 3/3 of the requirement. The spatial patterns analysis between CO concentration and traffic loading showed that high traffic loading induced high CO concentration in merely all the main streets of the region. As the vehicle emission is

increasing significantly following the 75% increase of vehicles from 1993, reducing traffic registration number and controlling vehicle emission should be emphasized by the local government.

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