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**A Framework for Sustainable Transport Development**

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**Abstract**

With increasing attention on climate changes and their impacts on sustainability, which is caused by the emission of greenhouse gases into the atmosphere, more research is being conducted looking at environmental issues and the impact of emissions on local and global air quality. Upon the principle of “the polluter pays”, or that those who are causing environmental harm by producing or utilising energy shall bear the cost of its remedy, investigations of transport policies which are specifically intended to reduce emissions and improve air quality are needed. Road use pricing for example, has become a popular policy for managing the demand for travel. The execution of the theoretical principles of congestion charging into practice is complex and will hardly, if ever, be met in reality. The idea has always been to charge vehicles where the extent of the charge should reflect negative externalities they impose on others and on the system, thus helping to reduce negative externalities of traffic. In theory that should include congestion, air quality, etc. However in practice congestion has been the only factor considered as the basis for any charging scheme and to a much lesser extent, if any, on air quality improvement. The purpose of this paper therefore is to present a framework for sustainable transport development which explicitly distinguishes the environment and air quality. Firstly, it is essential to use targets setting as the mechanism for devising transport policies. Secondly, to investigate policies and measures which explicitly identify environmental impacts and the set targets. Thirdly, when monitoring and modelling impacts of such policies on the environment one has to be at least aware of the modelling approach, assumptions and influence of these assumptions on the estimate of the impacts of the polices on emissions. More investigations into emission factors which reflect actual driving behaviour and local driving conditions are needed. Critical to achievement of sustainability is the principle of integration; at the level of setting targets and objectives, at the level of setting policies and measures and at the level of monitoring the impacts of such policies.

1. **Introduction**

In the 1950s the main sources of pollution came from the power and industrial sectors. This gradually changed with traffic becoming the major concern that causes delays and congestion as well as the negative impacts on air quality. While providing benefits to their users, transport networks also impose negative externalities on both users and non-users. Negative externalities are wide-ranging and include local air pollution, noise pollution, light pollution, congestion, safety hazards and others. Another environmental issue is climate change which is generated by greenhouse gases released into the atmosphere. Its global significance has increased enormously in the past few years (Department for Environment, Food and Rural Affairs, 2009). The world Governments first attempts to reduce emissions happened through emission control legislation in the early 1970s. Since then it has been possible to gradually tighten permissible limits (McCrae, *et al*, 2000). This consequently led to significant reductions in the emissions from individual vehicles, and combined with changes in fuel composition (less benzene, lead and sulphur) led to a cleaner vehicle fleet. All this caused a reduction in the primary pollutants[[1]](#footnote-1), whereas there has been little change in the secondary pollutants[[2]](#footnote-2) (McCrae, *et al*, 2000). Since then, reducing emissions from transport, as well as from different sectors has been a global responsibility. However, with the increase of awareness of air quality and pollution issues, more efforts at the local level have also been put to contribute to meeting the targets set for these global issues by including environmental targets on the local agendas. In most cases however, these targets have not been explicit nor stand-alone; rather they have been implicit targets which are planned be achieved through achieving reductions in congestion as discussed below.

Since the 1980s, a large number of research projects, frameworks and studies have been devoted to develop policies and standards to influence travel behaviour, reduce congestion in the first instance, *whilst* also improving air quality (see for example Saleh and Sammer, 2009; Muñoz, *et al*, 2008; Litman, 2003; Jara-Díaz and Gschwender, 2005; Bonsall, *et al*, 2007; Stewart, 2009; De Palma and Lindsey, 2006). Therefore, whilst congestion is one of the negative externalities, it has become much more widely targeted, researched and attempted to be improved by exploring specific policies than other externalities.

Examples of these policies include road use pricing, public transport policies, parking policies, access control and speed calming measures. Road use pricing for example, has become a popular policy for managing the demand for travel. The execution of the theoretical principles of congestion charging into practice is complex and will hardly, if ever, be met in reality. The idea has always been to charge vehicles where the extent of the charge should reflect the negative externalities they impose on others and on the system, thus helping to reduce negative externalities of traffic. In theory that should include congestion, air quality, etc. However in practice congestion has been the only factor considered as the basis for any charging scheme and to a much lesser extent, if any, on air quality improvement (Saleh, 2007; Saleh and Sammer, 2009). Similarly, other transport policies are designed in the first instance to target congestion, safety, etc., rather than environmental issues. The latter are assumed to benefit from the positive impacts on other externalities.

In conclusions, it has become apparent, that the impacts of transport policies on air quality and air pollution have not been fully and correctly properly investigated yet (Saleh, *et al*, 2009; Kumar, *et al*, 2008). In order to have more efficient estimates and predictions of these impacts it is important to set clear targets for emission reductions, use appropriate policies to achieve such aims and to use appropriate models for predicting impacts of such policies. Different models have different assumptions and limitations and have developed for specific situations. Integration of efforts and policies at the local and national level is also very important.

1. **Framework for Sustainable Transport**

In this paper, a framework for achieving sustainable transport systems is discussed. Three main stages are defined. These are setting targets and standards for achieving sustainability (with explicit consideration of environmental and air quality issues) to be the mechanism for devising transport policies, identifying a range of policies and measures which can be explicitly utilised to achieve the set targets and thirdly be aware of the nature and limitations of monitoring and modelling approaches of the impacts of the proposed policies on emissions and air quality. Each of these is discussed in the following sections.

**2.1 Set Targets and Standards for Achieving Sustainability to be the Mechanism for Devising Transport Policies**

Transport planners are often faced with transport problems which have negative impacts on the users and non-users of the transport system. Examples of these problems include congestion, delays, safety, air pollution, visual intrusion etc. These problems have been dealt with traditionally using a ‘predict and provide’ approach (i.e., predict demand and provide supply). More recently, a shift to predict and manage (i.e., predict demand and manage it) approach has been used. See for example Hensher (1998) and Litman (2003) for a review and discussions of TDM. Travel demand management (TDM) approaches are wide-ranging and cover tools and techniques ranging from pricing, parking, public transport, land use planning and raising awareness about the negative impacts of increasing demand (see Saleh, 2007 for discussions on TDM measures). It is not always clear however, how or why specific measures and policies are selected for implementation when targeting transport externalities.

Ideally, any transport planning process should begin with analysing the current situation, identifying a problem then setting targets. The motive for target setting is to ensure that there are measurable goals to assess the implemented policies against. The targets need to be tailored to solve the problems identified, and should therefore be informed by a clear plan of actions and policies to meet the local needs of the city or area. In practice this process is followed in some situations but not in all.

Transport safety is one of transport externality where setting up targets is a common practice. For example, in the safety strategy *Tomorrow’s Roads Safer for Everyone[[3]](#footnote-3)*, the aim for 2010 was to achieve a reduction of 40% in the number of people killed or seriously injured (KSI) in road accidents; compared with the average for 1994-98, a 50% reduction in the number of children killed or seriously injured; and a 10% reduction in the slight casualty rate, expressed as the number of people slightly injured per 100 million vehicle kilometers. Clear plans and measures have been set to achieve these targets. Regular updates on implementation and review of progress towards these targets are regularly updated on the DFT road safety strategy website:<<what is the specific website url? Or did you just want to make the ‘:’ a ‘.’?>>

Another case for setting targets is in devising cycling policies. For example, the then Department of Transport in the UK launched the National Cycling Strategy (NCS) in 1996. The strategy stated two major targets; to double the trips made by bicycle from the 1996 level of use by 2002 and to double it again by 2012. In order to meet these targets, local authorities, other public bodies, and private organisations have been asked to set local objectives and targets that can contribute to the increase in cycle use. Many local authorities responded in the late 1990s and early 2000s by developing and publishing their own cycling strategies; however, under the Transport Act (2000)<<not referenced in the reference section>> all local authorities have a statutory requirement to develop, implement and monitor cycling strategies[[4]](#footnote-4), which is incorporated in the Local Transport Plan process.

When it comes to setting targets for air pollution reductions and air quality, things become less clear. These targets are largely dealt with at a higher level; at an international level (e.g., pollution targets) or at a government level. For example, at the international level, the Kyoto Protocol and the United Nations Framework Convention on Climate Change beyond 2012 were agreed in Kyoto in 1997 and Copenhagen in 2009 respectively (EN, 2009) The Kyoto Protocol has committed the countries which ratified it to cut emissions of not only carbon dioxide, but of also other greenhouse gases, of which tailpipe emissions from the transport sector are a major contributor, while the Copenhagen conference just recognised the importance of climate change and the need for actions to be taken.

At the European level, national agreements have over the past decades focused on reducing pollution. The European Union has various directives[[5]](#footnote-5) on air quality and transport. Its directives oblige Member States to introduce policies that improve and protect the health and environment of their citizens (AEA, 2010). The European Community (EC) started the first initiatives concerning air quality in 1979 (Geneva Convention on Long-range Transboundary Air Pollution (AEA, 2010)). In the past years a number of Air Quality Directives and Decisions have been released to assess the ambient air quality of Member States, to generate information on ambient air quality to help to fight air pollution, and maintain air quality where it is good, etc., (AEA, 2010).

On a government level, local measures are taken in individual countries. For example in the UK, the Climate Change Act 2008 introduced a long-term legally binding framework to tackle the dangers of climate change. The Climate Change Bill was introduced into Parliament in November 2007 and became law in November 2008. The Act created a new approach to managing and responding to climate change in the UK by:

* setting ambitious, legally binding targets
* taking powers to help meet those targets
* strengthening the institutional framework
* enhancing the UK’s ability to adapt to the impact of climate change
* establishing clear and regular accountability to the UK Parliament and to the devolved legislatures

The main provision of the act is the legally binding target of 80% or more reduction in GHG emissions by 2050 on levels measured in 1990. Presently the main goal is to reduce emissions at least 34% by 2020 from 1990 levels (Transport, 2009). Hence a large number of European standards have been developed to achieve these targets. However, these standards are mostly for the private cars.

Environmental targets from the transport sector are in the main set at international levels and are largely met by car manufacturers. Withincreasing attention on climate change which is caused by the emission of greenhouse gases into the atmosphere, efforts at local levels have been spent more recently looking explicitly at environmental issues and further investigating the impacts of emissions on local and global air quality. There has been a realisation and sense of obligation that air quality and air pollution improvement targets had attracted less awareness and responsiveness than urban problems (e.g., congestion and delays) in the past. As a result, more dedicated research and recognition of explicit consideration of air quality in European cities have emerged at local levels (see for example Beck, *et al*, 2009; Howarth, *et al*, 2009; Marsden and King, 2009; Saleh, *et al*, 1998; 2009; Hung, *et al*, 2007; Joumard, *et al*, 2000; Tzirakis, *et al*, 2006**).**

Efforts have been made to contribute to meeting the environmental targets (emission reductions). However most of the efforts have been directed mainly into reducing congestion; reducing congestion has been stated as the primary aim of transport policies and environmental objectives have also been mentioned as the secondary aim. This is because congestion management has been regarded as the key for solving most other transport problems.

Setting targets for congestion reduction is a much more difficult task because there is no one definition of congestion available (European Conference of Ministers of Transport, 2007). The term “congestion” can be used to indicate congestion of roads, times of day, destinations, or modes of transport and therefore there are many indicators in use for congestion definition. Therefore, setting targets for congestion reduction may also take a number of approaches. In order to reduce congestion, one might set a target of reducing traffic on links, destinations, times of days, improving reliability or travel time variability, and so on. It is not very clear however, the impacts of each of these targets on environmental issues. Some of the targets are more feasible than others.

Further research and development in the area of formulating operational and widely applicable targets for congestion reduction is still needed in order to be used in formulating policies for a more sustainable transport system. Further research is also needed into setting targets for contributing to meeting the set requirements for air quality at the local level.

**2.2 Identify a Range of Policies and Measures Which Internalise Environmental Impacts**

In order to achieve the set objectives and targets as discussed above, policies considered have to be specifically designed to meet such targets. If the target set is to reduce congestion, policies have to be devised to reduce congestion. If the target set is to raise revenues, policies have to be devised to raise revenues. If the target set on the other hand is to reduce emissions or improve air quality, the policies considered have to aim for reducing emissions, and so on.

As discussed earlier, it is not uncommon in practice to employ policies for congestion reduction where the target is to improve environmental impacts of transport (Arentze and Timmermans, 2003). While charging drivers for congestion reduction as one of the negative externalities is a common concept now, still internalising environmental impacts of transport (i.e., charging users of the transport system upon the principle of the polluter pays) is not on the implementation agenda yet. This is despite the fact that the technology needed for its implementation is available (see for example Bricka, 2008; Fontaine and Smith, 2007). Maybe this is because congestion affects all users of the transport system in a direct and anticipated way. Also, congestion is perceived to be the primary cause of delays (which equates to money), the main contributor to worsening air quality and the main factor which increases accidents, increases stress and so on. However, there is lots of evidence that reducing congestion does not always result in reduced emissions.

2.2.1 Policies to Reduce Amount of Travel. These policies are designed to reduce number of journeys and distances travelled. The past few decades have seen a huge development in policies and measures for travel demand management. For example, in the 1980s, a large number of research projects, frameworks and studies have been devoted to develop policies and standards to influence travel behaviour, reduce congestion and improve public transport in the first instance, *whilst* also improving air quality (see for example Saleh and Sammer, 2009; Muñoz, *et al*, 2008; Jara-Díaz, and Gschwender, 2005; Bonsall, *et al*, 2007; Stewart, 2009; De Palma and Lindsey, 2006).

In particular, road use pricing, which is a transport policy where motorists are charged for using the roads has gained wide popularity in Europe and other parts of the world (see for example Ieromonachou and Warren, 2008; Schade and Schlag, 2003; Gehlert, *et al*, 2008; Sadler, 2002 and Department of Transport, 2007). In theory, the extent of the charge should reflect the costs that the user imposes on others and on the environment, thus helping to reduce negative externalities of traffic (Saleh, 2005). Although the principle of road pricing has been debated for many years, there are still very few practical applications of the policy in operation, and these few applications are mainly based on fixed pricing for congestion reduction and to a much lesser extent, if any on air quality improvement (Saleh and Sammer, 2009). Therefore, in most applications, price levels are not variable, they do not reflect levels of congestion[[6]](#footnote-6) nor do they reflect environmental externalities of the transport system. Even where pricing is implemented as fuel taxes, these have mainly been for the objective of raising revenues for infrastructure rather than improving air quality (see for example Beck, *et al*, 2009). Environmental issues have always been expected however, to benefit from the reduction in traffic congestion as discussed. Consequently, most of the advances and majority of the work on travel demand management have been for the objective of relieving congestion, changing travel patterns and raising awareness rather than straightforwardly improving the environment. The argument which has been used is that if we alter travel behaviour to reduce the quantity travelled then that would improve air quality as well as relieving congestion (e.g., Schade and Schlag, 2003; Gehlert, *et al*, 2008 and Sadler, 2002).

Most transport policies, *but not all* result in positive impacts on the environment and air quality (see Sammer, 2009; Sammer and Saleh, 2009). For example, building park and ride (P&R) schemes may help to attract a proportion of car users to use P&R, hence will result in reduction in air pollution. However, they may also result in increase in total mileage driven and, can in some cases attract those who previously used public transport for their whole journey and/or result in an increase in air pollution. These impacts will result in reduction of the positive impacts of the scheme. Public transport measures such as bus lanes might help achieve some modal shift objectives but they might also have negative environmental impacts as a result of concentration of pollution on the bus lanes and increase in idling, acceleration and deceleration times which will hinder the desired goals of these policies (Saleh and Sammer, 2009). In addition, implementing congestion charging and traffic calming schemes may reduce traffic, speeds, improve safety in some local areas, but these schemes may result in migration of accidents to other areas, reduced motilities and increased fuel emissions in some local residential areas.

It should be noted however, it is not always the case that the transport polices selected for implementation are those which tailored to meet the set targets. Sometimes policies are selected for implementation because they proved successful at other cities or other parts of the city. For instance, speed reduction measures, bus lanes, public transport real time information provision systems are examples of measures which spread from one location to others based on their claimed success in some cities or parts of cities. Sometimes, policies are implemented because they are convenient (i.e., there is experience in or budget for these types of policies). Sometimes polices are implemented to generate revenues which can then be used to further enhance the transport system and implement other policies, such as congestion charging schemes. In these cases, improvements of environmental issues are often claimed as one of the objectives of such transport policies, although not always explicitly.

Critical to success of any policy is clarity of policy objectives. Policies and measures for the reduction in pollution and improvement of air quality have to be considered explicitly for these objectives. For instance, variable pricing policies can be implemented based on air pollution and air quality targets of the local areas. Speed limits and speed calming measures, using speed adaptation technologies for instance can be also be designed based on air quality targets. Raising awareness of environmental impacts and air quality as well as other transport policies can also be used explicitly to devise transport policies which aim at achieving sustainability.

Testing and devising polices which meet specific targets is a major area of research and investigations. Very crucial to this area also is monitoring and modelling impacts of such policies on the environment.

2.2.2 Policies to Reduce Emissions from Vehicles. As well as reducing amount of travel (number of journeys and distances travelled) it is also important to reduce emissions from individual vehicles. Road transport accounts for more than 20% of the UK's total carbon emissions, with more than half of that coming from cars. In order to reduce these emissions and contribute to cleaner air quality a number of integrated efforts have to be considered. It is unlikely that a new vehicle type will be introduced to the market in the short to medium term. Different modal split, new fuels and technological developments can prove effective in reducing emissions instead. These can be achieved by adopting measures and policies to improve emissions from vehicles, fuels and technical advances.

**Vehicles**

Market share of modes of transport, other than the private car have to be encouraged to increase in order to reduce car dependency. Public transport offers a more sustainable mode of transport than the private car. Public transport, including trains, trams and buses can relieve traffic congestion and reduce air pollution from road transport. Railways are also more efficient and sustainable forms of transport than the private car; one commuter train may replace a large number of private cars. Two wheeler vehicles also have a great potential in reducing car dependency and increasing the more sustainable modes of transport.

While there are extensive research has been carried out to investigate policies to encourage more use of public transport modes of transport, less effort has been put into two and three wheeler modes (see Hung, *et al*, 2007; Kumar, *et al*, 2008; and Gandhi, *et al*, 1983). These modes are perceived to be more efficient means of travel than other modes since they are smaller in size and therefore deserve more investigation and considerations (Hung, *et al*, 2007; Joumard, *et al*, 2000; Saleh, *et al*, 1998; Tzirakis, *et al*, 2006). Although the share of two wheeler modes in the market has increased significantly over the past few decades especially in Asian countries (see for example Hung, *et al*, 2007; Gandhi, *et al*, 1983; Saleh, *et al*, 2009), the European standards have not forced reductions in emissions from two wheeler modes similar to that imposed on cars. For example, in the UK emission standards, there was no reference made specifically to motorcycles but motor vehicles as a whole. As a result, there have been significant reductions in emissions from other forms of road transport brought about by new emission standards and technologies, whereas the emissions from motorcycles and two wheeler vehicles have increased (Department of Transport, 2007; National Atmospheric Emissions Inventory, 2007). Saleh, *et al*, (2009), Hung, *et al*, (2007) and Joumard, *et al*, (2000) have reported investigations of emissions from motorcycles under various driving conditions.

An electric vehicle uses one or more electric motor for propulsion. Electric vehicles include electric cars, electric trains, lorries, motorcycles and scooters etc. Electric vehicles first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion. During the last few decades, increased concern over the environmental impacts of the petroleum-based transportation infrastructure, along with the oil crisis, has led to renewed interest in an electric transportation infrastructure. Electric vehicles differ from fossil fuel powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power and renew and renewable sources. However, electricity is not a primary energy source so the efficiency of the electricity production has also to be taken into account. As a result, the potential of electric vehicles is still undetermined. More research into impacts of various vehicle types on emissions and air quality is urgently needed.

**Fuels**

The role of fossil fuels in global warming and greenhouse gas emissions cannot be ignored. Governments have begun to act on this by introducing legislation aimed at increasing renewable resources including biomass, bioliquids and biogas (EN, 2009). The UK’s overall renewable energy contribution is set at 15% for 2020 but the transport sector is setting a target that 10% of total road transport fuel should come from renewable energy (Transport, 2009).

At the moment the government in the UK has introduced a Renewable Transport Fuel Obligation (RTFO) requiring transport fuel suppliers to ensure that 5% of total road fuel sales by volume are from renewable sources 2013-14. This target had first been set for 2010 but there is concern however that the production of biofuels may result in increased emissions rather than reducing them through the manufacturing process. More policies should be encouraged and supported to encourage R&D activities regarding renewable fuels. For example, production of bio fuels at local levels (small scale businesses) can be encouraged.

**Technical Fixes**

Emissions and air quality are global problems; therefore solutions to these problems come under international responsibility in the first instance. Quantifiable targets required from different sectors are usually set by the specialised international authorities. Transport targets for emission reductions are mainly met by car manufacturers and technology developers.

The propulsion of an automobile needs energy, which is in most cases obtained by the conversion of chemical energy from fossil fuels to mechanical energy by means of internal combustion engines (ICE). Hazardous emissions are emitted due to lower efficiency of the machine for combustion causes. Due to the increasing use of automobiles and thereby increasing environmental damage, the automobile industry is required to develop engines with higher efficiency and lower emissions to meet the targets set by emission laws. There is large number of variables that can contribute to the fuel efficiency. Examples of some technological options which improve fuel efficiency include variable induction, intercooled electronic control, partial leanburn, Air /Fuel control, stratified combustion systems, gasoline direct injection (GDI), Diesel Direct Injection (DDI), Fuel lean burn and DI diesel multivalve.

Other examples of technological options for engine improvement include Knock control[[7]](#footnote-7) which results in high efficiency due to optimum utilization of the fuel quality and consideration of the relevant engine status, transient control, two phase/high temperature, valve train friction, low viscosity oil, low viscosity diesel, cooled exhaust gas re-circulation (EGR), catalytic reduction, electronically controlled EGR, hybrid cars, new fuels- liquid hydrogen and fuel cells. Also, there are measures to improve aerodynamics and chassis friction as well as measures for weight reduction. There is evidence of the progress made by car makers in driving down CO2. It is not intended here to discuss these technical measures in any more detail, although they are very relevant for emission reduction and improvements in air quality. Further reading in this area includes (United States Environmental Protection Agency, 2005 and European Federation for Transport and Environment, 2006).

In conclusion, emission fell over the past two decades or so by more than 13% saving an estimated one million tonnes CO2 each year. This reduction follows moves to diesel, small cars and, more recently, growth in alternatively fuelled vehicles. This reduction is mainly a result of technical advances which have been implemented by the car industry in order to meet the targets set for emission reduction. The industry has to continue to invest in the technologies that bring greener cars to market, and is committed to working in partnership with government and other user groups. Furthermore, extra reductions in car emissions from using technical fixes are also achievable from combining influence of driving behaviour.

2.2.3 Driving Behaviour. Driving behaviour is a very important contributor to increase or reduce vehicle emissions and fuel consumption (see Saleh, *et al*, 2009; Kumar, *et al*, 2008). It is technically feasible to assess driving profiles and the associated emissions by installing GPS based devices and gas sensors in the vehicle. Instantaneous monitoring of speed, emissions and fuel consumption which would encourage environmentally friendly driving styles is technically feasible. The knowledge of the driving cycle[[8]](#footnote-8) is an important requirement in the evaluation of exhaust emissions, as driving cycles are widely used for the estimation of transport air pollutant emissions and in the building of databases for emission inventories. Some researchers have investigated the influence of driving cycles on emissions (for example Saleh, *et al*, 2009; Kumar, *et al*, 2008). Driving cycles for private cars and light goods vehicles (LGV) are used to enhance traffic management systems, determining fuel consumption patterns and reduce transport impacts on the urban environment (Hung, *et al*, 2007; Joumard, *et al*, 2000; Saleh, *et al*, 1998; Tzirakis, *et al*, 2006).

Therefore, investigations of driving behaviour and impacts on emissions and air quality are critical for analysing of and minimising emissions (see Marsden and King, 2009; Howarth, *et al*, 2009; Gense and Elst, 2003). Policies which can be used to improve driving behaviour include raising awareness and using feedback information about driving behaviour and impacts on emissions and air quality. Integration of information, ITS, modelling and optimisation techniques are very crucial for achieving modal shift, improved driving behaviour and sustainability (Kenyons and Lyons, 2003 and Khattak, *et al*, 1993).

**2.3 Monitor and Evaluate the Impacts of the Proposed Policies on Emissions and Air Quality**

Predictions and monitoring of impacts on air pollution and air quality are crucial if interventions in the transportation systems are to be logically investigated *before* or *after* implementation of transport policies. A prediction before implementation is useful to be carried out to maximise the efficiency of interventions. Monitoring after implementation is useful to be carried out to learn lessons and improve future implementations. In order to perform such predictions and monitoring, two types of models can broadly be identified; firstly simulation models (macro, micro or laboratory simulation) and secondly, emission monitoring.

2.3.1 Simulation Modelling. In these types of models, the behaviour of the transport system and its users are simulated using macro or micro level simulation models. The following sections briefly discussed each of these models.

On the macro level, the behaviour of the transport system under the policies implemented or considered for implementation, is simulated using a macro level or an aggregate approach. For example, travel demand forecasting which form the core of such models are based on the neoclassical economic assumption of rational decision makers and utility maximisation theory. A utility function is assigned to each option available for the decision makers and travel decisions are modelled based on assumptions of rational behaviour and perfect information. The outputs of these models, whether these are dynamic or static models) are in the form of traffic flows, travel times and link speeds and delays. Modelling impacts of transport policies on emissions and air quality using this approach requires the utilisation of some very crude estimates of emission factors which only enables a rough estimate of emissions and fuel consumption under a specific transport policy or traffic scenario.

The reason for the dominance of travel demand forecasting approaches is that the economic theory has provided an elegant, rigorous and easy to use model, designed to describe and predict individuals’ decisions. There has been lots of research and advances in travel demand forecasting models reported in the literature. However, most of these advances are concentrating on investigation of the functional forms of the models, the error components and estimation procedures (see for example, Lerman and Louviere, 1978; Hensher and Greene, 2003; Cherchi and Cirillo, 2008; Bolduc and Alvarez-Daziano, 2009; Bhat, 2003; McCrae, *et al*, 2000; Cherchi, 2009; Saleh and Sammer, 2009). The explicit modelling of impacts of environmental issues on the preferences is very lightly included in these advances.

An alternative to the above approach is micro-simulation which can be used to test and compare impacts of various policies on traffic and emissions (see Gipps, 1981; Saleh and Kumar, 2010). In these types of models, each vehicle class can be modelled and tracked second by second. However, many inputs are required in this approach for road, signal and traffic details which if not collected directly from the field instead of using secondary sources, can result in inefficient estimates and results. An essential input to this approach is the model building and assignment of vehicle types over the test corridor or junction in each case or traffic scenario. A micro simulation model can then be calibrated and validated using real-world speed- time data which can be collected over the corridor. Again, using average values of characteristics of the transport system will produce not accurate results. Instantaneous speed data can be extracted using the micro-simulation approach for any selected test corridor. Emission factors can then be estimated using the instantaneous speed for each vehicle, or vehicle type under various traffic and driving conditions.

Finally, laboratory testing and the simulation of choice decisions in the lab are useful to replicate the actual driving behaviour. For example using chassis dynamometer in the lab can be used to simulate driving cycle of any vehicle journey route in terms of vehicle speed against time, where on board measurement is not feasible. Emission estimates and fuel consumption under various policy scenarios and specifically to test various driving behaviours can also be obtained using this method. The exhaust emissions which are measured for a specified driving cycle (using vehicle speeds versus time trace) on a chassis dynamometer represent the tailpipe-out emission levels for a given route. The level of emissions produced at every instant can vary largely over the duration of a journey and this depends upon the nature of traffic conditions, the road network and road geometry. One major limitation of this method is that it is carried out under the controlled environment of the laboratory (see Saleh, *et al*, 2009 for some further discussions).

EMDC development

The assumptions of rational behaviour, perfect information, utility maximisation, macro and micro approaches of modelling transport decision making have all faced a lot of criticism (see for example, Cherchi and Cirillo, 2008; Bolduc and Alvarez-Daziano, 2009; Bhat, 2003; McCrae, *et al*, 2000 and Cherchi, 2009). Further investigation and developments in modelling approaches is vital for sustainable development. Integration of modelling approaches from different disciplines (e.g., psychology, engineering and market research) can enhance modelling capabilities and predictions. Using empirical evidence and observations to calibrate models will enhance their realism. More understanding of driving behaviour, emission modelling and emission factors would also enhance the prediction of impact of transport policies on air quality issues.

2.3.2 Direct Monitoring of Emissions. On-board measurements allow the various instantaneous emissions of CO, HC and NOX, and speed data as well as fuel consumption to be collected under different conditions. Using GPS equipment and gas analysers it is possible to obtain direct emission measurements under various scenarios. Although this method is more accurate than estimating emissions using simulation models and some average emission factors, it is main disadvantages are that it is expensive and time consuming. Measured instantaneous speeds during on-board measurements can also be used to estimate the emission factors under local conditions which should be more accurate than using the average emission factors.

1. **Conclusions**

There isincreasing attention to climate change which is due to the emission of greenhouse gases into the atmosphere and its impacts on air quality, health and the sustainability of the urban environment. Transport planners and decision makers have been recently attempting to explicitly looking at environmental issues and further investigating the impacts of transport policies on global air quality. There has been a realisation that air quality and air pollution improvement targets and sustainable development have been attracting less awareness and responsiveness than other urban transport problems such as congestion and delays. As a result, more dedicated research and recognition of sustainable development has evolved. Most of the research in this area historically dealt with pollution as a secondary target, with congestion being the primary one. Therefore, most of the effort has been spent to reduce congestion, assuming that improvements in air quality will subsequently follow. Setting targets for air quality improvement and air pollution reduction have always been imposed by national and international bodies. While internalising congestion impacts (congestion charging for example) is now a common concept, internalising environmental impacts of transport is not yet still a common concept. Therefore, the principle needs to be adopted and explicitly considered. In order to achieve the aim of reducing greenhouse gases and improving air quality, the extent of the problem must be identified and targets must be set and used to identify appropriate policies which explicitly consider and monitor environmental impacts. The set of policies and measures which can be used to tackle environmental problems includes transport and technical policies. Monitoring and predicting impacts of policies on air pollution and air quality are crucial if interventions in the transportation systems are to be sensibly investigated before or after implementation of transport policies. Simulation models or direct emission monitoring can be used to predict and analyse emissions from different policies or schemes. Finally, the challenges we face for achieving sustainability can be realized if we adopt an integrated framework; integration in transport policies, integration in modelling principles, techniques and levels, integration of information technologies, ITS techniques and transport facilities.

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1. pollutants released directly from their source [↑](#footnote-ref-1)
2. pollutants deriving through atmospheric chemical reactions between pollutants [↑](#footnote-ref-2)
3. http://www.dft.gov.uk/stellent/groups/dft\_rdsafety/documents/divisionhomepage/029352.hcsp [↑](#footnote-ref-3)
4. http://www.dft.gov.uk/pgr/sustainable/cycling/cyclingpolicyoverview [↑](#footnote-ref-4)
5. “Directives are a commonly used legislative instrument in the EU. They set specific objectives but allow Member States flexibility in choosing the measures to achieve them. Directives must normally be transposed into national legislation within two to three years of adoption” (European Commission, 2005). [↑](#footnote-ref-5)
6. Except in Singapore (Small and Verhoef, 2007) [↑](#footnote-ref-6)
7. The knock control can prevent knocking engine operation. It retards the ignition timing of the affected cylinder only as far as necessary and only if there is an actual risk of knocking. In this way, the ignition characteristic map can be adapted to the optimum consumption values. A safety distance is no longer necessary. The knock control handles all the knock-related corrections at the ignition point [↑](#footnote-ref-7)
8. Driving cycle for a vehicle is a representation of a speed–time sequenced profile developed for a specific area. [↑](#footnote-ref-8)