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Modelling uncertainty in the sustainability of Intelligent Transport Systems for highways using probabilistic data fusion

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ABSTRACT

The implementation of ITS to increase the efficiency of saturated highways has become increasingly prevalent. It is a high level objective for many international governments and operators that highways should be managed in a way that is both sustainable i.e. environmental, social and economically sound and supportive of a Low-Carbon-Energy Future. Some clarity is therefore needed to understand how Intelligent Transport Systems perform within the constraints of that objective. The paper describes the development of performance criteria that reflect the contributions of Information Communication Technology (ICT) emissions, vehicle emissions and the embedded carbon within the physical transport infrastructure that typically comprises one type of Intelligent Transport System i.e. Active Traffic Management – a scheme that is used to reduce inter-urban congestion. The performance criteria form part of a new framework methodology 'EnvFUSION' (Environmental Fusion for ITS) outlined here. This is illustrated using a case study where environmental performance and pollution baselines (collected from independent experts, academic, governmental sources and suppliers) are processed using an attributional Lifecycle Assessment tool. The tool assesses the production and operational processes of the physical infrastructure of Active Traffic Management using inputs from the 'Ecoinvent' database. The ICT component (responsible for data links) is assessed using direct observation, whilst vehicle emissions are estimated using data from a National Atmospheric Emissions Laboratory. Analytical Hierarchy Process and Dempster–Shafer theory are used to create a prioritised performance hierarchy: the Intelligent Transport Sustainability Index, which includes weighted criteria based on stakeholder expertise. A synthesis of the individual criteria is then used to reflect the overall performance of the Active Traffic Management scheme in terms of sustainability (low-carbon-energy and socio-economic) objectives.

1. Introduction

1.1. Problem rationale

The potential global warming crisis has called for technology within the transport sector which is able to produce efficiency benefits for the transport system, but which operates in such a way that it is not detrimental to the local and global environment. 'Intelligent Transport System' (ITS) is a broad term used to describe systems based on a combination of Information Communication Technology, positioning and automation technologies (Psaraki et al., 2012). In terms of road transport, their aim is to maximise the operational capacity of highways, offering enhanced performance within the transport network so that the need to construct additional road capacity can be avoided (Deakin et al., 2009; Žilina, 2009). These technologies can also serve to reduce emissions, maintain or increase safety, generate societal benefits (such as accessibility), maintain compliance and reduce economic expenditure. However, little is known about the actual contributions of Intelligent Transport Systems in highways to climate change mitigation of private vehicle transport.

The concept of sustainability has been widely applied and usually attempts to integrate environmental social and economic concerns although there is still ambiguity in its terms of reference (Hilty et al., 2006; Matthews et al., 2007). In this research a method to assess the performance (in terms of sustainability) of an ITS scheme is developed, where sustainability is used to reflect

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environmental, economic and social (safety and scheme compliance) terms. A range of both quantitative and qualitative indicators is used to reflect these three aspects, as defined in subsequent sections of the paper. In order to assess the sustainability of ITS, the emissions from ICT and infrastructure for their whole lifecycle need to be considered alongside the potential gains through increased traffic flow efficiency. ICT works as an enabler within ITS systems in order to improve the performance of the road network by improved control and supervision. According to Patey et al. (2008), no studies at that time had focused on the embedded lifecycle emissions in the construction, operation and disposal of ITS schemes. In addition, there is no evidence to date of a framework designed to assess the combination of environmental performance with the wider impacts (such as safety and social aspects) of ITS technology.

The environmental impacts of ITS also sit alongside the carbon offset that these technologies generate by improved management of the transport network (i.e. through smoother flowing traffic, reduced congestion overall). Using current methods, the ICT support infrastructure, physical transport infrastructure and the operational assessment of vehicle throughput have all been calculated in isolation. Without a calculation of the overall emissions generated there is the risk that some elements remain unaccounted for, for example 'cause and effect' chains and hidden consequences. The aim of the research here is to extend the scope of the emissions accounted for to include both the potential carbon reduction from operating an ITS scheme and the embedded emissions from constructing and implementing the scheme.

The paper therefore introduces a 'unified' environmental and socio-economic framework, covering both current ICT standards and transport impact assessment. It is also able to take inputs from various deficient or uncertain data sources in order to quantify overall performance against sustainability criteria. The method is illustrated using a case study assessment of one particular type of ITS: the UK Highways Agency's active traffic management (ATM) scheme as implemented in the Birmingham area on a 16.4 km intercity stretch of highway.

Measures which were implemented are temporary shoulder use, lane enforcement and queue warning systems. Furthermore the framework has been developed in a flexible way so that it may be applied with all forms of inter-urban ITS schemes internationally.

1.2. The introduction of Active Traffic Management

Active Traffic Management (ATM) is an international 'smarter highways' concept consisting of a collection of various systems working to reduce road congestion and improving traffic flow. It includes a feedback process of traffic data to the central highway control centre, which (following data analysis), allows human operators to implement dynamic changes to the highway signs and controls in response to current conditions. ATM also supports operations planning, which includes evaluating the expected road network performance under various future scenarios, such as increases in demand, lane closures, special events, etc. It is then possible to develop control strategies that may improve performance and test these strategies in terms of their cost and the benefits they bring under these future scenarios. Finally, the decision support system can be run in real time, which includes filtering the measurement data, providing short term prediction of the traffic state, and selecting the best available control strategy for the next one or two hours.

ATM has been introduced in many countries worldwide for several reasons, but its primary role is to reduce traffic congestion. For example, in the UK by 2005 the road network operator's highway building allowance was £3 billion over budget, causing the Department for Transport to consider alternatives to further conventional highway widening schemes. In 2006, the successful trial near Birmingham (UK) of the M42 ATM on the 16.4 km stretch of road between junction 3a to 7 took place.

By 2008 this type of scheme became a necessity as road traffic in Great Britain had grown by 84 percent since 1980, from 172 to 318 billion vehicle miles (Department for Transport, 2008). The majority of the growth was in car traffic which had risen by 87 percent since 1980, from 134 to 250 billion vehicle miles.

In the USA, the Washington State Department of Transportation implemented their first enforceable ATM schemes in 2010 in the Seattle Metropolitan area with heavy fines if road users did not comply with the stated speed limits (WSDoT, 2012). ATM systems were activated on 11.6 km (7.2 miles) of the I-5 northbound carriageway in August 2010 and were expanded in 2011. The primary ATM strategies were ramp metering, queue protection, temporary shoulder running, junction control, and lane-specific signalling.

In Germany, the Federal Highway Research Institute reported demand on the network had increased and is expected to increase an additional 16 percent for passenger transport and 58 percent for freight transport by 2015 (Bolte, 2006). Their traffic management strategies include speed harmonisation, queue warning, temporary shoulder use, junction control, truck restrictions, ramp metering, dynamic rerouting, traveller information and truck distance tolling (Mirshahi et al., 2007).

The Netherlands have implemented similar systems, including the addition of a tidal flow scheme. The only tidal flow lane in the Netherlands was originally opened as a car-pool lane in 1992. This lane operates in the morning peak inbound direction toward Amsterdam and outbound in the evening. It is noteworthy that ATM is preferred by international transport decision makers to road widening due to the reduced costs compared with widening highways and the decreasing availability of land for use in widening schemes.

For example, the M42 scheme in the UK cost £96.4 million compared with the £500 million that it would have cost to widen a section of highway. It is estimated that it takes on average 10 years to implement a widening scheme as opposed to 2 years for ATM with variances in road type, region and country. The following sections of this paper introduce the EnvFUSION methodology and illustrate the process to estimate the environmental and socio-economic impact using the case study of ATM on the M42 stretch of road.

2. EnvFUSION methodology and related literature

EnvFUSION has been designed as an internationally relevant, integrated assessment approach as part of a wider strategic performance management framework (Kolosz et al., 2012). The framework consists of a Lifecycle inventory (LCI) and Lifecycle Impact Assessment (LCIA) (taking an attributional assessment approach), together with priority setting and pair wise comparison using an Analytical Hierarchy Process (AHP). Dempster–Shafer theory (DST) is used in combination with AHP to form an intelligent transport sustainability index using subjective quantitative probability assignment. The rationale for integrating AHP and DST is that conventional DST does not differentiate the importance of different types of evidence (Ju and Wang, 2012). In reality, the decisions to proceed with many transport projects are founded on some subjectivities, including the prioritisation by decision makers of various targets which aim to reflect socio-economic and environmental objectives. There are therefore advantages deriving the method so that it can reflect both objective quantitative and subjective qualitative data.