SOURCE APPORTIONMENT OF PEDESTRIAN EXPOSURE CROSSING A STREET TO A TRAFFIC QUEUE SOURCE IN THE VICINITY OF AN INTERSECTION

Hongbin Wang[1], Roy Colvile[1], Elsa Aristodemou[1], Christopher Pain[2]
[1]Centre of Environmental Policy, Imperial College London, UK
[2]Department of Earth Science & Technology, Imperial College London, UK

INTRODUCTION

Personal exposure is pollutant concentration at the person's breathing zone. In contrast with the pollutant concentration at a fixed point, personal exposure is a function of the person's movement, in addition to the concentration field which is determined by the combination of the pollutant emissions and wind fields. Modelling the pollutant concentration at a fixed receptor has been the main focus in air quality management and numerous studies have been done. Both average pollutant concentration and the concentration fluctuations are modelled by a range of dispersion models (e.g., Hanna 1984; Thomson, 1992) to meet requirements of air quality standards in which not only the limit of average pollutant concentrations are designated but the concentration fluctuations are also regulated. For example, the UK National Air Quality Strategy objective for SO2 states that the 99.9th percentile of 15 minute average concentrations should not exceed 266μg m^{-3}. Due the fact that the movement of a person may be correlated to the change of the concentration field, the average exposure and exposure fluctuations cannot be correctly derived without considering the person's movement. This is very true to the situation where a pedestrian crosses streets in the vicinity of a traffic intersection.

Vehicles emit most their emissions at their acceleration phase (e.g., Tate, 2005) and therefore it is believed the area of a traffic queue is the periodic emission sources in the vicinity of a traffic intersection synchronising with the traffic signals. Pedestrians, however, wait at the kerbside while the vehicles passing the intersection and cross the streets when the vehicles are stopped by the traffic lights. An exposure modelling system, consisting of a traffic emission model, a pedestrian movement model, a flow and dispersion model, has been constructed to model the exposure of pedestrian crossing roads (Wang et. al, 2005, 2007). The exposure modelling system was applied to produce instantaneous exposure profiles of pedestrians crossing a traffic intersection in central London. In the emission submodel of the modelling system, the traffic sources were approximated as uniform volume sources synchronising with the traffic lights of which the size was set as being comparable to the traffic queue. This paper is a follow-up paper aimed to investigate the approximation made to the emission source by looking at to what extent different parts of a traffic queue contribute to the pedestrian exposure.

METHODOLOGY

An exposure modelling system, consisting of a traffic emission model, a pedestrian movement model, and a flow and dispersion model, has been constructed to model the exposure of pedestrians crossing roads (Wang et. al, 2005, 2007). In the emission model, the traffic queue areas plus the central area in the vicinity of the intersection of Marylebone Road and Gloucester Place are seen as a volume source (see Fig 1 (a)). This approximation was initially made in DEMO (Colvile, 2003) in which personal exposure was calculated based on a crudely estimated source – receptor relationship, taking account of vehicles moving speed and acceleration and traffic volume. The pedestrian model assumes pedestrians cross streets with constant walking speed (1.25 m s^{-1}) while the green man is on. Periodicity of the traffic lights and allocation of the time between the green light and red light at the intersection are shown in Fig 1 (c). The flow and dispersion model is the large eddy simulation implemented by FLUIDITY which employs capability of adaptive mesh (Piggott, 2006). Wang et al. (2005) presented flow and concentration patterns and studied personal exposure in the vicinity of the intersection of Marylebone Road and Gloucester Place. In the study, a traffic intersection consisting of four buildings with the coming wind from 45 degree off the constituent street was set up for numerical modelling (Fig 1 (a)).

In this paper, a simulation is set up in which, in contrast with the one in the last paper (Wang et al, 2005), only Source VI is present and divided into six sub-sources of equal size (Fig. 1 (b)). Each sub-source is therefore of 16.67x9.38x3 (m). The emission rate of each sub-source is set to be 1. The inflow wind direction is the wind direction points to 45 degree north to east Marylebone Road. All the parameters in the simulation are the same as those in the simulation in the last paper including the time step which is 0.006. The total simulation time is 34.8, out of which 6.36 is deducted, making 28.44 of useful time series.

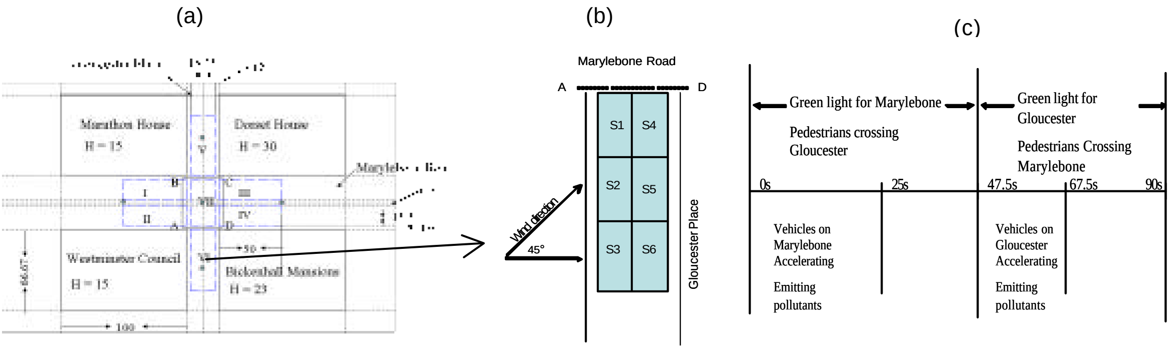

Fig. 1; (a) Traffic sources and pedestrian walking routes designed in the vicinity of Marylebone Road -- Gloucester Place intersection. The sources are treated as transient homogeneous volume sources. Sources are numbered from I to VII, and sources I to V are intended to be the actual queue sizes the length and width of which are assumed to be 50m and the road width, respectively. The lines connecting ABCD are pedestrian walking routes. denotes the place where vertical wind profiles are plotted. (b) Simulation of exposure to six sub-sources of equal size. (c) Simplified diagram of activity of vehicles and pedestrians at the intersection of Marylebone road and Gloucester place.

RESULTS

Concentration time series at a fixed receptor

Fig. 2 shows the simulated concentration time series measured at the middle point of A—D due to a continuous source and a periodic source. The receptor is 2m downstream to the closest edge of the source (Fig. (a) (b)). It can be seen that the concentration due to the periodic source shows a periodic pattern, whilst the concentration time series due to the continuous source appears to be more chaotic. Also can be seen is that the average concentration due to the continuous source is larger than that due to the periodic source.

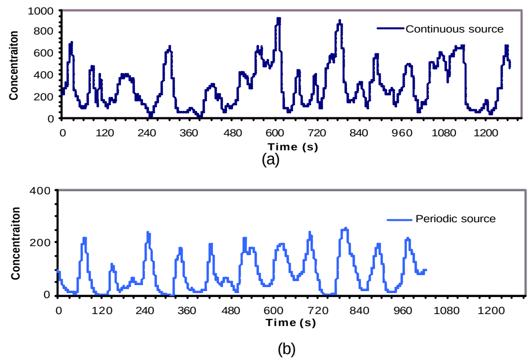

Fig. 2; Concentration time series at the middle point of A—D (Fig 1(a) (b)) at pedestrian level. (a) – continuous source, data from the simulation for six sub-sources; (b)– periodic source with period of 90s, data from the simulation described the last paper (Wang et al., 2005).

Concentration distribution along the Route (A--D)

Fig. 2 (a) shows the distribution of average concentration along the crossing route (A—D). The concentration is averaged over the entire simulation time with the first 6.36 deducted. It can be seen that that the six sources cause different concentrations along the route. Among the six sources, the sources S1 and S4 make higher contributions, due to the fact that they are closest to the route. The north edges of the two sources are 2m from the route. The sources S2 and S5, whose north edges are 18.67m from the route, contribute much less to the total concentration, and the sources S3 and S6, whose north edges are 35.3 m from the route, contribute very little. shows that combination of the sources S1 and S4 contributes 30% to 70% of the concentration at different receptors along the crossing route. However, the combination of the sources S1, S4, S2 and S5 contributes 75% to 90% of the concentration of the crossing route, and 90% for most of the route. This indicates that for most of the route, the combination of the two furthest sources (S3 and S6) only contribute 10% of the concentration.

With regards to the integrated concentration over the whole route, the combination of S1 and S4 contributes 57% of the total concentration, the combination of S2 and S5 contributes 29%, almost half of S1 and S4, and the combination of S3 and S6 contributes 14%, approximately half of S2 and S5.

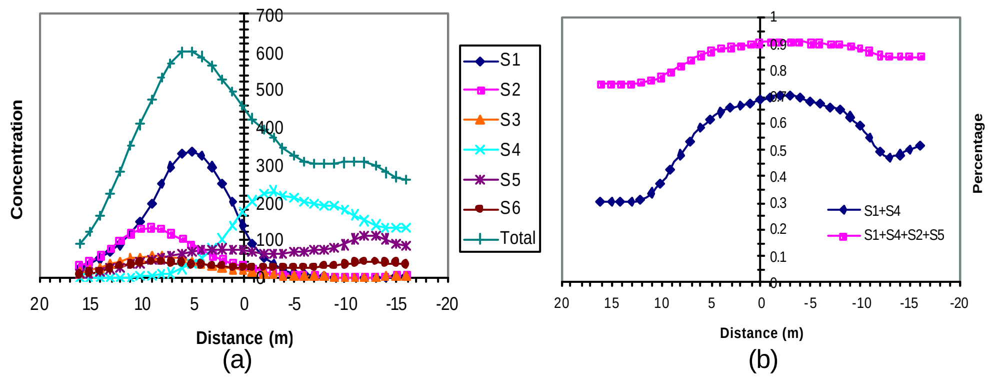

Fig.3 (a) Distribution of average concentration along the crossing route A -D. – Negative D, Positive – A. Total is the sum of concentration due to all 6 sources. (b) Contribution in percentage of the average concentration along the crossing route A -D.

Exposure of a pedestrian walking from D → A

Fig. 4 (a) shows ensemble average exposure profiles of a pedestrian crossing south Gloucester place from D to A. Surprisingly, the sources S1 and S4 do not contribute significantly larger than the sources S2 and S5 as they do to the concentration distribution along the route shown in Fig.3 (a). The pedestrian starts off walking from the point D where he/she is close to source S4, and receives pollutant from S4 around -15m, then S5 takes over at about -12m. By the time the pedestrian reaches close to S1, the pollutant from S1 have been blown away and the pollutant from S2 just arrives, causing higher exposure than S1 does. The sources S3 and S6 contribute very little to the exposure, due to the fact that they are too far away from the route and the pollutant plumes released from them are much diluted when they reach the route, which is similar to the situation for S3 and S6 in the concentration contribution in the previous section.

In terms of the integrated exposure, the order of source contribution is S5, S2, S1, S4, S6 and S3, contributing 32%, 19%, 16%, 15%, 12% and 3% of the total exposure, respectively (see . 4 (b))

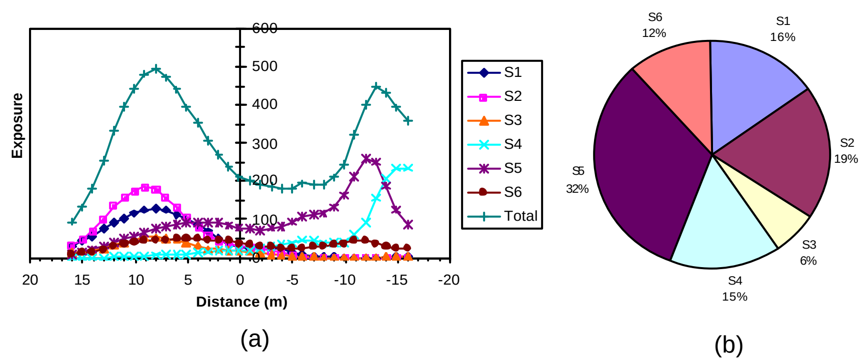

Fig. 4; (a) Ensamble average exposure profiles of a pedestrian crossing south Gloucester place from D to A. The exposure profiles are obtained by averaging 14 instantaneous exposure profiles which take place immediately after the favourable light(the green man) is switched on. Total is the exposure profile due to the combination of S1, S2, …, and S6. Negative – D, positive – A. (b) Percentage contributions of the six sub-sources to the integrated exposure of a pedestrian crossing D → A.

IMPLICATIONS

Averaging emission rate

From Fig. 2, the concentration magnitude of the two time series is of a factor of 3.4 difference, with the continuous source being 294 and the periodic being 82. The time average emission rate of the periodic source can be calculated by 20/(40+50) = 0.22, $\frac{2}{9}$ that of the continuous source. For two emission sources of the same temporal pattern, such as the continuous source, the ratio of the two resulting concentrations is equal to the ratio of the two emission rates. In this case, the average emission rate of the continuous source is 4.5 times that of the periodic source, but the resulting average concentration of the continuous source is only 3.4 times that of the periodic source. In practical modelling, often, concentrations resulting from transient sources are usually approximated to be the concentrations of continuous sources with the same average emission rate, which is now shown to overpredict pollutant concentrations.

Individual highly polluting vehicles

From Fig. 3 and different parts of the traffic volume source in north Gloucester Place contribute to a different degree both to the concentration at fixed receptors and to the exposure in terms of unitary emissions. In the simulation carried out in the last paper (Wang et al., 2005), the traffic source is not only assumed to be comparable to the traffic queue in size but also homogeneous in emissions. However, if highly polluting vehicles happen to be at the places where unitary emissions make more contribution to the concentration and exposure than they do elsewhere, the assumption leads to underestimation of the concentration and exposure. On the other hand, if the highly polluting vehicles are at places where unitary emissions make less contribution, the assumption overestimates the concentration and exposure.

When considering long term average exposure, the effects of the underestimation and overestimation due to the inhomogeneity of the traffic sources might cancel out. However, the movement of a pedestrian adds variability to the total exposure variability in addition to that caused by concentration fluctuations.

CONCLUSIONS

This paper examine the approximation made to treat a traffic queue as a whole uniform volume source in the exposure modelling system, consisting of a traffic emission model, a pedestrian movement model, and a flow and dispersion model. It is shown that different parts of the traffic source make different contributions both to the concentration at a fixed receptor and to the exposure of walking pedestrian, and consequently the inhomogeneity in emission of the traffic sources could lead to under- or over-prediction of the pedestrian exposure.

Also shown in this paper is that concentration resulting from a periodic source would be overpredicted if it is modelled as a continuous source with the same average emission rate.

REFERENCES

Colvile, R. (2003): *Modelling the relationship between urban form and variability in exposure to vehicle emissions*. 13th Annual conference, International Society of Exposure Analysis, pp. 280.

Hanna, S.R. (1984): *Concentration Fluctuations in A Smoke Plume.* Atmospheric Environment, 18**:** 1091-1106.

Piggott, M. (2006): *Fluidity/ICOM Manual Applied Modelling and Computation Group (AMCG).* Department of Earth Science and Engineering, Imperial College London.

Tate, J., (2005): *A Study of Vehicular Emissions and Ambient Air Quality at the Local-scale.* University of Leeds, PhD thesis.

Thomson, D.J., 1992: The fluctuations modules. ADMS 3 technical specification. http://www.cerc.co.uk/software/pubs/ADMS3-1TechSpec/P13_01.pdf

Wang H., Colvile R., Aristodemou E., Pain C., 2005: Modelling the causes of vehicle exhaust exposure micro-episodes. presented to the 10th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Crete, Greece, October 17-21, 2005.

Wang H., (2007): Numerical Modelling Of Pedestrian Exposure To Traffic Pollution At An Intersection. Imperial College, PhD thesis.