AUTOMATING EXPOSURE ANALYSIS THROUGH GIS ALGORITHMS

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ABSTRACT

Traffic emissions are a major source of atmospheric pollutants in urban areas. The process of identifying areas with high concentrations and potential population exposure ("hot spots") is currently conducted by environmental officers. This non-computerised assessment is extremely time-consuming and is dependent on the judgment of the environmental officer. In addition, transport planners rarely take into account the impact of traffic management schemes on public health. Traffic scenarios have to be tested to determine if they are likely to create a positive impact on the environment. It is therefore important to be able to automatically determine risk areas with likely population exposure arising from traffic-related sources. This paper describes two new tools specifically developed in a Geographical Information System (GIS), to automate the evaluation of population exposure.

The first tool was developed to automate the detection of "hot spots". These were identified as populated areas where the pollution concentrations exceeded the relevant health-based air quality standards. The second tool was then developed so that once the "hot spots" had been identified, alternative traffic scenarios could be tested in order to reduce or remove the "hot spots". A range of GIS algorithms were devised to allow quick scenario testing, including traffic reduction schemes, traffic calming and variations in traffic composition. The tools are presented in a user-friendly integrated environment known as IMPAQT. These new tools may be used to help decision makers assess air quality from current and future situations, in addition to increasing the efficiency of air quality assessments.

INTRODUCTION

The implementation of air quality improvement schemes in areas with relevant population exposure is the main driving force behind air quality research and assessments. At present, the computational side of an air quality investigation ends when the pollution levels at a specific time and place have been predicted. These pollution levels are generally used as the basis of air quality assessments by researchers or environmental officers. Hence, air quality assessments are currently conducted through good engineering judgement, i.e. by using a manual comparison of predicted air pollution levels with existing air quality standards to identify "hot spots". This process is time-consuming and dependent on the judgment of the researcher or the environmental officer. In addition, the impact assessments of different traffic scenarios on air quality are conducted separately from air quality investigations. Air quality researchers or environmental planners rarely take into account optimal traffic flow. Conversely, transport researchers/planners do not account for the impact of traffic schemes on the environment. There is, therefore, a growing need to develop decision support tools that automatically links air quality with both population exposure and transport schemes. This paper describes such tools developed within an integrated air quality assessment framework known as IMPAQT [1]. The following sections include a brief overview of IMPAQT and the newly developed decision support tools. A case study is then presented, in which a full air quality assessment, including exposure evaluation and "what-if" scenarios are demonstrated.

METHODOLOGY

A schematic diagram of the air quality assessment framework, IMPAQT, is shown in Figure 1. Essentially, data from a transport model are used to determine traffic emission rates, which in turn are used in a dispersion model. The pollutant concentrations predicted from the dispersion model are then input into the first newly developed tool, namely the population exposure tool. This automatic exposure detection tool is designed to determine areas with pollution concentrations that are above the relevant air quality standard. If these areas coincide with populated areas, then, they are identified as pollution "hot spots". Conversely, high concentrations of pollutants in places such as open fields are excluded, as they are generally not of primary concern in air quality assessments.

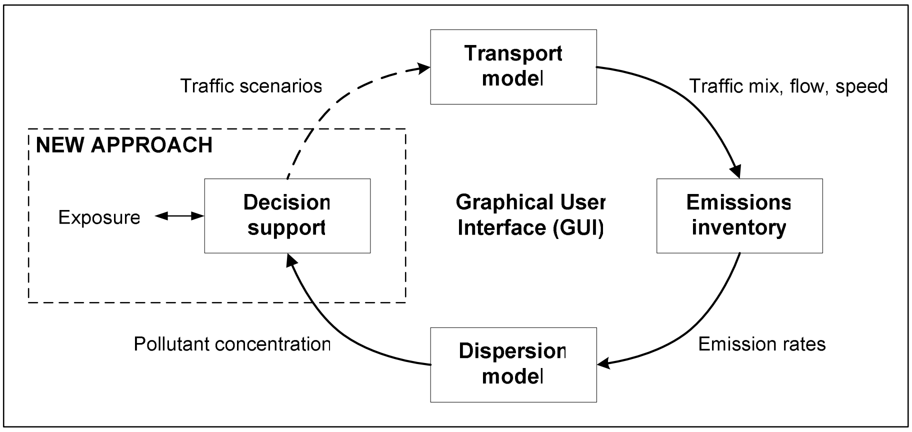

Figure 1: IMPAQT – a computerised air quality assessment system

Once an air quality "hot spot" has been identified, the second newly developed tool is implemented to test "what-if" traffic scenarios. These are used to evaluate pollution reduction schemes or the impact of new urban development/regeneration schemes, thus creating the link between population exposure and traffic schemes. The "what-if" scenario tool allows the user to select from a range of traffic schemes, which can be applied to modify the traffic emissions on the road links identified in the "hot spots". Some examples of these schemes include pollution reduction scenarios such as the decrease of heavy duty vehicle (HDV) and light duty vehicle (LDV) flows, or changes to vehicular speeds. Alternatively, potential pollution elevation scenarios, such as new urban development/regeneration sites may also be investigated.

For the schemes that involve traffic flow, the changes are applied directly to the "hot spots", while the traffic flow on links in nearby zones are gradually modified. This concept meant that flows outside the vulnerable areas are not simply eliminated but are phased in. An air quality calculation is then repeated with the new "what-if" scenario. This scenario forms the basis of a new emissions inventory and the selected traffic scheme is tested to determine if it is likely to create a positive or negative impact on the environment. If the new scenario produce satisfactory results, the user can then choose to carry out more detailed traffic modelling by re-running the transport model.

CASE STUDY

Study area

The area selected for the case study was Guildford, an urban area in the south-east region of the UK. It is located about 42 km from the centre of London. The roads within Guildford are major commuter routes, linking London and Heathrow Airport with the southern and western counties of the UK. These roads have high traffic throughput, typically with average daily traffic flows twice the UK national average [2]. There is already a growing concern in Guildford regarding both high levels of traffic congestion and the potentially elevated pollutant concentrations close to the urban population. The pollutants in this region were attributed primarily to traffic-related sources [3]. The study area consisted of 125 major road links. 32% of these had average weekday flows in excess of 25,000 vehicles per day and 12% with over 50,000 vehicles per day [4].

Tools and dataset selection

The transport model used to predict traffic flow and speed, was the Surrey County Transportation Model (CTM), base year 1998 (CTM98) [4]. This was coupled with ADMS-Urban 1.6, a PC-based commercial dispersion modelling package, to simulate pollutant concentrations at specified locations and times [5]. The results from the dispersion simulation were represented spatially using a desktop GIS, ArcView GIS 3.2 [6].

Weather conditions were recorded by the UK Meteorological Office. The 1998 hourly sequential data were obtained from a weather station situated at London Heathrow Airport. The weather station is located approximately 28 km north-east of Guildford. This is the nearest weather station with an appropriate meteorological dataset representative of the study area.

Air quality calculation

A detailed air quality calculation was undertaken using the tools and dataset selected. A set of contour plots for the pollutant investigated (NO_2) was produced. Figure 2(a) shows the high-resolution NO_2 map for the study area. The areas with the maximum levels of NO_2 (> 40 $\mu g/m^3$) were identified along sections of the A3, a major trunk road in the region. Areas with levels approaching the 40 $\mu g/m^3$ UK 1-hr annual mean objective were also found to be along major urban routes into the town centre. These roads were the A322 and A320. They did not have traffic levels as high as the A3, although they were known to be congested during peak hours. It was, therefore anticipated that these routes would have high NO_X emissions and hence, elevated levels of NO_2.

Exposure evaluation

The exposure evaluation tool was then applied via IMPAQT to the NO_2 pollution map, to identify the “hot spots”. These vulnerable areas, as depicted in Figure 2(b), have both elevated pollution levels and potential public exposure, i.e. areas with buildings and NO_2 levels above 40 $\mu g/m^3$. A total of 31 road links were identified as the road sources most likely to have caused these “hot spots”. Several “what-if” scenarios were then tested to try and reduce the pollution levels along these links.

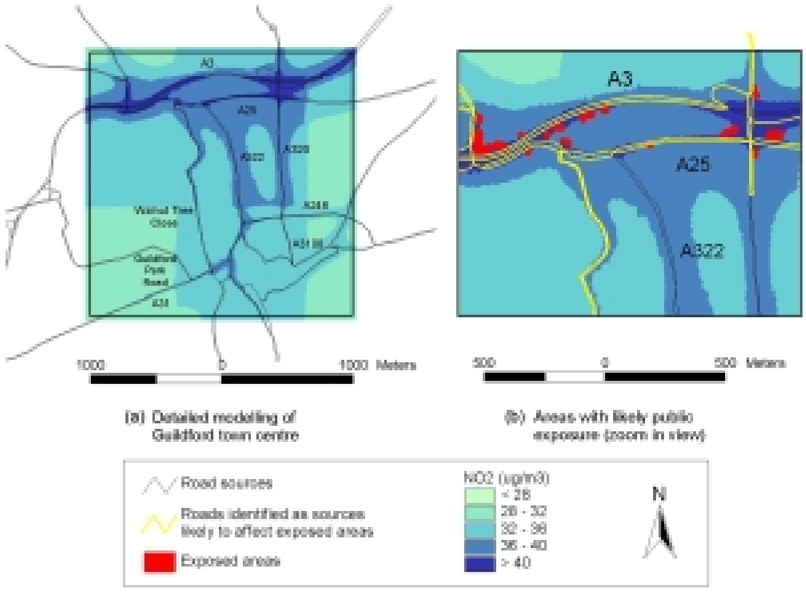

Figure 2: Detailed modelling of Guildford town centre (annual mean NO_2)

"What-if" scenarios

Two traffic scenarios were applied to this case study via IMPAQT. The first scenario was a hypothetical option where HDVs were totally excluded from the road links in the town centre. This scenario was tested to investigate the extent of the influence of HDVs on NO_2 concentrations in the study area.

The second scenario adopted a more practical approach for improving air quality in urban areas. In this scenario, the hourly traffic flow was reduced by 20% on the 31 road links identified in the air quality assessment. In addition, the hourly traffic flow along roads within a 5 km radius from these links was reduced by 10% (87 road links).

These scenarios were applied to the original traffic flows and two new emissions inventories were constructed. ADMS-Urban was re-run with these new emissions inventories. The results for Scenarios 1 and 2 are presented in Figure 3(a) and 3(c) respectively.

Scenario 1 – Without HDVs

Figure 3(a) showed that the NO_2 "hot spots" along the links identified in the air quality assessment were significantly reduced. The reduction in NO_2 concentrations was most significant along the A3, the A25 and the southern edge of Guildford town centre. The exclusion of HDVs from the "hot spots" reduced the number of exposed areas down to a single location at the edge of a busy roundabout, next to the A3 (Figure 3(b)).

Scenario 2 - 20% reduction on hourly "all vehicle" flow

The results for Scenario 2 are presented in Figure 3(c). There was a reduction of NO_2 concentrations on the critical links along the A3, the A25 and the southern edge of Guildford town centre, which was similar to Scenario 1. There was also evidence of "boundary shrinkage" effect along these links. A 20% reduction in hourly traffic flow confined the exposed areas to the north-west region of the town centre. This area was the same as that identified in Scenario 1, i.e. the region located next to a busy roundabout next to the A3, as illustrated in Figure 3(d).

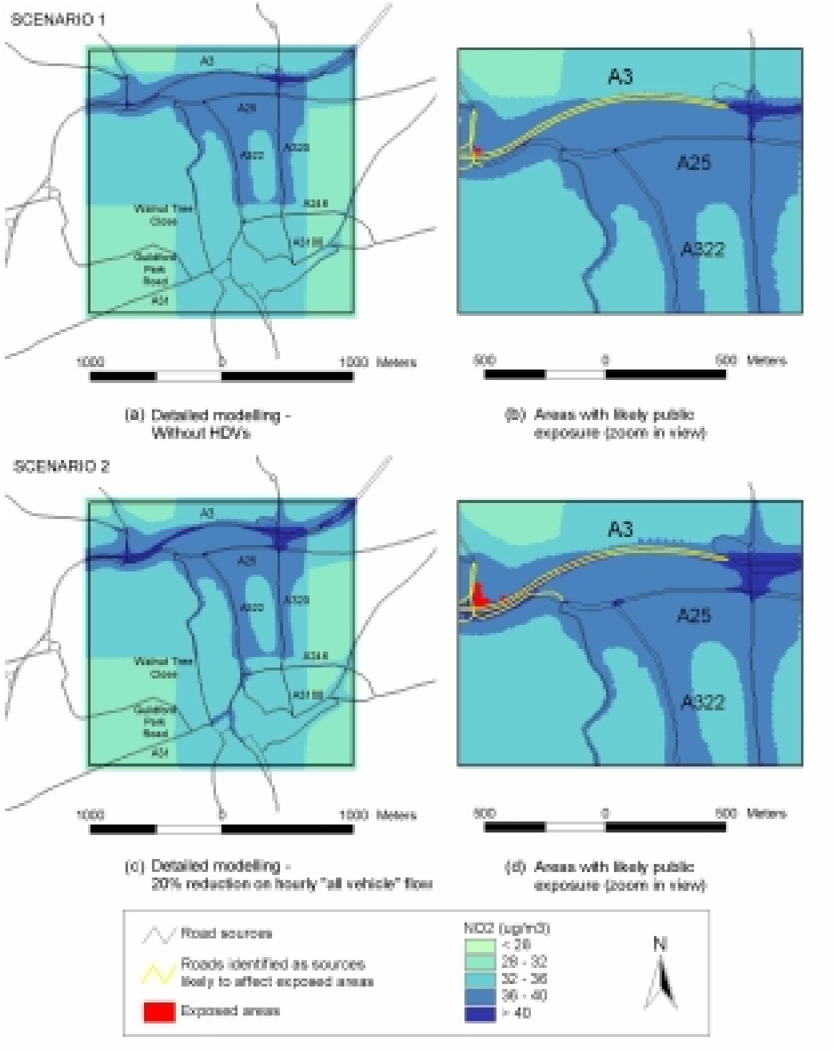

Figure 3: Results from "what-if" scenarios

Discussion

A comparison between Scenarios 1 and 2 showed that the emissions were the most significant around busy junctions, where there was potential traffic congestion. As expected, Scenario 1 showed that HDVs contributed the most pollution in the "hot spots". Both scenarios reduced the number of "hot spots", thus reducing the number of areas with likely public exposure.

In the "real" world, however, preventing HDVs from travelling along these routes may not be feasible. A traffic management scheme, which can reduce the hourly traffic flow by 20%, may, however, be possible. In terms of long-term sustainability, this will depend on several factors such as traffic growth, changes in emission factors, etc. The emission factors are predicted to decrease in the future (when compared with the DETR vehicle fleet model, from which the emission factors were derived [7]). Thus provided there are no significant changes in traffic growth or composition, then these factors coupled with a traffic management scheme of this nature may be sufficient to eliminate all the "hot spots" from within this study area.

CONCLUSIONS

This paper describes two new decision support tools that automatically detect population exposure and test "what-if" traffic scenarios. The two tools were integrated into an air quality assessment framework, known as IMPAQT. This meant that areas with likely population exposure were fully automated (previously determined manually by environmental officers). These "hot spots" could then be linked with alternative traffic scenarios within the same environment (previously tested by traffic planners, independent from air quality assessments).

The case study undertaken using IMPAQT demonstrated the benefits of these two new tools in terms of air quality assessment efficiency. The results showed that the laborious and time-consuming task of identifying "hot spots" manually was completed automatically and quickly. Traffic scenarios were also applied to the road links within these "hot spots", in order to reduce pollution levels in these areas. Hence, only cases that warrant further investigations were recommended for detailed traffic modelling.

The development of these new decision support tools within IMPAQT was designed to assist both environmental officers and traffic planners in their assessment of air quality, public exposure and the environmental impact of new/alternative traffic schemes. This was achieved in a fully automated mode, which had the additional benefit of significantly increasing the efficiency of these processes, in terms of time and ultimately cost.

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