IMPACT STUDY ON INTELLIGENT MOBILITY

A sustainability impact framework and case analysis of energy and environment

April 2013

innovITS

Foreword

For many years, the industry and its detractors have identified the need for objective evidence of the benefits and economic impact of Intelligent Transport Systems (ITS). Specific projects have assessed the benefits for particular schemes or technologies. There has been a long term international collaboration, in the form of IBEC, to assess methods for understanding and evaluating benefits. In Europe, the POLIS project has done much to characterise benefits for local decisions when choosing solutions to local traffic problems. None of this work to date has satisfied the more general call for a comprehensive understanding of the actual and potential benefits that can be gained from applying telematics in a vehicle and road traffic environment.

In commissioning this study, innovITS intends to progress the debate with a comprehensive and objective analysis of the impact derived from ITS The first challenge stems from what scope should be proscribed for the analysis and for this the key source has been the Intelligent Mobility report recently published by the UK Automotive Council. The authors are Transport economists based at Oxford University, not individuals drawn from the ITS community, and this provides a greater objectivity and independence to what is produced.

This report should be regarded as a starting point. The analysis is comprehensive but there is much scope for more detailed analysis within the framework it provides. Although innovITS is closing and cannot do so, it is hoped that this study can form the basis of more detailed, informed and objective examination of the impact of ITS and also inform decisions about investment in this area of innovation.

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April 2013

Executive Summary

Governments and industry around the world are beginning to recognize the potential of intelligent transport systems (ITS) to transform the future of mobility across all modes and infrastructures. This report builds on the idea of intelligent mobility. Achieving intelligent or 'smart mobility' where travellers are able to plan and execute their journeys seamlessly and optimize the full range of mobility services has become enabled by ITS technologies that provide a set of strategies for advancing transportation safety, mobility, and environmental sustainability.

It is anticipated that ITS technologies have the potential to revolutionize surface transportation by connecting vehicles, infrastructure, and passengers. This will allow drivers, operators and commuters to send and receive real-time information about transport options, potential hazards, road conditions and all other means of information to optimize mobility services. Despite recent advancements in ITS technologies there is a lack of a comprehensive framework to evaluate the full range of potential impacts from widespread deployment of ITS.

This report develops a novel sustainability impact framework to assess the potential benefits from widespread deployment of ITS technologies. The framework has identified the following 4 key impact domains that ITS can positively impact including 1) energy and environment, 2) mobility and efficiency, 2) productivity, and 3) safety. Each of these domains is multidimensional and interdependent. ITS can be applied to each of these domains with interconnected and beneficial impacts such as reduced congestion and emissions, while improving safety and time savings.

Given the global and UK policy agenda to reduce the energy and environmental impacts from transport an in-depth case analysis of the potential for ITS to address these challenges is undertaken. Based on empirical case studies and evaluations around the world it was found that the deployment of ITS can have positive impacts on transport systems across a range of modes, infrastructure and activities. For measures related to network efficiency there are reductions in carbon (CO_2) emissions of 10 - 15%; reductions in other environmental emissions (CO, NOx, PM_{10}) ranged from 2 – 20%; fuel consumption decreased 5 – 15%; traffic congestion reduced from 12 – 30% and average vehicle speeds increased 5 – 25%.

ITS measures related to fleet operations and management were found to reduce vehicle emissions from 5 – 20%, improve travel time 2 – 15% and reduce fuel consumption 8 – 18%. ITS also influenced driver behaviour and was found to improve fuel efficiency by 8 – 18% through ecodriving. The review of the evidence base therefore indicates that the deployment of ITS technologies can make a positive contribution to transitioning to a more sustainable transport system in accordance with UK and global policy goals. The sustainability framework developed could be further used to assess the multidimensional and interconnected impacts from current and next generation ITS, and provide a comprehensive and integrated way of thinking about the future evolution and progress of ITS enabled intelligent mobility.

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1 Introduction

1.1 Background

Governments and industry around the world are beginning to recognize the potential of intelligent transport systems (ITS) to transform mobility across modes and infrastructures. This report builds on the idea of intelligent mobility where travellers are able to plan and execute their journeys seamlessly and optimize the full range of mobility services. Achieving intelligent or 'smart mobility' is enabled by intelligent transportation systems that provide a set of strategies for advancing transportation safety, mobility, and environmental sustainability. This is possible by the rapid advancement and integration of information and communication technologies (ICT) into the management and operation of the transportation system across all modes.

Intelligent transport systems can be broadly categorized into different technology areas including: intelligent vehicles, management and operations, transit, roadway operations and freight. There is now increasing global evidence of the impact of ITS deployment based on evaluations that have measured cost and benefits and a variety of other indicators that are discussed in detail in the following sections. Figure 1 shows the growth in global ITS evaluations from 2008 to 2011, which gives an indication of recent deployment across broad technology categories. The highest growth has occurred in the area of intelligent vehicles (42%), followed by transit (37%), management and operations (29%), freight (23%), and roadway operations (21%).

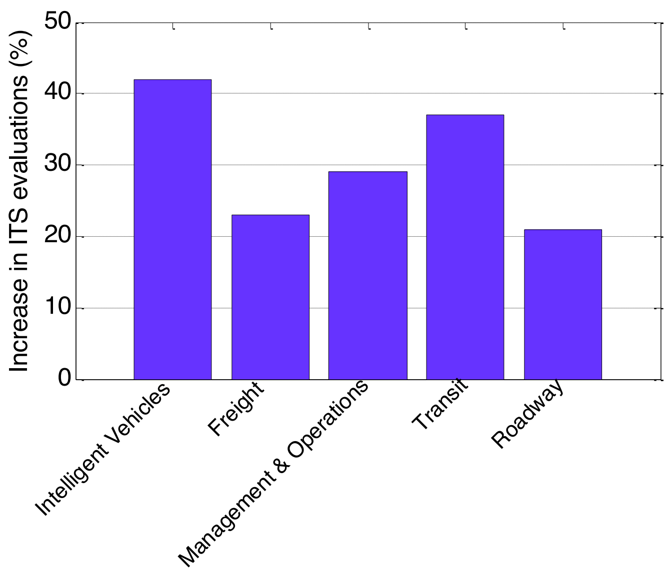

Figure 1. Increase in ITS impact evaluations by technology area (2008 - 2011). Data from USDOT, 2013.

Figure 2 shows the growth in impact evaluations by application area. Applications that are being implemented at a faster pace over the last several years are more likely to have been evaluated. For example, transit agencies have been rapidly investing in ITS, and transit management is a top growth area for ITS applications. As a result, both the increase in evaluations by ITS technology area and by specific application can be used as proxies to give an indication of the recent growth in ITS deployment around the world.

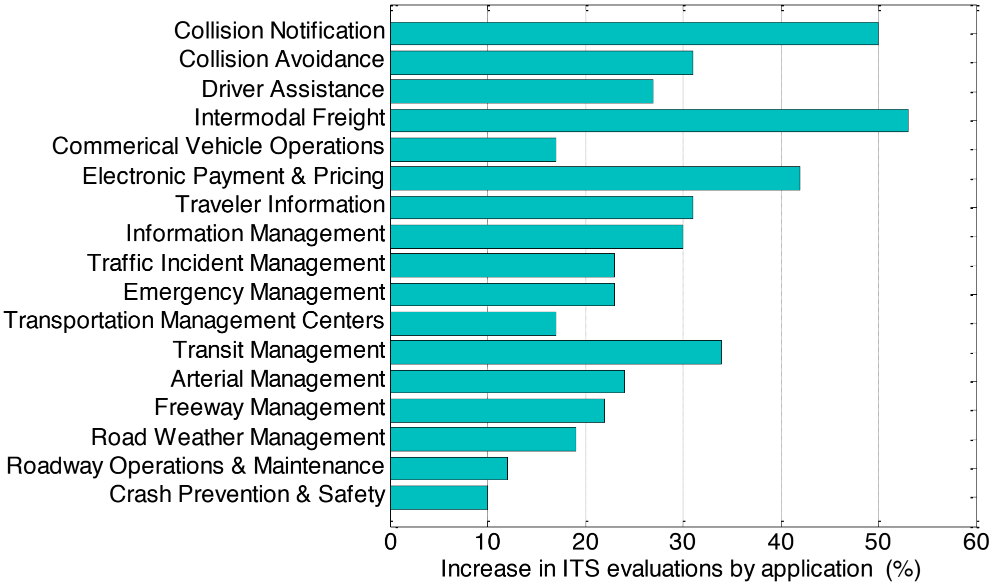

Figure 2. Growth in ITS impact evaluations by application area (2008 – 2011). Data from USDOT, 2013.

1.2 Objectives and Scope

It is anticipated that ITS technologies have the potential to revolutionize surface transportation by connecting vehicles, infrastructure, and passengers via wireless devices and other real-time information dissemination applications. This will allow drivers, operators and commuters to send and receive real-time information about transport options, potential hazards, road conditions and all other means of information to optimize mobility services. Despite the potential of ITS and recent advancements in specific technological applications there is a lack of a comprehensive framework to evaluate the full range of potential impacts from widespread deployment of ITS technologies. This report aims to address this gap by achieving the following objectives:

- To develop an innovative sustainability based framework to quantitatively evaluate the multidimensional impacts from widespread deployment of Intelligent Transport Systems (ITS) in the UK and around the world.

- To apply the framework to a detailed case study of energy and environment given the increasing UK and global policy agenda to reduce transport impacts on climate change and environment, and the general lack of analysis in this increasingly important area.

- To integrate the sustainability framework, case study and other relevant global evidence in order to provide a comprehensive state of the art assessment of ITS impacts, and take the debate forward in terms of potential ITS benefits, opportunities and challenges.

In terms of scope, we build upon the Intelligent Mobility Report (ACUK, 2010). However this report draws upon global evidence to develop a flexible evaluation framework and provides a preliminary assessment focusing on the interconnections between different impact areas from ITS deployment including energy and environment, mobility and efficiency, productivity and safety. This report then provides a detailed case analysis of ITS impacts on energy and environment, in the context of meeting EU and UK energy and climate change policy goals. This report therefore draws upon global case evidence but focuses on the recent UK policy agenda to reduce the impact of transport on energy and environment. While we case analyse energy and environment, the sustainability framework aims to be flexible enough to pursue further analysis of the role of ITS enabled smart mobility across a number of other impact domains including economic productivity or health and society.

1.3 Methods

We use a combination of methods to develop this report including:

- *Development of Analytical Framework* - This involved identification and development of relevant economic, social, and environmental indicators based on an assessment of relevant theoretical and policy based literature on sustainability. A sustainability based framework has been selected because it is able to address the multidimensional impacts related to ITS. The framework has drawn upon authoritative work from national (UK, US, etc.), international (United Nations) and intergovernmental (European Commission, International Energy Agency, etc.) bodies as well as academic literature.

- *Review of Global Empirical Evidence* - This included a review of global case studies based on government and industry sources publically available (US, Singapore, Japan, South Korea, Europe) based on academic, technical, industry and policy related literature. The objective was to assess the potential benefits, opportunities and constraints for widespread ITS deployment based on empirical evidence reported from case sites.

- *Assessing Global Evaluation Data* - Among the largest databases reporting on the impacts of ITS deployment is The US Department of Transport which contains over fifteen years of summaries of the benefits, costs, lessons learned, and deployment status of specific ITS implementations. This data is drawn primarily from written sources such as ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers. The reported findings include both empirical and modelled results.

  As of August 1, 2011, there were a total of 1418 impact evaluations for ITS benefits, costs, and lessons learned and around the world, as shown in Table 1.

Table 1. Summary of global impact evaluations for ITS

Location	Number of evaluations
US Nation wide*	159
US state level	983
International	276
Total	1418

* Nationwide summaries are often based upon experiences of several states e.g. crosscutting studies, or other summary measures from survey results across the U.S. Data base source: URL: http://www.itskrs.its.dot.gov/

2 Sustainability Impact Framework

2.1 Theoretical Background

Transport plays a fundamental role in nearly all social and economic activities of modern society. The transport sector currently contributes around 7% to GDP and 5% to employment in the European Union. Transport demand is being driven by a variety of factors including urbanization, globalization, domestic trade and the international division of labour. Freight volumes for example are expected to increase 70% by 2020. Between 2001 and 2006 air, water and land transport services grew 5.4% per annum, which was the fastest growing nonfinancial sector (EC, 2008).

When transport systems are efficient they can benefit the development and welfare of the population but when they are inefficient they can incur tremendous economic and environmental costs. In the EU, over 60% of the population now lives in urban areas. Throughout Europe and the world, increased traffic in cities has caused chronic congestion with negative impacts including lost productivity, time delays and congestion costing EUR100 billion per year. Health and safety issues are also related to this where 33% of fatal road accidents occur in urban areas. Environmental problems are also linked to health and safety. Urban traffic for example is responsible for 40% of carbon dioxide (CO_2) emissions and 70% of other pollutant emissions. Importantly, these local problems scale up impacting the global system including global warming, pollution, productivity and health (EC, 2007).

From a theoretical perspective, the central problem is that in contrast to the benefits from transport services gained by individuals and firms, the costs of the negative impacts are borne by society and environment at large, which are called external costs (Hickson, 2006). In general the division of costs in transport can be classified as:

- Internal costs – are the private expenses paid by the traveller for transport activities, and by service providers and their customers;
- External costs – are the expenses generated by the user but paid by all of society. These costs generally relate to adverse environmental impacts including pollution, which also effects population health (Mikulski and Kwasny, 2010).

The use of taxes for example to reduce emissions is based on the argument that emissions are an externality created by private consumption of transportation services. The increase of Greenhouse Gas (GHG) emissions and the potential costs of climate change are absorbed by the public and therefore privately negotiated solutions are not feasible. Thus, government intervention is necessary (Myles and Uyduranoglu, 2002; Hickson, 2006).

Figure 3 illustrates the actual versus ideal market equilibrium when accounting transport externalities such as vehicle emissions. The demand curve faced by the consumer of transport services is, *D*. The supply curve is the private cost, C_p to the consumer for the transport service. Assuming only private costs are considered, the quantity of transport activity produced and consumed is, Q_p. But that private consumption incurs an externality or social cost, C_s. When social costs are considered, the amount of activity produced and consumed is Q_s. When consumers only account for their personal private cost, C_p they pay a private price, P_p when in fact they should be paying a higher price, P_s to account for the external cost, C_s such as environmental pollution that is being incurred by their personal transport activity. From a policy perspective, to correct for the externality a tax, $T = P_s - P_p$ would be imposed (Hickson, 2006; Lafont, 2008).

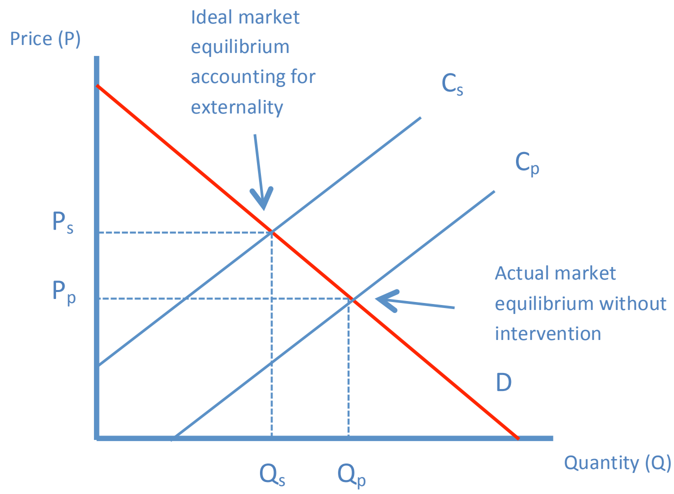

Figure 3. Externalities from transport

Therefore, the external costs of transport impact society, but are not paid for by the user who generated them. Common externalities from transport include:

- Environmental costs (e.g. damage due to air pollution, climate change, noise, and other environmental consequences),
- Uncovered accident costs (e.g. morbidity, grief and suffering),
- Congestion (e.g. time losses caused by other participants in traffic).

It is estimated that in the EU, total external environmental costs (excluding congestion) is around 7.3% of GDP. And that by 2015 without a change in current European transport policy, total external costs from transport will increase 40% with most of these externalities from transport (Mikulski and Kwasny, 2010).

Without policy interventions, these external costs are not accounted for by users when making transport decisions. Transport users can therefore face incorrect incentives which can lead to welfare loss and adverse environmental impacts (Maibach et al., 2008). To account for the multiple externalities that can arise from transport, there is growing recognition of the need to transition to more sustainable transport systems (Hull, 2008). General principles that reflect sustainable transport is to allow for basic access and needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health; and to ensure equity within and between generations (Richardson, 2005). The goal of sustainable transportation is therefore to ensure that environment, social and economic considerations are factored into decisions affecting transport services (Litman, 2007).

2.2 Analytical Framework

Rather than imposing a tax, ITS have the potential to reduce the negative externalities associated with transport. The widespead deployment of ITS has the potential to shape future transport systems (Hilty et al., 2006). ITS are becoming viewed as an important measure towards the sustainable transport system approach and an effective instrument for addressing the growth of freight transport and an increasing demand for seamless mobility (Maciulis et al., 2009). ITS technologies operate across a variety of modes, infrastructures and functions, and therefore require a multidimensional approach to assess its impacts calling for a sustainability approach (UN, 2009). Achieving sustainability is multidimensional and based on a variety indicators rather than relying on a single criterion such as GDP. Sustainability indicators are based on broad thematic areas which can be connected to basic mobility services summarized in Table 2.

Table 2. Sustainability themes and relation to transport systems

Theme	Function	Relation to Transport
Social	The institutions, relationships and norms that shape the quality and quantity of a society's social interactions	Transport connects people, and provides access to basic social services and is a necessary condition for social sustainability
Economic	The financial and economic resources that contribute to societal productivity which can be both tangible and intangible capital	Transport provides access, connects people and business and is essential for economic sustainability
Environmental	The natural resources including land, water and ecosystems that sustain the basic functioning of the physical, economic and social environment	Transport affects the environment through pollution, greenhouse gas emission, energy use, and loss of natural habitat. Minimizing these negative impacts is essential for the sustainability of transport systems

Adapted from UN, 2009, 2011.

Table 3 further elaborates on the sustainability aspects of transport outlining some of the key multidimensional challenges and opportunities for achieving a sustainable transport system.

Table 3. Sustainability challenges and opportunities for transport systems

	Sustainability Pillars		
Challenges	**Social**	**Economic**	**Environmental**
Accessibility	Social inclusion through access to services	Competitiveness through access to markets	Congestion in urban areas and network inefficiencies have negative environmental impacts
Affordability	Social inclusion through affordable mobility	Social affordability of transport infrastructure and competitive business	Maintenance backlogs reduce environmental efficiency of transport systems
Health/Safety	Safe transport ensures mobility is not a health risk	Loss of human life and injury related costs to society	Safe transport of dangerous goods
Environmental	Minimize local air pollution, noise and other risks to human health	Transport impacts on the environment and has economic costs (externalities i.e. air pollution, health costs)	Minimize transport impacts on natural resources, biodiversity, air pollution, and GHG emissions

Adapted from UN, 2011

We can see that based on some of these challenges and opportunities, it is widely recognized that policy and industry must take immediate measures to transition to a more sustainable transport system. The widespread deployment of ITS provides potential solutions to address these sustainability challenges and opportunities outlined above.

A new paradigm of smart mobility enabled by ITS is now intersecting with the global sustainability agenda. The key principles for ITS enabled smart mobility are integrated information, telecommunications and computer-based technologies to make infrastructure and vehicles safer, smarter and interconnected with the overarching goal of improving the quality and performance of mobility services. The convergence of the transport and communications sectors has been driven by innovations in information and communication technologies (ICT), and particularly by new developments in a range of ITS technologies (UN, 2012).

We can see that there is no single measurement of sustainability that allows us to assess the full potential of ITS deployment on transport. We therefore develop a framework that builds on the three pillars of sustainability focusing on key aspects of 1) environmental protection, 2) economic productivity and 3) social well-being.

We therefore apply these principles to an ITS enabled smart mobility system to provide a more integrated approach to assessing the impacts of widespread ITS deployment. Figure 4 depicts an overarching impact framework informed by sustainability and ITS enabled smart mobility, which is disaggregated into 4 key domains including: 1) energy and environment, 2) mobility and efficiency, 2) productivity, and 3) safety.

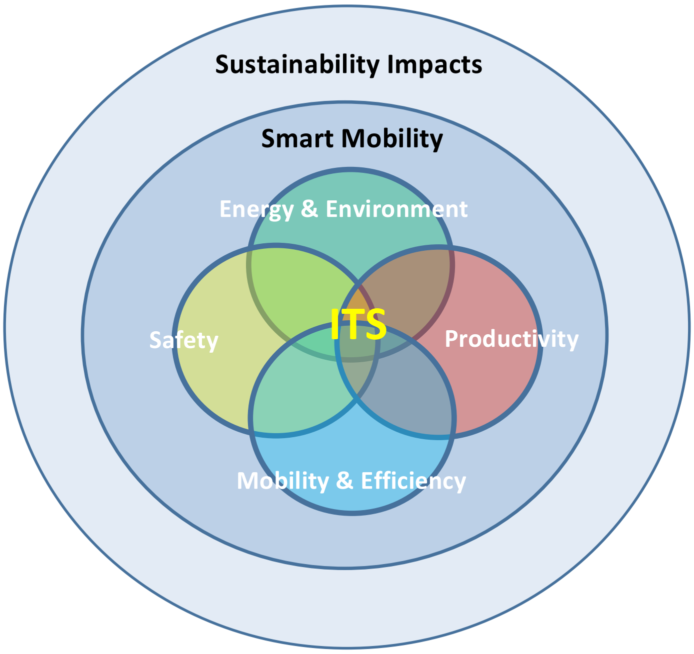

Figure 4. Sustainability impact framework for ITS deployment and related benefits.

Key impact indicators under each of these domains are summarized as follows:

- *Energy and Environment* - Impacts in the area of energy and environment are typically documented through fuel savings and reduced vehicle pollutant emissions. This includes carbon dioxide (CO_2) the main greenhouse gas (GHG), and other environmental emissions including nitrous oxides (NO_X), sulphur oxides ($SO_{X)}$, hydrocarbons (HC) and particulate matter ($PM_{10, 20}$). These emissions are closely related to vehicle and driver behaviour in terms of free flow traffic where for example there is a direct relationship between congestion and increased vehicle emissions. Therefore indicators of mobility and efficiency also relate to environmental performance.

- *Mobility and Efficiency* - Mobility and efficiency impacts typically relate to improvements in travel time or delay savings, travel time budget savings, and on-time performance across the transport network. This also includes benefits to operational efficiency including reduced congestion, greater capacity, and planning and management e.g. data gathering and analysis, scheduling and planning services, freight logistics.

- *Productivity* – These impacts are typically related to improvements in cost savings to transportation providers, travellers, or shippers. This includes positive benefit-to-cost ratios for freight management, passenger vehicle safety, corridor management, decision support systems, and a wide variety of other application areas.

- *Safety* – These impacts are related to a reduction in accidents, injuries, incident management and response time, reduced fatalities and overall improved passenger safety, across a wide variety of transport modes and infrastructure use.

2.3 Sustainability Assessment of Intelligent Mobility

There is currently a strong initiative at the global level to deploy ITS to address sustainability issues. For example, EU transport policies are aimed at halving traffic-related casualties by 2010, transport network efficiency is also a major priority, leading the way to more cost-effective transportation. The UN also foresees that improvements in environmental protection and the potential beneficial effects on society and health could be directly linked to the EU's action plan for ITS and the EU directive on ITS which was adopted on 7 July 2010 (UN, 2012).

We now apply the sustainability framework by assessing global evaluation data and other government and academic literature on the impacts of ITS deployment on the four main impact categories energy and environment, mobility and efficiency, productivity and safety emphasizing the interconnections between each domain.

2.3.1 Energy and Environment

Vehicle transportation is a major cause of greenhouse gas emissions (GHG) which are the main contributors to global warming. Vehicles are also a major source of other environmentally harmful emissions including carbon monoxide (CO), nitrogen oxide (NO) and hydrocarbons (HC). In England, the transport sector contributes about 25% of the country's CO_2 emissions (which is the central GHG), and 93% comes from road transport. In France, 31% of final energy consumption and 26% of GHG emissions are from transport, and in the US, 33% of final energy consumption and nearly 30% of CO_2 emissions are from road transport. Globally, transportation accounts for 25% of worldwide GHG emissions (Ezell, 2010).

There is also a strong link between the economic and environmental impacts of congestion in the transportation system. Traffic congestion causes extensive CO_2 emissions. For example, vehicles traveling at 60 km/hr. emit 40% less carbon emissions than vehicles traveling at 20 km/hr. (Haynes and Li, 2004). Intelligent transportation systems can deliver environmental benefits by reducing congestion, enabling more efficient and smooth traffic, and by reducing the need to build additional roadways through maximizing existing capacity. Importantly, ITS can also influence driver behaviour by coaching motorists how to drive more efficiently, reducing fuel consumption, cost and vehicle emissions. Various studies show on average ITS can influence driver behaviour resulting in 5-15% reductions in vehicle emissions through ecodriving (IEA, 2010).

Benefits in the area of energy and environment are typically documented through fuel savings and reduced pollutant emissions. Figure 5 shows the energy and environmental benefits from various ITS deployments based on around 80 evaluations from 1992 – 2012. Advanced signal systems are reported to have the greatest benefits. A detailed assessment of ITS impacts on energy and environment is discussed in section 4.

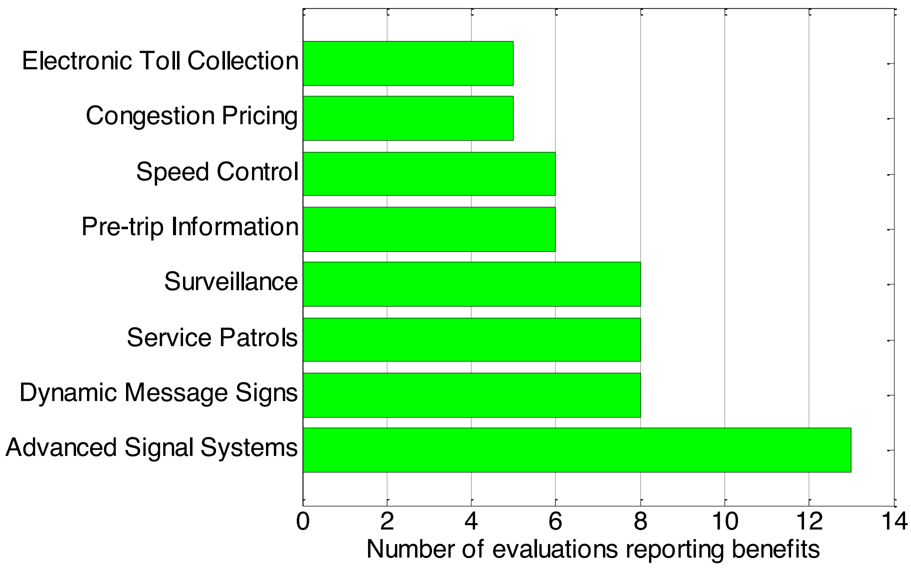

Figure 5. Technologies reported to have the most energy and environmental benefits from 1992 – 2012. Data from USDOT, 2013.

2.3.2 Mobility and Efficiency

A major consequence of an inefficient transport system is the economic and environmental costs related to traffic congestion. In 2007, U.S. road congestion cost USD 2.8 billion gallons of fuel, and more than 4.2 billion hours of lost productivity, for a combined cost of USD 87.2 billion (Frost and Sullivan, 2010). In the EU, 24% of driving time is spent in traffic congestion incurring an annual cost of 1% of EU's GDP (EC, 2007).

ITS can improve the performance transportation networks by maximizing the capacity of existing infrastructure, and reducing the need to build additional capacity. Maximizing capacity is important because, in almost all countries, increases in vehicle kilometres (VKM) travelled have surpassed increases in roadway capacity. For example, from 1980 - 2006 in the US, total vehicle kilometres increased 97% while the total number of highway lane kilometres grew by a mere 4.5% (Ezell, 2010). This means twice as much traffic has been moving on nearly the same roadway capacity in recent years.

A number of ITS applications contribute to enhancing the operational performance of transportation networks: traffic signal light optimization can improve traffic flow significantly by reducing stops by 40%, fuel consumption by 10%, vehicle emissions by 22%, and travel time by 25%; ramp metering can increase vehicle throughput (the number of cars that pass through a road lane) from 8 – 22% and increase road speeds from 8 – 60%. Additionally, up to 30% of highway congestion occurs at toll stops, deploying electronic toll collection systems have been found to reduce vehicle emissions by 16 – 60% (USDOT, 2008). Assessing the impact of ITS including ramp metering, incident management, traffic signal coordination, and arterial access management, the US government found a reduction in urban delays of 9% (336 million hours) led to a further reduction in annual costs of USD 5.6 billion due to reduced fuel consumption and hours of delay (GAO, 2005).

Mobility and Efficiency improvements are typically measured in travel time or delay savings, reduced congestion, improved capacity, and planning and management (e.g. data gathering and analysis, scheduling and planning services, freight logistics). Figure 6 shows 265 evaluations reported net benefits for mobility and efficiency from various ITS deployments from 1991 – 2012, with greatest net benefits from dynamic message signs and advanced signal systems.

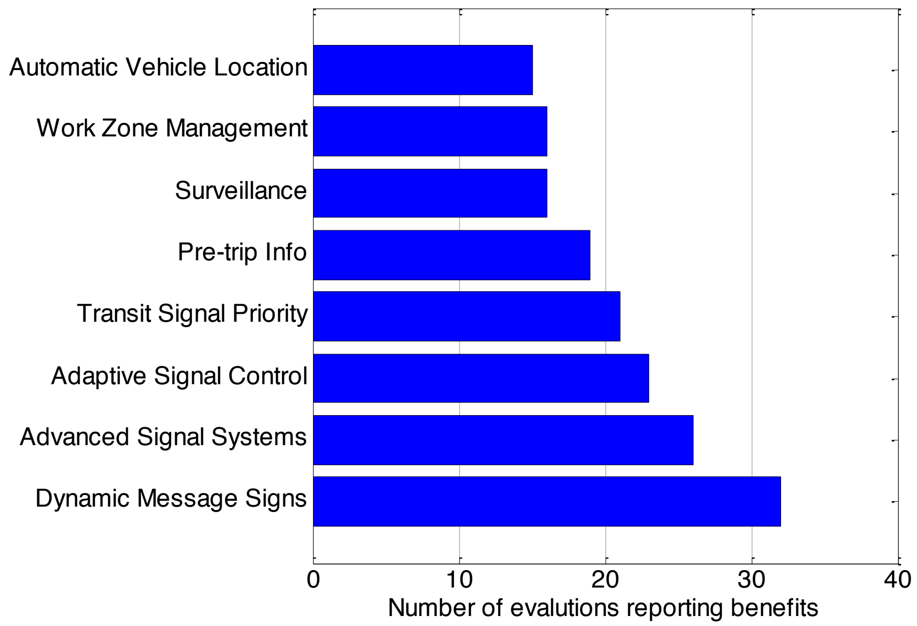

Figure 6. Technologies reported to have the most mobility and efficiency benefits from 1991 – 2012. Data from USDOT, 2013.

2.3.3 Productivity

In the European Union, 20% of GDP is generated by the transport sector. This equates to 1,900 billion euros, 16 million jobs, or 9% of all EU employment (Meyer, 2008). The automotive industry supports over 12 million jobs with direct employment of over 2 million people, and indirectly employs another 10 million people. It is estimated that the European and North American fleet green telematics market will increase from USD 80 million in 2008 to USD 700 million by 2015, which is a compound annual growth rate of 36%. Much of this growth is due to increasing pressure on fleet companies to reduce their carbon footprint and develop a greener image, and therefore productivity has become linked with both energy and environment and improved efficiency (Janota et al., 2012).

Productivity improvements related to ITS deployment are typically documented in cost savings to transportation providers, travellers, or shippers. This includes positive benefit-to-cost ratios for freight management, passenger vehicle safety, corridor management, decision support systems, and a wide variety of other application areas. Intelligent transport systems can deliver positive benefit-cost returns when compared to conventional investments in highway capacity. The benefit-cost ratio of systems-operations measures enabled by ITS systems has been estimated at about 9 to1 compared to conventional highway capacity expansion with a typical benefit-cost ratio of 2.7 to 1. It is estimated that if the US were to implement a national real-time traffic information program, the present value cost of deploying and operating the program would be USD 1.2 billion, but could deliver present value benefits of USD 30.2 billion, a 25 to 1 benefit-cost ratio (Ezell, 2010).

Figure 7 shows 173 evaluations between 1990 – 2012 reporting net productivity benefits, with positive benefit-cost ratios. Automatic vehicle location, commercial vehicle operations electronic screenings and road weather information systems have reported the most benefits.

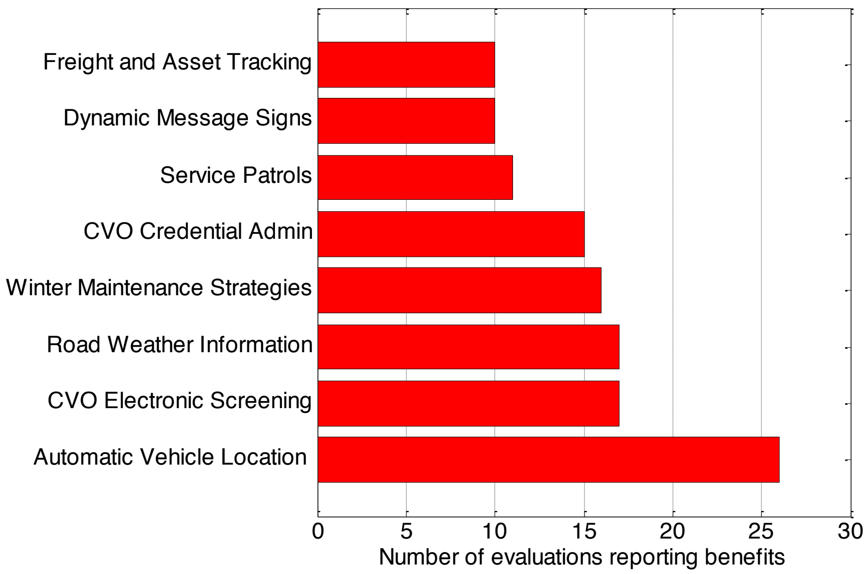

Figure 7. Technologies reported to have the most productivity benefits from 1990 – 2012. Data from USDOT, 2013.

2.3.4 Safety

Mobility comes at a high price with around 1.3 million accidents a year causing 40 thousand fatalities and 1.7 million injuries on EU roads. The direct and indirect costs are estimated at EUR 160 billion or 2% of GDP per year (UN, 2012). The health costs related to accidents and congestion are significant around the world. The World Health Organization (WHO) estimates total worldwide traffic fatalities in 2009 were over 1.2 million. In the US, traffic fatalities are similar to the EU at around 40 thousand per year and related costs around USD 150 billion per year (IEA, 2009). We can see that safety is also related to improved mobility and efficiency, which can reduce congestion in turn improving energy and environment and productivity.

ITS technologies can have important safety impacts. A wide range of ITS applications including real-time traffic alerts, intersection collision avoidance, on-vehicle systems such as anti-lock braking, lane departure, collision avoidance, and crash notification systems have been developed to enhance transportation safety. For example, a study of ramp metering in the US found that metering reduced total crashes on area roadways between 15 – 50% (USDOT, 2003). Various traffic incident management programs have also demonstrated success. One of the most important findings is the ability to reduce the duration of traffic incidents from around 15 – 65%, with the majority of programmes reporting 30 – 40% improvements (Bunch et al., 2011).

Safety improvements from ITS deployment are typically measured in reduction of accidents, injuries, fatalities and overall improved passenger safety, across a wide variety of transport modes and use of infrastructure. Figure 8 shows the different level of safety improvements per ITS application based on 188 evaluations reporting net benefits from 1993 – 2012. Collision avoidance systems along with dynamic messaging, and speed warnings were reported as having the most net benefits for safety.

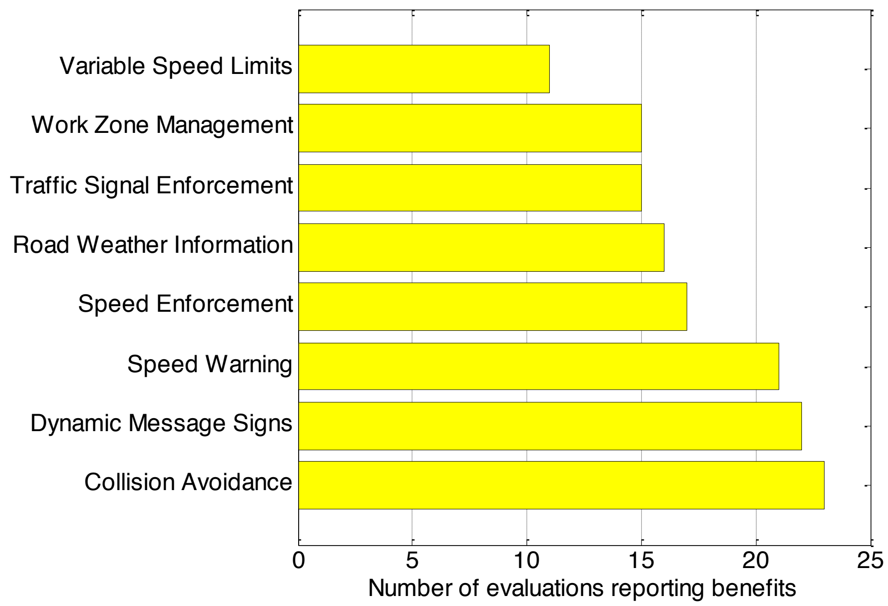

Figure 8. Technologies reported to have the most safety benefits from 1993 – 2012. Data from USDOT, 2013.

2.4 Summary

The vast majority of evaluations reported ITS deployments to be beneficial to transportation operations. However, it is important to note that a handful of ITS evaluations reported cases where ITS had a neutral or negative effect on the transportation network. For example, one case indicates that safety risk for individual vehicles can increase when traveller information guidance directs them to alternate routes with higher crash rates (e.g. arterial routes to avoid congested freeways). However, network wide safety improved through overall reductions in traffic congestion and smoother traffic flow. Another case documents an increase in toll plaza crashes due to driver confusion following the deployment of electronic toll collection, emphasizing the need for appropriate signage and guidance to drivers. However, increasing experience over the past 30 years indicates that ITS has had net positive benefits for transport operations. Figure 9 shows a breakdown of reported benefits per impact category from 1990 – 2012. The most reported benefits are in mobility and efficiency (38%) followed by safety (27%), productivity (25%) and energy and environment (11%).

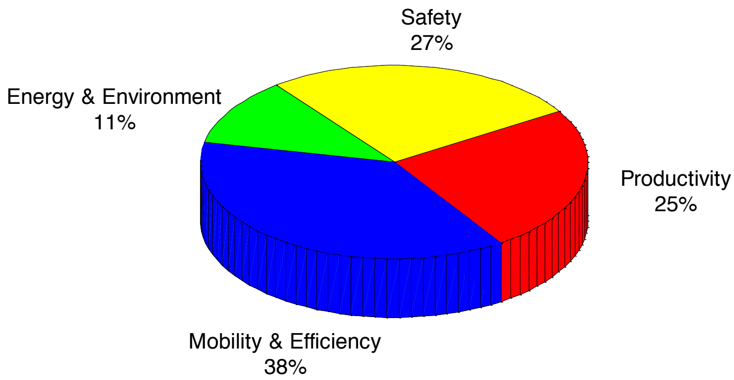

Figure 9. Breakdown of benefit categories by proportion of total evaluations reported over the period: Energy and Environment, 1992 – 2012; Mobility and Efficiency, 1991 – 2012; Productivity, 1990 - 2012; Safety, 1993 – 2012.

Key findings include:

- Safety benefits are captured most by collision avoidance, dynamic message signs, and speed warnings. These are followed closely by road weather management systems and traffic signal enforcement. Safety benefits are expected to increase as more of these systems are implemented.
- The highest productivity benefits (including cost savings, benefit-cost ratio, or cost-effectiveness measures) are automatic vehicle location which includes computer aided dispatch, commercial electronic vehicle (CVO) screening, road weather information and management, and winter management strategies. Those measures generally relate to freeway management, traffic incident and transit management.
- Mobility and efficiency benefits are captured by dynamic message signs, advanced signal systems and adaptive signal control. These measures have been successful in getting travellers moving. Closely related to this are efficiency improvements through transit management and electronic payment and pricing systems, which are often associated with efficiency benefits, such as increased passenger throughput.

- The sustainability framework indicates that there are interconnected impacts between all areas. For example, there are co-benefits from energy and environment such as improved passenger and environmental health, which is also related to improving mobility and efficiency through reduction of congestion, all of which positively impact upon the economic productivity of transport systems. These interdependencies are difficult to monetize, but it is clear that taking a more integrated approach to assessing the potential benefits of ITS technologies is important to ensure long term deployment and viability.

- Although a substantial number of evaluations capture energy and environmental impacts, many ITS evaluations are still not addressing this important goal area. Recent trends indicate that traveller information systems, driver assistance, and freeway management applications are more likely to be evaluated for environmental benefits. Given the global and UK policy agenda to reduce energy demand, carbon emissions and mitigate environmental impacts, the potential energy and environment benefits from ITS have to be better evaluated and reported. We now seek to address this important gap by focusing the sustainability framework on the potential ITS impacts upon energy and environment as a detailed case study.

3 Assessing ITS Impacts on Energy & Environment

3.1 Policy Context

In 2007, the European Council adopted the 20:20:20 objective of reducing GHG emissions by 20%, increasing the share of renewable energy to 20%, and making 20% improvements in energy efficiency by 2020. The GHG emissions targets are legally binding (UKHM, 2011). Recent EU policies focus on reducing transport CO_2 emissions summarized in Table 4. In May 2009, the EU adopted Regulation 443/2009 to reduce CO_2 emissions from new passenger cars to reach a fleet average of 130 grams (g) CO_2/km by 2015. From 2020 this limit will be 95 gCO_2/km. The regulation will be complemented by measures to further cut emissions by 10 gCO_2/km. Complementary measures include efficiency improvements for car components with the highest impact on fuel consumption, and a gradual reduction in the carbon content of road transport fuels. A similar type of regulation for new vans was adopted in May 2011 (Regulation 510/2011) (DTI, 2007).

Table 4. European Union greenhouse gas (GHG) reduction targets for the transport sector

Transport Sector		
GHG Emission Reduction (%)	Reference Year	Target Year
20	2008	2030
60	1990	2050

Source: EC, 2011

The UK is obliged to respond to EU directives and has developed a unilateral legally binding target to reduce GHG emissions by at least 80% from 1990 levels by 2050. The target was set as part of the 2008 Climate Change Act. The 2050 target is to be delivered through Carbon Budgets which limit UK emissions over successive five-year periods (UKHM, 2009). Analysis by the UK Energy Research Centre (UKERC) indicates that this will require major efficiency improvements across sectors with transport among the most difficult to decarbonize due to its 94% dependence on fossil fuels (UKERC, 2012).

Governments around the world are now taking action to reduce the negative impacts of transport on climate change, energy and environment. During the United Nations Ministerial Conference on Global Environment and Energy in Transport (MEET) held in Japan in 2009, and Rome in 2010, it was agreed and recognized that,

"Transport is an important foundation of our society, supporting a wide range of human activities, and contributing to economic and social development. It is, at the same time, responsible for considerable emissions of carbon dioxide (CO_2), which impacts global climate, and air pollutants, which impact public health and the environment of many urban areas" (UN, 2012).

In response to this challenge, the EU has formally adopted an action plan and directive (Directive 2010/40/EU; COM (2008)886) for supporting deployment of ITS on 7 July 2010 (UN, 2012). This directive requires member countries to respond. The UK Department for Transport (DfT) has since submitted a report on ITS activities in the UK in August, 2011 but does not currently have any overarching policy framework for ITS deployment (DfT, 2011). However, the DfT report does state,

'The future deployment of ITS must therefore be not only policy led but backed by rigorous cost-benefit analysis and sound business cases focussing on value for money and the effectiveness of the ITS applications concerned. This represents a clear and distinct move away from the previous top-down model' (DfT, 2011).

Given the global and UK policy emphasis on reducing the impacts of transport on energy and environment we explore the case evidence for the potential role of ITS for addressing these challenges. While the focus here is on energy and environmental impacts, we also saw from the sustainability framework that energy and environmental impacts are closely linked with improved mobility and efficiency, economic productivity and health. Therefore the impact that ITS has on energy and environment will have co-benefits in the other domains, which could be the focus of future research.

3.2 Measuring Energy and Intelligent Transport Technologies

In 2008, global final energy consumption was 8423 million tonne oil equivalent (Mtoe) and is expected to increase on average 1.4% per year reaching 12239 Mtoe in 2035 shown in Figure 10. The transport sector accounts for around 27% of global final energy consumption and will increase approximately 50% by 2035 (IEA, 2010).

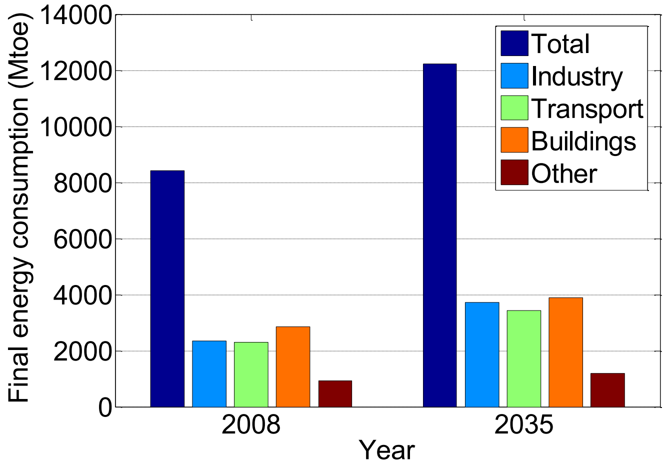

Figure 10. Change in global final energy consumption by sector from 2008 and 2035. Excludes electricity and heat; Buildings include residential and service sectors; other includes agriculture and non-energy use (Tran et al., 2012).

Due to 94% reliance on oil, transport is the second largest source of CO_2 emissions at 6.3 gigatonnes (Gt) in 2008 or 24% of total CO_2 emissions, compared to power generation (40%), industry (16%), buildings (12%) and agriculture and non-energy use (8%) shown in Figure 11. Two main factors influence transport CO_2 emissions: change in total volume of travel and fuel efficiency of mode. From

1990 to 2004, travel by light-duty vehicles (LDVs) including passenger cars, small vans, and sport utility vehicles (SUVs) in the OECD increased 20% from 13,000 to 15,000 kilometres per person per year and truck travel (tonne kilometres per capita) increased 36%. There is little indication that these trends will reverse. And given the relatively low average rates of vehicle ownership in emerging economies coupled with rising GDP growth rates vehicle travel is expected to increase. The fastest growth in transport is expected from air travel, road freight, and LDVs.

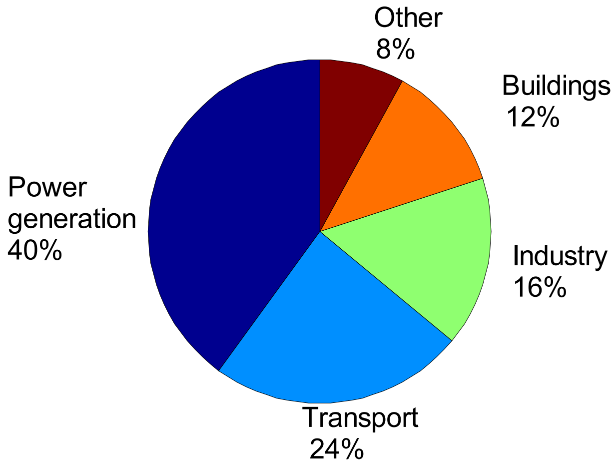

Figure 11. Global CO_2 emissions by sector in 2008. Buildings include residential and service sectors; other includes agriculture and non-energy use. Data from (IEA, 2010).

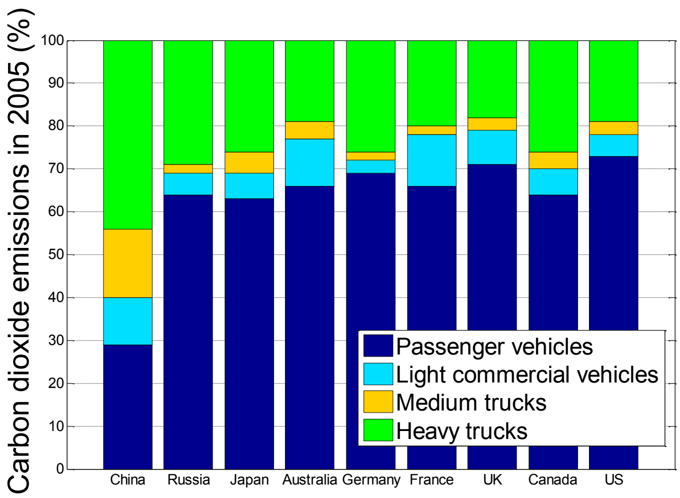

Figure 12. Road transport CO_2 emissions by mode across selected countries in 2005 (Tran et al., 2012).

Across industrialized countries, 60-70% of road transport CO_2 emissions are from light duty vehicles (LDVs), and 20-30% is from road freight shown in Figure 12. The energy security, climate change and environmental implications of oil-dominated road transportation has led to the wide agreement that reducing the fuel used in this sector is one of the highest priorities for all countries (IEA, 2010). In terms of calculating the negative impact from transport we can see that transport energy use, fuel consumption and related emissions are a product of three main parameters shown in Figure 13.

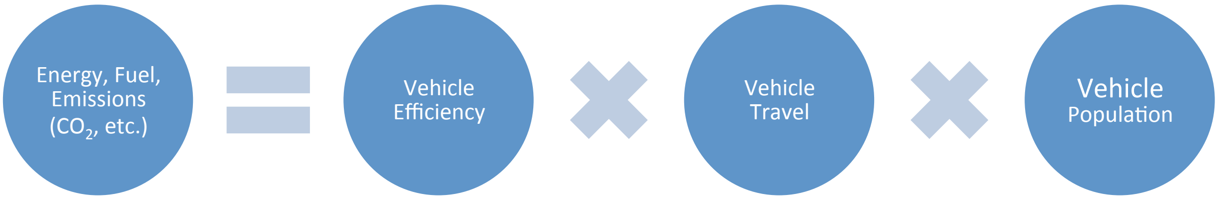

Figure 13. Key parameters in transport influencing vehicle energy consumption and related emissions. Adapted from IEA, 2010a.

Transport energy use, fuel consumption and vehicle emissions is a product of 1) vehicle efficiency which is determined by the technical performance of the vehicle; 2) vehicle travel which is the type of travel and/or driving, which includes driving behaviour; and 3) vehicle population which is the number and composition of vehicles on the road at a given time. Across all these parameters, ITS has a potential role to play in reducing the energy and environmental impacts from transport. For example, we can disaggregate ITS enabled smart mobility into three main application areas where different ITS measures can be deployed including: 1) network efficiency, 2) operations and management, and 3) driver behaviour shown in Figure 14.

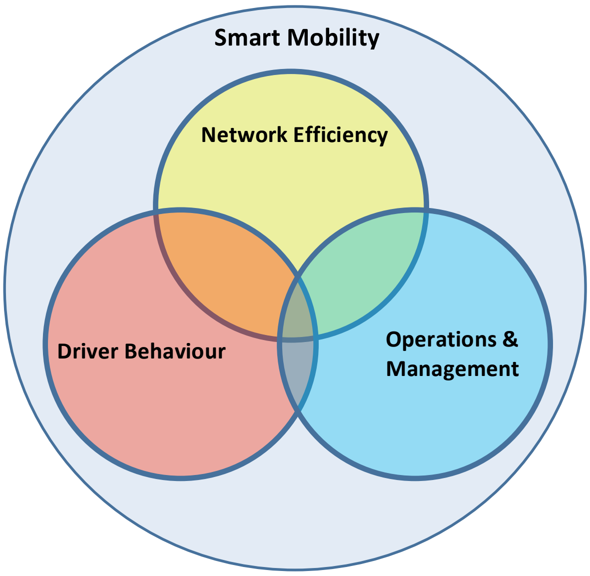

Figure 14. Smart mobility ITS application areas

- *Network Efficiency* - are measures that are aimed at managing traffic flows on the fixed infrastructure. This involves active traffic management on motorways through various information and communication technologies (ICT) along with direct measures to influence the volume, timing and mode of driving such as congestion charging, road pricing, automated tolls, along with parking management. Network efficiency measures can therefore target both vehicle travel and vehicle population.

- *Operations and Management* – are measures aimed at improving the overall performance of both commercial and public fleets and commuters including the travelling public and management of commercial operations. This usually involves improved fleet logistics, journey planning and other pre-trip information dissemination measures. These measures can therefore influence vehicle travel and vehicle population.

- *Driver Behaviour* – are measures aimed at providing direct support to the driver usually focusing on in-vehicle systems such as intelligent speed adaptation, eco-driving measures, satellite navigation, and pay as you go driving schemes along with vehicle system enforcement technologies. These measures can therefore influence vehicle efficiency and vehicle travel.

We now assess the potential role of ITS to reduce transport energy and environmental impacts based on detailed case evidence in each of these application areas. These measures are by no means exhaustive, but reflect the level of empirical evidence available on their effectiveness for reducing energy and environmental impacts.

4 Evidence of ITS Impacts on Energy & Environment

4.1 Network Efficiency Impacts

Improving the flow of traffic in urban areas and highways significantly improves fuel economy. This is especially true for freight and other heavy vehicles. Therefore, ITS technologies that can directly influence the flow of traffic on transport networks such as adjusting the timing of traffic lights can save energy and reduce emissions by creating a steadier speed profile and less idling. Integrating real-time monitoring infrastructure into the road network can provide valuable information to traffic management systems. Eventually, the use of wireless internet technology and GPS systems may further help to automate directing traffic to avoid congestion. Such systems are being implemented in some countries, but can be deployed more since some technologies are widely available and costs are affordable, especially when accounting for the fuel savings (IEA, 2009).

However, it is also important that measures to improve traffic flow do not induce greater demand through more frequent driving. It is important to manage the demand for car driving in coordination with available road space. Therefore different combinations of measures should be assessed to achieve optimal network performance. For example, congestion-based road pricing has been viewed as an effective measure as part of a broader ITS implementation strategy (IEA, 2009).

4.1.1 Congestion Charging

When vehicles are fully stopped for periods of time, this is known as a traffic jam. Within the US alone, the annual cost of congestion is estimated to be USD 63 billion, caused by 3.7 billion hours of delays and 8.7 billion litres of wasted fuel (USDOT, 2010). In EU, congestion costs 1% of its GDP around €100 billion per year. There are around 300 million drivers in the EU today, while in the past 30 years the distance travelled by road has tripled and is set to increase further. Wasted fuel increases air pollution and carbon dioxide emissions owing to increased idling, acceleration and braking (Bani et al., 2009).

Congestion pricing, also known as road pricing utilizes ITS technologies to charge, monitor and enforce variable costs for drivers to use a transport facility or network based on demand or the time of day. Pricing strategies include: cordon charging, area-wide charging, variable priced lanes, variable tolls on entire roadways or roadway segments, and fast and intertwined regular lanes among other measures (Bunch et al., 2011).

Road charging on urban road networks has been deployed in London, Stockholm, Singapore, and Milan summarized in Table 5. Four general types of congestion charging in these cities are utilized including: a cordon area around a city centre, which charges for passing the cordon line; area wide congestion pricing, which charges for being inside an area; a city centre toll ring, with toll collection surrounding the city; and corridor or single facility congestion pricing, where access to a lane or a facility is priced. Charges can be per kilometre, per time interval or per entrance. The charges can be differentiated per vehicle type or for all vehicles (Klunder et al., 2009).

Table 5. ITS applications for congestion charging

Location	Name	Implementation	Area (km2)	ITS applications
Singapore	Electronic road pricing	1975	7	Radio frequencies and cameras
London	Congestion charge	2003	40	CCTV cameras
Stockholm	Congestion tax	2006	35	Laser and cameras
Milan	Ecopass	2008	8	Digital cameras

Source: Adapted from IEA, 2009

Singapore - implemented its congestion charging system in 1975 the first urban charge system in the world. It initially used people to check that vehicles complied with the system, but automatic vehicle detection and payment system was implemented in 1998. The system then became known as Electronic Road Pricing. The system works as a charged zone with a cordon ring, requiring vehicles to make a payment each time the cordon line is crossed. The system automatically deducts a balance from a pre-paid account, with devices in each vehicle that keep track of the driver's available balance (IEA, 2009). No carbon and environmental emission data was found for Singapore. Although there has been a reported a decrease in traffic volumes during morning peak hours by 45%, and average speeds in the area increased from 19 to 36 km/hr. (Santos et al., 2011). It was also reported that the average total traffic decreased in the restricted zone 9% (Cervero, 1998).

London - launched its congestion charging scheme in 2003. It is a cordon zone system, which requires private vehicles entering the congestion charging zone to pay on a daily basis. The zone was expanded in 2007. The charge applies from 07:00 to 18:00 on weekdays with no charge at other times. Some types of vehicles, such as electric vehicles and other low carbon emission vehicles are exempt from charges. It is reported that the London congestion charging zones have resulted in a 16% reduction in CO_2 emissions and 12% lower emissions of NO_x and 7% reductions in PM_{10} from road traffic. It was also reported that there has been a 30% reduction in traffic congestion in the charge area (Komfner and Reinhardt, 2008; USDOT, 2008; VTT, 2012).

Stockholm - initiated a trial congestion tax scheme in 2006, with a cordon system covering a large part of the central urban area. Similar to London, revenues from the system were used partly to expand the bus system. Park-and-ride lots were also added to key commuter corridors. In 2007, residents voted to make the system permanent (IEA, 2009). It has been reported that the cordon system resulted in a 22% reduction in traffic and 10 - 14% reduction in CO_2 emissions, 7% reduction in NO_x and 9% in PM_{10} in the inner city (Klunder et al., 2009; Bunch et al., 2011).

Milan - has a system in place called an "Ecopass" charging system since 2008, where high-emitting vehicles pay a charge to enter central Milan. Vehicles compliant with the EURO 3 emissions standard (or better) are exempt; however, very high-polluting vehicles are completely banned from the city (IEA, 2009). This charge-scheme was prolonged until December 31, 2011 and starting from January 16, 2012 a new scheme called Area C was introduced, converting it from a pollution-charge to a conventional congestion charge. It is reported that the scheme resulted in reductions of 14% in CO_2, 23% in PM_{10} and 15% in NO_x emissions (Klunder et al., 2009). Figure 15 summarizes the energy and environmental impacts from the charging schemes facilitated by ITS for each city.

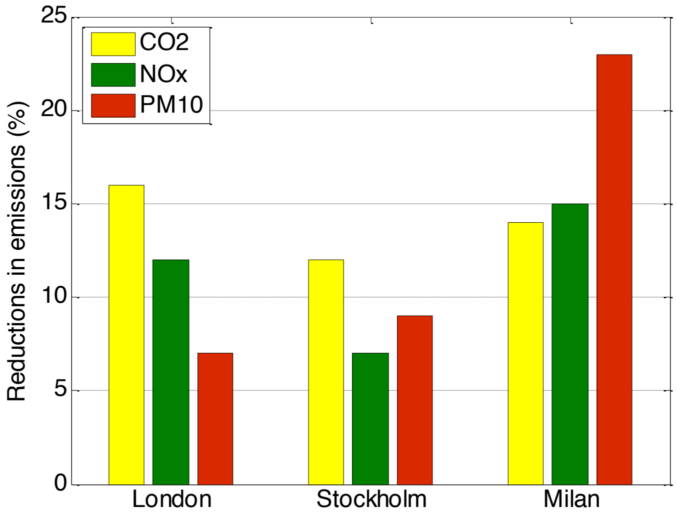

Figure 15. Reported decrease in carbon (CO_2), nitrous oxides (NO_x) and particulate matter (PM_{10}) emissions from ITS enabled charging schemes. Each of the impacts is based on the immediate area where the charging scheme was implemented. No emissions data available for Singapore.

Congestion imposes large costs on individuals and society. European Union countries experience 7,500 kilometres of traffic jams every day on their roads, with 10% of the EU's road network affected by congestion. Around 24% of Europeans' driving time is spent in traffic at a yearly cost of 1% of the EU's GDP. If ITS is able to reduce these costs by even a few percent, the potential savings are significant (IEA, 2009). Figure 16 shows the reported ITS impacts on lowering traffic and congestion in the four case studies. The impacts on traffic were monitored over 10 - 12 months showing substantial reductions in traffic and congestion, implying ITS can play an important role in enabling traffic reduction measures.

Positive impacts from ITS on reduced congestion have also been reported in other countries. South Korea for example found that in the initial cities in which it deployed ITS, average vehicle speed increased 20% and delay time at critical intersections decreased 39%. It has also been estimated that in the United States, traffic jams could be reduced as much as 20% in areas that use ITS (Ezell, 2010).

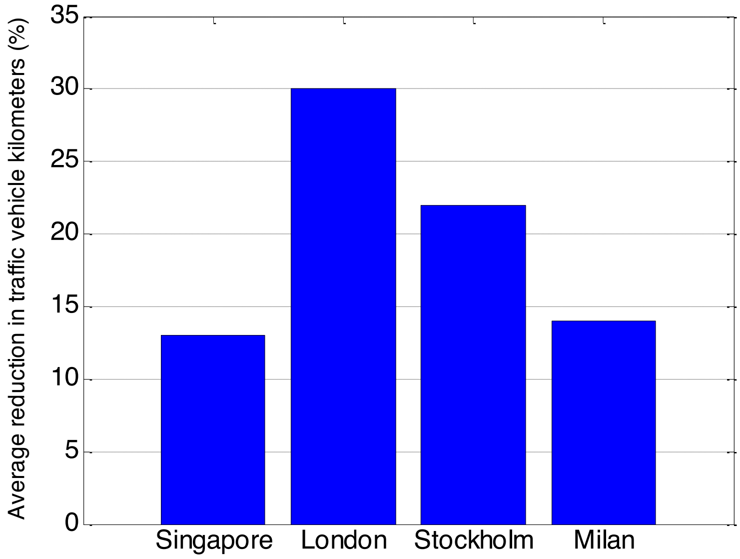

Figure 16. Average percentage reductions in traffic vehicle kilometres within restricted areas based on monitoring and reporting over 10-12 months Sources: Cervero, 1998; Komfner and Reinhardt, 2008; Klunder et al., 2009.

4.1.2 Traffic Signal Control

Advanced signal control systems coordinate traffic signals across a signal network, adjusting the lengths of signal phases based on current traffic conditions. The objective of dynamic traffic light synchronization based on actual traffic conditions is to optimise journey times and delays in urban areas. This is done by controlling in real-time the green-times, cycle times and offsets (green waves) of the network's junctions (Klunder et al., 2009). Advanced signal systems can include coordinated signal operations across neighbouring jurisdictions, as well as centralized control of traffic signals, which may include technologies for the later development of adaptive signal control.

Figure 17 provides comparative evaluation data for advanced traffic light control systems across Europe, North and South America and Asia showing improvement in mean vehicle speed and the estimated reduction in CO_2 emissions. It is assumed that the reduction of CO_2 emissions equals half of the speed improvement percentages because of fewer stops and shorter acceleration periods. We can see that there are improvements in mean speed of approximately 5 - 25% and estimated reductions in CO_2 emissions of around 2 - 12%. However, similar evaluations were also done for Nijmegen, Netherlands and Anaheim, US where no improvements were found. Another study estimates that across the EU27, wide spread deployment of advanced signal control could reduce road traffic CO_2 emissions by 5 – 15% (Klunder et al., 2009).

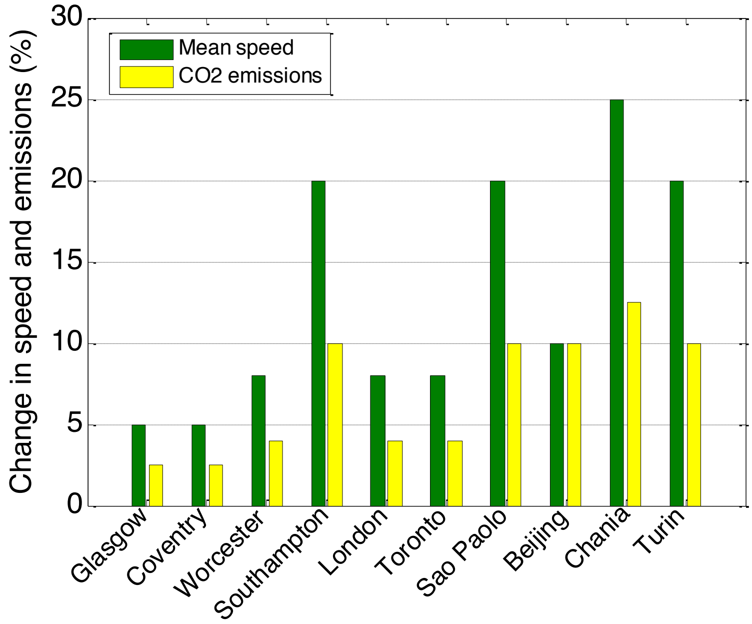

Figure 17. Improvements in traffic network mean speed and estimated reductions in CO_2 emissions from traffic signal control implementation. CO_2 emission reduction estimates assume half of the speed improvement percentages because of fewer stops, shorter acceleration periods. Evaluations are based on 2nd generation urban traffic control (UTC) systems and optimised fixed time non-dynamic UTC systems (Klunder et al., 2009).

Figure 18 reports the impacts on fuel consumption and various vehicle emissions from deployment of advanced traffic control signals in North America. We can see the wide range of benefits on fuel consumption with the highest reported in Los Angeles at 13% reductions. Substantial reductions in carbon monoxide (CO) of 13% were also reported in Abilene, Texas. No specific emissions data was available for Los Angeles and Richmond, Virginia but did report fuel consumption reductions of 13% and 11% respectively.

Various adaptive systems to time the traffic light cycle to fit the vehicles are in place around the world (Fehon and Peters, 2010). The US Oak Ridge National Laboratory estimate that poor signal timing causes 296 million vehicle hours of delay a year. Appropriate timing of traffic signals can decrease congestion, improve air quality, and reduce fuel consumption. It is also reported that optimising signal timing can have average benefit to cost ratios near 40 to 1. Across the US, traffic signal retiming programs have resulted in travel time and delay reductions of 5 - 20% and fuel savings of 10 - 15% (Bani et al., 2009). However, modelling studies of coordinated signal control in 5 U.S. localities found reductions in fuel use ranging from no significant change in Seattle, Washington to a 13% decline in Syracuse, New York (USDOT, 1999; Harris, 2003). Figure 19 shows the percentage reduction in stops with traffic signal coordination across North America ranging from 5 – 78% improvements.

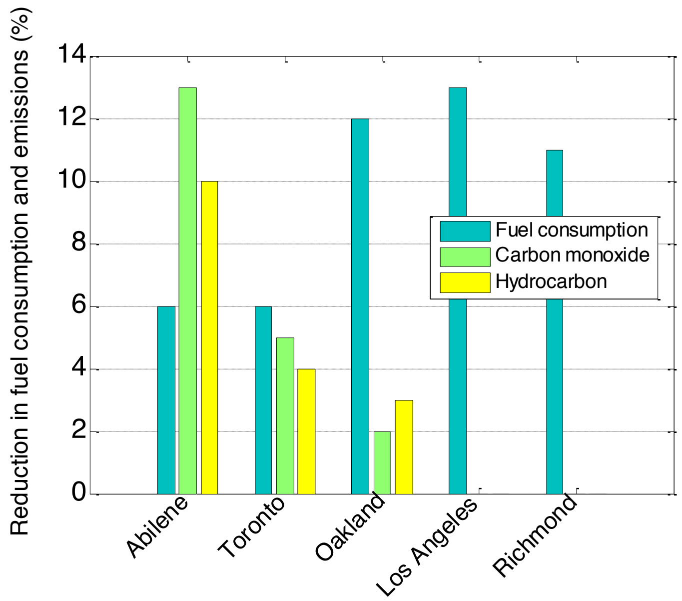

Figure 18. Reductions in fuel consumption, carbon monoxide (CO) and hydrocarbon emissions (HC) from traffic signal control implementation in North America. Note: Abilene, Texas; Oakland County, Michigan. Los Angeles and Richmond, Virginia reported 14% and 5-22% reductions in vehicle emissions but no break down for CO and HC given (Mehta et al., 2001; USDOT, 2008; Bani et al., 2009).

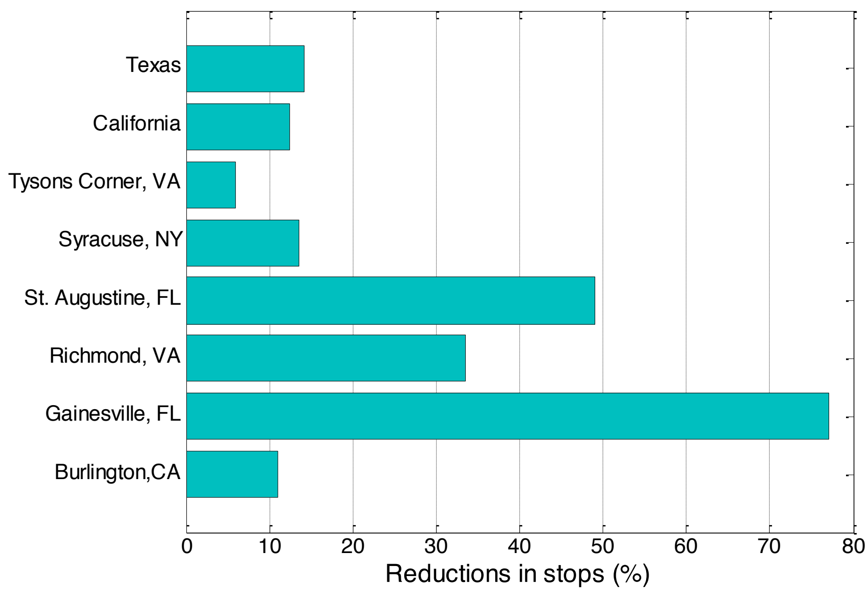

Figure 19. Percentage reduction in number of stops with implementation of traffic signal light coordination in Canada and US. Note: average values are used for Richmond, VA and Syracuse, NY. Adapted from, USDOT, 2008.

In the EU studies have shown that adaptive traffic lights can reduce CO_2 emissions by up to almost 30%, although results vary greatly based on the location, time of day, and amount of traffic (Hutton et al., 2010). Nevertheless, yearly CO_2 emission savings of 2.4 million tonnes across the EU have been estimated from substituting half of the current traffic lights with modern dynamic ones that would optimize traffic flow (Kompfner & Reinhard, 2008).

Some of the most advanced ITS applications are Virtual Traffic Lights (VLT) which is infrastructureless traffic control systems based on Vehicle-to-Vehicle (V2V) communication. One study using a real-city case study in a simulation framework, which included microscopic traffic, wireless communication, and emission models, reported a 20% reduction in CO_2 under high-density traffic (Ferreria and d'Orey, 2012). Traffic signal control can also be applied to freeway ramp meters to control the flow of vehicles entering the freeway. A simulation study in Minnesota, US found 2-55% fuel savings at individual ramp metering locations along 2 modelled corridors under varying levels of travel demand (Hourdakis and Michalopoulos, 2002).

4.1.3 Speed Control Systems

Speed control systems involve using variable speed limits on both motorways and urban areas to smooth the flow of traffic. In the UK, traffic management solutions termed "Managed Motorways", includes using variable speed limits to smooth the flow of traffic as well as using the hard shoulder of some highways as an extra lane during busy times of day (DfT, 2011). Variable speed limits on motorways have been reported to reduce vehicle CO_2 emissions by 6%, but for other types of roads there was little impact and in some cases increased emissions were reported for low speed limit urban roads (Carslaw et al., 2010).

However, in Torino, Italy, an automated speed control system able to automatically adjust vehicle following distances, and use real time signal control timing data to regulate intersection approach speeds, and optimize travel speeds between green lights was reported to improve travel times by up to 10%. The European Telematics Application Program conducted a study in conjunction with four major auto manufacturers. The auto manufacturers upgraded their factory vehicles with adaptive cruise control (ACC), stop & go (S&G) functions, and traffic light approach control (TLC) systems.

Figure 20 summarizes the impacts of the TLC system in Torino on emission reductions in CO_2 by 4-5%; hydrocarbon (HC) by 4-7%; nitrogen oxides (NO_x) by 8-11% and fuel consumption by 8-14% (Bani et al., 2009). Another study indicated that urban speed control in Rotterdam, Netherlands resulted in 15% reductions in CO_2 emissions showing a wide variation from reported impacts in Torino, Italy. Rotterdam also reported improved traffic flow and less air pollution but no specific values were given (Kroon, 2005).

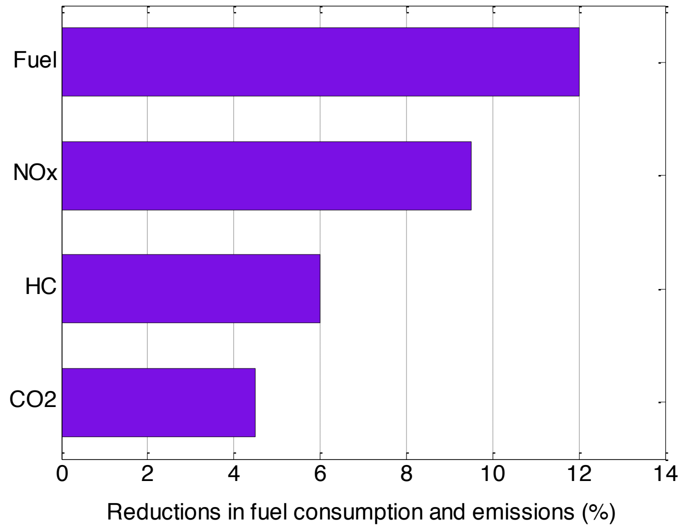

Figure 20. Impacts of automated urban speed control in Torino, Italy showing percentage reductions in fuel consumption (Fuel), nitrous oxides (NOx), hydrocarbon (HC) and carbon dioxide (CO_2) emissions. Note: average values are plotted based on reported impacts from Bani et al., 2009.

4.2 Management and Operations Impacts

Closely related to improving infrastructure network efficiency is the potential ITS impacts upon the management and operations of commercial fleets and public transit systems. ITS applications can improve transit reliability through implementation of automated vehicle location (AVL) and computer-aided dispatch (CAD) systems which can reduce passenger wait times. The systems enhance security and improve incident management through improved vehicle-to-dispatch communications, enabling quicker response to accidents and vehicle breakdowns. This can minimize vehicle downtime and improve service reliability. Data records from AVL/CAD systems, along with automated passenger counters, are enabling a transition to improved transit planning and management strategies which rely on large quantities of data regarding system operations (Bunch et al., 2011).

ITS systems can therefore help improve transit systems substantially, both via better routing and dispatching (e.g. of buses, using GPS information on where they are located) and by providing better real-time information to travellers on expected waiting times. Delivery of real-time information via the internet, cell phones, and at bus and rail stops has proven popular with travellers around the world and has become a priority investment area for many transit authorities (IEA, 2009).

In terms of optimizing the management of commercial fleets, ITS could improve efficiency in a number of ways, such as improved transport network design, seamless and centralized distribution networks and flexible management systems for delivery services. Additionally, increased utilization of vehicle capacity, reduced empty running, and driver training are considered important factors in improving logistics and performing freight operations more efficiently. It is estimated that such improvements could achieve CO_2 reductions by cutting the distance travelled by trucks by 10–40% (Bani et al., 2009; VTT, 2012). We review the empirical evidence for specific ITS initiatives below.

4.2.1 Integrated Traffic and Mobility Management

Integrated traffic and mobility systems deploy a range of ITS technologies that include traffic control and traveller information systems designed to make travel more efficient and safer by providing travellers with real-time information on congestion, navigation and location, weather and traffic conditions. Integrated systems can also include pre-trip electronic route planning systems, electronic route guidance and position locating systems, and attention warning and collision warning devices (Haynes and Li, 2004). Figure 21 summarizes the impacts on vehicle emissions from cities around the world from deployment of integrated traffic and mobility systems.

Integrated systems have been deployed around the world. In the US, the Advanced Regional Traffic Interactive Management Information System (ARTIMIS) provides traffic management and traveller information on 88 miles of heavily travelled freeways in greater Cincinnati and Northern Kentucky. An evaluation of the system indicated emission reductions of 3.7% in hydrocarbons (HC), 3.7% in carbon monoxide (CO), and 4.6% in nitrous oxide (NOx). It was also found that the benefits of ARTIMIS outweighed the costs by a ratio of 12 to 1 resulting in net benefits of $125 million per year (USDOT, 2002). In Tuscon, Arizona, a model study of ITS deployment consisting of 35 technologies including highway advisory radio, dynamic message signs, a telephone and web-based traveller information system, and kiosks found that implementation could reduce annual fuel use by 11% and lower annual emissions of carbon monoxide, hydrocarbon and nitrous oxides between 10-16% (Ezell, 2010).

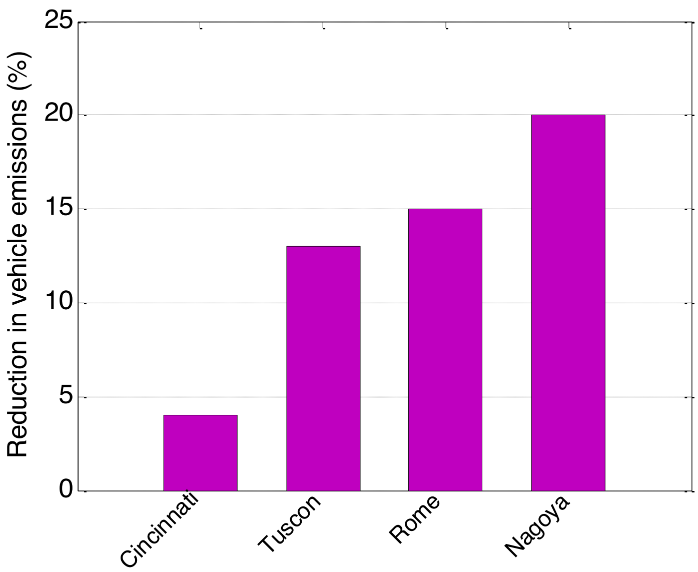

Figure 21. Reductions in vehicle emissions from deployment of various integrated traffic and mobility systems. Note: Reported vehicle emissions for Cincinnati include HC (3.7%), CO (3.7%), NOx (4.6%) average value of 4.1% used. Tuscon based on modelled results reporting 10-16% reductions for HC, CO, NOx, median value of 13% used. Rome only reported emissions without breakdown of

compounds. Nagoya only reported CO_2 emission reductions. Here we aggregate these emissions into a common vehicle emissions category. Data from USDOT, 2002; Ezell, 2010; VTT, 2012.

In Rome, Italy, an integrated traffic and mobility management system called the Traffic Control Centre (TCC), monitors, manages and controls urban traffic to improve traffic flow. ITS functions include traffic light regulation, traffic flow monitoring, user information via variable message signs, restricted traffic area access monitoring, video surveillance, monitoring and communicating parking spaces, and traffic information provision. Along with reduced travelling times and accidents, evaluations indicate that emissions have fallen by 15% in areas managed by the TCC (VTT, 2012). And in the Netherlands, dynamic road information panels were found to reduce congestion by providing localized traffic information to end users. It was found that providing information in real-time influenced 35% of travellers to change route, time and modality leading to less congestion. And it was estimated that providing the information in real-time prior to leaving could persuade up to 35% of travellers to change (DfT, 2011; MIEN, 2011).

In Nagoya, Japan a personal integrated travel assistance system to help commuters make travel and commuting decisions was developed and tested. It was found that it helped commuters choose environmentally friendly routes and modes reducing CO_2 emissions by 20% and car usage decreased by 20% while walking and bicycling increased by 80% and transit use increased by 100% (Tomotaka et al., 2008).

4.2.2 Transit Signal Priority

A more specific ITS technology widely deployed is transit signal priority systems. Information on current vehicle location and schedule status can support transit signal priority, which improves transit trip times and schedule adherence. Transit signal priority systems use sensors to detect approaching transit vehicles and alter traffic signal timing to improve transit performance. For example, some systems extend the duration of green signals for public transportation vehicles when necessary. Figure 22 shows the range of documented impacts with improvements in transit travel times after the implementation of transit signal priority, with improvements ranging from 1.5% in Portland, Oregon to 15% across a range of EU cities.

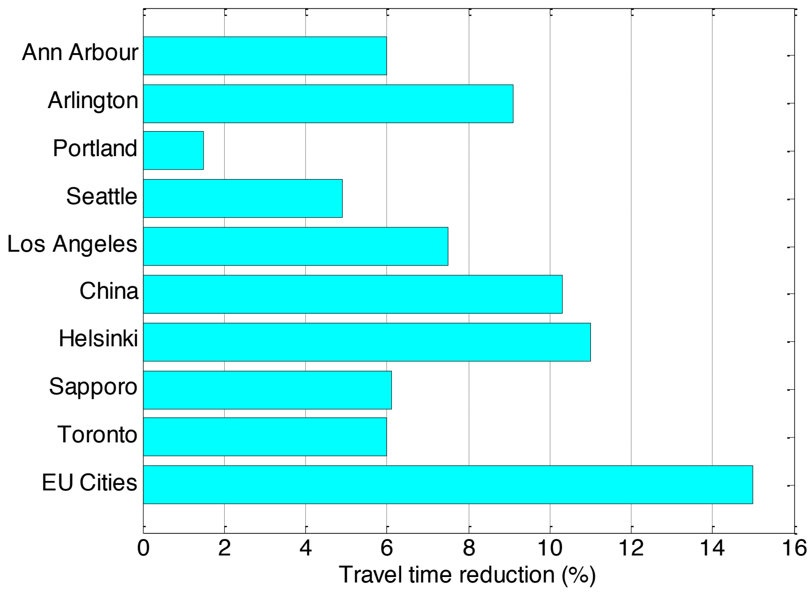

Figure 22. Travel time reduction benefits with transit signal priority implementation across various countries. Note: specific EU and Chinese cities not provided from data source, it is assumed that the figures given represent a median case scenario across the cities/city involved. Data from (Maccubin et al., 2008; Bunch et al., 2011)

4.2.3 Trip Planning Systems

ITS enabled trip departure planning systems can optimize commercial fleet scheduling based on real-time and predicted traffic conditions. This has the potential to reduce the overall fleet journey time saving fuel and reducing emissions. These systems rely on a number of telematics which use remote devices on freight vehicles, real-time traffic data and communication links between the vehicles, and a control centre to manage and monitor freight operations. These systems also have the capability to present a large amount of data in a useable format to inform freight managers. This can lead to improvements in fleet efficiency and productivity due to reductions in fleet mileage and reduced operational costs (Klunder et al., 2009).

Vendors claim these systems can result in 30% improvements in journey times and fuel consumption. Table 6 summarizes real world evaluations of these systems showing lower improvements than 30% but substantial gains nonetheless ranging from 8 – 16% reductions in fuel consumption after deploying trip planning systems.

Table 6. Fuel consumption and journey distance reduction from trip departure planning systems across various companies.

Company	System	Fleet Size	Km travel reduction (%)	Fuel consumption reduction (%)
Marks and Spencer	ISOTRAK	>240 vehicles	15	8
Riggot & Co Ltd.	Minor Planet	12 vans	-	15
Sainsburys	ISOTRAK	12 vans	-	15
Taiwan Taxi	-	16 vehicles	-	16

Note: no data available for km travel reductions for Riggot & Co. Ltd., Sainsbury's, Taiwan Taxi and system used in Taiwan. Adapted from Klunder et al., 2009.

As of 2009, there were 27.4 million commercial vehicles owned by enterprises and 1.4 million owned by public entities in Europe. Those commercial vehicles are comprised of around 20 million light commercial vehicles, 7 million trucks and 0.5 million buses and coaches. There are also an additional 2.5 million heavy trailers or semi-trailers, 2 million construction equipment type vehicles and another 3 million agricultural units. An EU level study indicated that dynamic trip departure planning across all of these commercial vehicles could result in a 5 – 15% reduction in road traffic CO_2 for 10% of all commercial vehicles in Europe. If the system was applied to all goods transport vehicles and buses which is around 18% of the total vehicle fleet, there could be CO_2 reductions of around 0.9 – 2.6% (Klunder et al., 2009).

4.2.4 Incident Management

Managing traffic incidents effectively can reduce congestion problems. In the US, approximately 25% of all delays are from roadway incidents including vehicle crashes, roadway debris, stalled vehicles, etc. Traffic incident management programs deploy a variety of ITS technologies to detect, manage, and clear traffic incidents. This can improve safety for travellers by reducing the risk of secondary crashes, and minimize lost time and fuel in traffic backups. These programs utilize ITS deployed specifically to detect and manage traffic incidents, along with components for traveller information, and freeway management. Different technologies include inductive loop, microwave or acoustic vehicle detectors, and camera systems providing video surveillance of roadways.

Empirical evidence from the US indicates one of the major benefits from ITS enabled incident management is the reduction in duration of traffic incidents shown in Figure 23 ranging from 10 - 70% reductions in incident duration. These reductions benefit traveller safety through reduced likelihood of secondary accidents. There are also positive effects on mobility and economic productivity of travellers through reduced incident related delays and associated costs, while improving the environment through reduced fuel consumption from idling vehicles (USDOT, 2008).

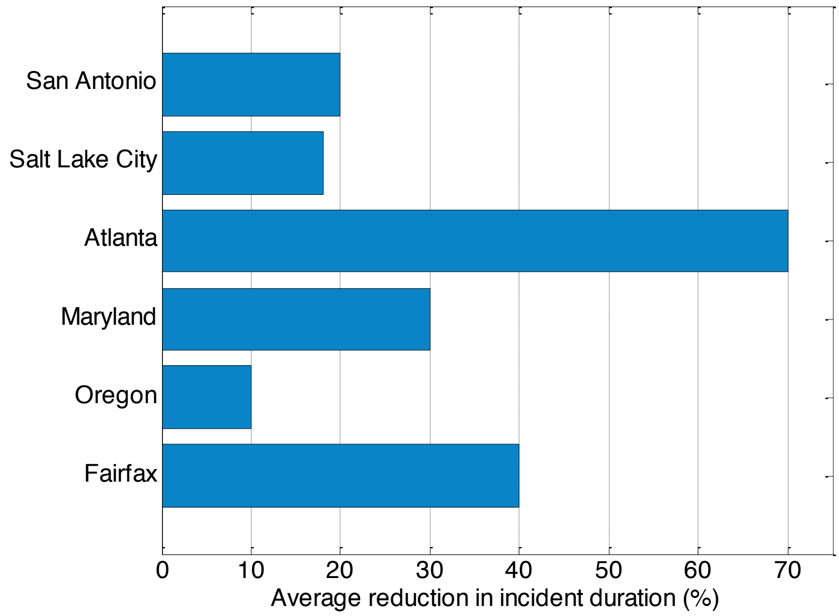

Figure 23. Average reduction in incident duration after deploying range of ITS technologies to assist incident, monitoring, response time and management. Data from USDOT, 2008.

4.3 Driver Behaviour Impacts

Increased fuel consumption and environmental emissions are a result of not only poor network efficiency and congestion but also driver behaviour such as abrupt acceleration and heavy braking (Jama, 2008). ITS enabled vehicles have the potential to communicate with surrounding vehicles to avoid collisions, harmonise individual vehicle speeds and lane changes so that traffic flows freely with less need for acceleration and deceleration. Specific technologies such as on-board radar and computers will facilitate these functions. While not yet fully developed, first-generation applications of these technologies are increasingly deployed. For example, rear-obstruction sensors for parking and real-time fuel economy readouts are readily available. Increasingly, the interfaces between technology and driver will improve providing better information for travellers to help drive safely and efficiently (IEA, 2009).

4.3.1 Eco-driving

Eco-driving is enabled by ITS by integrating driver decision making and real-time engine performance data to optimise fuel economy. Allowing the vehicle ITS system to coach the driver on efficient driving can help make eco-driving a habit. It is estimated that eco-driving can improve fuel efficiency by 10% for drivers over the medium term (more than 3 years after initial training) that use it where ITS systems can help maximise this benefit (IEA, 2009). Figure 24 provides short term estimates (less than 3 years after initial training) on fuel consumption improvements from eco-driving programmes across Asia and Europe showing a high of 17% in Japan to a low of 8% in the United Kingdom. Table 7 summarizes both the short term and medium term impacts from various ecodriving initiatives.

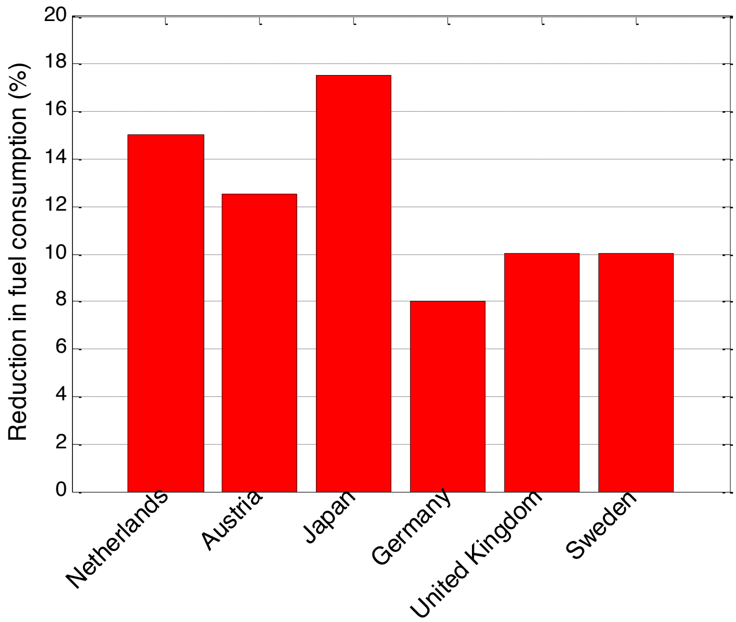

Figure 24. Short-term fuel consumption improvements from eco-driving programmes in Japan and Europe. Average values are used from reported sources. Results are for cars, buses and trucks. Data from Jama, 2008; IEA, 2009.

Table 7. Fuel efficiency impacts of eco-driving programmes over the short and mid-term and the scope of the initiative across different countries.

Country	Short-term impact	Mid-term impact	Scope of initiative
Netherlands	10-20%	5-10%	National
Austria	10-15%	5-10%	National
Germany	10-25%	10-15%	National
UK	10%	-	Fleet operations
Japan	10-25%	-	Driver training courses

Data from Jama, 2008; Notes: short-term = less than 3 years; mid-term = more than 3 years.

Programmes across Europe such as ECODRIVEN ran across 9 countries from 2007 - 2008 raising awareness for eco-driving techniques. The programme reporting average fuel savings of 5-10% (Kompfner & Reinhard, 2008). Table 7 shows the reported impacts of individual programmes on both a short-term (less than three years) and medium-term (more than three years) basis. Immediately after eco-driving training, average fuel economy improvements of 5 - 15% were recorded for cars, buses and trucks. Over the medium term, fuel savings of around 5% were sustained where there was no support beyond the initial training or around 10% where further feedback for drivers was available (IEA, 2009).

Eco-driving can enable lower driving speeds, and avoiding acceleration and full to substantially reduce vehicle emissions (Rakha and Ding, 2003). Additionally, enforcing reduced speed limits near urban areas by the use of ITS enabled automatic number plate recognition can reduce the environmental impact from vehicle emissions (MIEN, 2011).

4.3.2 Intelligent Speed Control

Closely related to eco-driving initiatives are intelligent speed control systems that can limit maximum vehicle speed via a signal from the infrastructure to a vehicle. An overview of studies conducted in the United Kingdom, Finland, the Netherlands, Sweden, Denmark, and Australia reported that when all vehicles are equipped, mandatory dynamic automatic controlling could reduce fuel consumption and harmful emissions by 4-11% (Morsink et al., 2008). Additionally, in Los Angeles, California, a simulation study transmitted optimal speed values to an in-vehicle display and drivers were able to limit vehicle speeds to those recommended by the system servers. To control the study a second vehicle was operated in the same traffic except the recommended speed information was not provided. The study found that eco-driving with dynamic speed recommendations can reduce fuel consumption by 10 – 20% without increasing freeway travel times (Barth and Boriboonsomsin, 2009).

In the Netherlands, a dynamically adjusting speed suggestion system involving dynamic road signs and in-car display for reaching traffic lights when they are green was implemented on some roads (MIEN, 2011). The system gives the end-user speed advice based on the time of day, car in front, place in queue, place on road, and possible congestion at an upcoming intersection. Carbon dioxide emissions were reported to have been reduced by 17% compared to vehicle-adaptive cycle time controllers in a limited number of emission measurements (VTT, 2012).

4.3.3 Driver Information Systems

Advanced communications have improved the dissemination of information to the driving public. Drivers are now able to receive relevant information on location-specific traffic conditions in a number of ways including in-vehicle displays and other specialized information transmitted to individual vehicles. Simulation models show that real-time on-board driver assistance systems that recommend proper following distances can improve fuel economy by approximately 10%. However, the system would be more suitable for urban roadways where traffic signals and congestion are more frequent (Kamal, 2009).

Additionally, pre-trip traveller information provided via internet web sites, and other wireless devices, including mobile telephone services, television, radio, or kiosks can assist drivers to make more informed decisions for trip departure, route choice, and mode of travel. In Boston, Massachusetts, a modelling study estimated that changes in travel behaviour due to better traveller information could result in a 25% reduction in volatile organic compounds, a 1.5% decline in nitrogen oxides (NOx), and a 33% decrease in carbon monoxide (CO) (USDOT, 2008). However, it should be noted that these impacts are based on modelling studies since it would be difficult to determine the specific impact of these systems since they are supporting measures. Nevertheless, as these technologies are improved and the interface with drivers becomes more effective, they could have a range of benefits including driver safety along with improved fuel consumption and lower emissions.

5. Summary & Next Steps

This report developed a novel sustainability impact framework to assess the potential impacts from widespread deployment of ITS technologies. The framework is multidimensional and sufficiently flexible encompassing the interdependencies between 1) energy and environment, 2) mobility and efficiency, 2) productivity, and 3) safety. Each of these domains intersects with intelligent mobility and the potential role of ITS for meeting broader UK and international policy to improve the performance of transport systems.

Given the global and UK policy agenda to reduce energy demand, carbon emissions and mitigate environmental impacts, the potential energy and environment impacts from ITS were assessed in depth based on detailed case analysis drawing from empirical studies around the world. It was found that the deployment of ITS can have positive impacts on transport systems across a range of modes, infrastructure and activities. For measures related to network efficiency there are reductions in CO_2 emissions of 10 - 15%; other reductions in environmental emissions including CO, NOx HC, PM_{10} ranged from 2 – 20%; fuel consumption decreased from 5 – 15%; traffic reduced from 12 – 30% and average vehicle speeds increased from 5 – 25%.

ITS measures related to operations and management were found to reduce vehicle emissions from 5 – 20%, improve travel time from 2 – 15% and reduce fuel consumption 8 – 18%. Technologies related to influencing driver behaviour primarily focused on eco-driving initiatives where substantial case evidence indicates fuel efficiency improvements of 8 – 18%. All of these findings are based on reported results documented in industry, government and academic literature, and so should be taken with some precaution since access to the original data and methodological detail was not available. But despite this shortcoming, based on a range of literature, what can be concluded with some certainty is that the deployment of ITS technologies has substantial potential to positively contribute to achieving a more sustainable transport system in accordance with UK and global policy initiatives.

The framework developed in this report could be further used as a benchmark in the future to assess progress in the field, or a methodological approach to lead integrated analysis of the interconnections between each impact domain, or used to pursue more detailed analysis in any one of the domains. The quantitative data reported here can also serve as the basis for more detailed modelling work, or other forecasting approaches to assess the future impacts of widespread ITS deployment across a range of geographical and temporal scales. The framework also highlights the important interconnection between sustainability impacts and an emerging paradigm of intelligent or smart mobility, which will have important implications for optimizing urban growth and development. In this regard, the sustainability framework provides a comprehensive and integrated way of thinking about the future evolution and impact of intelligent mobility enabled by specific ITS initiatives.

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