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THE ROLE OF PERVERSIVE SENSOR DEPLOYMENTS
IN THE EVALUATION PROCESSES FOR
TRAFFIC DEMAND MANAGEMENT STRATEGIES (TDMS)

Prof. Margaret Bell, Dr. Fabio Galatioto, Dr. Graeme Hill
Transport Operations Research Group, Newcastle University

Abstract

This paper describes a new approach, which is designed to be able to evaluate the impacts of TDMS (Traffic Demand Management Strategies) on congestion and the environment. Performance measures will be based on a combination of data from pervasive sensors, namely motes measuring pollution, carbon monoxide [CO] and nitrogen dioxide [NO₂], and noise, and legacy systems including SCOOT (Split Cycle Offset Optimisation Technique), traffic loop detectors, AURN (Automatic Urban and Rural Network) and meteorological conditions.

The proposed framework has been evaluated using a case study area in Leicester. Analysis of pollutant levels measured by inexpensive static (located on street furniture) pervasive sensors known as motes, will be presented in the paper. Next the process by which the SCOOT data is used to validate parameters of traffic simulation models (congestion states, flows, origin-destinations, etc) will be shown. The microsimulation model is used to predict tailpipe emission, taking into account the second by second drive cycles and the canyon model OSPM is then used to predict pollutant concentrations in the canyon at positions that coincide with the motes. Using the SCOOT data for flow and a speed estimate based on delay and independent estimate of emissions and concentrations is produced and compared with that derived by AIMSUn and measured by the motes. In this way an in-depth understanding of the spatial and temporal changes in the congestion and associated carbon monoxide across an area due to recurrent congestion occurring at the shoulders of a football event was made possible. The limitations of the both the AIMSUn and SCOOT derived pollutant estimators were explained. The results of this work showed that both AIMSUn and the SCOOT based estimates emissions estimates along with the Osmp model and measured meteorological conditions can provide estimates of roadside concentrations in a Canyon with a level of statistical confidence reflected by the regression coefficient $R^2=0.70$. Given that this is a first attempt at developing a real-time Canyon model and there is scope to address the shortfalls identified in this work the results presented in this paper show much promise. The paper has highlighted the benefits of pervasive sensors and how they can compliment legacy systems through their flexibility in covering detection gaps in existing urban networks.

Keywords: Traffic Model Validation, UTMC, Quantifying Impacts

INTRODUCTION

Throughout the world, Governments are committed to delivering reductions in carbon dioxide emissions. This requires novel ways to manage increasing travel demand from a growing population, whilst seeking to reduce the number of vehicles on our roads. The Eddington Report [1] acknowledged that transport is vital to the economy and in most developed countries the basic connectivity is good but localised crowding or congestion is a problem. It sets out the priorities for congestion management in key urban areas, inter-urban corridors and international gateways. The Stern Report [2] provided a wake-up call by translating the impact of traffic on climate change in the context of its implication on our economy. The Stern Report sets out an economic and moral case for taking immediate steps to deliver a 60% reduction of carbon dioxide, CO₂, emissions over 1990 levels, by 2050. The report demonstrates that immediate action is likely to cost about 1% of global GDP (higher for developed countries) but will yield far greater benefits by avoiding 5-20% hit on GDP at a later date. The Climate Change Act (2008) increased this target reduction to 80%. In the UK, Local Authorities are made responsible for delivering National Policy under the direction of International law. Policy that delivers sustainability has congestion and environment control and management as key challenges but the biggest challenge of all is delivering CO₂ reduction without compromising air quality and noise levels, and associated health impacts.
Local Authorities are continuously under pressure to address congestion. Whilst congestion related to incidents is often wide-spread, it lasts for a long time and is unpredictable. Traffic managers in these situations take steps to alleviate congestion, as best they can, to minimise impacts. On the other hand recurrent congestion in a network can appear fairly regularly and takes a similar pattern spatially over time in a predictable way. A common example of recurrent congestion is late night shopping, heavy rain, factory turn-out, etc.. Effective management of recurrent congestion is fundamental to the successful delivery of sustainable policy. In order to achieve congestion management, a robust real-time monitoring and modelling framework is needed to provide automatically: complementary information concerning network status; analysis of data to identify problems; validate models and create remedial actions. In this context, this paper presents evidence that demonstrates the value of inexpensive pervasive monitoring networks, referred to as ‘motes’ to complement data available from Intelligent Transport Systems (ITS). By integration with models a framework is provided to better manage the impact of recurrent traffic congestion on the environment. Event traffic from football matches will be used as an example of recurrent congestion in this study.

The specific objectives were:

1. To capture the mote data synchronised with the SCOOT (Split Cycle Offset Optimisation Technique, demand responsive control [3]) traffic data to explore the spatial changes in congestion across an air quality management area,
2. To use SCOOT traffic data to validate the AIMSUN micro-simulation model,
3. To develop two independent estimates of tailpipe emissions, the first using AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks, [10]) and the second based on SCOOT,
4. To use the OSPM canyon dispersion model and assess the relative accuracies of the predicted pollutant concentrations based on SCOOT data and the AIMSUN microsimulation within known limitations,
5. To demonstrate the role of motes in validation air quality canyon models.

Following a brief description of the pervasive sensor technology, the methodological approach to setting up and validating traffic microsimulation in the case study area of Narborough-Upperton road in Leicester, where SCOOT operates, will be explained. A comparison of the flows and occupancy measures from the SCOOT data prior to, during and after, the match on days with and without the event traffic will be presented. Next two methods, the first using SCOOT and the second using the AIMSUN model, used to estimate tail pipe emissions will be described. Following an outline of the use of canyon dispersion model along with integrated meteorological data the estimated air pollution in the street are compared with those measured by the pervasive sensors in the context of with and without a football match event. Following concluding remarks suggestions for future work will be presented.

THE PERVASIVE SENSORS NETWORK

The project Mobile Environmental Sensing System Across Grid Environments, MESSAGE, jointly funded by EPSRC (UK Engineering and Physical Sciences Research Council) and DfT (Department for Transport) has delivered pervasive sensors which co-exist with legacy systems to enhance network wide monitoring. This project, led by Imperial College, was in collaboration with
the Universities of Cambridge, Leeds and Southampton. The sensors (motes) developed at Newcastle University, monitor traffic occupancy, and therefore assessment of traffic flow characteristics namely; free flow, smooth flow, stop-start, congested, location (using GPS), accelerometer (movement for dynamic sensors), temperature, humidity, noise, carbon monoxide and nitrogen dioxide. The mote has a data logger and uses ZIGBEE wireless mesh networking standard IEEE [4], to communicate data through a gateway to a remote central server. These inexpensive monitoring sensor systems can operate for up to six months with the same battery and the measured signals are sent in real-time every minutes in their raw state to an UTMC compliant database. The raw data is calibrated, using the manufacturer’s specifications and algorithms to compensate for temperature and humidity depending on the pollutant. Subsequently, the data is quality assured and missing values are dealt with by interpolation. The motes may be mounted on static or mobile platforms and the full specification is available in Neasham et al [5]. Motes can be deployed pervasively because of their low cost. Their low measurement accuracy is compensated by higher deployment density across areas and by the longer sampling periods at one minute resolution. Crucial to the success of the mote application, is establishing the statistical confidence with which changes can be measured. When deployed in the field, sensors have to be evaluated to assess their fitness for purpose. Preliminary studies of the performance of each sensor have been reported in Bell et al. [6, 7].

METHODOLOGICAL APPROACH FOR SIMULATION ASPECTS

In the quest to develop an integrated monitoring and modelling capability, as proposed in the EU project HEAVEN [8], efforts are being made to seamlessly pass data from sensors to a database warehouse and into micro-simulation models. When a model can be demonstrated to simulate existing situations, usually referred to as the base case, realistically with statistical confidence, then the model can be used to test scenarios and thus to explore solutions to network problems. When these solutions are implemented, the motes are used to measure the consequential impacts and to assess the accuracy of the model’s predictions. This feedback enriches the credibility of the modelling capability as well as quantifying the magnitude of the measured benefits delivered by the strategy implementation.

CASE STUDY AREA

Figure 1 shows the demonstration area of Leicester which is centred on a main radial route from the motorway in the south east into the city of Leicester (Narborough Road). The east – west route is Upperton Road which provides crucial access in the area. Fifty motes (see Figure 1a) have been deployed across the area in the vicinity of the critical signal controlled junction Narborough-Upperton road to measure the environmental impact (CO, NO₂ and noise) on the primary and secondary roads as well as in residential streets. A SCOOT Region operates in the area coordinating the signals and controlling traffic entering and leaving this, and all neighbouring, junction(s) in all directions. The micro-simulation model was set up for the area and was validated for flows, queues and turning flows using a comprehensive analysis of video footage of vehicle movements of traffic along Narborough Road and more specifically moving through the junction.

The traffic and environmental data from different sources (CCTV camera, SCOOT, mote sensor) were collected during a period covering respectively 12:00 – 20:00 on Saturday and 18:00 – 24:00 on Tuesday. By associating a mote measurement location with a link modelled flow and validation parameter then it was possible to set up the database infrastructure to deliver the analysis framework. This is illustrated in Figure 1a where the Google icons mark the static mote positions associated in figure 1c with the simulated links (red dashed lines) with identifiers in figure 1b.
EXPLORING CHANGES IN FLOW AND OCCUPANCY

It is important to look at both flow and occupancy when interpreting the effect of the event traffic on congestion across the area. With reference to Figure 2a and 2b it is clear (NB the shaded area identifies the period of the match itself) that the event traffic arrivals are spread over a couple of hours before the match and its effect on some links continues after the start of the match, see peak in occupancy from 15:00 – 15:30. Also, the flow towards the end of, and after, the match is seen to have an even bigger impact on congestion (i.e. high occupancy peak). This is consistent with the bunched departures, from parking areas at the stadium and in local streets, at the end, compared to the more gradual arrivals at the start, of the match.

Figures 3, 4 and 5 show how the traffic impact on flows and associated occupancy, for before, during and/or after the match, for different roads considered to be affected by the football event relative to a “typical” day. In fact, for a Saturday match (Figures 3 and 4) the values and variations of flow and occupancy are lower than is the case of Tuesday (Figure 5) where for the one and a half hours before the match the flow is more than 30% higher, 600 veh/15’ instead of 450 veh/15’ in the case of the Saturday match. In terms of occupancy, the impact that this flow produces is more than 100% higher on the Tuesday, while on Saturday the occupancy increment is around 40-50%. Interestingly on Saturday, on road 5, before the match the traffic flow is similar to the case without the match but the occupancy increases significantly due to the tail back effect of queues from the downstream traffic effecting the traffic travelling from west to east towards the football Stadium.
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DEVELOPMENT AND VALIDATION OF THE TRAFFIC MICROSIMULATION

An AIMSUN micro-simulation model was built for the Narborough Road SCOOT Region in Leicester. The basic data for model development was made available by the Leicester City Council as recordings of CCTV camera images of traffic at junctions along with SCOOT data. The model was built to include road layouts, lane allocations, signal junction stop lines, pedestrian crossings, banned turns, bus only lane road sections, bus stops etc. The set of traffic data chosen for this study was related to the football match event that took place on the 3rd of March 2009 (Tuesday – 19:45 kick off time) and the 7th of March 2009 (Saturday – 15:00 kick off time). In addition to the geometric layout of a network traffic signal control specifications and a description of the vehicle fleet, micro simulation models require the origin-destination matrix of trips made into, out of and within the modelled area. Using the ME2 facility the traffic flow data from SCOOT detectors in the area were used to update the origin and destination matrix within the SATURN (Simulation and Assignment of Traffic to Urban Road Networks, [9]) for each 15 minute period throughout the day. The origin-destination matrix for each 15 minute period were used in AIMSUN to simulate flows on an individual vehicle basis.

The accuracy of the model prediction, and impacts, were evaluated by comparison with data on a Tuesday and Saturday without football events.
VALIDATION OF THE TRAFFIC MODEL AIMSUN

Figure 6 gives the comparison of measured, from direct observation of CCTV video recording, with the predicted flows, from the micro-simulation. The agreement is good (with a regression coefficient of $R^2$ of 0.89) up to about 200 vehicles/15mins. The simulated flow reached a threshold at about 200-250 vehicles/15’ beyond which traffic flows were underestimated compared to SCOOT flows. This feature of the data was consistent with the assumption of fixed time control in AIMSUN, throughout the day. In reality, because SCOOT was in operation, the signal timings continuously vary, increasing green splits and/or cycle times to increase capacity particularly during the peak periods. The assumption of fixed-time operation was necessary in the absence of the dynamic signal timings from SCOOT.

![Figure 6 – Observed flow from recording of actual micro-simulation model](image)

TAILPIPE EMISSIONS PREDICTION

Within this model limitation, tailpipe emissions were estimated for each link (1 to 8). The micro-simulation model calculated the tailpipe emissions based on the second by second estimates of speed and acceleration of the traffic at their specific positions on a road in the network and using the fleet composition (car, LGV, HGV, bus) observed from the video analysis. For the purpose of this modelling an equal number of petrol and diesel engines in the car fleet was assumed. The NAEI emission factors were used in the microsimulation model and the in-built algorithms, available in the micro-simulation model, were used for the emissions estimation. As a first order estimate, emissions from all the vehicles in the link were estimated as a mass in kilograms. Emissions estimates were produced for each 15 minute interval during the selected time period, and for each of the 8 links distributed around the junction.

For comparison an independent estimate of emissions was derived using the data provided by the M29 SCOOT message, which provided the number of cars passing along a stretch of road per second. Assuming all cars are petrol, the CO emission rate per car was setup of 10g/km giving rise to a total emission rate per second per metre of road. In order to make a direct comparison of the SCOOT derived emissions with the microsimulation, the latter were multiplied by the length of the link and the time period of the simulation. This is because the traffic microsimulation model AIMSUN calculates the emission by modelling all traffic through a link and estimating the total CO emitted over the link for the specified simulation time period. A scaling factor is used to convert the emission to be a similar fleet as that modelled in AIMSUN.

DISPERSION MODEL USED TO ESTIMATE ROADSIDE POLLUTION

The model used to disperse the emissions estimated by AIMSUN and SCOOT, was the Operational Street Pollution Model (OSPM) [11]. OSPM uses the street-wide emission estimate and calculates the dispersion using a simple plume and box model within an urban canyon environment. Direct contribution to the roadside concentration (at the mote position) from vehicles, is calculated using the plume model while the box model was used to calculate the contribution due to recirculation of pollutants, depending on the meteorological conditions. The meteorological data (available from the Leicester City MetStation sited at the periphery of the city) include average wind
speed, wind direction. Other parameters needed for the OSPM include average vehicle speed, canyon geometry, (height of buildings, width of road - facade to facade) and the emission within the canyon. The version of OSPM used in this research is a simplified model based on the original paper by Berkowicz et al (1997). Amongst the simplifications used, is an assumption of a single street with no intersections and an even distribution of emissions throughout the canyon. Clearly the OSPM will perform better as a distance away from the junctions. At this stage, approximations of the widths and heights of the canyon have been used whilst in the future, it is expected that the e-Science database platform will be integrated with a building height model which uses the Lidar data from Infoterra. In this way the shape of the canyon can be more accurately modelled and automatically result in a better estimate of the dispersion effects on pollutant emissions.

RESULTS OF DISPERSION OF AIMSUN and SCOOT DERIVED EMISSIONS

The data in figure 7 has been created by separating the output from the OSPM, into two different groups of roads, those which show good correlation (roads 1-2-3-5-7-8) and those which show poor correlation (roads 4 and 6). The data plotted in Figure 8 are those roads closest to the junction. In general AIMSUN values are systematically underestimated compared to those predicted by SCOOT. Because the OSPM uses the same meteorological conditions and is common to both, the difference between the two estimates, namely SCOOT and AIMSUN, is governed mostly by the way in which the emissions have been estimated. For SCOOT the average speed and flow are used within the OSPM algorithms to derive emissions whilst in the case of AIMSUN, its own estimates of emissions instead are used in the OSPM. Given that fixed-time rather than demand responsive signal control was modelled in AIMSUN the levels of congestion, compared to AIMSUN are better reflected by the SCOOT. It can be seen from Figure 6 that higher flows are measured by SCOOT toabout 350veh/15'. These model limitations mean that the estimates of the CO from AIMSUN is overestimated on some roads and underestimated on others.

It can be seen that there are two distinct families of points are created within the OSPM and further investigation is needed to fully understand from where the difference originate. There are several possible explanations, some are discussed here. One likely source of discrepancy is in the assumptions made in deriving the emissions. From SCOOT it is assumed that the traffic is entirely composed of petrol cars with an emission of 10g/km. If a high proportion of the traffic for this link are diesel (HGV or buses for example) then SCOOT will overestimate CO emissions. Appropriate scaling factors are used to compensate for this. Figure 7 shows the results of comparing the OSPM derived CO concentrations for SCOOT plotted on the x axis from AIMSUN plotted on the y axis for each road. The correlation between the data sets relating to the roads 1-2-3-5-7-8 appears to be good in relative terms and poor in absolute terms, in fact there is a factor of 10 between the AIMSUN and SCOOT values, probably due to the application of previous National Atmospheric Emissions Inventory (NAEI) factors. On the other hand, the poor correlation for roads 4 and 6, at the periphery of the network, is probably due to the different flow regimes experienced at the edge of the network compared with the roads close to the junction. In fact roads 4 and 6 are dominated by high average speed (more free flow) compared with stop-line links where vehicles are continuously varying.

Another potential explanation could be due to the different way speed is calculated in SCOOT compared to AIMSUN. In the former the SCOOT (constant) cruise time for the road is modified by the average delay and using the link length to calculate the speed, whereas in AIMSUN speed is a more “true” speed calculated by the sum of the journey speeds of individual vehicles divided by the number of vehicles. The OSPM assumes that the emissions are from one line source, therefore the flows are summed and the speeds are averaged over the traffic on both sides of the road. Turning now to the distribution of points in figure 7 and figure 8 the outliers (very high and very low values (in brown) for AIMSUN compared to SCOOT) respectively are overestimated and underestimated probably because of the limitation of assuming fixed-time in AIMSUN. Overestimates of idling emissions (and therefore concentrations) are due to longer queues and therefore longer delays forming along road 7 (and to a lesser extent road 3 – 18:00 to 19:00hrs) at high flow when green times are fixed. The outliers at low levels are explained by the fact that the AIMSUN average speeds are underestimated when traffic is calmed on the shoulder of the peaks or that SCOOT journey speed estimate is too high.
Selecting only that data in those periods where concentration estimates are considered valid (not due to a limitation with one or other model estimate) the regression coefficient for the hourly predictions based on SCOOT compared to AIMSUN is $R^2 = 0.70$ (see Figure 7). Overall these results are encouraging.

**Figure 7** – Correlation between concentrations derived from SCOOT and AIMSUN data using OSPM for all links. In red points related to roads 4 and 6. In green to road 7, and black crosses are outliers.

**Figure 8** – Correlation between concentrations derived from SCOOT and AIMSUN data using OSPM for the links nearest the junction (1-3-5-7). In green the point related to road 7, and black crosses are outliers.

**VALIDATION OF DISPERSION MODELS USING PERVASIVE SENSORS**

The next step is to compare the SCOOT and AIMSUN concentration estimates with those measured by the motes with and without event traffic on Tuesdays and Saturdays. In this way the pervasive sensors have made it possible to validate the OSPM dispersion applied to two different emissions estimates (SCOOT-based and micro simulation – AIMSUN). Validation of the dispersion model requires that certain parameters such as the position of the receptor to be matched to those of the physically placed sensor. For this project the sensors were placed at a height of 3.5m and at a distance of 1.5m from the street edge. It is important to note exactly where in the street the pervasive sensors are placed as the position of the sensor with respect to the wind direction and distance from the stop-line of the junction is important. Figure 9 shows the comparison for sensors located on the side of the road (a) downwind and (b) upwind, CO concentration between measured and predicted on road 2 for Tuesday football event both for SCOOT and AIMSUN. The two sets of
predicted data where adjusted by the scaling factor of 1.165 to convert CO estimated in mg/m$^3$ into ppm, and a scaling factor of 11 to convert g/sec to g/m.

**Figure 9** – Time series between Pervasive sensors and SCOOT and AIMSUN corrected derived CO concentrations, for upwind (a) and downwind (b) motes locations.

**Figure 10** – Correlation between Pervasive sensors and corrected SCOOT derived CO concentrations for downwind (a) and upwind (b) mote locations

**Figure 11** – Correlation between Pervasive sensors and corrected AIMSUN derived CO concentrations for downwind (a) and upwind (b) mote locations

The results in figure 9(a) show that the AIMSUN model performed better than SCOOT without the event whilst the reverse is true for the football match. This is consistent with the earlier observation that the better performance of the AIMSUN model in under-saturated compared with over saturated

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traffic conditions and the limitations of the SCOOT speed estimate particularly when the flow regime is different on each side of the road. Figure 9(b) for motes on the upwind side of the canyon, consistent with earlier findings AIMSUN performs very badly in saturated conditions and well in under-saturated conditions. SCOOT performs well in both saturated and under-saturated traffic flow environments. The data of figure 9 is presented differently in figures 10 and 11 where, respectively, the concentrations are based on SCOOT and AIMSUN. The results clearly illustrate the higher performance of the SCOOT ($R^2 = 0.71$ and 0.70 for down- up-wind respectively) compared with AIMSUN ($R^2 = 0.44$ and 0.16, ditto). This work will be repeated in the future as soon as an opportunity arises to have the dynamic signal timings from SCOOT simultaneously with traffic flow and mote data.

DISCUSSION

The use of OSPM and traffic data from SCOOT to predict canyon concentrations performs better than AIMSUN. However, the fact that the continuously changing green durations in SCOOT affects the capacity of the junction AIMSUN has not given a fair trial in this study. In AIMSUN due to the assumption of fixed time it follows that AIMSUN appears to cap the flows creating high levels of congestion in some parts of the network and removing congestion from other parts. In the case of road 2 it is likely that in AIMSUN the right hand turn flow, road 7 to road 5, is given insufficient green time and therefore queues build up on the South arm (road 7). This means that the southbound traffic flow, along roads 2 and 1, is not delayed but instead flows freely flushing out the traffic prior to the match, therefore resulting in lower flow during the match. This results in underestimates (and overestimates) of emissions because congestion is not being predicted realistically on all arms of junction affecting both the flow and occupancy to a lesser and greater extent depending on flows on each link into and out of the junction.

The use of a pervasive sensors network to validate micro-simulation traffic models has obvious and potentially significant benefits. When the model input data is automatically passed from sensor through the data warehouse and into the model and vice versa for model output back into the data warehouse further efficiency and accuracy of the model set up and validation occur. This is because the human error will be reduced by automating information flow from sensors through the database to the model. There will be time savings by automating the updating of the OD matrix based on data from the database. This in turn will avoid expensive traffic surveys, data cleaning and analysis.

The potential value of the pervasive sensors in environmental model validation is enormous. Currently air pollution models, used to define air quality management areas, are based on average speed - average flow emissions factors and grid dispersion modelling. As such current environmental assessment tools fail to adequately model acceleration, deceleration and idling emissions correctly. In addition the significant affect of congested related emissions is underestimated so the significant benefits offered by ITS (which tend to smooth flow, calm speeds and manage demand) are not correctly quantified. Continuous assessment of traffic in networks, simultaneously with monitoring using motes, also offer a unique opportunity to improve our understanding of the build-up of emissions. The consequential effect on air quality in the street canyon resulting from the subtle changes in the traffic flow regimes as well as the often quite substantial effects of local meteorological conditions depending on time of the day can also be investigated. Future generations of models will provide much better monitoring of network status definition and thus able to identify hotspots. Estimates of the benefits to the environment of ITS implementation, particularly if based on real-time SCOOT-type measurement of traffic flow regimes which map onto sources of vehicle emissions, will result.

CONCLUSIONS AND FUTURE DEVELOPMENTS

This paper has described the hardware and software technologies developed in the MESSAGE project. Through an application to a case study in Leicester, ways in which pervasive monitoring systems, integrated with legacy data sources can be used to validate a micro-simulation traffic model as well as to predict the link emissions of pollutants. The validated micro-simulation model has been used to also predict link emissions. The OSPM model, along with the meteorological conditions, has been used to examine the two different methods of estimating emissions proposed in this work, with interesting results. In general, a good match between the data derived from micro-simulation and from existing legacy systems was achieved in undersaturated traffic flow conditions.
and the limitations of current model assumptions have been clearly exposed. The importance of reliable continuous data capture has been highlighted. The results here represent a beginning of new research opportunities that have been made possible with the novel integrated hardware and software technologies presented here and developed in the MESSAGE project.

The long term plan is to use micro-simulation to estimate the emissions at 10m along the road and through the junctions so that the emissions estimates are profiled along the street. This will provide important data (namely probability density functions) that will improve the estimation of human exposure to air pollution. The dispersion model OSPM, using knowledge of the meteorological conditions, has been shown to give good emissions estimates (R²=0.70) along specific road sections in the network where SCOOT operates, through direct comparison with concentration measured at actual mote positions. By comparing the observed pollution level with that estimated, base case model validation has been achieved at a greater resolution than previously has been possible. Given that the validation of modelling tools for the recurrent congestion from event traffic has been successfully demonstrated in this work with improved confidence, they will be used in the EPSRC: 4M project to explore policies (green travel plans for schools, workplace and event traffic) to alleviate congestion. The research started in MESSAGE continues and future possibilities include the use of co-located motes to measure vehicle composition and speed. Ultimately the goal is to use the integrated monitoring and modelling framework to deliver solutions to recurrent congestion and assess the impacts of traffic management measures on the environment in real-time.

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