

Environmental Factors in Future Transport

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EXECUTIVE SUMMARY

Increased car use has highlighted the problem of congestion, not only because of its threat to economic growth but also as a substantial contributor to poor air quality, noise and global warming. Vehicle technologies and intelligent transport systems can play an important role in addressing environmental problems in urban areas and in developing long-term sustainability of towns and cities.

Transport is a major source of air pollution. It also contributes to emissions of carbon dioxide (CO₂), the main cause for concern about global warming and climate change. Primary air pollutants include carbon monoxide (CO), carbon dioxide, water vapour and un-burnt fuel, hydrocarbons, including volatile and non-volatile organic compounds, oxides of nitrogen, sulphur dioxide (traces), and particulate matter. Pollutants, such as small particles arise not only from the exhaust but also from the road-tyre interface and from the brakes, engine, bodywork and catalytic converters.

Some pollutants, such as CO, are relatively stable; others are less so, including nitrous oxide, which, depending on the meteorological conditions, oxidises to nitrogen dioxide (NO₂) and reacts with other pollutants. Nano-particles and NO₂ are the major causes of breaches of the recommended air quality limits in towns and cities in the UK.

Emissions per vehicle have declined in Europe, thanks to advances in engine design and the introduction of computer controlled engine technology to reduce fuel consumption and consequently decrease emissions.

Dependence on oil

Concerns over our dependence on oil products to power road transport has provoked interest in alternative fuels such as compressed natural gas, liquid petroleum gas, biofuels, hybrid petrol/electric vehicles and fully electric vehicles. Research suggests that 'damage costs' for buses fuelled with diesel could be three to five times higher than buses fuelled by natural gas.

Concerns about the global warming and the effects of carbon dioxide from fossil fuels, have renewed interest in the use of biomass. The Government is committed to increasing renewable energy usage to help to reduce emissions of greenhouse gases.

The only cleaner option, as far as local emissions are concerned, is for 'zero-emissions' vehicles powered by electricity or hydrogen fuel cells. For such vehicles, we have to consider their total environmental impact: emissions from remotely generated electricity or hydrogen production could exceed the emissions of conventional vehicles.

Hydrogen is sometimes presented as 'the answer' to problems of energy and global warming. However, an economy based on hydrogen may not be sustainable in the longer term. Hydrogen may offer clean combustion but we must also consider the environmental impacts of creating hydrogen, be it from the dissociation of water or methane, the resources needed for its manufacture, its distribution and disposal of the fuel cells that release its energy. The main advantage of 'zero emissions' vehicles, is that the emissions can be moved away from people. Thus we may achieve benefits to human health but without reducing environmental impacts.

Systems solutions

We can also achieve environmental gains by changing how we use the infrastructure. For example, traffic signals can be used to shift traffic queues to open spaces where natural ventilation disperses emissions. Traffic control can also favour public transport, making this a more attractive option, persuading travellers to abandon their cars in favour of buses and trains. Indeed, any technology that encourages ride share, changes in mode to surface public transport and encourages walking and cycling could reduce vehicle emissions.

Variable message signs can also reduce car emissions in towns and cities. Messages can inform drivers on speed limits, to calm traffic, or on parking information, reducing how long it takes to find parking spaces. Variable message signs supported by an intelligent system that continuously monitors and forecasts local pollution and identifies dynamic traffic signal control to manage emissions, can be particularly effective.

Detailed modelling of traffic flows and emissions can demonstrate that measures, such as road pricing and enforcing speed limits, could also bring about environmental gains as well as reducing congestion. Other measures, such as traffic calming humps, can lead to less desirable driver behaviour and can have an opposite effect.

Intelligent speed adaptation, with GPS and an on-board computer, can control vehicles over particular road stretches and could deliver the significant accident savings. Unlike fixed systems such as road humps and fixed speed limits these techniques have the advantage of being able to change during the day, in response to traffic and road conditions and to specific air pollution episodes.

Traveller information systems

The movement of goods by road also has substantial environmental impacts. Here, advanced traveller information systems can reduce unnecessary mileage, and hence pollution, by suggesting optimal routes.

In-vehicle information and guidance systems can help to reduce congestion by warning drivers of trouble spots, but research suggests that when too many vehicles are equipped with the technology the benefits can decline as too many drivers respond and try to avoid congested stretches. In-car guidance systems could also give real-time information on the location of pollution hot spots, advising drivers on alternative routes and spreading the pollution burden. Ideally, information for drivers should also include details on other modes of transport, possibly providing details of how to make the specific trip, instead, by public transport, as drivers are reluctant to use public transport as an alternative to the car.

While travellers seem to be prepared to pay for services that help them to avoid congestion, it may require government action to encourage and facilitate the collection and dissemination of environmental information. There are clearly benefits in developing public understanding of the environmental implications of the increasing demands to travel and the health benefits of walking and cycling.

1 Introduction

Over the past few decades, increasing car use within our urban centres has brought the problem of congestion to the forefront of the political agenda not only because of its threat to economic growth but also as a substantial contributor to poor air quality, noise and global warming. The earliest air quality problems were caused by the burning of fossil fuel for domestic heating and industrial processes which gave rise to excessive levels of sulphur dioxide and smoke. Since the 1950s, at the same time as such emissions have been reduced substantially, the number of vehicles on our roads has systematically increased and air quality problems experienced today are caused mainly by emissions from road transport, DETR (1997a). With the exception of sulphur dioxide, traffic is currently a major contributor to levels of most of the pollutants. In the UK, in urban areas, the contribution of road transport to roadside pollution is such that hot-spots occur and typically traffic produces between 60% and 80% of nitrogen oxides in large towns (DETR 1998a and b). Over recent years, in the UK, local authorities have carried out a rigorous assessment of their air quality and currently are delivering solutions to solve the problems of excessive levels of pollution that they have identified and declared Air Quality Management Areas, (see Local Transport Plans for UK Authorities).

Noise problems, historically caused by free flowing traffic on trunk roads and motorways, DoT (1998), now manifest themselves in urban areas with continuously varying noise throughout the day due to congestion and intrusive noise problems in the early hours of the morning and late at night. Recent

European Directives have resulted in a control measure (L_{DEN}) that is a weighted sum of noise levels measured for four hours in each of three periods of the day namely day, evening and night, EU (2002). This measure recognises the need for less intensive traffic noise for evening leisure activity and to avoid sleep disturbance over night.

There is strong evidence to support the statement that exposure to air pollution, including particulate matter, has a deleterious effect on human health, COMEAP (1998), and although noise from traffic is not necessarily responsible for hearing damage, it can affect the ability to concentrate, reducing performance, increasing the risk of industrial accidents and making mistakes, especially when noise causes sleep deprivation. Research evidence has been presented to show links between noise and cardiovascular risk factors.

This review aims to qualitatively and, where feasible, to quantitatively demonstrate how vehicle technologies and intelligent transport systems can play an important role in reducing the impact of traffic on the environment and health as well as in the development of long-term sustainability of our towns and cities in the future. Given the wide range of technologies that can be embraced by the term Intelligent Transport Systems, ITS, this article cannot possibly deal with them all. Therefore, their omission does not imply that they are less important and no attempt is made in this review to establish the relative importance of the technologies considered here. Firstly, this paper reviews the effect on health of the different pollutants emitted from transport and the ways in which the pollutant emissions can be reduced at source through engine and exhaust gas treatments and the use of cleaner fuels. This is followed by a discussion of how intelligent transport systems have the ability to manage the location and intensity of pollution emissions across a network over time. These are presented as short term methods to alleviate specific pollution hotspots. Thirdly, the more strategic technologies that require investment in infrastructure to provide environmental benefits in the longer term, are presented. Finally, those technologies that promote the use of public transport systems and supply information to persuade people to change their attitudes and lifestyles in order to achieve sustainability of our city transport networks in the longer term, will be discussed Guo and Blythe, (2005).

2 Pollution and Health

A summary of the health impacts of traffic related pollution is given in a state of art review by Colville et al (2001). The review suggested that in the early 1990s there was much evidence to confirm particulate emissions were harmful to health, Pope et al, (1992), Dockery et al (1992), Diaz-Sanchez, (1997) and expert groups such as QUARG, (1993) all found evidence that particulate emissions might be responsible for measurable increases in cardiovascular and respiratory diseases. The recent AQEG (2005) reports 'it is clear that, although road traffic emissions are a major source of particulate matter near to roads, the regional contribution to particulate matter is substantial. Controlling background particulate matter must, therefore, be a central part of any UK strategy to control exposure to particulate matter.' The report continues, 'In addition, because there is no known safe level for exposure to particulate matter, it is not appropriate to rely solely on the use of air quality objectives. They focus attention on hotspots – places where the pollutant concentration is high, for example close to busy roads, but where relatively few people tend to live.' Public concern over air quality have resulted from the evidence of the links with asthma, which has increased substantially in recent decades, Holgate et al 1995, Jarvis and Burney (1998), Miyamoto, (1997), Ninan and Russell (1992), and its effect on children Burnekreef et al (1997). There is evidence that the pollution from traffic exacerbates symptoms in those who are already sufferers, Krishna and Chauhan, (1996), Venn et al (2000), but little evidence that it is a cause of asthma, Holgate et al (1995).

Specific hydrocarbon components of exhaust emissions, especially polycyclic aromatic hydrocarbons, PAH, bound to diesel exhaust particulates are feared to cause cancer, whilst benzene and 1,3 butadiene, Perera, (1981), US EPA, (1990, 1993) are known carcinogens. Carbon monoxide, CO, concentrations are high enough in developing countries to exacerbate cardiovascular disease by impairment of the oxygen carrying capacity of the blood, but not in the UK. The introduction of catalytic converters led to a significant fall in most exhaust emissions in the UK since the late 1990s, DETR, 1998a.

Lead emissions were shown to cause neuro-toxicological damage and lower Intelligence Quotient Scores in children, Smith (1998), WHO, (1995), EPAQS (1998) but since the introduction of lead free petrol and catalytic converters, lead levels have substantially dropped, Delves, (1998), SMEPB,

(1994), Oliaz et al (1996), Yang et al (1996). Sulphur dioxide causes coughing on short-term exposure but levels of sulphur dioxide into the atmosphere from traffic have been substantially reduced due to the introduction of low sulphur fuels.

Babisch et al (1990) has presented cardiovascular risk factors for transport and work related noise. Meidema et al (1997), Meidema and Vos (1998) and Vos (1992), present sleep disturbance and road traffic noise as a night measure and exposure–effect curves for the association between the day, evening and night, weighted noise level for noise annoyance from different transport sources (air, road and rail). Much of the early research that derived noise parameters correlating with human response, is based on the assumption of freely flowing traffic. Noise problems of today are mainly associated with the disruptive traffic flows due to signal control and congestion. Often the noise parameters are lower on average but more variable and therefore more irritating. Also, the noise from the different transport modes has widely different spectral content and frequency of occurrence. This necessitates modelling noise across the audible range at one third octave band resolution to capture the ‘noise annoyance’ of the diverse mobile sources of noise from cars, vans, buses, trucks, trains, boats, ships, aircraft etc.. This has created academic challenges that are being addressed in projects funded by Europe. As reported by Willmink et al (2005), ROTRANOMO (ROad TRaffic NOise MOdel), (www.1) will derive traffic emissions models that are sufficiently detailed in respect to fleet composition, vehicle performance, diurnal variations in traffic conditions and source contributions, that suitable estimates of noise perception will deliver information that can be used to assess action plans designed to reduce road traffic noise. IMAGINE (Improved Methods for the Assessment of the Generic Impact of Noise in the Environment), (www.2) will provide guidelines, examples and databases that allow for a quick and easy implementation and expansion of the noise calculation methods for road and rail developed in the HARMONOISE project (Harmonised, Accurate and Reliable Methods for the EU directive on the assessment and management of environmental noise), EU-5th Framework Programme (www.3, Jonasson et al (2004), Nota (2005)).

In an attempt to ensure that air pollution is kept at levels below which there is minimum or no significant risk to a nation’s health, the EU has taken action, EU (1996) and daughter directives, and thus put pressure on governments of countries throughout Europe to ensure that air quality objectives are met. In addition, the European Parliament set out the procedures for the assessment and management of environmental noise, the ‘European Noise directive’, EU(2002). These directives have resulted in the need to assess the effects of traffic flow patterns and to design measures to mitigate the environmental effects. Willmink et al (2005) acknowledges the need to find a balance between all the different environmental effects of traffic, because reduction of more than one particular air pollutant or noise level cannot necessarily be achieved together. Due to the high cost of monitoring, traffic models are usually employed to assess the effects of current traffic flow patterns and of the measures designed to mitigate those effects.

These days, ITS technologies are often named as promising alternatives to the more traditional policy measures (e.g. building new roads, improving public transport infrastructure, providing acoustic screening, etc). However, ITS technologies are usually introduced to improve network efficiency and to solve congestion rather than solve environmental problems, although the former often leads to the latter. Policy makers have demonstrated the possibilities of ITS measures, such as lowering of the speed limits or adapting traffic signals, improve air quality and/or reduce noise levels. However, the subtle changes in the driving profiles and traffic flow conditions that bring about environmental benefits cannot adequately be assessed with current models, a subject of research programmes such as LANTERN, Leeds, health, Air pollution, Noise, Traffic and Emissions Research Network (www.4), Andrews et al (2004, 2005), Boddy et al (2004a, 2004b), Tate (2004), Goodman et al (2002). In fact, although not addressing the traffic congestion problem, European Legislation on vehicle emissions controls has been the main driver to engage industry into significantly advancing in-vehicle technologies to realise substantial reductions of vehicle exhaust and noise emissions from new vehicles. Whilst technologies that reduce air pollutant emissions are tackling the air quality problems in the short term, they do not address the longer term global warming problems. This is because they aim to burn fuel and reduce it to CO₂ and water. ITS technologies have an important role to play in controlling, managing and policing traffic restraint and demand management thus reducing emissions and given the political will, curbing the use of private vehicles.

3 Mobile Source Emissions

Primary air pollutants include carbon monoxide, CO, carbon dioxide, CO₂, water vapour and un-burnt

fuel, hydrocarbons, HC, including volatile and non-volatile organic compounds, oxides of nitrogen, NO_x , sulphur dioxide, SO_2 , and particulates, PM. Some pollutants are fairly stable, like CO whereas others, including nitrous oxide, NO, rapidly oxidise to nitrogen dioxide, NO_2 , and react with other pollutants depending on the prevailing meteorological conditions. PM10 and NO_2 are found to be the major causes of breaches of the recommended air quality limits in UK towns and cities.

Colville et al (2001) provides a Millennial review of the transport sector (road, rail and air, passenger and freight) as a source of air pollution. The review reports that the OECD (1988) considers regional and global impacts of transport emissions on air pollution, but is mostly concerned with the impact of emissions on local urban air quality and considers only road transport. Jourmard (1995) and Faiz (1993) both re-affirm the problem of traffic related pollution both locally and globally by highlighting the large contribution made by the mobile sources in Africa and Latin America.

Pollutants such as particulate matter have origins not only from the exhaust but also from the road tyre interface and metallic particles resulting from the brakes, engine, bodywork and catalysts etc. In the UK emissions by road transport in the year 2000 for particulate matter, PM10 was 20% (15% combustion, 3% wear, 2% others) and for levels of CO – 69%, for CO_2 – 21%, NO_x – 48% (42% road, 6% non-road vehicles), NVOC – 24% (18% combustion, 6% evaporation), Benzene – 47% (45% combustion, 2% evaporation) for 1,3-butadiene – 81%, and for SO_2 – 1%. The particles from a modern diesel engine, after modification by coagulation and other processes that occur in the first few seconds after emission, have a bi-modal size spectrum with a large number of particles below 20nm in size and another mode between about 30 and 100nm, Shi et al (1999), with approximately equal total mass in each mode. This reflects the differences in the origins of the particulates and the complex chemistry and physical processes that govern the size distribution of particle matter, Colville et al (2001).

4 Vehicle and Fuel Technologies

In recent years, emissions per vehicle of CO, HC, NO_x and PM from road transport has reduced in Europe, CONCAWE(1997), EC (1996). The largest reductions have already taken place with substantial technical advances in engine design and after burn treatments such as catalysts and particle traps. More recent reductions in emissions have been achieved through the introduction of computer control engine management technology that aims to improve their efficiency and reduce fuel consumption and consequently decrease in pollutant emissions.

Exhaust emissions from vehicles are sensitive to many factors, including the ambient temperature, Andrews et al (2004, 2005), the engine design and size, whether or not it is operating cold or hot, the type and quantity of fuel used, the control technologies applied, the age and state of repair of the engine and exhaust system technologies, its speed, whether it is accelerating, decelerating or idling. The driver behaviour affects emissions, with harsh acceleration, De Vlieger et al (1997, 2000), Rapone et al (2000) and using the gears instead of the brakes to slow down vehicles, creating elevated levels of pollutant emissions, Samuel et al (2004).

At ambient temperatures of -2°C , CO emissions are twenty times higher and at 30°C , ten times higher, Andrews et al (2004). Elevated pollution emissions at the beginning and end of a journey means that care should be taken to locate park and ride sites away from residential areas to minimise the impact of cold starts and hot soaks on human exposure. In Europe, the USA and Japan, passenger car emission regulations are for a cold start. However, this is defined at a summer's day temperature of 25°C and much lower temperatures are experienced in winter in many areas of the world. The impact on air quality of these lower cold start temperatures has led to the introduction of a -7°C cold start emissions test in Europe and the USA. Engine technologies that seek to remove cold start emissions by heating catalysts, for example, play an important role in achieving substantial reduction in source emissions.

Environmental concerns over our dependence on liquid petroleum and diesel fuels to power road transport, has led to the consideration of a number of alternative fuel sources. These include for example compressed natural gas, CNG, liquid petroleum gas, LPG, biofuels, hybrid petrol/electric and fully electric vehicles.

Rabi (2002) carried out a life cycle assessment to compare the performance of buses fuelled with diesel (standard EURO2) compared to the same bus equipped with natural gas engine for use in Paris and Toulouse. The data for the pollutant emissions were based on the European Commission (EC) MEET: Methodologies for Estimating Air Pollutant Emissions from Transport, TRL (2001) project, supplemented by measurement for diesel and gas buses in Paris. The damage cost of a diesel bus is significant, in the range of 0.4 – 1.3 Euro/km. Natural gas allows an appreciable reduction of the emissions, lowering the damage cost by a factor of about 2.5 for Toulouse and 5.5 for Paris. A sensitivity analysis was carried out to evaluate the effect of uncertainties. Finally a comparison between a EURO2 diesel bus with a particle filter and a gas fuelled bus with the multiple points injection, MPI, engine of IVECO, a more advanced and cleaner technology. With this engine the damage costs of the gas fuelled bus were about 3 – 5 times lower than those of the diesel with a particle filter, even though the latter had very low emissions already.

Recent concerns about the effects of carbon dioxide on global warming, from the use of fossil fuels, have led to a renewed interest in the use of biomass. The EU and the UK governments are greatly concerned over the issue of greenhouse gas emissions and are promoting the use of fuels with low CO₂ emissions namely CNG and fuels derived from Biomass (e.g. ethanol and bio-diesel) blended with conventional transport fuels. The UK Government is strongly committed to increasing renewable energy usage in order to help reduce greenhouse gas emissions and thereby contribute to national and international targets for emissions reductions. The increasing importance attached to this form of energy production was recently highlighted in the Energy White Paper, Stationery Office, (2003).

Biomass fuels are considered to be CO₂ neutral, absorbing CO₂ during growth and releasing CO₂ on burning, ECOTEC, (1999). There has been several studies that have quantified the emissions from biofuel mixtures of 5% to 100% blends of various oils for example, rape seed, recycled chip oil, with stock diesel. The results are highly inconsistent with some evidence to suggest that NO₂ is often higher than the diesel used in the biofuel mixture. CNG has lower CO₂ emissions than liquid hydrocarbon fuels, but has the potential to produce inferior fuel consumption and also may emit higher methane emissions, which are 10 times worse as a greenhouse gas than CO₂ ETSU, (1996, 1998). All of these alternative fuels have been shown, when used in low emission vehicles, to give lower emissions over legislated test cycles, but their emissions need to be assessed more fully under the more severe conditions of congested traffic.

Typically the blending of ethanol with petrol produces a reduction in hydrocarbons and increases in NOx and aldehydes for legislated test cycles, Andress, (2000). Ethanol is easily vaporised and hence the cold start problems of Euro 1 and 2 vehicles may be reduced in city driving. Bio-diesel also tends to increase aldehyde emissions, as the components are oxygenated hydrocarbons, AQIRP, (1999). Congested traffic is the usual situation in most large cities in the UK and Europe and the stop/start, idling and slow speed nature of such traffic movements results in the operation of engines under conditions of high emissions. This is exacerbated by the large number of people who live on and in the vicinity of busy roads and cold start into traffic jams. There is a need for microscopic emissions data for alternative 'clean' fuels that can be used in models to better predict the influence of driver behaviour, cold starts, hot soaks, a particular traffic control policy measure or Intelligent Transport System Operational Regimes, ITSOR.

The only cleaner option, as far as local emissions are concerned, is for zero – emissions vehicle powered by electricity or hydrogen fuel cells. For such vehicles, it is important to consider, however, the total environmental impact of their use, as the air pollution emissions from remotely generated electricity or production of hydrogen fuel could possibly exceed the exhaust emissions that a conventional vehicle would produce. Electric vehicle technology, although not reducing our dependence on fossil fuels and addressing the global environment issues, do have a role to play in reducing local emissions and therefore can address air quality management problems. The use of electric powered light rapid transit and small vehicles, exempt from road user charging and low emissions zones, also have a role to play in encouraging a modal shift, promoting public transport and thus maintaining good air quality in urban environments. These modes will become increasingly important in the future.

Hydrogen is thought to be the answer to energy and global warming problems in the long term, however an economy based on hydrogen in the longer term may not be sustainable. Whilst attention is focused on its clean combustion products in air, much less consideration is being given to the environmental impacts of the creation of the hydrogen, whether it be from the dissociation of water or

methane, the resources needed for its manufacture, its distribution and disposal of the fuel cells. Notwithstanding these issues, the safe methods to store, distribute and use hydrogen on board vehicles is not completely proven. The main advantage of zero emissions vehicles is that the emissions can be located in places away from human receptors, so benefits to human health can be obtained, although other environmental impacts, such as global warming, may not be reduced.

Karlstrom (2005) presented a quantitative assessment of the local environmental benefits of using fuel cell buses in comparison with EURO 5 diesel buses and compressed natural gas buses along a central bus route in Goteburg, Sweden. The local benefits to the environment were presented in terms of monetary costs. If diesel bus technologies improve, and therefore comply with the EURO 5 emissions reduction demands, then the relative local environmental benefits for zero emissions fuel cell buses will be EUR₂₀₀₁ 0.06 (0.024-0.25)/km and EURO₂₀₀₁ 0.04 (0.001 – 0.11)/km for CNG compressed natural gas buses. The local environment costs are rather small compared to the annualised capital costs of prototype fuel cell buses. The allowed driver train cost increment of mass-produced fuel cell bus along the bus route considered in the paper would be EURO₂₀₀₁ 23,900 (best estimate) for local benefits and EURO₂₀₀₁ 47,800 if including greenhouse gases and the hydrogen produced from natural gas.

Unfortunately, even if the current environment benefits are not considered large enough, investments in fuel cell buses could be worthwhile if they are seen as the first step of a long-term transition strategy to a hydrogen economy. This niche can be seen as important for demonstrating fuel cell technology as a way to decrease costs and improve performance, which could encourage wide spread use of fuel cell technology in other applications not only in the private car market but also for stationary use, Karlstrom (2005).

The impact assessment of noise by Karlstrom (2005), was a rough estimate. The environmental cost of diesel buses relative to the fuel cell buses is EURO₂₀₀₁ 0.02/bus km. Even if this estimation is uncertain, the noise reduction potential for fuel cell buses seems to be an interesting issue that requires further study. This is mainly because the character of the noise emission from vehicles will change and the noise parameter correlating with human annoyance may be different. Measurement and modelling of noise may have to be carried out across third octave frequency bands and for the propulsion noise separate from the road-tyre interface noise.

Whilst, noise from the power units of modern vehicles and electric motors is substantially less than from their predecessors, the noise generated at the road/tyre and rail/wheel interface, Sandberg and Hammerstrom (1998), Watts(1994), remains a substantial and increasing problem. Also, the introduction of both mass-transit systems and low-noise road surfaces are fundamentally changing the acoustic environment within city streets. The secondary noise from vibration and rail-wheel 'squeal' are often cited as major problems, and whilst new road technologies are able to reduce noise levels without compromising safety, Bernhard and McDaniel (2005), they are expensive to lay and require regular maintenance. Variation in levels and spectral frequency content of the noise is changing such that urban noise is becoming more irritating despite on average quieter. Therefore significantly different sound signatures than existing internal combustion engines require more sophisticated noise measures, van Blochland (2003), Watts et al (2004). This led to standardisation of modelling and assessment as laid down within the HARMONOISE guidelines, Jonnasson (2004).

5 Systems solutions

Despite considerable efforts to reduce source emissions it will be some time yet, before new vehicle technologies have penetrated the market sufficiently to have a substantial impact on roadside concentrations. Therefore, currently, Local Authorities are managing air quality using several different integrated approaches often tailored to solve a specific environmental problem. However, a common goal to all strategies is to reduce the number of vehicles on our roads, Harris et al (2003); create a calmer smoother movement of traffic flow; alleviate congestion and avoid stopping vehicles. In this section the impact on pollution of more strategic systems solutions including: traffic signal control and network management, public transport related infrastructure and technologies to encourage travel by public transport; demand managing with park and ride, road user charging and speed control; and finally public information provision to promote more effective use of road space in our networks, by passengers as well as freight.

5.1 Traffic Signal Control and Network Management

Traditionally signal control systems were optimised to minimise delay to traffic in a network Robertson (1969), Hunt et al (1982) but today demand responsive traffic control signal systems can operate to minimise air pollutants, either aggregated overall pollutants or simply by targeting the reduction of a particular pollutant to address a particular exceedance, such as NO₂ or PM10, Wood and Baker (1995) In addition, signal control can be used to relocate queues from closed to open spaces so that the natural ventilation of the built environment can disperse pollution more effectively or if more appropriate Tate and Bell (2000), cascade queues to spread the congestion along a route Wood and Baker (1995), a radial or round the ring road to prevent a particular air pollutant limit value being exceeded. The latter tactical demand management strategies, whilst able to solve a problem of hot spot formation, do not reduce emissions per se but control the location of those emissions to where they will do less harm. Technologies such as variable message signs to inform on speed limits to calm traffic or car parking information systems to reduce search time for parking spaces are commonly implemented in towns and cities and play an important role in reducing pollutant emissions

Clement et al (2004) describes and models the performance of a conceptual intelligent system for automatic progression of vehicles through a signalised intersection, under automatic control of in-vehicle and roadside infrastructure. The fundamental principle is the notion that the queue of vehicles assembled at a red signal can be moved simultaneously as a single block or platoon once the signal switches to green. Once clear of the junction the vehicles in the platoon are progressively released back to individual driver control. The advantage of this automated platoon advancement strategy may be seen in increased throughput and decreased delays for approach lanes at signalised junctions. This technology could offer the opportunities for substantial increases in the capacities of existing intersections. However, from the environmental perspective the increased road space should be re-allocated to pedestrians or priority for buses whilst maintaining current capacities for road vehicles otherwise the vehicles may speed up or the spare capacity is eroded by suppressed demand. This technology potentially has an important role to play in reducing emissions by taking control of the acceleration of the block of vehicles, avoiding aggressive acceleration and smoothing flows. Also, by adjusting the magnitude of the green splits the size of the block, and therefore the total volume of traffic, could be regulated in a timely manner to ensure that local pollutant concentrations remain below the exceedance limits. By building in intelligences regarding the meteorological condition acceptable levels of air quality can be maintained spatially and temporally.

The aim of the project EFFECT (Environmental Forecasting For the Effective Control of Traffic), (www5), was "To predict poor local air quality in real time and then to instigate Traffic Demand Management Strategy (TDMS) as management measures to reduce pollution levels in particular problem areas." At the heart of the EFFECT system there was an Air Quality Monitoring and Management (AQM&M) system. This predicted the location, time of occurrence and duration of pollution 'hot-spots' and then provided data to permit the selection of a strategy from a pre-defined library, Bell and Hodges (1999). The EFFECT system was demonstrated in the cities of Leicester and Maidstone (UK), Gothenburg (SE) and Volos (GR). The strategies that have been developed in the EFFECT project were limited to addressing high levels of pollution at localised hotspots.

Two tactical control strategies that were identified for Leicester included *gating and cascading of queues*. Each strategy was designed to reduce the amount of vehicle generated emissions on the links at the hotspots and across the air quality management area at the expense of increasing emissions in less polluted areas of the city. The objective of each strategy was the same, their use and selection being determined by the severity of the predicted levels of pollution. The political and practical implications of announcing air quality problems, was high on the agenda. Therefore, it was agreed by the Local Authorities that actual implementation of strategies on the street could not be justified unless the new DETR threshold for low pollution was breached.

The *gating* strategy to alleviate a pollution hotspot', www6, Tate and Bell (2002), was defined by using traffic assignment and signal optimisation and the reduction in emissions was achieved by using the micro-simulation model DRACULA, Dynamic Route Assignment Combining User Learning and microsimulAtion, Liu (2003) and the meso-scale model SATURN, Simulation and Assignment of Traffic to Urban Road Networks. A pollution hot spot was identified at the cross roads of an inbound radial route and the ring road where the built environment created a steep-sided canyon which limited dispersion. There were residential properties and high levels of pedestrian activity in the vicinity of the junction. Consequently there were concerns that human exposure on pollution episode days may

become unacceptable. Therefore, by changing the offsets and green durations of the traffic signal timings, the traffic queues, causing the excessive levels of emissions, were relocated to an upstream junction close to a park where the natural ventilation of the built environment aided dispersal. The environmental performance of the TDMS was evaluated by direct measurement and by modelling.

Using the detectors to measure traffic levels every five minutes during the morning peak hour, the SATURN and DRACULA models were used to predict the emissions. The predicted emissions were compared to the measured concentrations. The results showed that there was a greater measured decrease of carbon monoxide, of up to 5 grams/sec, at the closed site compared with the increase, of up to 1 gram/sec, at the open site, demonstrating the significant value of tactical control of queue location. The reductions measured could be sufficient to prevent breaches of the limit values on days when temperature inversions occur. As expected the modelling showed substantially larger changes in emissions compared to changes in measured pollutant concentrations. Also, the micro-scale modelling resulted in estimates of emissions reductions of up to a factor of 5 greater than those predicted by the meso-scale modelled estimates. This is due to the fact that the latter ignores elevated emissions related to the driving modes, acceleration and idling, Tate and Bell (2002).

The Transport and Road Research Laboratory Wood and Baker (1995) carried out an evaluation of the benefits achieved by optimising the dynamic signal traffic control system SCOOT, Split Cycle Offset Optimisation Technique using a performance measure that minimises aggregate pollutant emissions rather than a sum of flow, delay and stops. The results showed that for SCOOT over Fixed-Time signal control pollutant benefits were CO -20%, VOC -16%, PM10 -10% and NO_x -7%. The additional benefit of SCOOT optimisation using a weighted aggregated emissions rather than a traffic network performance measure based on flow, delay and stops was found to be for CO: -2%, VOC: -2%, PM: -1% and NO_x: -1%. However, it must be pointed out that, although not demonstrated to be statistically significant within the budget constraints for collecting data, the reductions were nevertheless important. An exercise of cascading queues along a radial into the city centre of Leicester, showed that reductions of CO: -13%, VOC: -11%, PM10: -6%, NO_x: -5% and CO₂: -8%, on the protected junction were substantial but at the expense of increases on the cascaded links. This demonstrator endorsed the value of tactical traffic control found in the earlier research Tate and Bell (2000).

5.2 Public Transport Related Infrastructure and Technologies

Bus services are being promoted through the provision of designated bus lanes with signal priority at junctions, Hounsall et al (2004). Implementation of vehicle tracking gives a wealth of information to operators to improve the reliability of services. Real-time passenger information regarding time of arrival at bus stops makes the use of the bus more attractive. In some cities, for example Leicester, such public transport information can be given to the public via mobile phone as the Startrak system in Leicester, (www7). Park and ride schemes have an important role to play in reducing the amount of traffic on the roads. Successful park and ride services with high profile buses travelling on bus only lanes with priority at signals have substantially reduced journey times into the city and they are becoming a real and attractive alternative to the car in places such as York, Leicester and Cambridge. However, from an environment perspective, some of the benefits of removing congestion from city streets can be eroded by the increase in speed attained by the bus.

In the HEAVEN project, (Healthier Environment through Abatement of Vehicle Emission and Noise), (www8) EU: Fifth Framework Information Society Programme, Leicestershire County Council identified the potential for the installation of five peripheral Park and Ride sites as a means to manage traffic demand to reduce congestion and to ensure that the pollutant concentrations in the Air Quality Management Area (AQMA) would meet the National Air Quality Objectives by 2005. TRIPS (TRansport Improvement Planning System) Citelabs Europe (2001), was used to model the effect of the Park and Ride. The resulting changes in flow and speed were input to the air quality model Airviro. The results demonstrated that there was a significant reduction of vehicular flow to improve air quality in the city centre thus honouring their commitment to the UK Government, Namdeo and Bell (2005).

The air quality modelling results show that despite an assumed 4.5% growth in traffic, the Park and Ride scheme would result in a reduction in vehicular flow sufficient to improve air quality in the air quality management areas in the city centre and will at least maintain the status quo for noise levels.

Park and ride is allowing LCC commitment to the UK Government by maintaining air quality levels below those considered harmful to health by year 2005 to be honoured. However, engineers have to be mindful to ensure that the spare capacity in time and space created in the network by the modal shift is not eroded by localised suppressed demand and traffic travelling at higher speeds, Namdeo and Bell (2005). It is important in implementing park and ride that partnerships with local authorities and bus companies are formed so that clean technologies are implemented in bus fleets with a shift to more sustainable fuels such as low sulphur fuels or electricity etc or in the future, hydrogen cells.

Daytime noise levels estimated using the noise emissions module in the air quality model Airviro, SMHI (2002), for the park and ride scheme were within 0.2 dB(A) of the base case, Harris et al (2003). Such a small variation in levels would be completely unnoticed by the human ear. Larger benefits of \approx 0.5 dB(A) were predicted for the evening/night time levels, through the reduction of vehicle flows along the main radial of Narborough Road, Leicester. The project highlighted, the need for better profiling of the 24-hour flows used in the model, and improved method of the reallocation of traffic from cars to buses, especially during the peak hours, in order to more accurately and realistically assess the changes in noise levels.

Any technology that creates an environment for enhancing modal shift potentially can substantially reduce vehicle emissions. Bell (1974) in an early study of public transport interchange demonstrated that success lay not only with the co-ordination of the road network with and between all available public transport services (bus, rail, ferry etc.) ie short walking distances, timetables etc. but also, through ticketing, building aesthetics and provision of facilities and information were also important. Lo et al (2004) studied multi-modal trips where the traveller used more than one public mode and/or service to complete a given journey in an environment with competing private sector operators of transit services and different fares structures and systems. In order to model the complexity of the multi-modal trips a nested logit modelling framework was demonstrated as a method to examine the effects of fare competition on traveller behaviour, operator profitability and network performance. The approach was demonstrated successfully in Hong Kong for airport services. ITS technologies, including mobile phones, VMS, bus priority in urban traffic signal control, in-cab ferry confirmation systems in commercial vehicles, smart card technology for ease of payment of car parking, to ride a bus or train etc., offer much potential to deliver integrated solutions to contribute to the success of public transport interchanges and more efficient movement of commercial vehicles to and from ferry services.

5.3 Managing Demand

One of the main aims of the HEAVEN project, Harris et al (2002), was to conceptualise generic systems architecture, for an integrated decision support system, DSS, which was applied in the cities of Leicester, Rome, Prague, Paris and Rotterdam. A component of the DSS is the modelling of measures designed to reduce the environmental impact of transport. These measures have been of two types; short-term tactical and long-term strategic measures. In HEAVEN, emphasis was placed on developing and quantifying the impact of the more strategic citywide traffic demand management strategies (TDMS). In Leicester, in addition to the park and ride described above the potential to improve air quality and noise levels through appropriate control and management of traffic included the reduction of traffic speeds by 20% across the Leicester conurbation, banning of heavy goods vehicles and the impact of the introduction of new technologies. These three demand management scenarios were modelled using the same TRIPS modelling procedure as applied to the Park and Ride scenario as described above.

The Airviro air quality dispersion model was used to determine the changes in concentrations on the scale of 250x250m cells across the Greater Leicester area. The results of the modelling of the impacts using TRIPS showed that the network capacity changes substantially, with significant consequential effects on pollutant levels. Firstly, for the reduction of speeds by 20%, 18% less traffic is able to complete their journeys in the peak hour and consequently the peak period became spread over a longer duration. Also, the 82% of traffic travelling in the peak spent more time in the network by driving at a slower speed. This created more delay resulting in a 9.2% increase in journey time and traffic travelled longer distances due to rat running. The resulting effect, in winter, was to increase emissions by 116%, 175% and 202% for NO_x , CO and PM_{10} respectively, and in summer to increase emissions by 119%, 175% and 1.5% for NO_x , CO and PM_{10} respectively. This substantial increase in all pollutants would be totally unacceptable and therefore reducing speeds by 20% is not an option for

Leicester, Bell and Namdeo (2004).

The air quality benefits of banning HGV during the winter period, were to decrease emissions by 36% and 13% for NO_x and CO respectively, and in summer to decrease emissions by 37% and 12% for NO_x and CO respectively. The modelling took into account the fact that the highest volumes of commercial vehicles tend to travel along the more heavily traffic radial and ring road routes. Consequently as a result of the drop in flows on these routes meant that the remaining car and light vehicle traffic tended to speed up thus eroding some of the potential benefits of the remaining traffic speeds were kept at a lower level. Furthermore these decreases in all pollutants can only be sustained if steps are taken to ensure that that the increase in capacity is not further eroded by suppressed demand, Bell and Namdeo (2005). Clearly there is a role for intelligent speed adaptation in the future.

Not surprisingly by far the largest benefits were achieved by ensuring that 100% of vehicles by 2005 were all Euro4 emissions. NO_x levels were found to reduce by 78% and 81 % for winter and summer respectively, despite an assumed 4.5% growth in traffic pollution levels across the network from the base scenario. Although this scenario was unrealistic it demonstrates the potential of clean technologies as a means to mitigate air quality problems.

A parallel assessment of roadside noise in terms of the equivalent continuous noise levels, the L_{Aeq} , at a distance of 10m from the kerb was carried out. No attempt was made to include complex propagation effects (topography, meteorology etc.), as would be required for noise mapping, Goodman et al (2006). The study focused on changes in noise emission solely due to input traffic parameters. The most effective strategy to reduce noise emissions was found to be the complete removal of HGVs from the area considered. This led to an approximate reduction in daytime $L_{Aeq, 1-hour}$ levels of ≈ 2.7 dB(A). At night the reduction is higher, being up to 3.1 dB(A). Obviously, the strategy of removing all HGVs from the roads is unrealistic. It must also be noted that the TRIPS modelled HGV flows ($\approx 10\%$) were generally greater than the HGV proportions observed during an on-street monitoring campaign during summer 2002 ($\approx 6\%$ HGVs). Therefore, it is suggested that the effectiveness of the HGV removal scenarios was slightly over-estimated in this study, Harris et al (2003).

In the context of noise, the reduction of speeds by 20% is a less effective strategy, with corresponding reductions in roadside $L_{Aeq, 1-hour}$ levels for the studies of Narborough Road being of the order of ≈ 0.4 dB(A). Indeed, when using the UK CoRTN procedure, reducing speeds below ≈ 25 km/h in the model gives no benefit. This is because of the assumption of increased congestion levels at lower speeds increasing the calculated $L_{Aeq, 1-hour}$ levels. Some specific sections near junctions on the secondary links and on Narborough Road actually show increases in roadside noise level of the order of up to 1.0 dB(A) when the speed decrease is applied, as speeds move away from the minimum for emissions at 20-40km/h. In the HEAVEN project, compared with reducing speeds by 20% or banning commercial vehicles, the Park-and-Ride scheme showed the least improvement in noise levels over the base case.

The main result of this study, both in respect of air and noise pollution, was the importance of modelling the network capacity effects when modelling the traffic demand management scenarios because ignoring capacity effects leads to an over-prediction of the benefits on some stretches of road and redistribution of traffic occurs complicating the situation further. Also, the work highlights the importance of re-allocating the spare capacity generated, for example, by removing HGV to give priority to other modes eg pedestrians or buses to ensure that drivers do not travel at higher speeds.

In the UK, Atkins (2001) has presented a variety of case studies, looking at synergies between potential measures to reduce air-pollution and their effects on road traffic noise. Amongst the considered measures are: park and ride schemes, bus priority lanes, speed limit changes, vehicle access restrictions, road alignment changes, acoustic barriers and heavy goods vehicle size limits. The report states that *"relatively few mitigation measures designed to improve the air quality or noise environment will lead to a worsening of conditions for the other factor and some will be beneficial to both."* A notable exception to this statement related to measures affecting a reduction in vehicle speeds. Air pollutant emissions are noted to be optimum at speeds in the 70 – 90 km/h range, whilst noise emissions in the new HARMONOISE road source model, Jonasson et al (1999, 2004) show a minimum in the 20 – 40 km/h range.

Atkins' examination of the effects of altering urban speed limits in residential areas from 50km/h to 30km/h, suggested a decrease in noise levels of 0.8 dB(A) was achievable, but at the expense of an increase in pollutant emissions by over a quarter. A similar examination of motorway traffic concluded speed restrictions would be beneficial to both noise and air quality. Atkins' report concludes with a number of package measures considered to have the greatest benefits on both air-quality and noise, including Park-and-Ride/High-Occupancy Vehicle (HOV) lane operation utilising new technology low-emission vehicles and Urban Traffic Control (UTC) systems capable of optimising speeds and prioritising flows for public transport lanes.

5.4 Road Pricing

In general curbing congestion is synonymous with reducing total pollution so any road pricing or space rationing policy that seeks to alleviate congestion, is important also for the environment. However, in the event of the forecast of an air quality episode then more dramatic measures are needed. Current emergency measures include only allowing vehicles with an odd numbered registration plate to enter the town one day and even the next, a policy implemented in Athens, Paris and other large European cities.

Road pricing is a policy measure that currently seeks to manage traffic demand during the peak periods. Modelling of the effect of introducing road charging in Leeds was quantified by Mitchell and Namdeo (2003, 2004). A chain of dynamic simulation models of traffic flow, pollutant emission and dispersion was integrated within a geographic information system model to assess the impact of alternative transport scenarios on air quality for the city of Leeds, UK. The scenarios addressed included "business as usual" traffic growth to 2015; network development; road pricing with cordon charging; road pricing with distance charging; and the wider adoption of clean fuel vehicle technology. The impact of these developments on exceedence of air quality standards for NO₂, PM and SO₂ was identified. Finally, differences in the spatial distribution of air quality (as NO₂) between scenarios were highlighted, in light of their significance to social equity concerns. The study showed that air quality in Leeds is generally good, with forecast exceedences of PM₁₀ and SO₂ standards attributed largely to point sources, not road traffic. The management of road traffic does, of course, modify air quality. The network development for Leeds is likely to increase capacity which increases trips and hence emissions and of course degrades NO₂. The drop in air quality is most noticeable close to the new roads, particularly along stretches of some radials and more widely across much of the eastern suburbs. The associated rerouting led to an improvement in air quality in the south of the city, where air quality was poorest due to the urban motorways.

Implementation of road user charging was shown to have strong implications for the redistribution of air pollution. The single cordon in particular reduced pollutant concentrations significantly in the city centre, but did so at the expense of all areas immediately surrounding the cordon. Road pricing only brought major improvements in air quality (> 10g/m³ NO₂ reduction) under high distance charges. However, considering the overall impact and distributional effects, a modest distance charge appeared to be the most effective in reducing concentrations. The clean fuel analysis demonstrated a need for much improved CFV emission factors. However, Euro II-IV vehicles have very low emissions so it was difficult to make an air quality case for CFV's at the strategic level. However, they may of course have a role to play in tackling local pollution hot spots (which was confirmed to be more numerous under street canyon than flat terrain modelling), in low emission zones (LEZ) for example. But even ambitious LEZ's only achieved the gains which would arise by 2005 through natural fleet renewal, Watkiss et al (2003). The study concluded that, from an air quality perspective, the lesson was to ensure effective control of point sources, and adopt 'do nothing' strategic traffic management. However, reducing congestion (where emissions are poorly modelled) was also likely to be important.

Moreover, Blythe (2005) has suggested that the potential exists for developing road user charging using low-cost wireless sensors which could provide continuous road to vehicle communications and environmental sensing in real-time using nano-scale 'smartdust' devices.

5.5 Enforcement of Speed Limits

A study carried out by TNO for the Transport Research Centre of the Dutch Ministry of Transport, Riemersma et al (2004), aimed to determine the optimal speed limit on motorways near bottlenecks from the point of view of traffic throughput, safety, noise, emissions, etc. Three different speed limits were studied: 80, 90 and 100 km/h, all with strict enforcement and the results compared with a base case of 100 km/h without strict enforcement. The results demonstrated significant reduction in noise and emission levels are achievable. A reduced speed limit will normally primarily influence average speeds. But, introducing *strictly enforced* speed limits will also alter speed distributions. Empirical data revealed that under strict enforcement, drivers tended to stick more closely to the speed limit than normally. This behaviour results in significantly narrower speed distributions. The micro-simulation model MIXIC was used to determine the effects on noise of the driver behaviours resulting from different levels of enforcement.

Using MIXIC, simulations have been carried out for 100 km/h and 120 km/h *without* strict enforcement, and 80 km/h, 90 km/h and 100 km/h *with* strict enforcement. Using this scheme, noise emission levels had to be computed for three different vehicle types: light vehicles (primarily cars), medium-weighted vehicles (vans/small trucks) and heavy vehicles. Due to the type of road surface modelled (pervious asphalt, ZOAB), only limited reductions in noise emission levels were obtained by lowering the speed limit. On normal asphalt, the effects are estimated to be approximately twice as large. By combining microscopic traffic simulation modelling and a common Dutch noise calculation scheme, it was concluded that from the three different speed limits, a strictly enforced speed limit of 80 km/h was the most effective. However, more generally it was concluded that introducing strictly enforced reduced speed limits was not a very effective measure to reduce noise emission levels.

As noted by Peeters (2005) and Watts et al (2004) the inclusion of a distribution of speeds in the HARMONOISE method, generally increases predicted levels, over the use of a single average speed value. The subtle and complicated changes in the distribution of speeds resulting from the implementation of speed limit enforcement measures requires much more detailed and sophisticated micro-scale models, not just for traffic but also for air and noise emissions models. For noise, two sources (engine and transmission separate from road tyre interface) for third octaves across the audible range rather than broadband and for air quality, second by second emissions, Tate (2004), combined with sophisticated Canyon models, Boddy et al (2004, 2005) are necessary for quantifying the benefits, respectively for noise and air pollutant concentrations, of tactical control strategies.

Another example of the uses of speed control in urban areas is to reduce accidents in areas where often rat-running occurs. The next section discusses research that has quantified the environmental impact of the low technology traffic calming measures such as speed humps. This gives some measure of the potential benefits that can be achieved by ITS technologies such as intelligent speed adaptation.

5.6 Traffic Calming

Traffic calming measures, including humps, chicanes, junction tables, etc have traditionally been introduced to reduce speeds in urban areas where there are high traffic flows and speeds creating high risk of accidents. When traffic calming substantially reduces traffic flows air and noise emissions reduce in the treated areas but often with consequential increases on the alternative routes. Also, a disadvantage of traffic calming humps, in particular, is the additional noise and air pollution caused by drivers decelerating and braking in advance of the hump then accelerating up to the next. Often drivers' aggressive acceleration in traffic calming areas is responsible for high emissions of both air and noise pollution, particularly at the speed hump. The other types of traffic calming, such as chicanes, junction tables, central pedestrian islands etc, all, to a lesser extent cause disturbances in what would otherwise be more freely flowing and therefore potentially more polluting.

In some respects, any traffic calming investigation is similar to studies concerned with driving behaviour. This is because aggressive drivers tend to be on and off the throttle more often and more aggressively compared to normal drivers, Andrews et al (2004). A normal or calm driver tends to be smoother, therefore producing a smooth speed-time profile similar to a non-traffic calmed road. The aggressive driver has a speed-time profile similar to a traffic calmed road since acceleration and braking events will be more frequent. Consequently, parallels can be drawn between driver behaviour studies and traffic calming studies.

De Vlieger's (1997) work investigated driver behaviour and found that aggressive driving produced a dramatic increase in CO and THC emissions, but less so for NOx. CO emissions were up to three times higher for aggressive drivers, while HC and NOx were up to two times higher. Fuel consumption

was generally 30-40% higher for aggressive urban driving compared to rural and motorway traffic. Average trip speeds remained almost the same. In a similar study performed by Rapone et al (2000) comparing congested and free flowing traffic conditions, HC was found to be 12 times higher, NO_x was 5 times higher and CO was 4 times higher. This test used a small-engined, instrumented car to obtain on-road data which was then reproduced on a chassis dynamometer for emissions analysis.

The most comprehensive and authoritative study carried out on the impact of traffic calming measures was set up by the Charging and Local Transport Division of the DETR. It commissioned a three-year study on the impacts of traffic calming measures on exhaust emissions from passenger vehicles. The study was carried out by the TRL and included in it was an analysis of nine types of traffic calming measures using many types of vehicles. It was the first study of its kind and the results are important in assessing the impact of traffic calming measures on the environment and the local community. It was a wide reaching study that took nine different measures into account, assessing the emissions produced, speed, safety and delays caused to emergency vehicles. The test procedure involved using a LIDAR (Light Detection and Ranging) system to produce speed-time profiles for the vehicles passing through each of the schemes. Afterwards, the impacts on the emissions were determined using the driving cycles and a chassis dynamometer with constant volume sampling. The pollutants measured were CO, CO₂, HC, NO_x and particulates.

The results, for two types of vehicles, clearly showed that the calming measures increase the emissions of the pollutants. Catalyst cars were shown to be most sensitive to traffic calming methods, although they tended to have the lowest absolute emissions rates compared to the diesel and non-catalyst vehicles which were also studied. The results found in the TRL report were compared to an average speed model MEET: Methodologies for Estimating Air Pollutant Emissions from Transport TRL (2001). While the MEET model tended to underestimate CO and overestimate NO_x and CO₂, it was found that the percentage change in going from a non-calmed road to a calmed road was very similar for the TRL and MEET data for all the pollutants.

Andrews et al (2004) showed that emissions for a traffic calmed road employing speed humps were shown to be 2-3 times as high as a non-calmed road negotiated smoothly. This was measured on a mass basis using an FTIR installed in-vehicle on a EURO1, petrol-fuelled, passenger car. CO₂ was found to increase by 90%, CO by 117%, NO_x by 195% and THC by 148%. Five toxic species of hydrocarbons also, were examined and found to increase dramatically due to speed bumps.

The TRL results were similar to those obtained by Andrews et al (2004) although the latter yielded much higher changes in emissions. This was because the TRL study used a rolling road dynamometer to reproduce drive cycles that were obtained from real-world driving speed profiles. Consequently, the emissions produced probably were limited in terms of acceleration by slippage between the tyre and the rolling road. Another reason for the increase is the slightly aggressive nature of the driver negotiating the speed bumps in the study by Andrews et al (2004). Normally, well-designed speed cushions do not require the driver to slow to 10mph as was the case for the more aggressive round-top speed-hump in the Andrews study that needed heavier retardation. Also, another factor in the Andrews study was the heavier weight of the car almost fully laden with equipment and two people on board. For all the reasons mentioned, it was not surprising to see that the results from the Andrews study did not agree very well with those of TRL.

An important inference from the traffic calming studies is that Intelligent Speed Adaptation (ISA) vehicle control systems can potentially achieve significant reduction in air emissions by managing speeds through satellite communication along vulnerable streets.

5.7 Intelligent Speed Adaptive Vehicle Control Systems

ISA vehicle control systems ISAVCS are able to control the vehicle speed for particular stretches of road in an urban area. This is achieved with GPS and an on board computer. The main advantage of ISA systems, relative to other forms of urban speed control measures (such as 20mph speed zones or traffic calming), is their ability to allow different control speed depending on time of day (such as slowing along major roads at night time), position in the network (such as in the vicinity of hospitals and schools) during different weather conditions (when there is snow and fog), incidents and special events (such as football matches and bank holidays). In addition ISA has an important role to play on trunk roads and motorways to calm traffic, delay the on-set of the peak and to better manage capacity following incident. In these situations environmental benefits result from reducing the

interaction/conflicts among vehicles, smoothing flow which in turn also reduces accidents. Pollutant emissions are known to vary depending on the cruise speed, harshness of acceleration and deceleration and length of time spent stationary in the queue. For the same level of traffic flow, recent research has suggested that busy but not congested traffic is cleaner than when the vehicles are cruising at free flow speeds, Jalihal and Bell (2000). Furthermore, the optimal speed to minimise pollutant emissions varies with pollutant type. It may be that ISA vehicle control systems can be used to calm traffic to optimise the emissions of the particular pollutant threatening to exceed limits in a particular area, in time. However, a trade-off with safety may need to be accepted. As more ISA vehicles penetrate the market their value in regulating speed may increase. Also, in particular, in sensitive areas such as residential streets as explained above, ISA can achieve traffic calming instead of road humps with significant environmental benefit for both air and noise pollution.

As reported by Liu and Tate (2004), on-road trials of in-vehicle speed limited vehicles were first conducted in Sweden, Almquist et al (1991), and more extensive trials have been subsequently carried out in four Swedish cities, Lind (1999). In the earlier Swedish road-trial projects, focus was on the design specifications rather than evaluation of their environmental impacts. Simulation experiments of different penetration rates of ISA vehicles into traffic networks, was carried out by Liu and Tate (2004). The traffic micro-simulation model DRACULA, Liu (2003), was modified to explicitly represent the complex interaction between controlled vehicles and other traffic and the control impacts on driver behaviour, network congestion and pollution caused. The results showed that the speed control is more effective in less-congested traffic conditions than in high congestion; that, whilst ISA reduces excessive traffic speeds in the network, it does not induce more congestion to the network; that ISA reduces variation in speed which in turn reduces accidents, and helps to reduce fuel consumption and its consequential impact on the environment. Simulation analysis of ISA on a rural two-lane road and a motorway network was also carried out and showed that in general, the ISA effect on network performance was found to be less significant compared to that in the urban environment.

Wilmink and Versteegt, (2005) studied two urban networks in the Brabant area of the Netherlands, and formed the basis of the modelling for the PROSPER (Project for Research On Speed adaptation Policies on European Roads) project. As a component of the IMAGINE project Goodman et al (undated), the sensitivity of the noise prediction was studied depending on which of four different methodological approaches for modelling the impact of ISA. The methodologies varied in their level of detail and the changes in noise levels resulting from ISA was modelled for the Brabant area and an urban area of the city of York in the UK, Goodman et al (undated). The DRACULA model was used to assess the noise with 0% and 100% ISA penetration. The results showed that for the chosen links there was little variation in predicted sound power emission, or roadside $L_{Aeq,1h}$, between the 0% and 100% ISA penetration cases. The minor variations that do exist may be just as readily explained by differences in the bulk flow and speed parameters between the simulation model runs, rather than any subtle changes in speed distribution affected by ISA.

5.8 Movement of Freight

Goods movement by road has substantial environmental impact. Firstly, they require much stronger road foundations making road building more expensive and a higher drain on natural resources. The wear and tear of roads by heavy vehicles requires high levels of maintenance and the subsequent environmental impact caused by congestion associated with road works can be substantial. Goods vehicles are noisier and produce higher levels of pollutants due to the power needed to move their large payloads. Currently enforcement technologies that constrain the movement of goods vehicles to those major roads built to accommodate them and away from environmental sensitive areas particularly residential streets during the early hours of the morning and night achieve substantial environmental benefits. Any information or vehicle tracking technology that makes freight operations more efficient also has environmental spin-offs.

The recent publication of the AQEG (2005) has endorsed that diesel traffic emissions are the major source of particulate matter near to roads and the regional contribution to background particulate matter. As commercial vehicles are largely diesel fuelled, control of their emissions must be central to any UK strategy to control exposure to particulate matter. Also, as there is no known safe level for exposure, it is not appropriate to rely solely on the use of air quality objectives for their control as those places where pollutant concentrations are highest, for example close to busy roads, are often where relatively few people tend to live. The emphasis of the advice, AQEG (2005) was to maximise the benefits of controls on particulate matter but aim to reduce exposure more widely. The

recommendation was to implement forms of regulation based on reducing the average exposure to particulate matter experienced by the UK population which would complement the 24hourly and annual averages.

In addition to the strategic management of commercial movements in a conurbation as outlined above, Advanced Traveller Information Systems, ATIS, play an important role in delivering benefits to the environment in the freight industry by reducing unnecessary vehicle mileage by suggesting optimal routes. Ridwan (2004) used a fuzzy preference based model of route choice which can account for drivers who do not necessarily minimise travel time or cost in their route choice decisions. The uncertainty of decision making is captured by the fuzzy preference model that supports ATIS project implementations. Taniguchi and Shimamoto (2004) designed a dynamic vehicle routing and scheduling model that incorporated real-time traffic information using variable travel times in a road network, using dynamic traffic simulation to update travel times. This ATIS specifically targeted for use in urban freight operations was shown to have the potential to substantially decrease the total hours of travel of freight vehicles with obvious financial benefit amelioration of congestion and consequential substantial reduction in air pollutant emissions.

6 Informing the Public

Public Information provision aims to cut down congestion, influence mode choice to more sustainable transport modes and inform the public of pending air quality episodes.

Information provision includes:

- In advance of their journey to plan the choice of mode, route and time of departure
- During their journey, through radio broadcast advising the public where congestion problems are so that they can take steps to avoid them.
- Using variable message signs at the roadside advising drivers to use park and ride to avoid congestion or prevent air pollution hotspots.
- In the popular press and on the web advising of the location and expected time of occurrence of poor air quality and steps to take to alleviate and avoid exposure.

There are numerous technologies available to deliver information to the public to meet the needs of users, these include world-wide web, radio, television, mobile phone, variable message signs, parking information signs, etc. One of the limitations of information provision is its accuracy, timeliness and most importantly the delivery of the personalised information. In this section some evidence of the environmental benefits of information systems as found in the literature will be presented.

Yin et al (2004) demonstrated the means by which ITS technologies can improve congestion levels in urban road networks. The paper recognised the significance of the reliability of travel times in route choice and departure time choice decisions by individuals and the impacts that Advanced Traveller Information Systems (ATIS) may play in these decisions. Interestingly the work of Yang and Huang (2004) showed that the benefits of using ATIS initially increases with market penetration but in some cases, after some optimal level is reached, even negative benefit (increased total travel time) may result. This was due to the fact that there is over-reaction of ATIS users. This has led to a general policy conclusion that it is only necessary and desirable to equip a limited proportion of vehicles with ATIS. However, if implemented as a component of a more global integration of technologies for example dynamic signal control system, the latter can monitor and forecast the consequential changes in traffic levels and conditions and thus modify the ATIS message accordingly. There is a need for hardware and software challenges to be overcome before technology integration becomes a reality.

The EU Fourth Framework project, EMMA, (Integrated Environmental Monitoring, Forecasting and Warning Systems in Metropolitan Areas), (www9), the sister project to EFFECT, Environmental Forecasting for the Effective Control of Traffic, (www5) with partner cities Leicester (UK), Madrid (Spain), Gothenburg (Sweden) and Genoa (Italy). The EMMA project developed a co-ordinated approach to the provision of information. This included a newsletter, pre-trip planning, via the web, and dynamic message systems DMS, using radio broadcasts and variable message signs, during the journey. The aim was to inform and update travellers of congestion and air pollution problems in an attempt to influence their choice of mode (use park and ride or use public transport) or even post-pone the trip on pollution episode days.

EMMA aimed to produce 24 and 48 hour forecasts of air quality in Leicester, based on the weather forecast obtained daily from the UK Met office. These forecasts were used to both inform and warn the public, and to draw to the attention of the traffic signal control operator any pollution “hotspots” which could be alleviated using traffic demand management strategies as described above. Gothenburg city council attempted to influence driver behaviour by providing information and advice using VMS signs. The effectiveness of 7 traffic and 6 environment VMS signs was established by carrying out a telephone questionnaire survey and to measure the degree of re-routing achieved by giving drivers advice by measuring actual traffic flow levels.

The controlled experiments showed that the actual wording of the message given on the signs affects how drivers interpret the message and in the end the action taken. There was clear evidence that the driver must be able to trust that the information given was up-to-date. It was shown that drivers were not familiar with the names of all the interchanges and roads, there advice ‘*to follow the signs to...*’ was more useful. The experiment showed that the messages relating to traffic incidences were taken more seriously than those relating to pollution episodes and the difference in the public responses were influenced by prior knowledge of the network and traffic conditions. However, as a consequence of the information provision there was no statistically significant reduction in traffic flow levels measured on street on the day of the pollution episode studied.

In a parallel study carried out in Leicester, on the eve of a pollution episode, the public were informed by radio broadcasts, television and local newspaper articles and given advice to use public transport, park and ride or even postpone the trip, if possible. On street surveys in the central area of the city, (of mainly shoppers as the pollution episode took place on a Saturday) demonstrated that in the morning about one third of shoppers were aware that pollution levels were high. By the afternoon this had risen to two thirds. However, of 104 subjects interviewed by telephone in the evening one member of the public had not entered the city when advised that there was a temperature inversion. The survey was carried out the first time that information and advice had been given to the public. It is hoped that through time and education programmes the public will begin to respond more positively to the advice given during periods of poor air quality. Both surveys highlighted the potential problems of persuading drivers to act responsibly and change their travel behaviour, in response to incidences of poor air quality, Bell and Hodges (1999), Bell et al (2002).

7 Integrated Information Platform for Decision support

As ITS is assuming an increasing role in the *implementation stage* of air quality management action plans developed by Local Authorities they are becoming a vital tool for the delivery of sustainable cities. However, in the future such technologies should be seen as an important source of data. Asakura and Hato (2004) demonstrate fundamental concepts and methods for the use of mobile communication instruments such as cellular telephones for tracking movements of individual subjects. Algorithms were developed to provide trip attributes describing travel behaviour for each point recorded. The accuracy of measurement and validity of the algorithm was assessed for 100 individuals surveyed using the combined data logging system. This technology whilst designed for transport operations it potentially has the ability of providing travel activity descriptors (ie mode of transport, duration of exposure according to the different modes etc) essential for the assessment of human exposure to pollution levels to feed into health assessment tools. The value of mobile phone technology as a source of information to enhance the management of urban networks was described by White and Quick (2004)

Chen and Bell (2001) outlined a system’s architecture for an integrated monitoring and modelling platform, as a basis for a sophisticated decision support system. A *Database Platform* forms the kernel of the DSS by capturing and storing the data from all of the available technologies on vehicles, systems and people. The *Database Platform* will be mined by statistical algorithms to identify problems, either related to congestion or environment, and with faster than real time modelling capability, provide solutions to the problems in real-time.

As ITS develops further vehicle tracking is allowing data on journey times and speeds of vehicles through cities to be made available to fine tune the operation of traffic demand strategies and urban traffic management control to further reduce pollutant emission. Smart card technology used to pay for car parking, to ride a bus or train provides valuable information on understanding the demands of trip making to be understood and thus to better manage public transport services Blythe et al (2000).

Furthermore the data from these systems would allow information on people activity to be collected. This may then be used as input to exposure models to better reflect the impact of demand management strategies and policy on health rather than pollutant concentrations, European project HEARTS, Health Effects And Risk of Transport Systems, (ww10), Ashmore et al (2002).

If engine technology advances some may argue that in 15 years hence air quality problems will almost be solved. However, that is not so as unrestrained growth in the number of cars in our cities is not an option. This is because of their limited capacity of our city and inter-city roads and the drain on the world's energy resources and consequential effect on global warming is not acceptable. Today's policies to curb congestion aim to reduce the number of trips made by private vehicles in order to reduce pollution. These policies are consistent with a tolerable level of traffic of zero emission cars in the future consistent with energy availability.

ITS technologies are the mechanisms through which up-to-date information concerning the state of the traffic and transport network can be deposited directly on to the information platforms for dissemination and action by both the public transport operator, traffic manager and the public (Guo and Blythe 2005). Indeed, it is anticipated that the World Wide Web and the mobile phone will become increasing media for the public to gain access to information concerning congestion, arrival time of buses at stops, and perhaps in the future, access to a fully integrated real-time private-public transport information system. The personal hand-held web based information systems giving Traveller Information Services will have an increasingly important role in the future.

Another important role for *Database Platform* is to use the historic data to advise policy and land use decisions and to evaluate the impact of policy intervention and TDMS. Research has shown that currently, information provision, whilst having an important role to play, has limited impact as drivers are reluctant to use public transport as an alternative to the car. Therefore, ATIS, mobile phones, VMS, www, ISA, smart cards etc should be considered as technologies that can be used to facilitate the implementation of policies and demand management and control strategies rather than be entities in themselves. However, as the vehicles and the nature of traffic flows in our urban networks change, as a result of technology, so the need for the models used to validate the impacts need to also change. This is because current models are not sufficiently sensitive to the subtle changes that occur for example when calming traffic flows and speeds, modifying driving profiles etc. all effect emissions profiles of vehicles in the network. This is not an easy task as the frequency of occurrence and the character of the noises from, cars, buses, trams, trains, light rapid transit are widely different and vary differently according to time of day and meteorological conditions. The assessment models for air quality impact across different modes whilst more developed for strategic evaluation, need substantial improvement to assess the impact on the environment of future technologies that require modelling at a microscopic level. Fundamental research in this area is being carried out by Tomlin et al (2005) and Tate et al (2005).

Furthermore, if the information platforms could also deliver reasons for actions, ie to provide education to encourage a change of attitude and lifestyle then uptake of advice and use of technology may be accelerated. There are clearly benefits of taking steps to educate the public to develop an understanding of the environment implication of their increasing demands to travel and the health benefits of walking and cycling. This may influence their choice to live within walking distance of their place of work or in the vicinity of public transport facilities.

8 Summary

This review has demonstrated how vehicle technologies and intelligent transport systems can play an important role in reducing the impact of traffic on the environment and health and in the development of long-term sustainability of our towns and cities in the future. Evidence has been presented to demonstrate the effect on health of the different pollutants emitted from transport. The ways in which the pollutant emissions are reduced at source through engine and exhaust gas treatments and the use of cleaner fuels have been outlined. How intelligent transport systems have the ability to manage the location and intensity of pollution emissions across a network over time as short term measures to alleviate specific pollution hotspot problems have been described. It has been shown that no one technology will achieve significant benefit, instead an integrated approach is required. Also, it is essential to make sure that the capacity recovery needed to reduce environment impact is reallocated simultaneously to more sustainable modes.

Finally, only those technologies that seek to influence the public's use of transport systems and provide an education to change the public's attitudes and lifestyles to reduce their need to travel will sustainability of our city transport networks be achieved in the longer term. Government intervention is needed to regulate emissions to ensure levels of pollution concentrations are kept to levels that are not harmful to health. However, given that measures to reduce one pollutant does not also reduce another, tough decisions are needed by the policy maker that will result in the changing shape of our towns and cities as they adapt to the reduction in unnecessary travel in the future. Radical and innovative solutions combining policy, science and engineering are the greatest of challenges.

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