A CONGESTION SENSITIVE APPROACH TO MODELLING ROAD NETWORKS FOR AIR QUALITY MANAGEMENT

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Abstract

Air Quality monitoring by Durham County Council has indicated that significant areas of the City of Durham are failing the national annual mean objective / EU limit value for nitrogen dioxide. In response to this an Air Quality Management Area was declared in May 2011.

This research aims to establish an approach to modelling the Durham road network for air quality management, which enables the assessment of traffic management solutions that may create only subtle changes in the traffic flow regimes. Road network emissions have been calculated using standard factors taking into account details of vehicle fleet composition, traffic speeds and road type. Additionally, the use of microsimulation traffic modelling in conjunction with an instantaneous emissions model has been adopted to allow comparison between methodologies and enable congestion sensitive analysis of the impact of air quality management measures on the network.

Findings from microscale modelling have revealed that the signalling of two key junctions and co-ordination with several adjacent junctions could reduce emissions in Durham, as well as improve journey times and total network delay. Furthermore, relationships between air pollution, health and deprivation potentially result in cost to both the public and the government in terms of increased mortality and morbidity; hence establishing links between them is justifiably important. Consequently, the effect of the proposed traffic scheme on environmental justice is discussed in relation to the spatial distribution of areas with poor air quality.

INTRODUCTION

Today the major threat to clean air in urban areas is posed by traffic emissions (DEFRA, 2011). There is clear evidence of the adverse effects of outdoor air pollution, especially for cardio-respiratory mortality and morbidity (Kapposa et al., 2004). It is estimated that each year in the UK, air pollution is associated with 50,000 premature deaths (EAC, 2010a). In 2010 air pollution was estimated to reduce the life expectancy of every person in the UK by an average of 6 months (DEFRA, 2010). Despite existing air quality legislation, EU countries (including the UK) are failing to meet targets, particularly for nitrogen dioxide (NO₂) (EAC, 2010b).

The City of Durham is located in the North East of England in County Durham. Durham is the largest urban area within the county with a population of 38,000. It is a significant administrative, educational, employment and service centre within the region (Durham County Council, 2010). Air quality monitoring by the County Council has indicated that significant areas of Durham are failing the national annual long-term mean objective / EU limit value for NO₂. In response to this an AQMA (Air-Quality Management Area) in the City of Durham was declared in May 2011. The AQMA incorporates the Highgate, Milburngate and Gilesgate areas (Figure 1). Durham County Council (DCC) is currently working in accordance with the UK Environment Act 1995 to produce an AQMA Action Plan (DEFRA, 2010).

This paper presents initial findings from a comprehensive study of the feasibility of a particular traffic engineering scheme proposed by Durham County Council. Depending on the final outcome of the study, the scheme may come under consideration as an Air Quality Action Plan Option. The stated aims of the scheme are to reduce network emissions (specifically NOₓ); improve bus journey time and reduce overall traffic delay. Key features of the scheme include the introduction of traffic signals at two roundabouts (Gilesgate and Leazes Bowl Roundabouts), amending the layout of the Leazes Bowl Roundabout; and co-ordination of the timing of the traffic signals between both the roundabouts and across adjacent junctions.
METHODOLOGY

In this section the methodological approach to modelling traffic, emissions, air quality and environmental justice will be described.

Prior to modelling the scheme in microsimulation, the traffic signal design package Linsig v3 (JCT Consultancy, 2009) was used to develop and optimise the operation of signal in the proposed scheme. An S-Paramics (SIAS, 2001) micro-simulation model was then developed. It was necessary to adapt an existing Paramics microsimulation model of Durham to make it suitable for use with the AIRE IEM. The most significant development was the addition of gradient as it is accepted that gradient has a significant impact on traffic emissions (Harris, 2004). Given the hilly terrain of Durham, road gradient was considered an important aspect affecting the acceleration and deceleration of vehicles within the network. This necessitated a full recalibration and validation of the model, in line with DMRB 12 (DfT, 2013) guidelines.

Two independent emissions modelling techniques were adopted for modelling vehicular emissions. Firstly, the Durham road network was modelled using PITHEM (Platform for Integrated Traffic, Health and Emissions modelling) developed by Newcastle University. PITHEM contains an integral emission model which calculates emissions and particulates using latest UK emission factors (i.e. National Atmospheric Emissions Inventory (NAEI)). National fleet emissions factors are determined as a function of vehicle type, age, emission control standard, engine size and fuel used. These factors are applied via PITHEM to twenty-four hour traffic count and traffic speed data obtained for each link in the network. PITHEM is currently under development to take into account updated NOx Emission Factors taken from the latest DEFRA Emission Factor Toolkit - Version 5.1.3.

Additionally, a second methodology was adopted using a traffic microsimulation model (S-Paramics) in conjunction with an instantaneous emissions model (IEM) (AIRE) to estimate vehicular emissions in the Durham network. IEMs calculate the emissions of an individual vehicle, based on vehicle type, speed, acceleration and the gradient to which it is currently subject. In the case of AIRE, these conditions are matched against over 3000 vehicle emissions maps which were recorded in laboratory tests for a wide range of vehicles. This data was gathered from the Project Passenger car and Heavy Duty Emissions Model (PHEM), an output of the EU fifth framework ARTEMIS Project (Boulter, 2007). The principle advantage of the adoption of an IEM methodology is to better capture congestion related emissions and more accurately reflect the potential scheme benefits. This research concentrates on NOx outputs, given that the declaration of the AQMA in Durham was for NO2. NOx outputs may be subsequently converted to NO2 levels by appropriate dispersion and chemical modelling.

RESULTS

Comparative Emissions Results

Analysis was performed to investigate the relationship between the NOx emissions results derived from the traditional NAEI-based average speed emissions methodology and the AIRE derived IEM technique. Each network was split into approximately thirty road sections to aid comparison. Average speed NAEI emissions were analysed for a full 24-hour period, at one hour resolution. IEM emissions outputs were aggregated into fifteen minute averages, as well as hourly averages to compare directly with the average speed emissions results. A close correspondence between the two methodologies was identified on a number of links, providing confidence in the techniques adopted.

However, further analysis of the traffic and related outputs revealed that a large number of links showed evidence of ‘congestion’ emissions in the AIRE results. Generally, for periods immediately preceding or directly after the peak traffic period, a good agreement was found between the two methodologies. Conversely, during the peak, when congestion is highest, the emissions outputs derived using the AIRE methodology were found to be far higher than those from PITHEM.

Furthermore, an analysis of a number of arterial routes provided evidence of tidal congestion emissions. Figure 2 shows the Crossgate Peth area of Durham City. During the morning peak the east bound movement is congested with people travelling into Durham, with significant increase in emissions in the AIRE outputs compared to the average speed NAEI results. However, in the afternoon peak, when flows going in to Durham are lower, conditions were found to be less congested and the two methods were in better agreement. Conversely, for the west bound movement it is the afternoon peak when congestion is observed due to high volumes of traffic leaving Durham. Once again the AIRE emissions agreed well with the NAEI-based methodology except in the congested period.
Across the network significant differences in modelled emissions between the two methodologies were observed. The most heavily congested links revealed +200% higher emissions predicted using AIRE compared to the NAEI outputs. The overall network results can be seen in Table 1.

Table 1. Overall network results, NAEI vs. AIRE (NOx).

<table>
<thead>
<tr>
<th>Peak</th>
<th>NOx (mg) NAEI</th>
<th>NOx (mg) AIRE</th>
<th>Difference (mg)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>10,782,900</td>
<td>17,454,206</td>
<td>6,671,306</td>
<td>62</td>
</tr>
<tr>
<td>PM</td>
<td>19,261,700</td>
<td>26,830,555</td>
<td>7,568,855</td>
<td>39</td>
</tr>
</tbody>
</table>

Durham Traffic Engineering Scheme Results

Following the exploratory work and analysis of the emissions methods it was concluded that the impacts of Durham Traffic Engineering Scheme would be more accurately assessed using an IEM approach to emissions modelling. As a number of key areas of Durham’s AQMA are congested for significant periods of the day congestion sensitive modelling was deemed vital for estimating the potential benefits of the scheme.

Existing and proposed scheme microsimulation models were run for both morning and afternoon peak periods. Each microsimulation model was run three times (total twelve runs), the resulting output files were processed through AIRE, and subsequently analysed using a bespoke software program. The overall average network results from both of the modelled peaks can be seen in Figure 3.

Table 2. Scheme Appraisal network results for NOx emissions from AM and PM peak periods.

<table>
<thead>
<tr>
<th>Peak</th>
<th>NOx (mg) Existing</th>
<th>NOx (mg) Proposed</th>
<th>Difference (mg)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>47,387,363</td>
<td>43,913,854</td>
<td>-3,473,510</td>
<td>-7</td>
</tr>
<tr>
<td>PM</td>
<td>51,235,115</td>
<td>50,594,357</td>
<td>-640,759</td>
<td>-1</td>
</tr>
</tbody>
</table>

The results suggest that whilst the scheme shows a reduction of 7% in NOx emissions during the morning peak, the benefits are much less at 1% for the evening peak. This may be due to the fact that the morning trips into the city are more constrained to the start times of employment and schools. The peak period during the evening peak is less stressed during the afternoon peak due to greater flexibility at the end of the day for businesses, industry and the school run.

Air Quality Concentrations

The emissions based approached to modelling air quality provided insight into the sources of air pollution. This is necessary to inform remedial measures. However, it is important to gain an understanding of how those
emissions interact with local topography, built environment and meteorology to understand which areas and sectors of the population are affected by air quality concentrations.

Atmospheric dispersion models use link based emissions estimates to predict the spatial distribution of pollutants over a given area by simulating the complex relationship between emissions estimates and outdoor air pollutant concentration (Hirtl, 2007). Meteorological and topography data (or area coarseness) are required to complete this process.

Twenty-four hour estimates were produced for modeling, in order to allow the build-up and dispersal of emissions throughout the day to influence concentrations. The existing micro-simulation model was extended to include a diurnal profile when making estimates of emissions using AIRE. The ‘minute-by-minute’ emissions results were aggregated into hourly values for all links in the network. These were then fed onto a dispersion model enabling comparison of concentration levels for the existing network compared to the proposed scheme (Figure 4).

ADMS-Urban (CERC, 2011) was used for this research as it is user friendly, stable and has been extensively validated by over 70 UK local authorities (Riddle et al., 2004). In this assessment modelled NOx values were converted to NO2 using the DEFRA ‘NOx to NO2’ calculator (DEFRA, 2012).

Analysis of Annual Mean NO2 Concentrations across key Durham receptors show that despite reporting an overall network reduction in emissions the proposed scheme does not improve air quality across large areas of the study area (Figure 5). However, there were improvements in air quality levels at fifteen of Durham’s twenty five key receptors identified from the Durham County Council Local Air Quality Management Durham City Further Assessment report 2012.

DISCUSSION
Analysis of environmental justice (EJ) at the national level in the UK has produced evidence of injustice in the distribution and production of poor air quality. Consequently, the effect of the proposed traffic scheme on environmental justice is discussed in relation to the spatial distribution of areas with poor air quality.

A previous study by O’Brien et al., (2012) indicated that there was no evidence of environmental injustice in the distribution of air quality in the City of Durham. This current study provides an opportunity to review those findings at the microscale level. To complement microscale air quality modelling, household geodemographic data was obtained from Experian’s Public Sector Mosaic database. Geodemographic classifications provide an accurate understanding of each citizen’s demographics, lifestyles and behaviours by accessing a wealth of information on all UK individuals using more than 440 data elements (Experian, 2009). Public Sector Mosaic customer profiling classifies all UK citizens into 15 groups (A to O) and 69 types (A01 to O69). For this study household level Mosaic data was geocoded using OS Address-Point to provide coordinate information for every address in the Durham study area. This data was entered in to ADMS to enable air quality concentrations to be generated for each address.
Analysis of Mosaic and air quality data revealed that, in agreement with O’Brien et al., (2012), there was no evidence of any significant relationship between air quality and deprivation (R squared = 0.002). However, further analysis of group and type data revealed significant features in the groups subjected to poor air quality. Group G ‘Young, well-educated city dwellers’ account for 9% of UK population, 30% of the Durham study area population (2209 of 7471 households). However, 73% of study area households with air quality above 25 µgm⁻³ (151 of 208 households) and 100% of study area households with air quality above 35 µgm⁻³ (40 households) where classified as Group G. Therefore, the only households subject to air pollution levels above the mandatory EU air quality limit value for NO₂ of 40 µgm⁻³ belonged to this group. To investigate the significance of this identified grouping χ² analysis was performed. Households were classed as being exposed to air quality ‘Above 25 µgm⁻³’ or ‘25 µgm⁻³ and below’ and the Mosaic group values were themselves grouped into one of three groups; C, Wealthy people living in sought after neighbourhoods; G, Young, well-educated city dwellers; and Other. These groups were based on the numbers falling into the ‘Above 25 µgm⁻³’ category and each group was individually tested for significant variance (C, Wealthy people living in sought after neighbourhoods χ² = 5.961, df = 1, p = 3.841 at 0.05 probability level; G, Young, well-educated city dwellers χ² = 188.113, df = 1, p = 3.841 at 0.05 probability level). The overall three group result showed statistically significant differences at the 95% confidence level between the expected and observed values (χ² = 217.870, df = 2, p = 5.991 at 0.05 probability level).

The EJ of the proposed traffic scheme was assessed using the outlined methodology. Generally, the proposed traffic scheme had a negative impact in terms of EJ. Firstly, the number of Group G households suffering from air quality levels above 35 µgm⁻³ increased by 27%; Secondly, a small number of Group L ‘Active elderly people living in pleasant retirement locations’ households were adversely affected by poor air quality as a result of the scheme (5 households, 35+ µgm⁻³; 3 households, 40+ µgm⁻³).

CONCLUSIONS
The methodology outlined in this paper presents a framework for assessing the impact of traffic schemes designed to improve air quality. Results show that whilst traffic scheme tested in this paper reduced overall vehicle emissions, the impact on air quality was less positive due to the critical location of some increases in emissions. Furthermore, the existing pattern of poor air quality in Durham negatively impacts a specific social group as defined by Experian Mosaic data, namely student elements of Group G ‘Young, well-educated city dwellers’. Finally, the proposed transport scheme evaluated in this research failed to address this potential EJ issue.

REFERENCES


Harris, B. (2004) ‘The effects of street gradients on urban traffic emissions’, Materials Research Centre, University of Bath, Bath BA2 7AY.


