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Intelligent Transport systems: the propensity for environmental and economic benefits.

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Abstract

Whilst the economic and efficiency benefits of Intelligent Transport Systems (ITS) are well established, the goal of this research is to demonstrate the simultaneous propensity for low carbon benefits through the deployment of ITS. The foundation of this paper is therefore that the deployment of these technology measures contributes to the positive-sum game of both economic and environmental sustainability. Two research questions are addressed: firstly whether the evidence supports the notion that ITS systems can be implemented and operated in such a way to generate environmental benefits; and secondly whether policy priorities amongst national and international stakeholders reflect a propensity for ITS deployment in order to yield those benefits. The first question is addressed using a rationale based upon both underlying drivers and a synthesis of the empirical evidence. The second is addressed by the development of new propensity models using primary research on international stakeholders' perceptions of ITS as a priority solution to deliver climate and environmental goals. The research shows that Vehicle Density and High Technology exports were found to be significant variables in determining the propensity for ITS to feature as a high priority policy tool in future transport strategies. The research holds further value in positioning ITS as a policy tool able to deliver both economic and sustainability gains. It holds relevance for both policy analysts and transport strategists at international, national and regional tiers.

Keywords: Intelligent transport, propensity model, transport policy, environmental impacts, economic impacts, sustainability

1. Introduction and background

Transport has become fundamental to the everyday functioning of society and the economy. Yet the reliance on motorised transport as an everyday function is a substantive contributor to global climate change [1]. Without significant policy or technological advances, the likelihood of decoupling transport growth from emissions growth would appear slim given that 95 per cent of transport energy is derived from fossil fuels [2]

As there are a number of possible pathways for reducing the carbon intensity of transport, it is understandable that there has been lack of agreement on a definitive approach. Principal carbon reduction pathways include supporting low carbon technological innovation and deployment; encouraging modal shift from private car use to less polluting options such as walking, cycling and public transport; advocating more efficient forms of traffic management and driving behaviour; and employing strategies that seek to reduce the need to travel altogether (e.g. spatial planning). The main areas for debate appear to be between behavioural and technological innovation, and between reform and radical change. Whilst discouraging private car use through comprehensive behavioural measures would assure significant cuts in emissions from transport, a technological reformist approach could be seen to be more politically and socially expedient. In fact, as scholars working within the "socio-technical systems" school of thought maintain ([3], [4], [5]; [6]; [7]; [8]; [9]), a transition to a lower carbon society will almost certainly necessitate changes in and across both dimensions simultaneously: behavioural and technological, reformist and radical. Drawing upon the socio-technical perspective, [10] examine the car system as 'being made up of humans (drivers, passengers, pedestrians), machines, materials, fuel, roads, buildings and cultures', and therefore all the different elements- actors, artefacts and institutions- have to be aligned in a particular order for a sustainable transition to a lower carbon alternative to emerge. However, there has historically been difficulty in achieving a coherent behaviourally-orientated demand management strategy for private car usage, and because transport is a particularly difficult sector to decarbonise, much emphasis has been put on piecemeal technological innovation for providing more sustainable transport solutions ([11]; [1]; [12]). Intelligent technologies are therefore playing an increasingly important role in the drive for green innovation; however socio-behavioural barriers may still need to be addressed if comprehensive deployment of these technologies is to occur.

Given the potential for technology enabled low carbon futures, in section 1.1 the ability for ICT to support this through two alternative but potentially overlapping routes is described. Firstly by Information Communications Technology (ICT) working to link the transport sector with complementary sectors and facilities and secondly through ICT being embedded within the transport system and connecting different types of technologies and functions. These ICT connected technologies and functions within the transport sector are collectively referred to as Intelligent Transport Systems (ITS). As a 'system of systems' it is difficult to precisely define ITS, however a taxonomy of some common types is provided in section 1.1 with their main drivers towards delivering carbon benefits. In section 1.2 a summary of the evidence base on the likely size of impacts is discussed based on both synthesised and measured observations. Many ITS systems are focused towards enabling behavioural change. An introduction to the historical difficulties in following a coherent behaviourally orientated transport demand management strategy (and how technology solutions have emerged alongside) therefore follows in section 1.3. This past experience forms the backdrop to understanding future propensity to prioritise ITS systems.

1.1. Overview of ITS systems in the low carbon context

ICT acts a cross-sectoral enabler that exists in two contexts to engender a low carbon future. Either in systems which either sit alongside the transport sector (for example in sectors such as health, education, business or linked non-transport facilities) or being fully integrated into aspects of the transport system (for example as components of the vehicle, road infrastructure or management system). In practice these two contexts can be overlapping rather than mutually exclusive. Here a summary is given of ICT acting in both contexts and how each reflects either technological advance or supports behavioural change – an important precursor to establishing the case for ITS as a sustainable solution.

Much has already been written about the rise of (ICT), the associated information networks and flows, and the implications of pervasive computing for society and the environment ([13]; [14]; [15]). There is a growing literature exploring the existing and predicted implications of the ICT revolution for transport ([16]; [17]; [18]; [19]; [20]; [21]) and ICT-enhanced transport on spatial planning [22]. Significantly, for [23] this boom in ICT should be directed towards low carbon industries where the comprehensive deployment of intelligent technologies can be advantageous for the economy whilst simultaneously prompting the shift towards environmental sustainability.

Where ICT operates in the context of being complementary to the transport system it enables individuals to make choices that impact on both the overall demand for transport and for different models, for example in facilitating home working or encouraging mode switch. Where ICT is intrinsically embedded in the transport system it serves to optimise the use of the system infrastructure in some way – either towards efficiency, safety, enhanced traveller experience or potentially towards a more sustainable mode of operation. In Table A1 (Annex) a classification of the different ICT solutions is given according to the system and the extent to which they are in the context of being complementary to, or integrated within, the system.

Where ICT operates to connect complementary sectors and services to transport it can reduce carbon intensive physical transport movement. This occurs when remote communication via digital connection acts as a substitute for the physical negotiation of geographical space. In this context ICT can therefore reduce the need to travel for social and business purposes. Avoiding unnecessary travel through digital connection and planning unavoidable journeys using real-time traffic information (RTTI) prior to entering the transport network is certainly in line with the 'smarter choices' agenda ([24], [25]). Smarter choices are 'soft' techniques that positively influence travellers and encourage more sustainable voluntary behaviour in the school, workplace or at the home through the production and implementation of travel plans. Although evidence is far from conclusive, it would appear that workplaces are beginning to acknowledge the necessity of including environmental issues in their travel plans to bolster their corporate social responsibility and to attract potential employees to the organisation [26]. According to [24] the smarter choices agenda could potentially reduce traffic levels by 10-15% as a national average if complemented by ‘hard’ measures, and could therefore substantially reduce carbon emissions from the transport sector. However, although the Smarter Choices agenda has had some success in reducing private car usage and carbon emissions, it has failed to carve major inroads into transport policy [11].

When ICT becomes integrated within the transport system it is generally referred to as an Intelligent Transport system (ITS). ITS infrastructure can be *fixed* so that they function at one particular location, for example variable-message signs and electronic tolling stations. ITS infrastructure can also be *mobile* in that they can be located on board vehicles or on persons (for example satellite navigation systems, advanced traveller information systems and adaptive cruise control). ‘Cooperative’ systems, are an advanced form of ITS operating by means of vehicle to vehicle communication (V2V), vehicle to infrastructure communication (V2I) and infrastructure to vehicle communication (I2V) to develop better traffic management systems and to enhance road safety and efficiency.

Using dynamic and ubiquitous connectivity, integrated ITS applications aim to *sense* transport movement, *process* this incoming information, and then *communicate* information in real-time to private or public transport users and/or traffic managers and therefore facilitate more efficient transport networks. Information can be relayed to drivers to inform choices whilst travelling through the transport system, limit the drivers behaviour, act as alerts or even take drivers’ decisions if a swift response is required [27]. Significantly this information can enable individuals to take more sustainable actions (in a dynamic fashion within the journey) that are conducive to a lower carbon future.

In addition to directly enhancing traffic management through information provision, ITS can further influence and inform the decisions taken by the driver to encourage ecological driving or ‘eco-driving’ ([11] [28]; [01]; [29]; [30]). This denotes a driving style that avoids excessive and aggressive driving manoeuvres, erratic driving pace, sudden stopping and starting and unnecessary speeding and idling. It also refers to good general maintenance of a vehicle to optimise performance. With purposeful policy and planning eco-driving could be supported through information, encouragement and enforcement.

Further behavioural change is supported by ITS through encouragement and enforcement measures. ITS can be deployed to enable electronic payment for access to certain routes, zones or facilities, supporting the 'polluter pays' principle whilst associated technologies of access control (such as rising bollards), can provide the intelligent infrastructure required for charging schemes to go ahead [31]. Enforcement measures can also support the shift to less carbon intensive behaviour - Automatic Number Plate Recognition (ANPR) can provide the capacity for monitoring and surveillance to incur penalties and therefore mitigate excessive and aggressive driving such as speeding [29]. As eco-driving relies predominantly on voluntary actions, other measures such as fiscal incentives and education programmes may be needed concurrently ([28]; [32]).

ICT can also support greater automation within the transport system and thereby provide a further step towards reducing carbon, for example intelligent speed adaptation. In future more advanced cooperative ITS will utilise two-way communication to 'platoon' vehicles together into a moving nexus that is intelligently synchronised, for example the EU FP7 funded Safe Road Trains for the Environment (SARTRE) research. The aim of the platoon is to reduce air drag, fuel consumption and carbon emissions.

In considering the potential impacts of ITS schemes it is also important to acknowledge the possibility of disbenefits and negative secondary effects. Technologically enhanced transport may encourage people to travel more frequently as vehicular transport becomes more effective, leading to a rebound effect. Similarly, technical fixes may achieve efficiency savings in the short-term, but transport users may compensate or overcompensate by increasing consumption in tandem ([21]; [33]). Furthermore, some ITS may reinforce our dependency on cars rather than 'greener' modes

[34]. The primary consideration is therefore to account for the full range of possible impacts of ITS within transport strategy development.

1.2. Evidence base for ITS impacts

From a policy development perspective, the business case for greater roll out of ITS schemes as a means of achieving climate goals requires further quantified evidence. ITS is likely to be compared with other options before investment is made and may well be taken into an economic appraisal process. Quantified evidence for ITS climate benefits is not widely published and largely based on a relatively smaller number of studies than is the case with traditional infrastructure schemes. Evidence on impacts may be gathered from either field studies of real life implementation or through simulation and modelling studies. A summary of some recent evidence involving field trials, simulation and laboratory testing is provided in Table 1. It illustrates the degree of variation in the definitions of the schemes, the technologies involved and difficulty in therefore producing synthesised and scheme-relevant evidence that could act as inputs to a proposed scheme appraisal process. The outcomes generally suggest impacts of between 5% and 20% savings on carbon emissions – fuel savings are indicated up to 20% and other emission types are evidenced alongside. For teleworking, the evidence is still believed to be inconclusive and more research is needed to identify the true impacts - with the possibility of home energy costs replacing the savings from reduced transport demand. The need to consider shifts and displacement of impacts is also considered for teleshopping [35].

A further body of evidence exists at a broader policy level [29] and a more aggregate level of calculation (for example, [36], [37]). The advantage of a more aggregate estimation of environmental and other benefits is that it is a level of information that can support strategic/national level policy and financial decision making. For example [37] quotes an estimated $2.9m annual national environmental saving for the USA from electronic toll collection (2009 price).

Table 1: Indicative evidence on carbon, fuel and emissions impacts of a range of ITS schemes

Study	ITS scheme	Data collection method	Study location/Context	Reported benefits
[30]	Teleworking	review of studies and modelling	UK	2.4 % of carbon emissions from cars in UK may be reduced due to teleworking by 2050
[29]	Teleworking	Expert review	UK	Inconclusive and recommendation that more detailed research is needed.
[30]	Personalised travel planning	Field trial	Japan	A personalized travel planning system helps commuters choose environmentally friendly routes and modes; reduces carbon dioxide emissions by 20 percent.
[42]	Transport management system: Electronic charging	observed	London Congestion Charge	a) Between 2003 and 2006, a reduction in carbon emissions in the central congestion area of 16 % b) western extension zone introduced in 2007 led to a reduction of 6.5% by 2008
[43]	Transport management system:Hard shoulder running and variable speed limits (VSL))	simulation and observation	UK Motorways (M42 and M25)	M42: Most vehicle emissions reduced by between 4% and 10%. Fuel consumption reduced by 4%. Similar findings obtained from two other studies of VSL on M25
[28]	Eco-driving: In-vehicle control and performance systems	on-board monitoring	USA, Denver, normal driving conditions.	5% fuel saving with no feedback/coaching, 10% fuel saving with feedback/coaching. Assumes carbon saving equivalent to fuel saving.
[30]	Eco-driving	review of studies	Field trials	average 10% reduction in carbon emissions
[44]	Eco-driving: In vehicle (overridable) speed control	Field trial using instrumented vehicles and emissions models	UK (Leeds and Leicestershire), different road types	Motorway – average 6% benefit on CO2 Other road types – little benefit or small disbenefti on low speed urban roads. 20% difference in CO2 emissions between lowest and highest emitting drivers
[45]	Eco-driving: dynamic systems that utilise RTTI	Simulation	simulated environment	Reduction in carbon emissions and fuel consumption by 10%-20% per cent without a significant increase in journey time. Real world experiments showed similar but slightly lower findings
[30]	Eco-driving	field trial	Netherlands, 1999-2004	fuel consumption reduced 0.3%-0.8%
[46]	In vehicle technology and other measures	review of studies	Europe	5% to 25% carbon saving with 10% generally agreed
[47]	Platooning and road-trains	Laboratory testing of vehicles	Motorways	Fuel consumption and carbon emissions. Approx 20 %

A detailed estimation of the environmental impacts of e-commerce, including ITS supported logistics, has yet to take place but a broad overview for the case of China is provided by [38].

At a national level in the UK, the Department for Transport [39] examined the likely benefits and costs of a number of number of national strategies to support low carbon futures. The most 'radical' of these included the following ICT based measures, which have been the subject of previous research:

a) an extension of the 'Smarter Choices' programme (involving behavioural change such as dynamic travel time information, car sharing, encouraging walking);

b) far-reaching eco-driving lessons for existing car licence holders;

c) speed reduction and enforcement at 60mph (to be enforced by cameras to calculate average speeds) ;

The assumption in [39] is that 1% of existing drivers are trained each year with reduction in fuel consumption of 3%. Savings from speed reduction are difficult to estimate as there is some slowing of traffic due to congestion and different modelling assumptions produce considerable variation. The main cost is in the extensive roll out of enforcement cameras. The calculation of NPV is given in detail within [39], but includes assumptions on congestion costs, fuel savings, pollutants, accidents and noise. Health benefits are not included and there are background assumptions on demand measures to 'lock-in' benefits and the absence of rebound effects.

As can be seen from table 2, smarter choices and Eco-driving hold considerable promise in terms of environmental benefits and cost effectiveness (NPV). Speed reduction is forecast to have a less favourable overall outcome, but offers a more substantive level of savings. The negative NPV calculation (detailed in [39]) is largely attributed to the costs of enforcement and delay to journey times from reduced speed. Given the rapid pace of technology development this result may change in the short term – for example with in-vehicle pervasive devices to support automatic speed reduction or monitoring. It may be argued then that the cost has been transferred from central (highways or governmental) purses to that of the individual, but this would be in-line with a broader policy that 'the polluter pays'.

Table 2: Forecast sustainability Benefits and Costs for ICT enhanced transport measures

ICT enhanced transport measures	**Emissions savings in 2020 ($MtCO^2$)[1]**	**DfT assessment Cost/tonne**	**NPV (£m)**
Extended smarter choices programme	0.9	-£74	£1,475m
ECO driving lessons for existing car license holders	0.2	-£45	£152m
Speed reduction and enforcement at 60 mph	1.4	£307	-£5,008m
Total abatement potential	**2.5**		

Source: adapted from [39],

[1] Comparisons against base year 2009, assuming price of carbon £60

However such high level figures may not support decision making on investment at the local scheme level, or a comparison between an ITS option and more traditional scheme alternatives. Some research (for example [40]; [41]) has led to composite sustainability indices for ITS schemes that support policy review and goal achievement process. Other research demonstrates the efficacy of ITS schemes as part of a monitoring and modelling process to assess environmental impacts of transport [42]. As a whole, the literature doesn't yet describe the environmental and other impacts of ITS at a level that entirely meets the needs of a variety of stakeholders. In section 3, analysis of primary data suggests that either more research is needed or a more accessible means of reporting the environmental impacts could be adopted, so that policy making is better supported in practice.

1.3. Strategic policy and technology solutions for a low carbon future

Whilst the tangible evidence of low carbon benefits from ITS schemes is accumulating, a necessary condition for the benefits to be realised is that ITS schemes should be embedded in national, regional and local strategy. National governments can enact national regulation and enforce standards on efficiency; implement fiscal measures conducive to carbon reduction; support and fund low carbon transport projects; support initiatives to increase information and education; and formulate climate – related international accords. An appreciation of the political context therefore forms an important qualitative context within which the propensity for prioritisation of ITS can be studied through a more quantitative approach (section 2). Here the UK is used as a specific case study to illustrate the complexities in developing the transport and cross-sectoral strategies within which ITS measures would be placed. Internationally, these are expected to vary within different national and regional governance structures and according to factors such as the state of economic development and maturity of the transport system. However, fundamentally, an understanding of why and how technologies have been prioritised in past policy decisions is important for the understanding of future propensity to prioritise technology solutions. From the perspective of environmental objectives, a distinction is drawn here between the approaches towards mitigation and adaptation.

1.3.1 National strategy and legislation

Following the energy sector, transport is the second largest source of greenhouse gases in the UK representing 21% of total domestic emissions. Of this figure, domestic road transport is overwhelmingly the biggest contributor emitting 92% [39]. Moreover, until the economic downturn began in 2007 transport was the only sector to have experienced a continuous increase in carbon emissions on a 1990 baseline level [49]. As a response to the cross-sectoral decarbonisation challenge outlined by the Stern Review [50], the UK government introduced the Climate Change Act in 2008 as legislation that required the government to set carbon reduction targets and report on progress through the independent Committee on Climate Change (CCC). This legislation required an 80% reduction in UK domestic emissions by 2050 compared with 1990 levels, and has had significant implications for the way in which all UK government sectors develop and deliver policy. The *Low Carbon Transition Plan* [51] was published the following year and outlined a national route-map for a transition to a low carbon economy, with a dedicated carbon reduction strategy for transport [39] alongside it. The carbon reduction strategy for transport strengthened the long-term low carbon vision that was provided by the previous report *Delivering a Sustainable Transport System* [52] by outlining three overarching objectives: to support the shift to more efficient technologies and fuels; to promote lower carbon travel choices; and to employ market mechanisms to encourage less carbon intensive transport behaviour. If the plan to 2020 proves successful it will cut emissions from transport in the UK by 14% on 2008 levels, equating to 32.7 tonnes of CO_2 when existing policies are taken into account ([51]; [39]).

1.3.2 Adaptation and mitigation

In the UK planning for adaptation is now considered a major plank of climate change policy and transport research ([53]; [54]). Indeed the UK government is legally required to plan for climate change and ensure adaptive capacity alongside mitigation measures. The Department for Transport (DfT) and the Highways Agency released adaptation strategies in 2010 and 2009 respectively, with comprehensive cross-sectoral analyses of adaptive capacity provided by [55] and [56]. The strategy aims to increase the resilience of the transport system through long-term risk management, implementation of adaptive measures (such as new road specifications) and contingency planning for unexpected disruptive events [57]. If the strategy is delivered in practice, the UK transport system should be better prepared to cope with the predicted consequences of climate change, including unexpected changes in transport demand.

1.3.3 Role of regional and city stakeholders

According to previous research [53], the potential impacts of climate change on road transport in urban areas may consist of an increased frequency of accidents - though not necessarily severityand increased incidence and intensity of congestion. Much has been written about the increasingly influential role of city regions in climate change governance and their growing capacity for initiating sustainable transitions [58]; [59]; [60]; [61]). [11] argues that transport policy implemented at the 'city-region' scale can develop flexibly and therefore more effectively in relation to contextual circumstances.

In the UK, since the late 1990s the devolution of transport planning power from central government to local authorities has been part of a wider decentralisation of responsibility and accountability across all sectors ([62]; [63]). Yet [64] argue that there has not been a huge amount of divergence in transport policy between the devolved administrations since increased devolution. The Comprehensive Spending Review in October 2010 reinforced decentralisation in transport planning with the governments' statement for transport that 'radical devolution of power and greater financial autonomy to local authorities' will 'increase the sustainability of local transport systems', [65]. This would seem to offer greater opportunity for bespoke regional and city level sustainability solutions, though it remains to be seen whether ITS will play a role in those. As another signifier of decentralisation, the Traffic Management Act, was introduced in 2004 with the accompanying guidance putting a great deal of emphasis on the potential efficacy of ITS in overcoming local traffic problems and increasing network efficiency. As part of a survey of local Traffic Managers, [66] reveals, however, that there has not been sufficient funding forthcoming for the comprehensive implementation of intelligent technologies.

1.3.4 Integrated Policy challenges

By 2011, the overall picture in the UK was of a mosaic of carbon reduction strategies, confirming that low carbon transport objectives have been taken seriously in government policy making for some years. However, a lack of clarity across local, regional and national governance scales about how to achieve the strategies in practice has hampered tangible progress towards more sustainable and integrated transport policy ([67]; [68]; [69]; [21]), resulting in considerable fragmentation [70]. The extensive restructuring of the regional tier of governance- and the associated cuts in funding is likely to add to the complexity surrounding transport strategy at the local and regional levels. Policy fragmentation has been an historical issue at national governmental level however. In 1997 the government provided a window of opportunity for integrated transport policy and the adoption of the 'new realism' agenda [71], advocating a combination of demand management strategies rather than relying primarily upon further road expansion [72]. *A New Deal for* Transport [73] and *Transport 2010: The 10-Year Plan for Transport* [74] appeared to offer radical solutions to a congested and polluting transport system, with both appearing to advocate integrated transport policy and a return to longer-term planning [75]. Although the purposeful objectives of integrated transport planning were never rigorously pursued [67], the efficacy of policy integration, national intervention and sustainable planning was considered as an alternative to the 'predict and provide' model.

The issue of financial flows and funding sits alongside governance in consideration of alternative traffic solutions. Traditional infrastructure schemes have often needed substantial investment from a variety of sources and beyond the scope of a devolved budget – implying the need for coherent and centralised decision making. However the lifetime of many traditional schemes has meant that only on-going maintenance costs would then be incurred which would be the role of the devolved agencies. Many types of ITS schemes have a different funding burden between investment and maintenance which lend themselves to decentralised decision making and bespoke solutions.

In summary, it is against a backdrop of an unwieldy and largely piecemeal policy landscape that intelligent technologies have emerged as a major policy option in the UK to deliver a low carbon transport system. The challenges this brings may resonate with other countries internationally and whilst potentially even more complex for nations with more frequent change of government, they may be less so within a more polarised governance structure. The main forward challenges to achieving the benefits of ICT enhanced transport strategies emerge as:

- An acknowledgement of the enduring strategic priority of both economic and environmental sustainability, particularly in the post economic crisis period. A joint prioritisation would be receptive to ITS that can demonstrate both efficiency and environmental gains

- coherent horizontal (cross-sectoral) policies with a sufficiently seamless interface to allow full evaluation of - and funding support for - ICT related measures that impact beyond the transport sector
- a governance structure that is sufficiently flexible in terms of vertical strata of devolution and centralisation. This is needed to support both significant investment and on-going maintenance cost decisions that may vary in proportion between different types and configurations of ICT enhanced transport systems.

The evidence and arguments are presented here in the context of the UK strategy and policy development. However the emergent principles would provide a basis on which to assess the receptiveness and conduciveness of governance structures in other countries and regions to the economic and environmental sustainability benefits of ICT enhanced transport. In section 2, the propensity modelling approach is described, with a description of the survey and data collection to support model development in section 3. The model results are then presented and discussed in section 4, with concluding remarks in section 5.

2. Methodology: Development of Propensity models for ITS

Further to the governance challenges identified in section 1.3, it can be argued that neither environmental nor economic benefits of ITS will be realised unless stakeholders view these systems as a priority policy tool in future transport strategies. To explore this, research has been undertaken at international level to develop propensity models for the prioritisation of ITS within strategies and how these models vary according to whether the transport objectives are related to environmental concerns, global carbon or economic growth. Whilst there are numerous applications of propensity modes to understand individual choices and market share in transport, to date no published evidence has been found of ITS policy (or wider transport policy) propensity models of this type. Understanding this future prioritisation is an issue of increasing prominence on international agendas however, as reflected by the recently formed European ITS Advisory Group (March 2012, Brussels). The models offer a very different policy approach to other techniques such as transferability analysis. The rationale for the development of the models is that where national characteristics and indicators are used as independent variables in the model, they may be used to indicate how unit shifts in the values of such indicators can result in movements in the level of prioritisation of ITS measures. Multinomial logistic models were selected for this task as they can be used where the dependent variable is dichotomous [76]. The predictor values from the analysis can be interpreted as probabilities (0 or 1 outcome) or membership in the target groups (categorical dependent variables). Three separate models were developed concerning the role of ITS in future strategy priorities, giving three dependent variables as: 1) ITS as a future strategy priority to improve the environment, 2) ITS as a future strategy priority to decrease carbon impacts and 3) ITS as a future strategy priority strategy to encourage economic growth, with responses for each ranging from 0=not a priority to 5 = strong priority. The multinomial models were therefore used to classify responses into the priority classes based on values of the independent variables.

The criteria for the modelling process were as follows: the ability to interpret the model in a meaningful manner was a higher priority than absolute goodness of fit; the inclusion of variables that were available in published data was a priority over the inclusion of variables that required interviews and primary data collection (as a model usability concern) and finally, a degree of parsimony in the model was required. This set of criteria were driven by the objectives of the research and given the ordinal nature of the data a multinomial logistic model was fitted with the following general form below:

For a dependent variable with k categories, the probability that the i'th case falls in category k is given by π_{ik} where:

$$\pi_{ik} = \frac{e^{z_{ik}}}{e^{z_{i1}} + e^{z_{i2}} + ...e^{z_{ik}} + 1} \qquad .... \qquad (1)$$

Here k = 6 (not a priority, very low priority, weak priority some priority, moderate priority, strong priority)

z_{ik} is the value of the k'th unobserved continuous variable for the i'th case and is assumed to be linearly related to the predictors:

$$z_{ik} = b_{k0} + b_{k1}x_{il} + ...b_{kj}x_{ij} \qquad .... \quad (2)$$

x_{ij} is the j'th predictor for the i'th case, b_{kj} is the j'th coefficient for the k'th unobserved variable and J is the number of predictors. Substituting for z_{ik} in (1) using (2) gives equation (3)

$$\pi_j = \frac{e^{b_{k0}+b_{k1}x_{i1}+....+b_{kj}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + ... + e^{b_{k0}+b_{k1}x_{i1}+...+b_{kj}x_{ij}} + 1} \qquad .... \quad (3)$$

Z_k is arbitrarily set to zero creating a reference case against which others are compared. This is analogous to the use of a 'dummy variable' in linear regression. Here the reference case for ITS 'not a priority' was used.

For k=6, the model has five logit functions:

(i) Logit Function for k=6 relative to logit function for k = 1

(ii) Logit Function for k=5 relative to logit function for k = 1

(iii) Logit Function for k=4 relative to logit function for k = 1

(iv) Logit Function for k=3 relative to logit function for k =1

(v) Logit Function for k=2 relative to logit function for k = 1

For the propensity models for ITS in future strategies, the following equations apply:

$$\text{Probability (not a priority)} = \frac{1}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + ... + e^{b_{k0}+b_{k1}x_{i1}+...+b_{kj}x_{ij}} + 1} \qquad .... \quad (4)$$

$$\text{Probability (very low priority)} = \frac{e^{b_{20}+b_{21}x_{i1}+\ldots+b_{2j}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + \ldots + e^{b_{k0}+b_{k1}x_{i1}+\ldots+b_{kj}x_{ij}} + 1} \quad \ldots\ldots\ldots\ (5)$$

$$\text{Probability (weak priority)} = \frac{e^{b_{30}+b_{31}x_{i1}+\ldots+b_{3j}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + \ldots + e^{b_{k0}+b_{k1}x_{i1}+\ldots+b_{kj}x_{ij}} + 1} \quad \ldots\ldots\ldots\ (6)$$

$$\text{Probability (some priority)} = \frac{e^{b_{40}+b_{41}x_{i1}+\ldots+b_{4j}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + \ldots + e^{b_{k0}+b_{k1}x_{i1}+\ldots+b_{kj}x_{ij}} + 1} \quad \ldots\ldots\ldots\ (7)$$

$$\text{Probability (moderate priority)} = \frac{e^{b_{50}+b_{51}x_{i1}+\ldots+b_{5j}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + \ldots + e^{b_{k0}+b_{k1}x_{i1}+\ldots+b_{kj}x_{ij}} + 1} \quad \ldots\ldots\ldots\ (8)$$

$$\text{Probability (strong priority)} = \frac{e^{b_{60}+b_{61}x_{i1}+\ldots+b_{6j}x_{ij}}}{e^{b_{10}+b_{11}x_{i1}+..b_{1j}x_{ij}} + \ldots + e^{b_{k0}+b_{k1}x_{i1}+\ldots+b_{kj}x_{ij}} + 1} \quad \ldots\ldots\ldots\ (9)$$

Substituting the values of the independent variables in equations (4) to (9) gives probability values ranging from 0 to 1 subject to $\Sigma \pi_j = 1$. If $\pi_j >= 0.5$ then the response is classified in category j, if all values of equations (4) to (9) are <0.5, then it is unclassified.

The model does not require normality, linearity, and homogeneity of variance in the predictor variables, however it is based on two assumptions: 1) the dependent variable is dichotomous, with groups being discrete, non-overlapping and identifiable and 2) it considers the cost of statistical type I and type II errors in classification. In section 3 below, a description is given of the survey of international stakeholders that formed the dataset for modelling, including analysis and summary of policy and priority related features. This is followed in section 4 with discussion of the model results.

3. The data: Survey of International stakeholders

3.1 Survey Sample

The research was based on an on-line survey conducted between July 2010 and Feb 2011 that included a stakeholder mix of national and transnational policy makers, consultancies, industry, transport providers, academics and others. The sampling strategy was intended to capture stakeholders who were already knowledgeable with the nature of ITS schemes. The sample was drawn from various organisations and networks relating to intelligent transport, academics researchers in ITS and city planners, including: the IRF (International Road Federation), IBEC (ITS: International Benefits, Evaluation and Costs), POLIS (European Cities and Regions Networking for Innovative Transport Solutions) and national ITS associations. In total 75 responses were obtained from 27 countries spanning five continents, including Russia, Iran, Botswana, USA, South Korea, Mexico and European countries. The broad categorisation of the sample by country was: USA (n=12), UK (n=12), EU27 not UK (n=27) and International not USA (n=24). The questionnaire comprised 41 questions in a mixture of multiple-choice and free text format. 30 complete questionnaires were returned, with partial responses from the remaining 45 respondents. Whilst anonymous, country level of ITS expertise and occupation category was requested. The broad areas of questioning were as follows (see Annex A for further detail):

- ITS policy and priority: awareness of ITS in strategies, awareness of deployment plans, current and future strategy ITS priorities
- Uptake of priorities for ITS: perceptions of effectiveness of alternative measures, barriers to uptake, examples of transferability
- Skills and training needs: priority areas and potential delivery mechanisms
- Future research priorities for ITS

- Evidence of the Impacts of ITS: environmental and energy related, safety and personal security related (the number of responses here were low but used as a basis to research and inform Table 1).

3.2 Overview of survey findings

As anticipated, respondents were knowledgeable in the field with over 90% reporting that they had a ‘good awareness of ITS alternatives, direct involvement in an ITS scheme, research or development’. From the 75 respondents, approx 40% stated that their international, national or regional strategy already embodied ITS technologies in order to address one of more policy priorities, with around 50% stating it did not and 10% being unsure. Subsequent questions concerned the current strategy and therefore responses were limited to around 40% of the sample. Respondents were asked to give a score for the extent to which the ITS technologies were a priority in delivering a range of efficiency, economic and wider societal objectives including ‘protecting local environment’ and ‘minimising climate impacts’ . Scores were on a scale from 0= not a priority to 5= a strong priority with equal scores allowed and repeated for both current transport strategies and perspective on future strategies. The average scores (by stakeholder type, coded a-e) for ITS to support local environment, carbon and economic growth for current and future strategies in Table 3a and Table 3b below. A summary of the statistical significance of the observed differences in mean scores, based on 1-tailed t-tests of the null hypothesis of equality in underlying means, is given in Table C1 (Annex). Outcomes that are not statistically significant indicate a degree of consensus and as of much interest as significant differences. From Tables 3a, 3b and C1 the following points arise:

- ITS was seen as a priority delivery mechanism to support economic growth in current strategies, but for future strategies ITS was perceived as a priority tool to support climate impact reduction
- Academics were more inclined to prioritise ITS to support climate benefits than other stakeholder types, whilst regional/governmental stakeholders were most inclined to prioritise ITS to support economic growth

- The differences between stakeholder priority scores in current strategies demonstrated more statistically significant results than those in future strategies, indicating a greater consensus across stakeholder types for future priorities.

To investigate whether any differences in ITS priority scores could be attributed to the national context to which the strategy related, the responses were reported by broad country categorisation. The results (Figure 1) indicated noticeable differences:

- USA responses show score increases between current and future strategies for all three impact categories. Unlike other national responses, the largest increase is in the ITS priority score for economic growth. This is in particular contrast to the corresponding UK score which shows a noticeable decrease and may reflect prevailing concerns for the USA economy following the global crisis
- For EU27 responses, the ITS priority scores generally mirror those for the UK, but are overall much lower than either the USA or UK for all impacts. The scores are closely followed by those for International countries. Alongside the UK case, International priorities for economic growth show less of an increase for the future strategy than the other two impacts.

An overview of the relative positioning of all 15 priority categories is given in Figure 2 and noticeable shifts can be seen between current and future ITS priorities. Explicit prioritisation of economic growth, climate or environmental impacts related to ITS is low in current strategies with a tendency to increase in future - however there is strong prioritisation of the ITS impacts that indirectly engender both environmental and economic sustainability (see Annex A, table A1). There is little published comparative research to date, however a small sample cluster analysis of ITS added value services [77] highlighted benefits related to safety and security, information and management. As only 2 of 72 value options reflected environmental impacts, the relevance to the research here may be limited.

Finally, the priorities for future research and perceived efficacy of measures in enabling greater uptake of ITS are reported (Figures 3 and 4). Whilst not specifically linked to the three impacts under scrutiny here, they highlight the need for greater understanding and demonstration of the benefits of ITS generally. This resonates with the findings in Table 1 and the fundamental structure of many ITS schemes (ie the linking of different and potentially complex technologies), yielding high variation in impact evidence. Generalisation, transferability and rigour to support the decision making context are not yet established, also giving rise to a perceived need for better evidence. Financing mechanisms are a further main priority (Figure 4). Whilst substantial funds have been channelled into research programmes for sustainable transport solutions, more immediate concerns like safety and congestion have received greater attention and resources [78]. However it may be argued that this is also closely related to the need for rigorous supporting evidence on the wider range of ITS benefits – a key input to many economic appraisal approaches. According to [79], public policy intervention will be required for low carbon technologies to overcome the technology 'valley of death' between research and eventual deployment. Government led financing actions may be one manifestation of such an intervention.

Table 3a: Mean (S) ITS priority by stakeholder: current transport strategies
(0= no priority, 5= strong priority)

Perceived ITS priority in existing strategies	Transnational Government/ co-ordinator (n=5)	National Governmental/ co-ordinator (n=10)	Regional/local governmental (n=8)	Transport supplier/ Consultancy/ Other (n=8)	Academic/ research (n=8)	Overall Mean score
Improve local environment	3.00 (1.41)	3.10 (0.88)	3.38 (1.19)	3.25 (1.49)	2.50 (1.31)	3.05
Minimise climate impacts	2.40 (1.14)	2.90 (1.20)	3.63 (0.92)	2.63 (1.51)	3.13 (1.55)	2.94
Economic growth	3.00 (1.22)	3.20 (1.55)	4.25 (1.16)	2.78 (1.72)	3.00 (1.60)	3.25

Table 3b: Mean (S) ITS priority by stakeholder: future transport strategies
(0= no priority, 5= strong priority)

Perceived ITS priority in future strategies	Transnational Government/ co-ordinator	National Governmental/ co-ordinator	Regional governmental/ Local	Transport supplier/ Consultancy/ Other	Academic/ research	Overall Mean score
Improve local environment	3.00 (1.41)	3.00 (1.22)	3.88 (0.64)	4.00 (0.93)	3.88 (1.13)	3.55
Minimise climate impacts	4.00 (0.82)	3.67 (1.22)	3.22 (1.64)	3.75 (1.04)	4.13 (1.25)	3.75
Economic growth	3.50 (1.00)	2.78 (1.72)	4.00 (1.20)	3.13 (1.64)	4.00 (1.41)	3.48

Figure 1: ITS priority scores by country classification

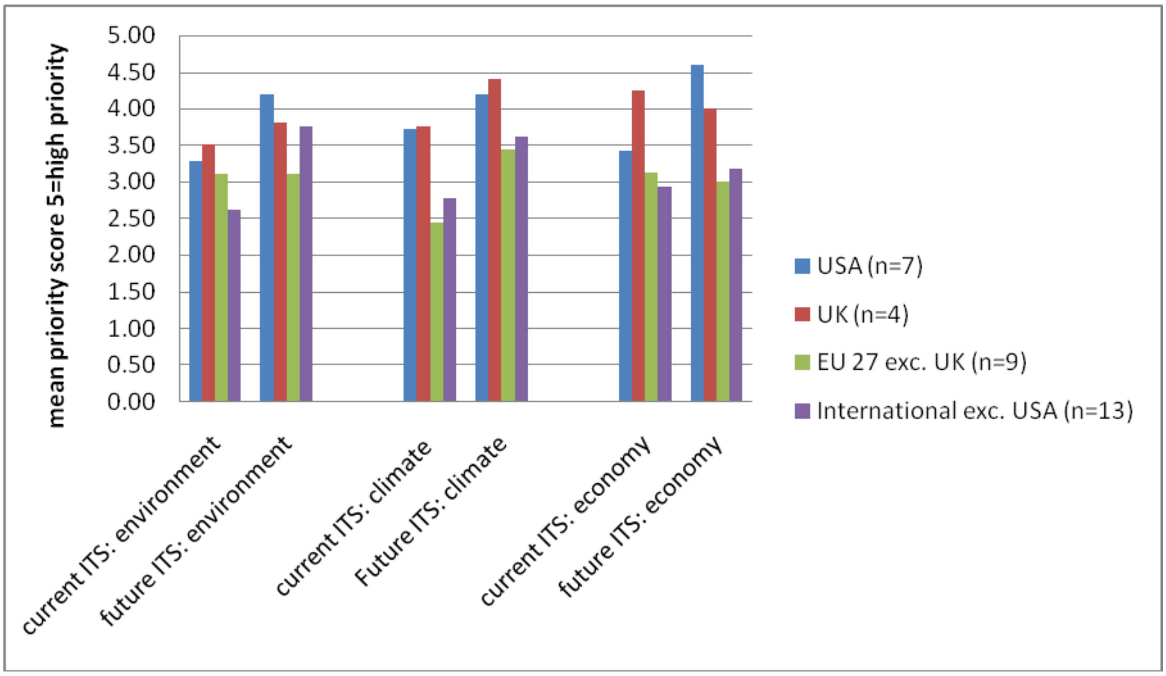


Figure 2: Relative ITS strategy priorities for all categories

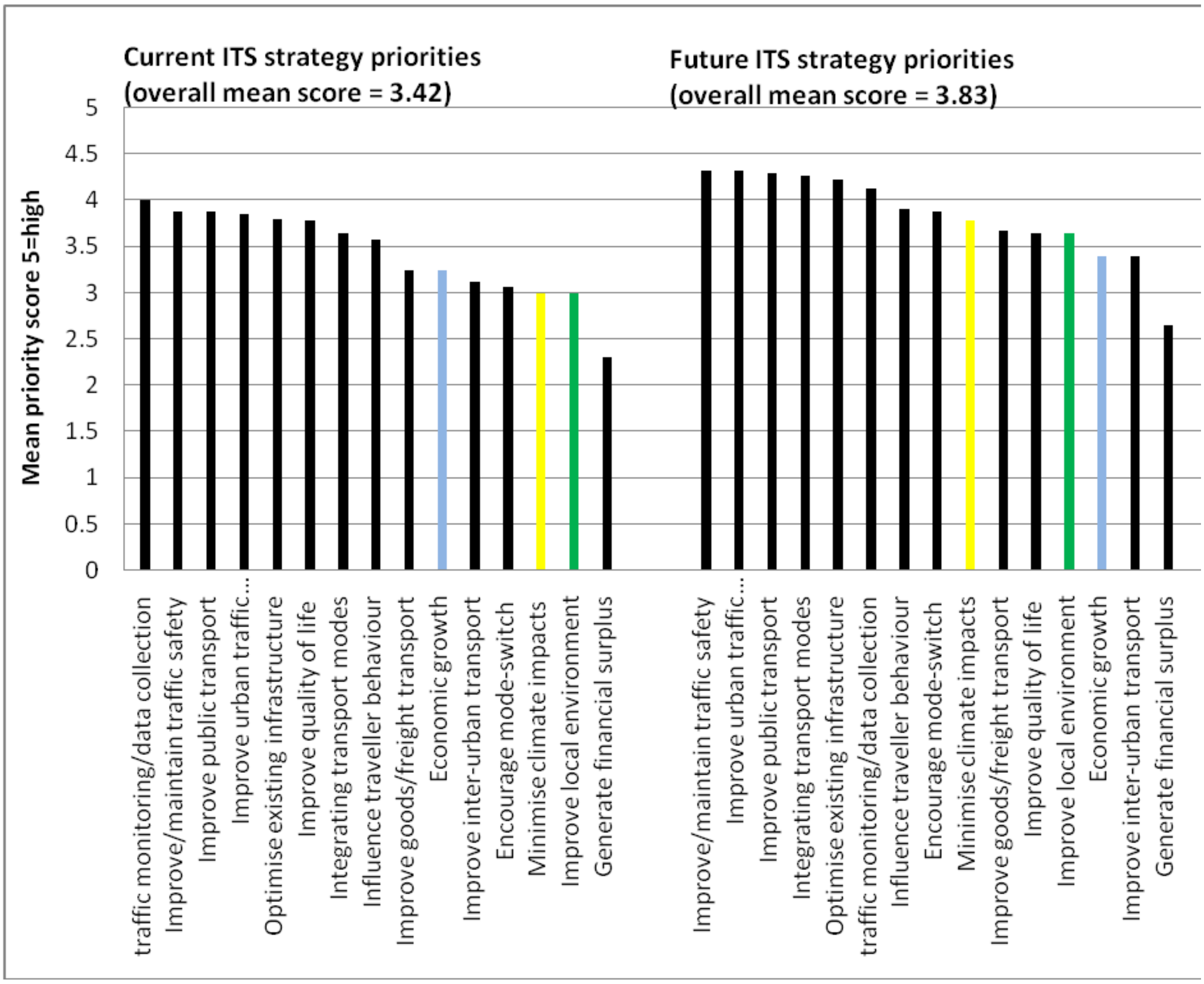


Figure 3: Future research priorities for ITS systems

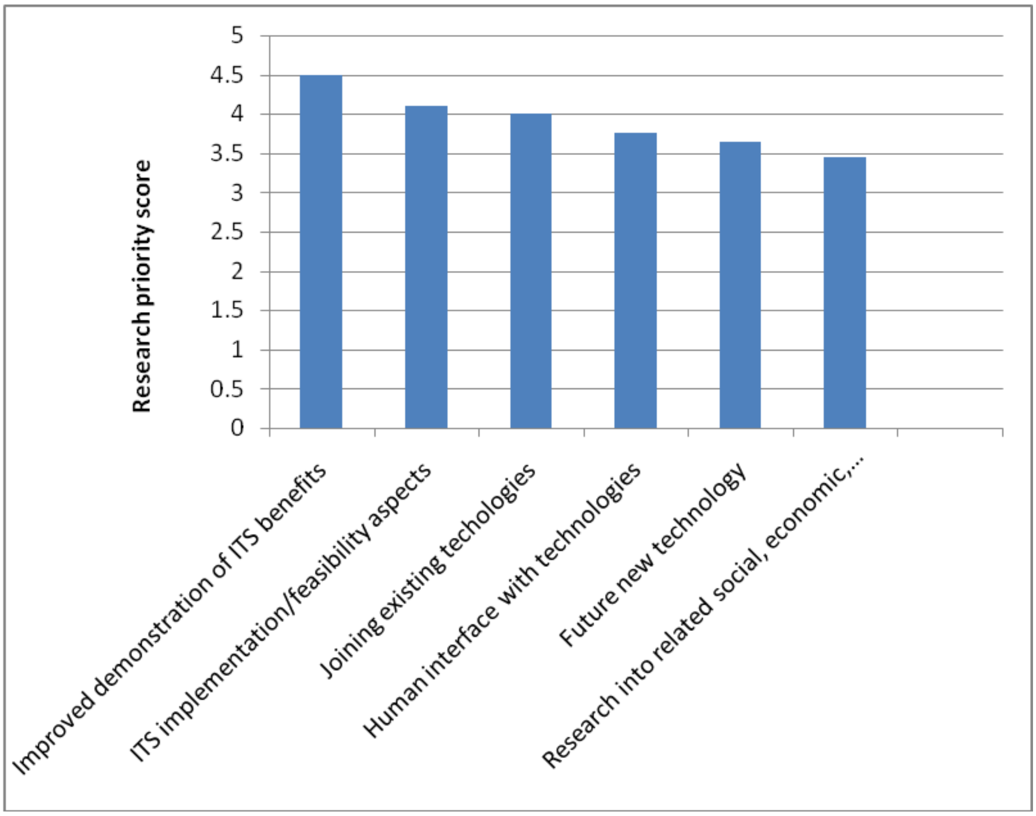
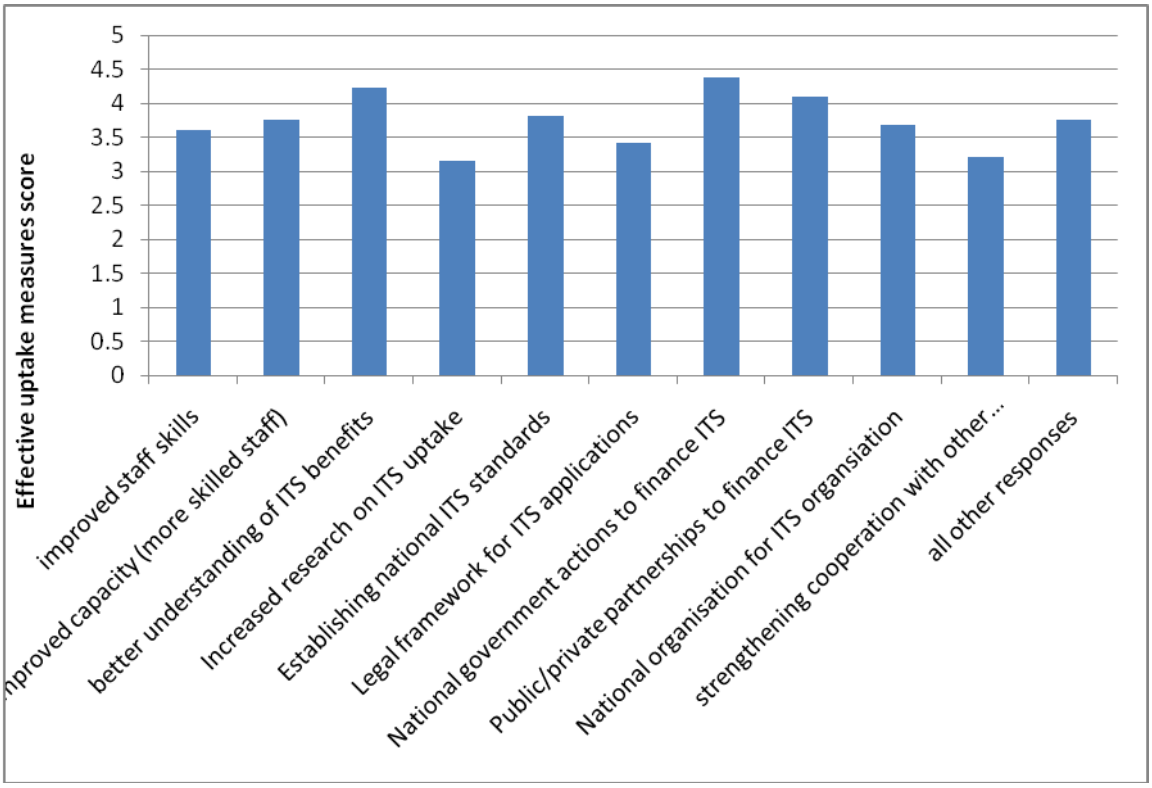


Figure 4: Prioritisation on effective measures to support ITS uptake



4. Results - Propensity models for ITS prioritisation

The final aspect to the research concerned fitting propensity models using the survey data and following the methodology outlined in section 2. Two types of independent variables were used in modelling:

(1) contextual variables relating to relevant attributes of the country (numeric indicators)

(2) predictors arising from the survey (categorical variables)

Independent contextual variables that were considered to be related to the transport infrastructure for the country concerned were sourced from the World Bank on-line databank http://data.worldbank.org/. A correlation analysis was undertaken with the response data together with consideration of the relevance of the variables to the research questions. This resulted in the selection of a short list of five contextual variables as input into the modelling stage of the research:

(1) Vehicle Density (Vehicles per km of road, 2008),

(2) Internet Users (per 100 people, 2010),

(3) High technology Exports (% of manufactured exports, 2010),

(4) Carbon per capita (CO_2 emissions, metric tons, 2008) and

(5) The World Bank Logistics Performance Indicator, LPI.

The most recent data available at the time of analysis was used, however this was 2008 rather than 2010 for two variables. The second category of variables were those included in other sections of the survey, with 15 candidate predictor variables (for example: country type, level of ITS expertise).

The multinomial logistic modelling process was firstly undertaken on each of the two sets of independent variables separately, then subsequently in mixed combinations of 2-3 contextual and survey-generated predictors. The initial separation was to avoid potential confounding effects but the modelling diagnostics suggested these were not sufficiently present to impact on the outcomes. A maximum of 3 independent variables were used to roughly preserve the ideal ratio of cases to independent variables of at least 10:1 [80]. Coefficients were estimated through an iterative maximum likelihood method using standard statistical software (SPSS). Goodness of fit criteria included the deviance and the significance of the χ^2 statistic for model fit (using significance level 0.05). The final models forms are given in tables 4-6, whilst summaries of the statistics indicating goodness of fit and adequacy of the models are in tables 7-9. Following the iterative process of model fitting it is interesting to note that only the contextual independent variables were included in the final models, with the survey variables proving weak predictors.

Table 4: Final propensity model: ITS priority on Future environment

Future ITS strategy: Improve/protect local environment		B	Std. Error	Wald	df	Sig.	Exp(B)
weak priority	Intercept	.012	2.180	.000	1	.996	
	Vehicle density	.004	.023	.039	1	.844	1.004
some priority	Intercept	2.220	1.958	1.285	1	.257	
	Vehicle density	-.015	.023	.442	1	.506	.985
moderate priority	Intercept	4.400	2.042	4.641	1	.031	
	Vehicle density	-.050	.028	3.136	1	.077	.951
strong priority	Intercept	4.865	2.115	5.290	1	.021	
	Vehicle density	-.070	.033	4.428	1	.035	.932

Table 5: Final propensity model: ITS priority on Minimising Climate impacts

Future ITS strategy: Minimise climate impacts		B	Std. Error	Wald	df	Sig.	Exp(B)
some priority	Intercept	1.579	2.402	.432	1	.511	
	High technology exports	-.127	.115	1.235	1	.267	.880
	co2 emissions	.064	.137	.215	1	.643	1.066
moderate priority	Intercept	3.013	2.213	1.854	1	.173	
	High technology exports	-.250	.121	4.261	1	.039	.779
	co2emissions	.139	.136	1.056	1	.304	1.150
strong priority	Intercept	.967	2.304	.176	1	.675	
	High technology exports	-.027	.097	.078	1	.780	.973
	co2emissions	.046	.116	.158	1	.691	1.047

Table 6: Final propensity model: ITS priority on Economic growth

Future ITS strategy: Economic growth		B	Std. Error	Wald	df	Sig.	Exp(B)
very low priority	Intercept	-1.422	5.404	.069	1	.792	
	Vehicle density	.030	.042	.514	1	.474	1.030
	Internet users	.015	.068	.049	1	.825	1.015
weak priority	Intercept	-1.777	5.790	.094	1	.759	
	Vehicle density	.028	.042	.437	1	.509	1.028
	Internet users	.018	.073	.060	1	.807	1.018
some priority	Intercept	1.231	4.642	.070	1	.791	
	Vehicle density	.012	.042	.074	1	.785	1.012
	Internet users	-.005	.060	.008	1	.930	.995
moderate priority	Intercept	2.096	4.506	.216	1	.642	
	Vehicle density	-.018	.045	.161	1	.689	.982
	Internet users	.003	.058	.002	1	.965	1.003
strong priority	Intercept	2.271	4.357	.272	1	.602	
	Vehicle density	.008	.041	.043	1	.837	1.008
	Internet users	-.005	.056	.007	1	.932	.995

A likelihood ratio test is used to assess the strength of the relationship between the independent variable and the dependent variable. The Wald test [81] then evaluates whether or not the independent variable is statistically significant in differentiating between the reference category and other categories. This is shown by the 'significance' columns in tables 4-6 where a value ≤0.05 indicates a variable is statistically significant in differentiating between the current and reference category. The interpretation of the statistics generated is as follows:

- For model 1, the variable Vehicle density had a significant relationship with the independent variable (p= 0.021, <0.05) and was able to differentiate between the category ITS as a 'strong priority' vs ITS as 'no priority' (sig = 0.035, <0.05, table 4). The interpretation is that an observed unit increase in national vehicle density results in a reduction in the probability of ITS being considered a high priority for future environmental strategy of 6.8% (calculated by (0.932-1.00)*100%, from table 4). This finding may be intuitively explained as representing the tension between the need for system efficiency and environmental concerns

- For model 2, the variable ‘high technology exports’ had both a significant relationship with the independent variable (p= 0.036, <0.05) and was able to differentiate between the category ‘moderate priority’ vs ‘no priority’ (sig = 0.039, <0.05, table 5). By way of interpretation, on observed unit increase in high technology exports results in a reduction in the probability of ITS being considered a moderate priority for minimising future climate impacts of 22.1% (calculated by (0.779-1.0)*100%, table 5)
- For model 3, whilst the model as a whole is effective in terms of classification success (discussed further below), none of the independent variables passed both statistical significance in the relationship with the dependent variable and the Wald test in differentiating between categories.

In terms of reporting the goodness of fit of models 1-3, overall, values of correlation statistics such as r^2 employed in linear regression analysis are inappropriate for multinomial logistic modelling, therefore other measures of accuracy and goodness of fit are used. To evaluate the accuracy of the model, the proportional by chance accuracy rate was calculated by summing the squared marginal proportion for each category in the sample (table 7). The commonly accepted benchmark for success of 25% improvement in by-chance accuracy was used [82]. For example, for model 1 the ‘by chance’ criteria benchmark for success is given by $1.25*(0.074^2+0.111^2+0.222^2+0.333^2+0.259^2) = 30.6\%$. The model is therefore deemed a good fit if the classification success rate is greater than 30.6%, where the classification success is calculated by the overall percentage of the data allocated to the correct classes by the model.

Table 7: Cases and marginal % by model

Model/ ITS Priority	Model 1: Local environment n (marginal %)	Model 2: minimise climate n (marginal %)	Model 3: Economic growth n (marginal %)
Not a priority	0 (0.0%)	0 (0.0%)	1 (3.7%)
very low priority	2 (7.4%)	0 (0.0%)	4 (14.8%)
weak priority	3 (11.1%)	5 (16.1%)	3 (11.1%)
some priority	6 (22.2%)	5 (16.1%)	4 (14.8%)
moderate priority	9 (33.3%)	9 (29.0%)	5 (18.5%)
strong priority	7 (25.9%)	12 (38.7%)	10
Valid	27	31	27

Table 8: Final classification fit for ITS future strategy

ITS future strategy propensity model:	Model 1: Future Environment	Model 2: Minimise climate	Model 3: Economic growth
ITS Not a priority	.0%	.0%	.0%
ITS Very Low priority	33.3%	.0%	25.0%
ITS Weak priority	66.7%	66.7%	.0%
ITS Some priority	55.6%	75.0%	.0%
ITS Moderate priority	42.9%	.0%	20.0%
ITS Strong priority	.0%	.0%	90.0%
By chance criteria/model classification success	30.6%/48.1% **(+17.5%)**	35.7%/48.4% **(+12.7%)**	28.6%/40.7% **(+12.1%)**

From table 8, it can be seen that the classification success rate for each of the three models substantially exceeds the 'by chance' criteria for goodness of fit. Model 1 (Environment) has the highest relative classification success rate, exceeding the 'by chance' criteria by +17.5%, with model 2 and model 3 achieving similar levels of relative success at approximately +12% compared with the by chance criteria.

Model goodness of fit is also seen from the Pearson and Deviance statistics (table 9). The null hypothesis is that the model adequately fits the data. If the significance value is small (less than 0.05), then the model does not adequately fit the data. From table 9, the values for each model on each statistic are substantially greater than 0.05 and the null hypothesis of an adequate model fit is upheld in each case.

Table 9: Model goodness of fit

	Model 1: Environment Goodness-of-Fit			Model 2: Low Carbon Goodness-of-Fit			Model 3: Economy Goodness-of-Fit		
	Chi-Square	df	Sig.	Chi-Square	df	Sig.	Chi-Square	df	Sig.
Pearson	42.395	40	.368	43.875	48	.642	66.702	60	.258
Deviance	33.375	40	.761	43.701	48	.650	51.471	60	.776

A summary of the main outcomes is as follows:

- Propensity models have been fitted for each of the dependent variables with varying degrees of fit, however the by-chance criteria is substantially exceeded in each case
- A final model for each dependent variable has emerged based on contextual independent variables only. This is advantageous in that the models could be applied with other countries or regions based on the availability of the input data, which in practice should be readily available
- Vehicle density features in the models for ITS priority on both environment and economic growth. This is an interesting outcome which supports the main proposition of the research that ITS systems can achieve a win-win gain on both environmental and economic sustainability. The negative sign associated with the variable is worthy of further investigation, but may reflect a pressing need to achieve transport system efficiency for some over saturated highways.
- High technology exports and CO2 emissions per capita emerge as key input variables to the propensity model for ITS priority on climate impacts. This has a ready intuitive interpretation related to recognition of an existing national objective on climate impacts.

The models offer a different approach to understanding the likely role of ITS systems as a policy tool internationally. They can be used to identify candidate countries where the level of technology development, transport system and environmental context are conducive to future ITS uptake, an outcome which would be of interest to the ITS supply sector as well as transport policy and decision makers. Similar models could be developed in alternative transport or wider policy sectors, for example with a focus on other types of technology or solutions. As a result the findings are of relevance across the policy science community and industry, being of use for sustainable transport policy development at both national and regional level.

5. Conclusions and discussion

The goal of this research was to better understand the propensity for low carbon benefits from deployment of ITS by addressing two research questions: firstly whether the evidence supports the notion that ITS systems can be implemented and operated in such a way to generate environmental benefits; and secondly whether policy priorities amongst national and international stakeholders reflect a propensity for ITS deployment in order to yield those benefits.

In response to the first research question, a review has demonstrated how ITS systems can provide the technological wherewithal to improve the efficiency of vehicles and existing transport infrastructure, and also support behavioural change. ICT facilitated remote communication can reduce the need for invariably carbon intensive physical transport movement, but if physical travel is unavoidable then ITS can reduce the carbon intensity of negotiating distance, however:

- The evidence base on the real-life environmental and climate related impacts of ITS systems isn't yet at the required level of detail, or routinely and rigorously collected, to fully support investment and related policy decisions.

The second research question has been addressed by the development of propensity models for the prioritisation of ITS, which sit within a broader historical context of technology schemes in national, regional and local strategy. The historical case study related to the UK policy landscape has indicated how wider political priorities can enable low carbon technology innovation (such as ITS) to transcend the technology 'valley of death' and become integrated within the existing transport system. The main forward challenges emerge as:

- An acknowledgement of the enduring strategic priority of both economic and environmental sustainability, particularly in the post economic crisis period.
- coherent cross-sectoral policies at national (and where appropriate international) level, that allow full evaluation of ICT related measures which impact beyond the transport sector
- a governance structure that is sufficiently flexible to support financial investment and maintenance that may vary in scale between different types and configurations of ITS.

The realisation of any potential ITS impacts is predicated on the notion that ITS schemes are already prioritised in national and regional strategies and therefore also part of the priority agenda of a variety of stakeholders from senior policy and decision makers to local transport and governmental providers. It may be argued that without recognition of both the environmental and economic potential for ITS there is less likely to be a full consideration of the benefits in evaluating ITS and alternative schemes, that the roll out of ITS is likely to be slower and more piecemeal, and that financial and investment decisions on large schemes will be on a less rigorous basis.

The findings reveal the need for a better understanding of ITS benefits - communicating cross-sectoral synergies (in terms of benefits and solutions) is also a necessary element to this. The cross-sectoral efficacy of ITS would appear to be strong given that it can potentially contribute to significant improvements in road safety ([83]; [84] and the economy ([85], [86]).

The key outcomes of the research however arise from the propensity models for future ITS prioritisation based on primary international data. Whilst there are numerous examples of the use of propensity models to understand individual choices and market share, to the best knowledge of the authors this is the first application of these models in the context of strategic transport policy. Three variables, ie vehicle density, high technology exports and CO2 are identified as key drivers in the future prioritisation of ITS to achieve both environmental and economic gains.

The models offer a novel policy tool that may be used in practice in sustainable policy development at both national and regional level, for example in identifying countries and regions where more targeted and tailored support to the development of ITS strategies (within the context of wider transport and other sectoral strategies) could take place.

A wider analysis of strategy priorities in the dataset has revealed notably differences between different countries and stakeholders acting within different parts of the transport sector. However there is a greater convergence in the future outlook than is seen in the current perspectives.

Finally, it is of course highly unlikely that comprehensive implementation of ITS will prove to be a sufficient measure for effective climate change mitigation and adaptation in the transport sector. Technological innovation has and will be essential for achieving a sustainable transport system, yet, it is unlikely to provide a silver bullet. A policy mix that encourages behavioural change through taxation, carbon pricing and regulation will be required, as will a more sustainable approach to spatial planning, vehicle and infrastructure design.

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Vitae

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Annex Table A1: ICT/ITS classifications and applications

	ICT as complementary to the transport system	ICT complementary to and embedded within transport system	ICT embedded in the transport system	Summary contribution to carbon reduction
(1) ICT systems and platforms	• Email, cloud computing, central databases, • videoconferencing, Skype and other online video facilities, • online shopping and services, • car-sharing schemes, • social networks	• Smart card payment		• Allows trip substitution(demand reduction) • Adaptation during climate extremes (remote transactions) • Pre-trip planning – greener travel choices • Pre-payment and en-route tolling to manage demand and mitigate environmental impacts of congestion
(2) Transport network management system		• Parking information and management • Data collection and monitoring • Payment systems (i.e. smartcharging)	• Urban Traffic Control (UTC) • Variable Message Signs (VMS) • Adaptive Traffic Signal Control and speed limits • Access Control (e.g. rising bollards) • Lane control and Active Motorway Management • Automatic Number Plate Recognition (ANPR)	• Mitigates environmental impacts of congestion by managing excess demand on parts of the system. • Reduces individual vehicle emissions by speed smoothing • Reduces overall demand through economic measures. • Supports adaptation during climate extremes by diversion and route management.
(3) Traveller information systems:		• Advanced Traveller Information Systems • Route Guidance navigation systems		• Supports adaptation to climate extremes with advance information on the state of the network. • Mitigates environmental impacts of congestion by managing excess demand on parts of the system.
(4) Advanced public transport (PT) systems	• Multimodal Trip Planning	• Passenger Information Systems • Electronic Fare Payment • Priority and Dedicated lanes.	• Automatic Vehicle Location (AVL) • Demand Responsive Management (DRM) • Lane Enforcement • Security enhancement (e.g. CCTV)	• Enhanced PT, prior information and pre-payment options encourage mode shift from private motor vehicle with ensuing environmental benefits of reduced congestion. • Enforcement systems maintain expected environmental and other benefits from infrastructure improvements such as

				dedicated lanes.
(5) In-Vehicle control and performance systems		• ECO-driving	• Adaptive Cruise Control, Intelligent Speed Adaptation • Collision Avoidance • Vehicle Platooning • Electronic Vehicle (EV) battery charging and storing	• Directly impacts on driver behaviour and performance of the vehicle to reduce emissions • improve fuel/energy use and maintain safety.

Annex B1: Summary of relevant survey questions:

Q8. In the current ITS strategy, which are of priority in deploying ITS (either alone or as part of a package of measures)? (rate 0= not a priority to 5 = strong priority, equal ratings allowed, pick list below)

Q11. In any future ITS strategy, in your opinion which of the following should be priority in deploying ITS (either alone or as part of a package of measures)? (rate 0= not a priority to 5 = strong priority, equal ratings allowed, pick list below)

traffic monitoring/data collection

Improve/maintain traffic safety

Improve public transport

Improve urban traffic management

Optimise existing infrastructure

Improve quality of life

Integrating transport modes

Influence traveller behaviour

Improve goods/freight transport

Economic growth

Improve inter-urban transport

Encourage mode-switch

Minimise climate impacts

Improve local environment

Generate financial surplus

Q13 In your view, what would be the most effective measures in promoting greater uptake of ITS? (Rate on a scale 0 = not effective to 5= highly effective, equal ratings allowed) (pick list below)

improved staff skills

improved capacity (more skilled staff)

better understanding of ITS benefits

Increased research on ITS uptake

Establishing national ITS standards

Legal framework for ITS applications

National government actions to finance ITS

Public/private partnerships to finance ITS

National organisation for ITS organisation

strengthening cooperation with other countries

all other responses

Q18 Please identify and rate the research needs below (rate 0= not important to 5 = highly important, equal ratings allowed):

Improved demonstration of ITS benefits

ITS implementation/feasibility aspects

Joining existing techologies

Human interface with technologies

Future new technology

Research into related social, economic, political aspects

All other responses

Annex Table C1: Significance of test outcomes

Hypothesis test on mean score	Priority category for ITS	t-significant at 10% (p value)	t-significant at 5% (p value)
H0: no difference in mean score by stakeholder role type (within **current** strategy)	Within category: Improve/protect local environment	(c) vs (e) (0.092)	None significant at 5%
	Within category: Minimise climate impacts	(c) vs (d) (0.065)	(a) vs (c) (0.028)
	Within category: Local, Regional or National Economic growth	(b) vs (c) (0.066)	(a) vs (c) (0.046) (c) vs (d) (0.029) (c) vs (e) (0.048)
	Between categories: (all between categories tested by all stakeholder roles)	None significant at 10%	None significant at 5%
H0: no difference in mean score by stakeholder role type (within **future** strategy)	Within category: Improve/protect local environment	(a) vs (c) (0.08) (a) vs (d) (0.083) (b) vs (e) (0.074)	(b) vs (c) (0.005) (b) vs (d) (0.039)
	Within category: Minimise climate impacts	(c) vs (e) (0.069)	None significant at 5%
	Within category: Local, Regional or National Economic growth	(b) vs (c) (0.057) (b) vs (e) (0.066)	None significant at 5%
	Between categories: (all between categories tested by all stakeholder roles)	None significant at 10%	None significant at 5%
H0: no difference in mean score by stakeholder role type (between **current** and **future** strategy)	Within category: Improve/protect local environment	None significant at 10%	None significant at 5%
	Within category: Minimise climate impacts	(b) (0.093) (d) (0.0517) (e) (0.089)	(a) (0.0254)
	Within category: Local, Regional or National Economic growth	None significant at 10%	None significant at 5%

Key

Transnational Government/ co-ordinator (a)	National Governmental/ co-ordinator (b)	Regional governmental/ Local (c)	Transport supplier/ Consultancy/ Other (d)	Academic/ research (e)