Jurnal Teknologi

Full paper

Effect of Vehicular Traffic Volume and Composition on Carbon Emission

Othman Che Puan*, Mustapha Mamadi Nabay, Muttaka Na'iya Ibrahim

Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: othmancp@utm.my

Article history

Received :26 May 2014
Received in revised form :
25 July 2014
Accepted :6 August 2014

Abstract

Road intersection is one of the causes of air pollution or toxic gases emission because at such location vehicular traffic are either required to slow down or completely stop for them to secure a safe and acceptable gap to perform a particular type of manoeuvre. The level of gaseous emissions usually increases with corresponding increase in traffic. The level of the environmental pollution depends on the type of intersection. This study evaluated the amount of carbon monoxide (CO) emissions from vehicular traffic for both morning and afternoon peak periods at roundabout and priority intersections. Carbon monoxide emissions at the intersections were first measured using GrayWolf Sensing Solution (GWSS) upon which the results obtained were used in calibrating SIDRA software for estimation of CO emission. SIDRA emission estimates were derived from traffic flow parameters; traffic volume, compositions, speeds and turning movements, as well as road geometry. Calibration factors were then derived in order to make SIDRA a reliable means for measurement of vehicle emission. Further, CO emissions traffic models were developed for the two types of intersections evaluated in this work for both morning and afternoon peak periods for two different observations periods (5 minutes and 1 hour traffic volumes) using multiple regression analysis. The models developed described how vehicular traffic volume and compositions affect CO emissions at road intersections. Further analysis revealed that roundabout is a better form of intersection as it reduces the amount of CO emission when compared to simple priority intersection.

Keywords: Traffic volume and composition; intersection; air pollution; CO Emission

1.0 INTRODUCTION

Road facility is regarded as the sole supply for drivers' demand. For situations where roadways are limited in terms of capacity; especially for high demand of the facility, traffic congestion is likely to occur. Owing to the fact that traffic volume increases faster than the road capacity, congestion level keeps rising despite the shift of trip makers to other modes of transportation. As traffic congestion increases, more fuel is consumed, and simultaneously more air pollutants are emitted. Traffic congestion with frequent stop and go situations causes substantial increase of air pollutants. Gaseous emissions from motor vehicles have variety of pollutants of which the common ones include carbon monoxide (CO), carbon-dioxide (CO_2), nitrogen oxides (NO_x), particulate matter (PM_{10}), hydrocarbons (volatile compounds) and ozone [1].

In Malaysia, three sources; i.e. mobile (motor vehicles), stationary, and open burning were identified as the major source of air pollution with a largest contribution of about 70 – 75% from vehicular traffic [2]. Ong *et al.* [3] also demonstrated that road transport has become a significant source of air pollution as well as one of the largest sources of emission in urban areas with subsequent harmful effects on human health. The Department of Environment, Malaysia [4] and Afroz, Hassan *et al.* [2] reported that emission from motor vehicles contributes over 70% to the total air pollution from all sources of which carbon monoxide being one of the common pollutants. In the year 2004, traffic alone contributed 98% to the entire carbon monoxide emission in Malaysia [5]. This considerable contribution of CO emission from just a source which increases on daily basis due to consistent increase in number of vehicles on our roads (particularly in urban centres) is alarming. The implication of the huge CO emission contribution to total air pollution in our environment is hazardous considering its negative effect on human health with the resultant increase in mortality rate [6]. Excessive air pollution endangers humans various diseases such as asthma, chronic lung diseases and nervous system defects [7]. Increase in the emission of CO from artificial sources (including vehicles) results in public health problem, especially to individuals within the vicinity of roadways; these are at high risk from CO emission from vehicles exhaust [8]. Other harmful effects of exposure to CO emissions could be found elsewhere [9-11].

Among road corridors, at-grade intersections common locations where emission CO is most pronounced as a result of frequent stop and go conditions at such locations. In queuing situation, idle vehicles emit nearly 7 times as much as CO as vehicles moving at a speed of 10 mph. Similarly, a stopped vehicle emits almost 4.5 times more than a vehicle traveling at a speed of 5 mph [12]. Several studies regarding CO and other pollutants emission at traffic intersections were conducted in many countries; few among reported the effect of intersection type on the amount of emission [13, 14]. Similar studies reported that there exist a direct relationship between vehicles emissions and traffic volume at urban intersections irrespective of the traffic control used [15, 16].

Having established that traffic intersections are the most contributing spots to CO emissions along roadways, an effort is therefore much needed to evaluate the effect of intersection type, traffic volume and its composition on the trend of carbon emissions at such locations in order to suggest appropriate carbon emission reduction measures as well as traffic management policies. This paper presents the application of *Signalised and Unsignalised Design and Research Aid* (SIDRA) software for estimating CO emission from traffic at roundabout and priority intersections by calibrating the software to suit local condition based on field direct measured CO emission using *GrayWolf Sensing Solution* (GWSS). Carbon emissions were estimated at the intersections based on easily observed traffic parameters as inputs into the SIDRA software and the results subsequently used in developing condition-based models for estimating CO emission for both morning and afternoon peak periods.

2.0 METHODOLOGY

2.1 Data Collection

Two sites within the vicinity of Universiti Teknologi Malaysia (UTM) were chosen for this study. The studied sites are; the roundabout along the main entrance and exit to UTM (*Jalan Universiti)* and the priority T-junction intersecting *Jalan Universiti* and *Jalan Meranti*. The study sites were chosen with a view to establish the baseline of the current situation regarding CO emission trend within UTM. This could probably aid the University management to propose and/or implement appropriate strategies regarding the current geometry of intersections, and traffic flow and compositions within UTM.

2.1.1 Traffic Parameters and Intersections Characteristics

A classified traffic volume count was conducted at the two intersections chosen for the study. Prior to the actual volume counts, preliminary counts were made at each of the intersections for the establishment of morning and afternoon peak periods being the desired study periods. A video recording system was employed for the data collection in which vehicles from the intersection approaches were video recorded and subsequently played back for extracting the respective classified traffic volumes from the individual approaches and flow rates for each of the turning movements. Traffic volume counts were made at the approaches' stop lines by observing the number of vehicles passing the point for the chosen study period as specified by the Highway Capacity Manual [17]. During the volume count, vehicles were classified into two classes; Light Vehicles (passenger cars, light vans and motorcycles) and Heavy Vehicles (trucks and heavy goods vehicles). Sample instantaneous speeds of approximately 300 vehicles were measured using radar gun at each of the intersections and the 85^{th} percentile established. Variables regarding the studied intersections characteristics and surrounding condition were also measured. These include the intersections geometric features and ambient temperature.

2.1.2 Measurement of Carbon-monoxide Emissions

Measurements of carbon-monoxide emissions at the intersections used in this study were carried out using two different methods: (i) GrayWolf Sensing Solutions (GWSS) method: GWSS is an advanced emission detection system based on the power of mobile and embedded computers for superior environmental test (survey) such as measurements of Indoor Air Quality (IAQ), toxic gases, ambient air condition, etc. (ii) Signalised and Unsignalised Intersection Design and Research Aid (SIDRA) software. SIDRA is traffic analysis software for various intersection analyses applications; of which emission detection and analysis model is one. While GWSS measures pollutants directly, SIDRA software requires inputs on traffic parameters, intersection geometric features and ambient condition to process and produce the amount of required pollutants. Even though both GWSS and SIDRA can be used for detecting various types of air pollutants or gas emissions, only carbon-monoxide was considered in this study being the common gas (a part from nitrogen dioxide, which was found to be negligible and thus discarded) between GWSS and SIDRA, and also a common type gas emission in Malaysia.

Due to the limitation that GWSS can only measure the air pollutants at the intersection without segregating the contributions from traffic and other sources (stationary and open burning), a modified approach was proposed for estimating the contribution from traffic alone. In this approach, emissions measurement was conducted at an isolated open field where the effect of traffic does not exist for both morning and afternoon periods. Results obtained from the open field measurements were then compared with those obtained at each of the intersections and the difference taken as the emission due to vehicular traffic.

As stated earlier, carbon emission was also estimated using SIDRA software by inputting the relevant variables into emission detection model. The estimated emissions from SIDRA software were compared with those from direct field measurement using GWSS method. This was carried out in order to validate the results estimated using SIDRA. On comparing the results from the two methods, a perfect linear relationship was expected for one method to be representative of the other. However, this was not the case; as such SIDRA was calibrated to establish a multiplier. This was done for each of the intersections studied. Regression analyses were subsequently run using Statistical Package for the Social Sciences (SPSS) to develop models for estimation of carbon emission for each of the intersections for the both morning and afternoon peak five minutes (5 mins). Further analysis was made by considering hourly volume estimated based on the peak 5 mins period volumes. Sensitivity analyses were also performed on the models developed for the 5 mins period for the two types of intersections.

3.0 RESULTS AND DISCUSSIONS

For the fact that the main objective was to evaluate the effect of traffic volume and composition on carbon emissions at intersections through the development of mathematical models for estimating the amount of emissions based observed variables at the intersections, a correlation analysis was conducted using Pearson's R to determine the degree of association between the independent variables (emission, traffic volume and vehicle classification). Results from the analysis revealed that the independent variables are not significantly correlated between each other and thus can be used in developing the model. This was supported by the low values of R for the both morning and afternoon periods for the two different types of intersections considered. Independent variables that show significant association between themselves were not used in developing the models. Tables 1 to 4 present the results of the analysis.

Table 1 Measure of association for afternoon peak for roundabout

Variables	V /5 mins	LV (Veh/5mins)	HV (Veh/5mins)
CO/5mins	-0.053	-0.053	0.019
V/5mins	1.000	1.000	-0.174
LV(Veh/5mins)	1.000	1.000	-0.188
HV(Veh/5mins)	-0.174	-0.188	1.000

Table 2 Measure of association for morning peak for priority junction

Variables	V /5 mins	LV (Veh/5mins)	HV (Veh/5mins)
CO/5mins	-0.379	-0.428	0.564
V/5mins	1.000	0.996	0.018
LV(Veh/5mins)	0.996	1.000	-0.071
HV(Veh/5mins)	0.018	-0.071	1.000

Table 3 Measure of association for morning peak for roundabout for 1-hr model

Variables	V /hr	LV (%)	HV (%)
CO/hr	0.829	-0.476	0.434
V/hr	1.000	-0.193	0.198
LV (%)	-0.193	1.000	-0.944
HV (%)	0.198	-0.944	1.000

Table 4 Measure of association for afternoon peak for priority junction for 1-hr model

Variables	V /hr	LV (%)	HV (%)
CO/hr	0.525	0.218	-0.218
V/hr	1.000	0.114	-0.114
LV (%)	0.114	1.000	-1.000
HV (%)	-0.114	-1.000	1.000

As mentioned in the preceding section that SIDRA was calibrated to establish a multiplier based on GWSS method; using the amount of carbon-monoxide emission from GWSS, calibration factors were established. Thus, for every unit of carbon-monoxide estimated by GWSS method, SIDRA would estimate the calibration factors for known traffic parameters for a particular type of intersection. The calibration factors for the different observation periods at the two intersections are presented in Table 5.

Table 5 Calibration factors for 1 unit of graywolf estimates

Type of Traffic Control	Period	Calibration Factors (SIDRA Vs GrayWolf)
Roundabout	AM	$45.405*10^6$
	PM	$92.429*10^6$
Priority Junction	AM	$59.608*10^7$
	PM	$33.901*10^7$

3.1 Carbon-monoxide Emission Models

Statistical technique using multiple regression analysis was utilized to develop models for estimating carbon-monoxide emission at intersections based on easily observable traffic flow parameters. Models were developed for the said purpose for both roundabout and priority intersections for both morning and afternoon periods for 5 minutes and 1 hour volumes respectively. Tables 6 and 7 present the models developed for the two intersections for 5 minutes and 1 hour periods respectively. Results presented in Table 6 show that the model developed for estimating CO emission at roundabout intersection for morning peak period is significant; implying that the independent variables have a significant effect on the dependent one. This is evidently confirmed by the value of F-statistics which is far greater than that of F-critical at 95% (α = 0.05) confidence level. However, the model for the same intersection for afternoon peak period was not found to be significant enough as the value of F-statistic is on the lower side of that of F-critical. This suggests that there is no convincing evidence that the independent variables have effect on the dependent variable for the period evaluated. For the same 5 minutes volumes for morning and afternoon peak periods, models were developed for estimating CO emission at priority intersection (Table 6). The resulting models were found to be significant as F-statistic values for the periods were both greater than those of F-critical ones.

Table 6 Regression models for 5-minutes volumes

Traffic Control	Period	Model	R^2	F-statistic	F-critical
Roundabout	AM	$CO = 0.964TVol - 0.940LV - 2.708$	0.830	22.003	0.0003
Roundabout	PM	$CO = -0.001LV + 0.012HV + 2.172$	0.300	0.013	0.998
Priority Junction	AM	$CO = -0.016LV + 0.247HV + 8.566$	0.469	3.976	0.053
Priority Junction	PM	$CO = 0.010TVol - 0.073HV - 0480$	0.316	2.076	0.182

Table 7 Regression models for 1-hour volumes

Traffic Control	Period	Model	R^2	F-statistic	F-critical
Roundabout	AM	$CO = 0.027TVol - 3248.613LV - 1410.629HV + 3210.988$	0.798	10.519	0.0004
Roundabout	PM	$CO = 0.004TVol + 45.590LV - 394.333HV - 7.057$	0.023	0.062	0.978
Priority Junction	AM	$CO = -0.012TVol - 1109.946LV + 1197.244$	0.458	3.805	0.058
Priority Junction	PM	$CO = 0.021TVol + 1510.306LV - 1363.840$	0410	3.117	0.088

The models developed for the 1 hour volumes were found to be consistent with those of 5 minutes volumes relative to the observation periods. Carbon-monoxide emission model at roundabout intersection for morning was significant (F-statistic > F-critical) while that of afternoon period was found to be insignificant (F-statistic < F-critical). On the other hand, emission models for priority junction were all found to be significant for both morning and afternoon periods. The trend portrayed by emission models for the 5 minutes and 1 hour volumes is not surprising as the data were observed under similar traffic conditions.

To further check the adequacy of the models, a sensitivity analysis was carried out on the 5 minutes volumes models on both roundabout and priority intersections (two tests for each of morning and afternoon periods) by inputting observed independent variables to predict CO emission. Tables 8 and 9 show the results of the analyses for roundabout and priority intersections respectively.

Table 8 Sensitivity analysis for roundabout for 5-mins models

Variable	Model 1 (AM)		Model 2 (PM)	
	Test 1	Test 2	Test 1	Test 2
Volumes	132	286	-	-
LV	132	285	99	291
HV	-	-	0	2
CO	0.46	5.096	2.073	1.905

Table 9 Sensitivity analysis for priority junction for 5-mins models

Variable	Model 1 (AM)		Model 2 (PM)	
	Test 1	Test 2	Test 1	Test 2
Volumes	-	-	272	417
LV	322	453	-	-
HV	0	14	1	7
CO	3.414	4.776	2.167	3.179

Results obtained from the analysis revealed that the models can be applied for estimating CO emission. Comparing the amounts of predicted CO emissions for the two types of intersections, it could be seen that the roundabout intersection reduces the amount of emission relative to the priority intersection. This could be attributed to the fact that at roundabout, vehicles do not stop completely (as in the case of priority junctions) before merging. Rather, they reduce their speeds and make the appropriate manoeuvre. These findings are however, based on the preliminary data used in this study. More data sets would be required in order to draw a more reliable conclusion.

■4.0 CONCLUSIONS

This study was carried out to evaluate the effect of vehicular traffic volume and composition on carbon emissions at intersections by developing mathematical models for prediction of CO emission. Carbon-monoxide emissions were measured at both roundabout and priority intersections using GrayWolf Sensing Solutions (GWSS) and SIDRA software methods. Results obtained from GWSS method were used to calibrate SIDRA. Calibration factors were determined and used for estimating the emission using SIDRA software. The estimated CO emissions using SIDRA were then used to develop mathematical models for predicting CO emissions at roundabout and priority intersections based easily observed traffic flow variables. The CO emission prediction models developed were evaluated using sensitivity analysis and thus found adequate. Traffic volumes and their compositions were also found to be among the factors affecting CO emissions at the intersections. On comparing the amount of predicted carbon emission obtained from the two intersections for the studied periods, it was found that roundabout reduces the amount of the emission relative to the priority intersection. Findings reported in this study require further investigation; perhaps, using additional sites with varying geometric features, vehicular traffic level and compositions.

Acknowledgement

The authors would like to express deep appreciations to the Ministry of Higher Education, Malaysia, through Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM) and UTM for providing a research grant (Q.J130000.7801.4L100), opportunity and necessary facilities to support this research work.

References

[1] WHO. 2006. Air quality Gguidelines. Global Update 2005: Particulate matter,Oozone, Nitrogen dioxide, and Sulfur dioxide. Regional Office for Europe, World Health Organization.

[2] Afroz, R., Hassan, M. N. and Ibrahim, N. A. 2003. Review of Air Pollution and Health Impacts in Malaysia. *Environmental Research*. 92(2): 71–77.

[3] Ong, H., Mahlia, T. and Masjuki, H. 2011. A Review on Emissions and Mitigation Strategies for Road Transport in Malaysia. *Renewable and Sustainable Energy Reviews*. 15(8): 3516–3522.

[4] DOE. 1996. Malaysia Environmental Quality Report. Department of Environment, Ministry of Science, Technology and Environment, Malaysia.

[5] Zaitun, H. Y. 2007. Air Pollution Management in South East Asia. *Urban Environmental Management and Air Quality in Less Developed Countries*. Copenhagen.

[6] Brunekreef, B. and Holgate, S. T. 2002. Air Pollution and Health. *The Lancet*. 360(9341): 1233–1242.

[7] Kampa, M. and Castanas, E. 2008. Human Health Effects of Air Pollution. *Environmental Pollution*. 151(2): 362–367.

[8] Raub, J. A. 1999. Health Effects of Exposure to Ambient Carbon Monoxide. *Chemosphere: Global Change Science*. 1(1–3): 331–351.

[9] Chan, L., Lau, W., Zou, S., Cao, Z. and Lai, S. 2002. Exposure Level of Carbon-monoxide and Respirable Suspended Particulate in Public Transportation Modes while Commuting in Urban Area of Guangzhou, China. *Atmospheric Environment*. 36(38): 5831–5840.

[10] Ghosh, S., Pal, A. K., Saxena, N. C. 1996. Impact of roadway Traffic and Transport on Human Health. *Energy Environment Monitor*. 12: 101–107.

[11] HKEPD. 2000. Environment Hong Kong 2000. Hong Kong Environmental Protection Department, Hong Kong Printing Department, Hong Kong.

[12] Barry, C. 2001. Report on Roundabouts. http://www.cccnh.org/cintroduction.htm4. Accessed May 15, 2014.

[13] Mandavilli, S., Russell, E. R. and Rys, M. J. 2003. Impact of Modern Roundabouts on Vehicular Emissions. Proceedings of the *Proc. 2003 Mid-Continent Transportation Research Symposium*.

[14] Varhelyi, A. 2002. The Effects of Small Roundabouts on Emissions and Fuel Consumption: A Case Study. *Transportation Research Part D: Transport and Environment*. 7(1): 65–71.

[15] Mustafa, M. A. and Vougias, S. 1993. Analysis of Pollutant Emissions and Concentrations at Urban Intersections. Proceedings of the *Compendium of Technical Papers, ITE, 63rd Annual Meeting*.

[16] Vougias S. and Mustafa, M. Prediction of Air Pollution Reduction from the Construction of Six Multi-Level Intersections in Thessaloniki. Proceedings of the *Proceedings of the XI IRF Conference, Madrid*.

[17] Transportation Research Board. 2010. *Highway Capacity Manual*. TRB, National Academies, Washington, D.C..