A Proposed Hybrid Evaluation Methodology for Intelligent Transport System Deployment

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Abstract
The rapid deployment of intelligent transport systems in practice requires serious evaluation of new construction projects. Traditional transportation evaluation methods are insufficient to capture the new features of intelligent transport systems, particularly the applications of recently developed information technologies. This research aims to develop a new conceptual framework to evaluate the social, economic and environmental impacts of intelligent transport systems deployment, with explicit consideration of impacts of information technologies on variant travel behaviours. The research will provide a systematic evaluation methodology to enable decision makers and publics better evaluating and understanding the social, economic and environmental benefits of implementation of intelligent transport systems.

1 Introduction
Intelligent transport systems (ITS) aims to apply information technology, communications technology, and sensor technology, including the internet to transportation systems to improve travel safety, reliability, and convenience, increase mobility, mitigate traffic congestion, and reduce fuel consumption and emissions. The targets of ITS development include a myriad of products and services such as intermodal transportation systems, intelligent traffic control systems, in-vehicle technologies, safety enhancement technologies, traveller advisory systems, and so on [1]. Intelligent transport systems show great potential in improving existing transportation systems. Although the concept of ITS debuted as early as the 1970s, many nations only started to apply intelligent transport systems to develop and improve the existing traffic control systems in the late of 1990s after the first ITS world congress in Paris in 1994. The use of car navigation systems and introduction of traffic information services on a large scale have started in industrial nations. Japan’s successful implementation of the vehicle information and communication system makes it the only country with the most advanced intelligent transport systems in actual operation in the world [2]. The continuing efforts to promote intelligent transport systems for solving transport problems have greatly accelerated the application of intelligent transport systems. Simultaneously, the recent boom in the information technologies has also sped up the deployment of...
intelligent transport systems, and allowed for more complexity in these intelligent systems than traditional transport systems. The rapid deployment of intelligent transport systems has led to an urgent need for a corresponding evaluation framework to tackle not only the social and economical impacts of deploying intelligent transport systems but also the environmental impact. Traditional evaluation methods are insufficient to deal with some newly developed features in intelligent transport systems, such as the impact of ITS on personal travel and commercial transport, the dynamic nature of the ITS, the adoption of new information technologies, and so on, especially the long-term impacts of ITS are not well addressed in the previous studies.

There is no doubt that intelligent transport systems represent the future of transportation systems and will eventually create a new industry sector with its implementation. The benefits and costs from intelligent transport systems deployment are examined from various aspects through the whole lifecycle of the ITS infrastructures, and variant user behaviours due to the implementation of information technology oriented ITS projects are explicitly considered in the proposed model. The research will fill a gap in the literature in evaluating the sustainability of practical intelligent transport systems, and provide a complex decision-making framework to provide decision makers and the public with a better understanding of the benefits of implementation of intelligent transport systems. Most evaluation frameworks available to date are based on cost-benefit analysis and multi-criteria analysis [3]. Although intelligent transport systems are a part of transportation infrastructure systems and traditional methods can be used to evaluate these systems, the traditional methods are too general in a number of aspects to be used in the evaluation of intelligent transport systems. Intelligent transport systems are information technology oriented, but the existing methods do not include such modules which are needed to properly analyse the growing impact of information technology in this field. Intelligent transport systems offer drivers a wide range of information on the performance of the transport system. This information has a great influence on the user behaviour, the existing evaluation framework, which is mainly based on cost-benefit analysis, is not suited to analysing these changes in user behaviour. In contrast to the traditional systems, intelligent transport systems are dynamic and interact with different agents, such as traffic information centre and vehicle users. Moreover, intelligent transport systems are market-driven compared with the other infrastructure systems. The government still plays a key role in building ITS infrastructure, such as traffic information and control centres, intelligent road systems, and so on. The successful implementation of ITS project also relies on the public understanding the benefits of the systems and being involved in their planning, which has seldom been considered in the past under the previous evaluation framework. The prospective evaluation is critical to transportation infrastructure construction such as intelligent transport systems because of the enormous and various long-term impacts. The aim of this research is to develop a hybrid evaluation methodology for the long-term social, economic and environmental impacts of intelligent transport systems deployment from the viewpoint of regional sustainability. The main modules in the new methodology will be described in detail in Section 3 following a key review on previous evaluation methods in the next section.

2 A review on evaluation methods for transportation infrastructure

Cost-benefit analysis is still the dominant method for evaluating transportation projects in developed countries despite its limitations [3, 4]. However, the situations in
developing countries are quite different. The World Bank uses an engineering-economic approach to evaluate all non-emergency road investments it supports through loans [5]. The current technical aspect of cost-benefit analysis in transportation projects are summarized based on the reports from different countries, including UK, Germany, France, Japan, USA, and EU [3]. In general, cost-benefit analysis or its variants serve as a guide in ranking the viability of projects. The framework of those methods comprise of the following parts: transportation demand forecast, value of time, traffic safety, environmental impacts, regional economic impacts, efficiency criteria, and financial analysis and post evaluation.

Although conventional stepwise method is widely used for transportation demand forecasting in practice, which leads to inconsistencies in the steps, there are several alternative methods for utilizing dynamic traffic assignment and simulation in considering the effects of congestions. Dynamics traffic assignments have been intensively studied in previous research [6]. It was presented how to evaluate the global traffic effect of a telematic route guidance system by using a developed simulation tool in [7]. A modelling framework was proposed for analysing the impact of transport measures in terms of network energy consumption and pollutant emission [8]. It utilized commercial transportation planning software and traffic simulation software to get network flow, speed, travel time, and so on. A generalized methodological framework was developed for evaluating the impacts resulting from transportation projects with a specific orientation to environmental impacts, which combines multiple-criteria analysis and cost-benefit analysis methods [9]. A new evaluation framework was developed based on a blend of several types of approaches [4]. The proposed multi-criteria decision support methodology is used for the evaluation of spatial-economic and environmental-economic policy issue. In Australia, a decision support system was developed to assist planner, regulators, transport operators and consultants to predict the impact of transport strategies and to make recommendations based on those predictions [10]. In connection with cost-benefit analysis in transport infrastructure, the ITS benefit priorities were investigated to identify what kind of costs and benefits should be included in the cost-benefit analysis [11].

3 Development of a hybrid valuation methodology

3.1 System structure building

Intelligent transport systems are complex systems, and it is quite important to find out what should be included or excluded in the evaluation system. This part is to build up the inputs and outputs of evaluation model, and identify the benefits and costs related to the implementation of ITS infrastructure. The ITS implementation may generate several effects, including engineering economics, transportation network performance, improvement of safety, environmental impact, regional economic impact, and efficiency and equity considerations. This module aims to develop a taxonomy of factors for evaluating new intelligent transport systems and develop performance indicators that give a measure of the effects on society, economics and environment. The factors are used to analyse both short-term and long-term impacts of ITS implementation. To date, relatively little is known about the long-term impacts due to the short history of intelligent transport systems. This issue will be solved by proposed system dynamics method in the evaluation model.

The requirement of first part is straightforward. The parameters related to network performance include travel time, traffic flow distribution, journey distance, speed, mode choice, and so on. The travel time saved by implementation of ITS projects is included in the
framework, including reduction of congestion. Two categories of time will be involved, namely working and non-working time. The improvement in convenience such as accessibility achieved through the implementation of intelligent transport systems is also included in the model. The cost of accidents is main index of traffic safety. It is expected that the ITS implementation will reduce accidents, and the measure of this improvement will be included into the framework. The assessment of environmental impacts mainly focuses on two aspects: air pollution and noise pollution. Those results will be obtained through an emission model, which provides the amount of pollutants and a dynamic traffic simulation model which will provide the flow distribution, queue length, time and location etc. The direct and indirect impact on the regional economy are one of the major indexes of the evaluation framework, such as the promotion of new industries brought about by the implementation of the ITS projects. Efficiency and equity of the ITS project are a concern not only for governments and decision makers, but also for the public. The explicit component focused on project evaluation should give the public good understanding of the ITS benefits, which is critical to the ITS implementation. Gaining support and recognition for ITS among the public is vital today as more than ever the public has become increasingly concerned about infrastructure projects and systems.

3.2 Evaluation model

3.2.1 Geographic information systems model: Geographic information systems (GIS) have been widely used in transportation research and management since the late 1980s, especially as GIS-transportation (GIS-T) data models were developed for sharing of data between GIS and transportation systems [12, 13]. Geographic information systems are also used for travel demand models [14]. The removal of selective availability by the American government on 1 May 2000 has lead to extensive use of global positioning system, one example of which is the rapid equipment of car navigation systems [15]. An integrated methodology combining both global positioning system and geographic information systems technologies was proposed to perform travel time studies [16]. Unlike previous studies, in which transportation systems are simplified as directed graphs without geographic information, the proposed model will exchange data directly with geographic information systems, and simulate users’ access of geographic information systems, so that the spatial distribution of the economic and environmental impacts of ITS project can be considered. The main purpose of this part is to provide spatial information for the other sub-models, all of which can be done by creating a user interface for the existing application programming interfaces of commercial geographic information systems software.

3.2.2 User behaviour model: The travel behaviours of users are not included in most of the above evaluation frameworks. Travel behaviour researchers often ignore the impact of information technologies, which is most important aspect of intelligent transport systems. The effects of future information technologies on travel behaviour are currently unknown, but it will be substantial in the future [17]. It is imperative to include travel behaviours to study the effects of queuing in the evaluation of intelligent transport systems, such as an advance traveller information system or an advanced traffic management system [18]. Moreover, there is increasing concern about environmental problems among the public. Previous research investigated the impact of travel behaviours and environmental concern in two empirical studies, and suggested that local implementation of new strategies to reduce private car driving might benefit from a better understanding of what will be accepted among the public [19]. Intelligent transport systems will greatly change the travel behaviours of users.
By incorporating route choice model and mode choice model, the proposed user behaviour model can predict the change of mode choice such as shifting from a private car to the public transit system, and the flow distribution on the network and over time. By interacting with system dynamics model, this sub-model will be capable of producing basic results for evaluation and further analysis, including reduction of congestion and pollution, saving of time, avoiding of accident, and so on.

3.2.3 System dynamics model: System dynamics has a long application history in the fields of transportation and traffic management, and the recent application of sustainable transportation systems has been reported. The underlying feature of system dynamics approach is its consideration of relationships between state and flow variables organized in feedback loops. In such a setting, the system dynamics approach is superior to the existing methods for the design and evaluation of a sustainable transportation system as it investigates the cause-and-effect relationship within an integrated system. In an economic sense, the approach allows one to model structural changes in the system as well as marginal changes, while the standard methodology only deals with marginal changes. The system dynamics method can be used to analyse the integrated system that includes the economy, society and environment. In comparison with the previous simulation methods, the system dynamics method can avoid time consuming computing and grasp the characteristics of feedback based on the interaction between travellers and ITS infrastructure, such as the transportation information and control centre. System dynamics is a heuristic modelling tool for studying real world problems and analysing behaviour under different real and simulated conditions. It can generate behaviour patterns to identify past performance and inferred future possibility, which is suitable to analyse the long-term impacts of ITS implementation that were not well addressed in previous methods. Another key feature of system dynamics is the interaction between the system and feedback from other parts. System dynamics has seen its application in sustainable transportation system [20]. By describing complex system by a simple differential equation over time, avoiding solving complex mathematical problems, system dynamic is a suitable method to evaluate projects over time. By incorporating system dynamics, the proposed model is able to predict both the short-term and the long-term impacts of inputs in the evaluation model.

3.2.4 Evaluation model: A method combining cost-benefit analysis and multi-criteria analysis will be used. As shown in literature review, cost benefit analysis is the dominant method used in practice despite of its weakness. As intelligent transport systems are very complex, and have multiple objectives, multi-criteria method should be useful in addressing those objectives, and cost-benefit analysis can be used to evaluate environmental impacts monetarily. An improvement on the traditional methods will be explicit consideration of the user behaviours. As intelligent transport systems are closely related to information technologies, which have great influence on people’s behaviours, lack of information on the user behaviours would make the results gained by traditional methods less believable. The model also interacts with the system dynamics model to analyse the impacts over time. The relationship among those sub-models is shown in Figure 1. In the first part of this hybrid model, we will identify the project’s parameters as input of model. The geographic information systems sub-model is a supplementary tool which will add more information to the user behaviour model. As shown in Figure 1, system dynamics model acts as bridge between travel behaviour model and evaluation model. Through the interactions among different sub-models, the travel behaviours are well integrated into the cost-benefit
analysis and multi-criteria analysis. The time-varying parameters required by the evaluation model are also obtained by system dynamics model. The overall evaluation is based on the output of evaluation model.

![Diagram of the structure of a hybrid evaluation approach](image)

Figure 1: The structure of a hybrid evaluation approach

3.3 Comparing of alternative projects
After obtaining results in form of different project alternatives, the comprehensive comparing of those alternatives is then carried out. In this section of the research, sensitivity analysis based on different input data, criteria, weights and value will be carried out so that possible variations of end results can be obtained. Uncertainty is incorporated into the framework by using traditional Bayesian decision analysis. Although Bayesian decision analysis is an old technique, it has sound theory background and poses less assumption compared with those non-Bayesian methods, such as Fuzzy decision analysis, analytic hierarchy process. Reliability analysis for the ITS project based on the results obtained in the previous section can also be conducted.

4 Benefit analysis induced from the evaluation methodology development
Intelligent transport systems are complex systems which provide us with a wider array of information-rich services in addition to the traditional transport service. For example, In Japan, five governmental bodies concerned with intelligent transport systems jointly prepared the national plan and future architecture on ITS services and development, including the National Police Agency, the Ministry of International Trade and Industry, the Ministry of Transport, the Ministry of Posts and Telecommunications, and the Ministry of Construction. There is no doubt that ITS represents the future of transport systems, although there are still some concerns about the proper implementation of ITS project. To deal with these difficult problems, different countries have put considerable efforts into development and redevelopment of transportation evaluation methods, and international cooperation on this topic makes it possible to share state of art technologies.

Australia launched e-transport as the national strategy by the Australian Transport Council of Ministers in 1999, in this strategy it is clearly stated that ITS Australia will help harness new technologies for managing Australia’s transport systems [21]. With a range of ITS applications already implemented by various governments, e-Transport includes plans to extend these applications both locally and nationally, as well as outlining Australia’s participation in various other international ITS projects and developments. CSIRO has also had intensive research projects on ITS, including ITS Connect: An extensive
programme to develop a national strategy, which will establish a pilot corridor in a major city to use advanced ITS technologies and techniques to study freight movements; LITRES-2: Simulation and scheduling of public transport services; TRITRAM: Simulating traffic on urban streets; RTSim: Group and personal rapid transit simulation; and The Electronic Travel Planner: Computer-aided planning for travellers. This intensive research has made significant contribution to the deployment of ITS [22].

The success of ITS deployment requires the evaluation of the impact economically and environmentally to ensure that the implementation of ITS delivers efficiency, safety and environmental benefits to society. The proposed project will fill the gap between the traditional transportation evaluation methods and those new projects brought about by the rapid deployment of ITS. The results of this research project will contain: (1) Identification of benefit and cost of various ITS deployments. Especially, the environmental impact of ITS deployment will be measured in monetary term. Those results can be used for both research projects and project implementation, to assist planners, regulators, transport operators and consultants to have full understanding of the expected impacts of ITS project. It also helps ITS to gain public recognition. (2) An evaluation model to analyse the economic and environmental impacts of a single ITS project, both private and public transport will be included with focus on private car users. (3) An overall evaluation framework to rank different projects, either of same type or not. It will help various governments to determine the priority of ITS projects, and will have direct impact on the decision which of project should be implemented, and when and how to implement it.

The implementation of ITS infrastructure requires considerable resources, and could potentially have huge impact on environments and local and regional economics. A large number of deployments of ITS in Australia will benefit from the proposed research which will evaluate those projects before the beginning of physical installations of ITS, and avoid the possible waste of natural and social resources. Development of such a comprehensive evaluation framework will make significant contribution to promoting intelligent transport systems in practice, and help ITS gain recognition from political groups, governments, and the public so as to achieve the objectives of ITS to deliver efficiency, safety and environmental benefits to both public and private transport users.

5 Discussions and conclusions

Up to now, very little literature can be found on the evaluation framework of ITS projects. The reason might be that intelligent transport systems have not been completely adopted and implemented by the government, especially intelligent vehicle technologies. However, the government plays an important role in the development and promotion of such technologies. Regional and local government planners and policy makers should need to pay attention to the impacts of intelligent transport systems on the accessibility of population groups, on land use, and on the timing and location of traffic flows on their transportation networks (Golob and Regan 2001). The rapid development in ITS technologies increases the urgency of developing an integrated evaluation method to assess the impacts of the ITS infrastructure.

There is an urgent need to analyse the economic and environmental impact of intelligent transport systems deployment so that the decision makers have reliable references to make sound choices and ensure that the greatest social benefit can be enjoyed from the implementation of ITS projects. However, most of current evaluation frameworks are for general transportation systems and are not suitable for evaluation of ITS projects.
Intelligent transport systems are market-driven and information technologies oriented, and they have great potential to change the travel behaviours of people. The evaluation framework developed in this research project can be used directly by national or local governments to demonstrate the feasibility of ITS projects and to show what social benefits and cost should be expected from their operation, especially including dynamic simulation and travel behaviours that have not been included in the previous methods.

There are several innovations with the proposed hybrid evaluation methodology in this research project: (1) the travel behaviours are explicitly included in evaluation model; (2) system dynamics is used to simulate the implementation of ITS projects to analyse both short-term and long-term impacts of ITS, especially with emphasis on the feedback on deployment of intelligent transport systems; and (3) the proposed method integrates geographic information systems into the transport analysis model.

The resultant comprehensive evaluation framework will be a significant contribution to existing evaluation methods, and make it possible for the decision maker and public to have better understanding the benefits and costs caused by the deployment of ITS projects, and potential social, economic and environmental impacts of those projects.

References


