Reducing Exposure to Air Pollution: A Network Approach

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ABSTRACT: In response to concerns over the health implications of journey-time exposure to air pollution, this paper applies GIS network analysis to identify low exposure routes through a path network. Results from this case study show that exposure levels on low exposure routes are typically 20% lower than those based on shortest distance, suggesting that the design of less exposed walking routes could have benefits for human health.

KEYWORDS: journey-time exposure, network analysis, dispersion modelling

1. Introduction and Review of Literature

Concerns over the health implications associated with exposure to airborne pollutants have led GIS techniques to be increasingly used in the analysis of human exposure to air pollution. (Gulliver and Briggs 2004; Maynard *et al*. 2007). Individual exposure can be significantly increased by walking in heavily trafficked environments (Greaves *et al*, 2008) with Kaur *et al* (2007) concluding that proximity to pollution source has a significant impact upon exposure and that pedestrians should make greater use of quieter back streets. Significant variations in pollution concentrations can also be found between two sides of the same road (Kaur *et al*, 2005). This paper presents a methodology for generating lower exposure walking routes through such environments.

Various approaches to generating lower exposure routes have previously been developed. Hertal *et al* (2008) used annual diurnal traffic flow as a surrogate for air pollution in their route finder approach. However, this failed to account for the increased exposure resulting from longer journey times. Meanwhile awareness raising initiatives such as the least polluted route option developed within the WALK-IT (www.walkit.com) route planning service are starting to promote the choice of less polluted routes for pedestrians within selected cities in the UK. WALK-IT uses a modelled pollution surface based on the dispersion of NO_2 for a 'typical' day which is then integrated with nodes in a path network to increase the impedance of polluted segments of the network making them less preferable to the route finder. Davies and Whyatt (2009) used an alternative raster-based least-cost method to define low exposure routes. Their approach used a mask to define areas of traversable space, however, while allowing freedom of movement through open spaces the derivation of this mask was time consuming which has implications for larger scale studies.

Drawing on some of the strengths from previous approaches the methodology outlined in this paper demonstrates the potential of network analysis for defining lower exposure routes for a number of scenarios taking into account day-specific meteorological conditions and background pollution concentrations. The analysis will focus on the case study of a city centre high school, surrounded by a network of busy roads and will examine the journey time exposure for a hundred year 8 pupils living within 2km of the school. The work builds on a wider project exploring the school journey (Pooley *et al* 2010).

2. Methodology

The method integrates high resolution pollution surfaces with a topologically structured path network, to create new cost evaluators representing exposure. This makes it possible to compute routes designed to minimise exposure to pollution in addition to those representing shortest distance. The method used is summarised in Figure 1.

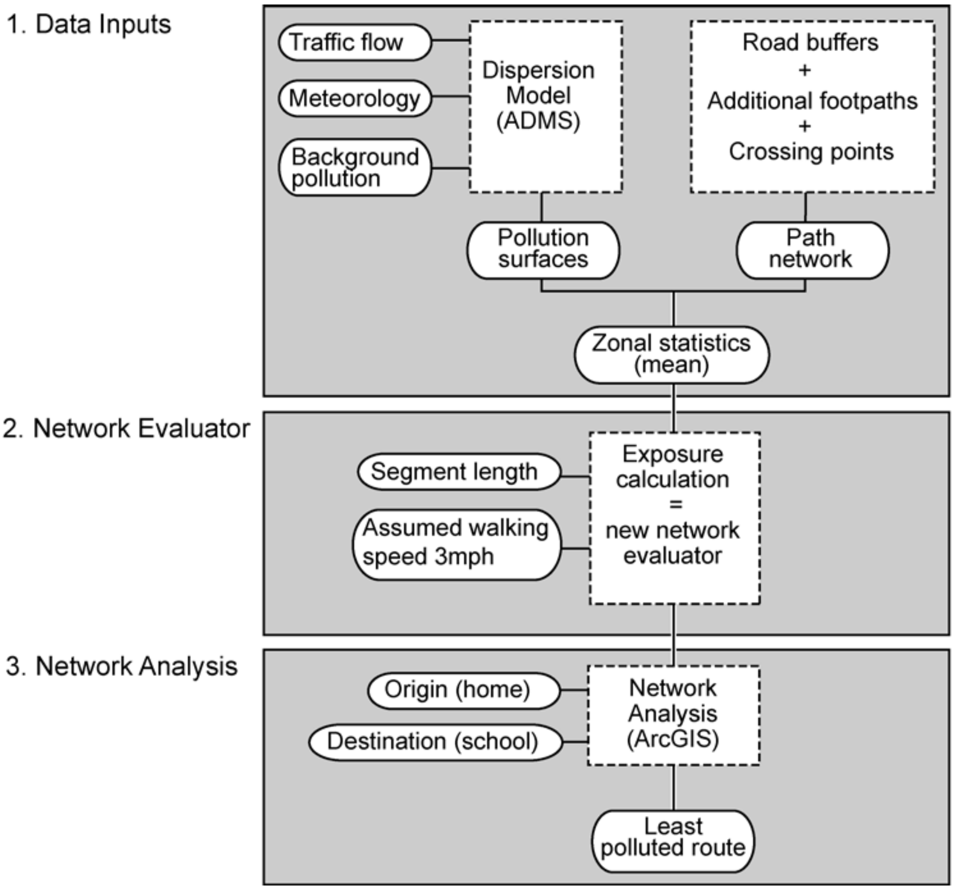

Figure 1: Methodology

2.1 Data Inputs

The first step of the methodology was to derive pollution surfaces which could later be used to calculate exposure through the network. In this case study the pollutant NO_2 was chosen, as this is one of the key pollutants known to have chronic and acute health impacts (Xia and Tong 2005). The pollution surfaces were generated using the dispersion model ADMS Urban, which calculates concentrations based on emission estimates derived from traffic counts. Other inputs included hourly background NO_2 concentrations and meteorology. Model output was used to create pollution surfaces at 1m spatial resolution, sufficiently fine to distinguish variation across the width of a road.

Most examples of network analysis use a road centreline approach in defining route choice, however, in order to test subtleties in route choice, such as which side of the road to walk along, a pavement network was developed. The initial network was based on Ordnance Survey MasterMap ITN data. Road centre-lines where then buffered at a distance representing the road widths and then converted to lines in order to define pavements either side of the road. Additional footpaths not adjacent to roads were then added to the pavement network. Road crossings were automatically included where the ends of the buffers met, which included all road junctions. Some additional road crossing options were also added to the network, including the location of pedestrian crossings. A typical walking speed of 3mph was assumed for most of the network, however, at road crossing points on busy main roads this speed was lowered in order to simulate the time required to wait before crossing the road, therefore accounting for impact on exposure of waiting times within potentially highly polluted environments.

2.2 Creating a network evaluator

Network analysis with ESRI's ArcGIS depends on the definition of evaluators, either cost evaluators such as distance or time, or restrictors such as oneway streets. Within this environment a new cost evaluator, therefore, needed to be created representing exposure to NO_2 for each segment of the network. This was achieved by using zonal statistics to calculate the mean concentration per segment, then subsequently calculating the total cumulative exposure per segment taking into account the length of the segment and the travel speed (3mph) in addition to the mean concentration.

2.3 Network Analysis

Once the network and relevant evaluators were established the Origin-Destination (OD) cost matrix tool with ArcGIS' network analyst was used to calculate sets of both the shortest and least exposed routes between a set of origins, in this example the homes of all year 8 pupils living within 2km of a city centre secondary school and a destination, the school. Under each scenario the accumulated exposure to pollution (NO_2) was calculated.

3. Results and Discussion

In order to assess the potential for exposure reduction when taking a route defined by least exposure to pollution rather than shortest distance, the methodology was applied using day-specific meteorology and background pollution levels. The sample days chosen were selected to represent a variety of differing meteorological and background conditions observed throughout a calendar year, 2006 (Table 1).

Table 1. Meteorology and background concentrations for selected days in 2006

	16th Jan	27th Feb	17th Mar	14th Jun	23rd Jun	12th Nov	20th Nov
NO_2 background $\mu g\ m^{-3}$	12	6	8	39	10	5	5
Wind Direction	160	290	40	300	230	250	200
Wind Speed ms^{-1}	11	8	11	4	5	15	6
Cloud Cover	6	6	8	0	1	3	0
Temperature ^{o}C	8	4	2	15	13	12	7

Figure 2 represents the range of potential exposure experienced by the 100 pupils for each of the sample days. It shows the reduction in exposure which may be achieved by choosing a least exposed route, while also highlighting the considerable variation in exposure between days. The average reduction in journey-time exposure to NO_2 using a least exposed route is 20%, however, on days such as the 20^{th} November this can be as high as 50%. For some individual route choices this variation may be greater, with exposure reduction of up to 86% recorded for one individual journey.

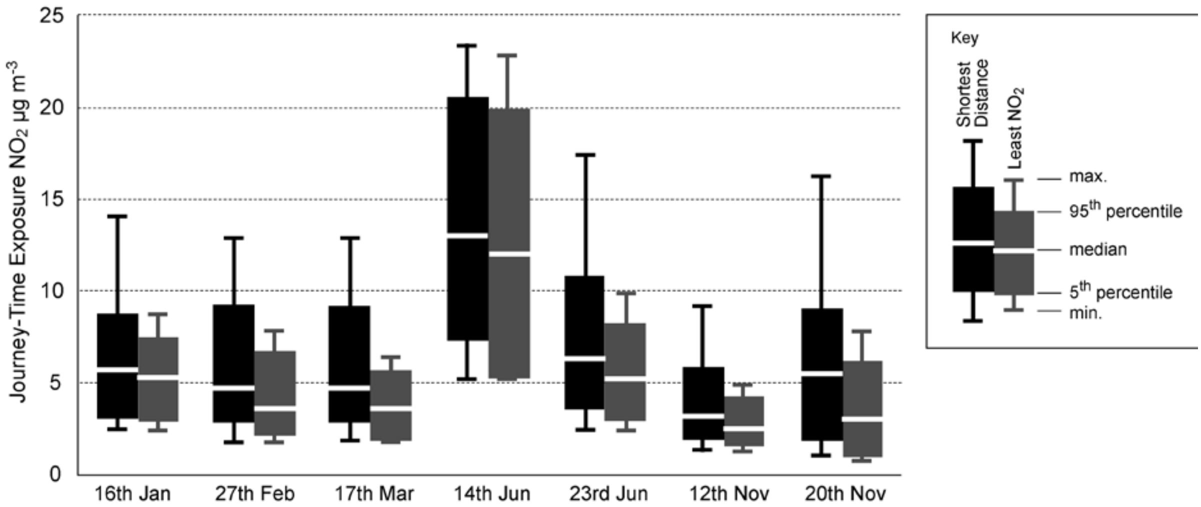

Figure 2: Journey-time Exposure to NO_2

Developing a path network with associated evaluators representing pollution exposure has a number of advantages over a least cost surface approach. While care needs to be taken to ensure that viable pathways are not omitted from the network, this editing process is easier to achieve and more adaptable than the process of ensuring an accurate analysis mask is derived to represent traversable space (Davies and Whyatt 2009). Network analysis also provides the flexibility to run from a large number of origins and destinations simultaneously. The network design is however, not without its limitations. Open spaces can, for example, only be crossed where specified pathways are defined as features in the network. Likewise while the network used in this paper is effective in enabling pavement choice, the locations at which the road can be crossed are restricted to the locations of junctions and a limited number of other specified crossing points such as pedestrian crossings. One additional advantage of the network is that it can allow for variable speed of travel through space, for example allowing for pause points along the journey while waiting to cross a road.

Results from the network analysis presented here assume a willingness to adopt suggested least-exposed routes, however, fails to take into account other factors which may affect decisions regarding route choice. For example an earlier study focusing on exploring the school journey with a sample of the pupils from the school used in this case study suggests route choice is influenced by factors such as parental control (Walker *et al* 2008). For instance, many parents will not allow their children to walk through the park opposite the school, yet for the majority of pupils a least polluted route would take them through the park. The model could therefore be expanded to account for restrictors accounting for areas to be avoided due to concerns such as safety, some of which only take effect during certain time periods such as after dark.

The challenge of realistically representing the real world extends to the complexities of attempting to accurately calculate actual journey-time exposure, which is affected by a number of factors besides route choice. These include background pollution concentrations, meteorological conditions, emissions from point sources, traffic concentrations, breathing height and level of physical activity (Cook *et al* 2008; Crabbe *et al* 2000; Gulliver and Briggs 2005). While any attempt to model the real world is met with limitations, the analysis presented here hopefully proves that the application of GIS techniques is potentially very useful in addressing the challenge of quantifying and potentially reducing journey-time exposure. In exploring the use of day specific conditions and pavements in preference to road centrelines, this approach moves us one step closer to simulating some of the complexities faced when modelling reality.

4. Conclusion

The application of network analysis provides an efficient way of deriving least polluted routes, although the success of this approach depends on the completeness of the path network and the availability of a relevant pollution surface from which to derive the network evaluator. The greatest reductions in journey-time exposure are generated when day-specific meteorological and background conditions are applied, however, applying the current methodology in real time is not yet practical due to data access and processing requirements. We are, therefore, left to assess whether the implementation of a set of 'typical' conditions may provide a useful alternative for defining least polluted routes and whether this in turn may in the future provide added benefit to the kind of route planning systems already in place such as WALK-IT. Further analysis is, therefore, needed to assess the extent to which a set of 'representative days' may be able to replace more precise day specific conditions, while still generating routes able to reduce an individual's exposure to airborne pollution.

In this case study we have only explored a series of short journeys, seeing relatively small reductions in exposure, however, the cumulative reduction in exposure over repeated journeys through the course of a year may have significant health benefits. This is especially the case with regards to exposure to particulate matter (PM) which is deposited in deep areas of the lungs and is not easily resolved by the human body (Xia and Tong 2006). In order to further this work to fully appreciate the impact such reductions in journey-time exposure may have for human health, further research in this field will require the input of epidemiological expertise.

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6. Biography

Gemma Davies is the GIS Officer for Lancaster Environment Centre.
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