MODELLING LOW EXPOSURE ROUTES IN URBAN MICRO-ENVIRONMENTS

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Abstract: This paper describes how modelled estimates of air pollution can be used within a GIS to derive typical and optimal estimates of journey-time exposure. It also explores the concept of personal exposure reduction and considers the extent to which mobile devices will support the selection of more informed routes through the provision of location-specific data on pollutant concentrations.

Key words: *GIS, least-cost path, optimal routes, mobile technologies*

1. INTRODUCTION

Clear and unequivocal associations have been made between air pollution and adverse health outcomes based on long and short term exposure studies (WHO, 2003). Exposure estimates may be derived at the individual level (personal exposure) or at the group level (population exposure) based on either direct (exposure monitoring) or indirect (exposure modelling) methods (Borrego et al, 2006). Research has increasingly focussed upon exposure to fine particulate matter ($PM_{2.5}$) in urban environments with road traffic the dominant source. For example, Kaur et al (2005) used high flow personal samplers to assess pedestrian exposure to $PM_{2.5}$ along a 500m stretch of road in Central London and found significant differences related to time of day and roadside position. Gulliver and Briggs (2005) developed a GIS-based system for modelling journey-time exposure to traffic-related air pollution using GIS techniques to simulate routes taken by children. Most recently Greaves et al (2008) combined the use of personal aerosol monitors with GPS receivers to provide detailed exposure profiles for individuals walking down heavily and lightly trafficked streets in Sydney, Australia. All of these studies highlight the importance of road traffic as the major source of air pollution in urban environments, however, they also suggest that pollution in the urban environment can vary considerably due to the complex spatial arrangement of roads, buildings and open spaces. Personal exposure is a product of the path that the individual takes through the heterogeneous urban environment. Alternative paths through such environments may potentially lead to reductions in personal exposure (Guardian Unlimited, 2007).

This paper reports on the novel application of GPS, GIS and mobile phone technology to derive exposure estimates for 30 children on journeys to and from school in NW England. The approach described here may be considered 'hybrid' in that pollutant concentrations are derived from a proprietary dispersion model whilst the movements of the individual are captured using GPS technology. GIS techniques are used to integrate these data to yield exposure estimates which are subsequently explained in relation to the characteristics of the urban micro-environment through which the children have travelled. The GIS is then used to derive 'least cost' routes to school for each child which minimise journey-time exposure to traffic-related air pollution. Wider implications of the study are then discussed, including the need to provide inform the general public of low exposure options and the extent to which the next generation of mobile phones will be capable of providing real-time location-specific advice on route choice based on modelled or monitored air pollution data.

2. JOURNEY TIME EXPOSURE

A methodology for generating journey-time estimates of exposure to traffic-related pollutants was described by Whyatt et al (2007) hence the detail will not be repeated here. In essence pollutant concentrations generated by ADMS-Urban are combined with positional data automatically captured by GPS using a customised mobile phone application at 1-second intervals (Bamford et al, 2008). Positional data were captured by 30 children who travelled to and from school using a variety of different forms of transport for 4 weeks in 2007. Journey time exposure (JTE) was simply calculated as the cumulative product of pollutant concentration over time and space. No adjustments were made for activity level or mode of transport. A selection of routes taken by children walking to school are shown in Figure 1 with corresponding statistics on JTE shown in Table 1.

Table 1. Journey-time exposure under typical and optimal conditions (units: μgm^{-3}).

Child	Distance km	Time minutes	% Time in Environment Road Side	Other	Park	Derived JTE Total	Least Cost JTE Total
Claire	1.2	15	1	41	58	**4.2**	**3.6**
Ella	1.1	20	48	29	23	**5.8**	**5.6**
Jessica	1.2	17	15	55	30	**5.3**	**3.5**
Louise	1.4	21	93	7	0	**7.3**	**5.6**
Peter	1.6	20	7	43	50	**5.5**	**5.0**
Vernon	0.8	10	57	43	0	**2.9**	**2.3**

Unlike previous studies (Kaur et al, 2005, Gulliver et al, 2005) these routes are real routes (not 'directed', or simulated) taken by real children on a daily basis. Consequently, there is great variation in the start and end times of each journey, distances covered and routes taken. JTE to PM_{10} for each child varies as a consequence. Louise experiences the highest JTE as a consequence of her decision to walk alongside a heavily trafficked road for the majority (93%) of her journey. Peter completes a journey of similar distance, however, his route primarily takes him through suburban streets (43%) and open park land (50%) hence his JTE is significantly lower. Vernon experiences the lowest JTE despite walking alongside a busy road for half his journey, the difference being that his journey is much shorter in comparison (10 mins).

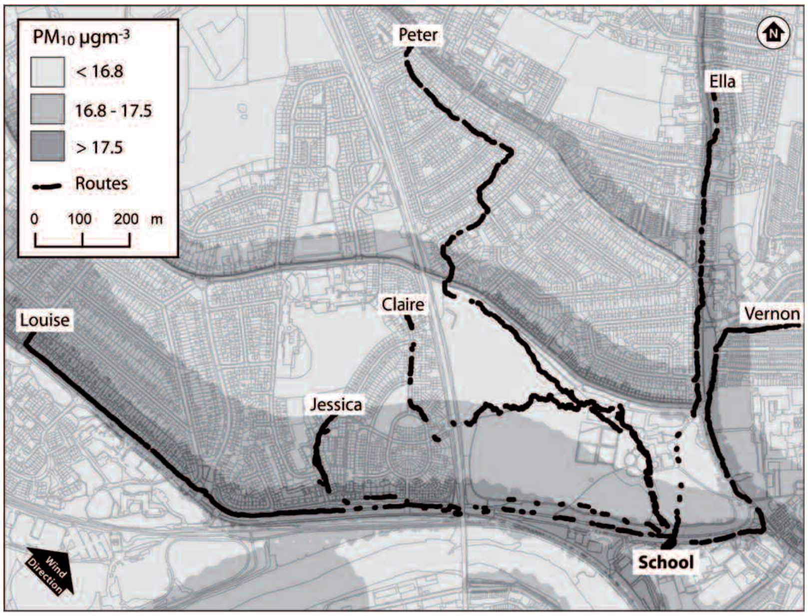

Figure 1. Routes for a selection of children who walk to school.

The exposure estimates derived using this hybrid approach are broadly consistent with those reported elsewhere using monitoring and modelling approaches (Greaves et al, 2008, Gulliver et al, 2005) though somewhat lower than those reported by Kaur et al (2005) whose study was based in Central London. JTE to traffic-related air pollution is clearly highly dependent upon route choice through the urban micro-environment. Colvile recently commented that one of the best ways to reduce exposure to air pollution was to avoid walking along busy streets and thoroughfares, choosing side streets and parks instead (Guardian Unlimited, 2007). This paper will now move on to describe how our hybrid approach can be extended to derive optimal routes for children which minimise exposure to traffic-related air pollution, embracing the practical recommendations of Colvile.

3. LEAST COST EXPOSURE ESTIMATES

The GIS environment not only provides the analytical tools to support the derivation of JTE but also tools to support simulation of movement across complex geographic surfaces. In this paper we simulate the movement of individual children from their respective origins (home addresses) to their common destination (school) across a high resolution modelled surface of PM_{10} which has been modified ('masked') to exclude non-traversable geographic features such as rivers, buildings and privately owned land. Simulation is achieved using a least cost function which ESRI define as 'the path between two locations that costs the least to traverse, where cost is a function of time, distance, or some other criteria defined by the user' (ESRI, 2008).

The least cost function was applied for each child listed in Table 1 in order to determine routes of least cumulative exposure between home and school addresses. Full details of the methodology and a selection of least cost routes are presented in Davies et al, 2008. These routes do not generally deviate significantly from those taken by the children on a regular basis. Differences are subtle, with the least cost algorithm typically deriving routes upwind, or some distance from, the most heavily trafficked roads in the study area. JTE exposure for each child, without exception, is lower if the least cost route is taken. JTE for Louise, who typically walks along a heavily trafficked road, is reduced from 7.3 to 5.6 $\mu g\ m^{-3}$ if the least option is taken. This simply involves walking along the opposite (upwind) side of the road under equivalent weather conditions. JTE for even the shortest journey is reduced, suggesting that the least cost approach described here provides an objective means of reducing exposure to air pollution at the individual level.

4. DISCUSSION

The hybrid approach described in this study provides a cost-effective and flexible alternative to JTE assessment using direct (monitoring) or indirect (modelling) approaches. Unlike the former, the approach is scalable at little additional cost, subject only to the availability of positional data which itself is increasingly being utilized by mobile applications. This approach can not only be used to assess current JTE, but may also be used to assess JTE under future scenarios, such as, perhaps, a major scheme to modify traffic flow in an urban area.

At a more practical level the least-cost approach described here endorses the view of Colvile and others that small adjustments to routes in urban micro-environments can result in significant reductions in exposure to air pollution. Some of these adjustments are simple and non-contentious, such as standing well back from a kerb when waiting to cross a busy road. Others, however, are more problematic. Walker et al (2008) interviewed the children who participated in the study reported here and found that parental concern over safety was an important factor affecting route choice in some children. One girl, for example, was encouraged to walk alongside a heavily trafficked road for visibility (hence safety) by her parents whilst another was instructed not to walk through the local park due to perceived threat of 'stranger danger'. Strategies to reduce personal exposure to air pollution are likely to be more effective than strategies to reduce emissions from traffic in urban environments in the short term, however, routes considered optimal for exposure reduction may be considered sub-optimal for other (social) reasons.

Clearly, a key challenge is to communicate the benefits of exposure reduction to the general public in a timely and effective manner. Jenson et al (2001) developed a decision-support tool to assist local authorities in the management of air quality and personal exposure at home and workplace addresses. The exposure assessment techniques described in this paper could be developed in a similar manner. A more attractive option, however, might be to provide location-specific advice on low exposure routes direct to the mobile phone such that the individual has the opportunity to make informed decisions in real-time. Such as service could be based on modelled estimates of air pollution, pre-calculated for a range of different wind speeds and directions, or based on real-time data captured by the mobile device itself. Nokia, for example, recently publicised their Eco Sensor Concept (Nokia, 2007), comprising of a wearable sensor (capable of sensing and analysing an individuals health and environment) and a dedicated mobile phone. Should such a unit ever go into production the opportunities for reducing personal exposure to air pollution would be considerable.

5. CONCLUSIONS

The hybrid approach described in this paper provides a cheap and flexible alternative to exposure monitoring. By analysing route data and pollution surfaces within a GIS environment we are able to explain differences in journey-time exposure relative to changes in the urban-microenvironment. Using least-cost techniques we can also simulate optimal low exposure routes for the individual. The challenge now is to educate the general public in the benefits of exposure reduction. Mobile devices may play a key role in this process.

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REFERENCES

Borrego, C., Tchepel O., Costa A.M., Martins H., Ferreira J. and Miranda A.I, 2006: Traffic-related particulate air pollution exposure in urban areas. *Atmospheric Environment* **40**, 7205-7214.

Bamford, W., Coulton P., Walker M., Whyatt J.D., Davies G. and Pooley C.G., 2008: Using mobile phones to reveal the complexities of the school journey. *Proceedings of the 10th International Conference on Human-Computer Interaction with Mobile Devices and Services*.

Davies, G. and Whyatt J.D., 2008: A least-cost approach to personal exposure reduction. *In* review, *Transactions in GIS*.

ESRI, 2008: Online GIS Dictionary. http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.gateway

Greaves, S., Issarayangyun T. and Liu Q., 2008: Exploring variability in pedestrian exposure to fine particulates ($PM_{2.5}$) along a busy road. *Atm. Env.,* **42**, 1665-1676.

Guardian Unlimited, 2007: Breathing Lessons
http://www.guardian.co.uk/lifeandstyle/2007/apr/04/healthandwellbeing.waste

Gulliver, J. and Briggs D.J., 2005: Time-space modelling of journey-time exposure to traffic-related air pollution using GIS. *Environmental Research,* **97**, 10-25.

Jenson, S.S., Berkowicz R., Hansen H.S. and Hertel O., 2001: A Danish decision-support GIS tool for management of urban air quality and human exposures. *Transportation Research,* Part D **6**, 229-241.

Kaur, S., Nieuwenhuijsen M.J. and Colvile R.N., 2005: Pedestrian exposure to air pollution along a major road in Central London, UK. *Atmospheric Environment,* **39**, 7307-7320.

Nokia, 2007: Eco Sensor Concept: http://www.nokia.com/A4707477

Walker, M., Whyatt J.D., Pooley C.G., Davies G., Coulton P. and Bamford W., 2008: Talk, technologies and teenagers: Understanding the school journey using a mixed-methods approach. *Children's Geogr.,* In press.

WHO, 2003: Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide, Bonn, Germany

Whyatt, J.D., Pooley C.G., Moser M., Bamford W. and Davies G., 2007: Estimating personal exposure to air pollution on the journey to and from school using GPS, GIS and mobile phone technology. In D.J Carruthers and C.A McHugh (eds) *Proceedings 11th International Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatory Purposes,* Volume 1, 81-85.