ASSESSING THE SAFETY IMPACT OF INTELLIGENT TRANSPORT SYSTEMS

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ABSTRACT

The seriousness of road traffic accidents in terms of personal injuries, fatalities, and property damage, has been recognised by the World Health Organisation as a social and public health problem. Intelligent Transport Systems (ITS), based on advanced telecommunication and information technology, offer a great potential for improving the road safety situation for all types of road-users. ITS can influence all of the key macroscopic variables commonly used to describe the magnitude of the road safety problem, i.e. exposure, risk, and the severity of accidents. This paper presents an ongoing multidisciplinary research project that is centered around models that describe and predict individual microscopic behaviour and patterns of interaction between different key elements of the traffic system in order to evaluate the potential safety impact of ITS applications.

INTRODUCTION

Ideas concerning the use of advanced technology and developments in communication to improve road traffic in general and enhance road safety in particular have been put forward many times during the history of road transport. The use of Intelligent Transportation Systems (ITS) has now become an accepted reality, but it was not until the eighties that technological development matched the expectations expressed by the vehicle, road, and traffic experts.

Since the eighties, many intelligent transport systems have been introduced as a result of independent market forces that have exploited the possibilities of technology rather than investigating the needs of individual road-users and the general traffic safety situation. The potential safety improvement offered by a particular ITS, even when well-investigated by various scientific disciplines in the design stage, often shows a diminished net safety gain, even a negative gain, due to unforeseen behavioural adaptation, or lack of attention to man-machine interface aspects. In order to make sure that these systems are developed to achieve a maximum safety benefit, it is of vital importance to conduct extensive safety evaluations based on behavioural studies [1].

In the traffic safety field, there is a lack of comprehensive models that allow safety to be assessed in quantitative terms. This fact can be attributed to the high level of complexity and dynamic nature of the road traffic system. This complexity becomes all the more evident when it comes to evaluating the safety impact of intelligent transport systems.
The paper describes the SINDI project (SINDI is an acronym for Safety INDIcators), which aims at assessing the safety impact of ITS in urban street network. It is based on a bottom-up approach which places emphasis on models that describe processes of individual behaviour and interaction between the different key elements of the traffic system in order to evaluate the changes brought about by ITS applications.

This paper is organised as follows. After briefly discussing the drawbacks of macroscopic (at the societal level) methods applied in the Swedish TOSCA project for assessing the safety impact of ITS, the need of more systematic approach at the microscopic level (at the road-user level) is further stressed. Then, the conceptual framework of the SINDI project and the difficulties involved are described.

MACROSCOPIC APPROACH TO SAFETY APPRAISAL

One of the more useful definitions of the safety concept has been suggested in [2] as “freedom from accidents or losses”. In her definition, Leveson states that there is no such thing as “absolute safety” and that safety should be defined in terms of acceptable loss. Safety is envisaged as a continuum where zero-loss continues towards increasing loss, and acceptable levels of safety can be placed somewhere along the continuum depending on other contradicting goals. Typically, traffic safety is described and quantified nationally, at the macroscopic level, in terms of the number of injuries/fatalities, and the amount of property loss occurring during a specific period of time. These statistics can be made more useful and internationally comparable through expression in accordance with three dimensions: risk, exposure, and accident consequence. While such figures are useful for identifying specific traffic safety problems associated with e.g. different age groups and/or modes of transportation, a more in-depth approach is needed in order to suggest possible traffic safety countermeasures.

MACROSCOPIC EVALUATION OF ITS SAFETY IMPACTS

TOSCA is a Swedish national project for evaluation of costs and benefits of ITS in Sweden [3]. Two basic alternatives have been used for estimating the safety impact of ITS applications, at the macroscopic level:

- An analytical approach comprising the establishment of safety models where parameters such as speed, time gaps, road surface conditions, queues, explain the occurrence of accidents

- A traffic-safety-expert-panel approach comprising subjective assessment from traffic safety experts. Experts rely on their basic knowledge in Transport Engineering, the future trend in technical development, the quality level and cost of the technology, and some understanding of expected behavioural changes brought by the introduction of ITS, to drive conclusions on the macroscopic safety impact of ITS applications.

Criticism against the analytical approach is detailed in [4]. The main findings are quoted here. “The opinion was that it is not possible to attack the ITS area analytically, as it touches, to a great extent, the man-machine interface. Severe criticism was therefore brought forward concerning the analytical approach which was considered as too
simplified”. In [5], Hydén commented on the reasons for this relative lack of success. “This is because a large number of factors interact in traffic. The system is often referred to as human-road/environment-vehicle. This encompasses a degree of complexity that can be very difficult to predict. When new information measures are introduced, so many variables may be involved in different ways that general models are difficult to design. One alternative is to bring expert know-how to bear by letting traffic safety experts evaluate the potential safety effects of traffic informatics on the basis of their own experience.” So, the second approach based on traffic safety experts. The Delphi methodology applied during the safety assessment was also criticised [4]. One of the difficulties faced by the experts dealt with the “total assessment of all direct and indirect effects of ITS applications”, which, as already stressed by Hydén, is extraordinarily tough to predict. The Delphi methodology needs to be refined to increase the credibility of the results.

Traffic safety evaluation of ITS is indeed a relatively difficult task, as the Field Trial guideline states it: “A potentially difficult area is to assess how safe an ITS is likely to be in the real environment. There are three main reasons for this: a) accidents, the direct measure of safety, are relatively infrequent occurrences in terms of vehicle kilometres, b) large samples would be required to identify with reasonable confidence a modest worsening of safety, c) it is often difficult to attribute the cause of an accident to a particular factor. This means that the safety aspects of ITS must be investigated by other means.” [6]. In the SINDI-project, a bottom-up approach is suggested that investigates how the driving patterns and interactions between the different components of the road traffic system are modified as a result of ITS application.

THE ROAD TRAFFIC SYSTEM

To study road safety in more detail, it is a fundamental necessity to identify the main components of the traffic system, and identify the way in which these components interact in different situations. The three key components are the road-users (e.g. car drivers, cyclists, pedestrians), the vehicle, and the roadway network (See Figure 1). The system state is the result of the interactions between these three components, and their surrounding environment. This “systems theory” perspective [7] allows the complexity and dynamic nature of the road traffic system to be brought to light. A terminology of useful concepts, including emergence, hierarchy, communication and control, is implied by this approach, and can be used to describe the functionality of the system and aid in the modelling process.

![Figure 1: The three main components of the traffic system](image-url)
Traffic safety is essentially an emergent property of the traffic system at a high level of abstraction. Accidents can be described as a breakdown in the functioning of one or more of the individual components, or as a breakdown in the interactions between different components. Usually, an in-depth investigation based on the components and their interactions can be used to identify and establish the often-complicated sequence of events that lead to this breakdown in the system.

While the societal or macro-approach may reveal some useful information, it implies a passive approach, i.e. waiting for accidents to occur in order that they can be investigated, and then finding ways of preventing similar accidents in the future. As accidents are essentially rare events in the traffic system and the circumstances leading to their occurrence are highly diverse, this approach is not suitable. In order to take a more active approach, it is necessary to take a multidisciplinary scientific approach that involves establishing models and theories [8]. These models and theories should investigate specific combinations of system components in order to identify the potential and limitations of individual components, and communication and control problems that produce deficiencies in the interactions between components.

TOWARDS A MICROSCOPIC EVALUATION

Our microscopic approach to traffic safety places emphasis on models that describe processes of individual behaviour and interaction between the different key elements of the traffic system. Using a microscopic approach to traffic safety will enable us to better identify the main features of changes in driving brought by ITS applications, and assess their safety impacts in different traffic situations, and for some groups of drivers. The ultimate objective is to be able to generalise the conclusions at a more aggregated level, linking the findings from the microscopic level to the macroscopic level [8].

THE SINDI PROJECT

OVERALL DESCRIPTION OF THE PROJECT

The SINDI project represents an integrated multidisciplinary approach to traffic safety research, and is at the present in an early stage of development at the Center for Traffic Engineering and Traffic Simulation, at KTH, Stockholm, Sweden, and at the Traffic and Road-User Behaviour Department, at VTI, Linköping, Sweden. Its purpose is to investigate the changes in driving patterns and the interaction between the different road-users, the vehicles and their immediate environment, resulting from the introduction of ITS applications. This project is greatly dependent on the construction of a human-behaviour model that is measurable in terms of relevant safety indicators (See Figure 2a). The current objective is to concentrate on modelling at the microscopic level in order to provide information concerning aggregated traffic safety indicators to traffic safety experts so that they can derive more accurate conclusions concerning the macroscopic safety impacts of ITS, as in proposed in Figure 2b. The issues addressed in this paper concern only the microscopic approach.

At the microscopic level, the available knowledge on the interactions between the road-users, the vehicle, the road infrastructure will be compiled by VTI from laboratory tests, driving simulator studies, field trials, and demonstrator projects will be used for
establishing and validating a driver behaviour model. The behavioural model will then be used to establish quantifiable changes in microscopic safety indicators.

A further point of interest with regard to the SINDI-project is the fact that it focuses specifically on traffic safety problems in urban areas. This has important research implications. Generally, there is only a limited amount of earlier research in relation to urban traffic safety, and those studies show that the types of accidents occurring in urban areas are proportionately different to those occurring on rural roads and motorways. A focus on urban areas also implies taking into consideration the interaction of the many different types of road-users (e.g. pedestrians, cyclists, cars, buses, heavy good vehicles) and a greatly increased potential for conflict between these different groups. This fact that is reflected in the accident statistics and has lead to the application of different planning or “traffic-calming” techniques [9].

The greater complexity of the urban environment requires a higher level of situational awareness and communication between road-users. In many of the existing traffic systems, there is a need to improve the urban traffic situation. It is hoped that some of the more important traffic safety problems encountered in urban areas can be approached in the SINDI-project with a view to evaluating existing ITS functions, and also suggesting new countermeasures based on the application of behavioural modelling and identification of relevant safety and performance indicators.

**BUILDING A TRAFFIC SAFETY SIMULATION TOOL**

The responsibility of the Center for Traffic Engineering and Traffic Simulation is to translate the outputs from the human-behavioural driver model elaborated by VTI into operational parameters that can be used as inputs in a microscopic traffic safety modelling tool. Initially, this involves the adaptation of an existing micro-simulation tool, and possibly to the development of a microscopic simulation tool designed specifically for the evaluation of traffic safety.
At the behavioural level, Draskóczy suggests a list of behavioural indicators as measurements of the observed changes in driving patterns and interactions with other road-users and environment [10]. Standard indicators include steering and braking behaviour, conflicts and driving errors, driver workload, physiological response, glance frequencies and durations, eyes movement, vehicle speed, lane change, overtaking. Critical parts of the SINDI project include the identification and selection of relevant behavioural indicators, and their translation into the parameters that can be made available to the traffic safety simulator. These indicators actually provide the critical link between the behavioural model and the micro-simulation model that is developed, and also represents a link between different scientific disciplines within the project.

**DIFFICULTIES RELATED TO BEHAVIOURAL FACTORS**

The majority of ITS affect road-user behaviour and patterns of interaction with the vehicle or environment. However, the behavioural impacts attributable to ITS do not always match up to the preconceived expectations of systems developers and scientific researchers. The impact of ITS can vary as a result of many different factors including the time period involved. Changes that are noticed in the short-term are sometimes found to diminish with long-term application. The exact nature of the impact brought about by a particular ITS is extremely difficult to determine before the implementation stage of development. A simplified classification of the most important safety impacts of ITS at the microscopic level, includes (See [11] for original classification):

- **Direct effects of in-car system or a road-side system on the user.** The main issues of concern here are the effects on attentional and cognitive task load capacity.

- **Indirect, behaviour modifying effects of the system on the user.** Behavioural adaptation is defined in [11] as “those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which are not consistent with the initial purpose of the change… These behavioural changes allow road users to use the system changes to satisfy their needs, and as a result the changes produce a continuum of effects ranging from a positive increase in safety to a decrease of safety”.

- **Indirect behaviour modifying effects of the system on the non-user.** Behavioural adaptation effects can apply not only to the direct users of a new ITS application, but also to non-users, who perceives some modification in the total traffic environment, and imitate the new way of driving of those who are assisted, warned or informed by the ITS application [12].

- **Modification of interaction between users and non-users.** Some ITS functions may influence safety critical communication between users and non-users.

Figure 3 goes deeper into the analysis of one specific type of indirect behavioural effect: the compensation mechanisms [13]. Following to the identification of a problem, an ITS application is introduced with the purpose of improving safety in a certain part of the road traffic system. If the application fulfils the expectations, it is referred to as a “primary effect”. If it does not result in adaptation processes on the part of road users and there are no other consequential effects within the system, the effect of the measure has permanence. However, if some adaptation processes are involved, i.e. there is
adaptive reaction by the road user, the effect of the ITS application is usually influenced. This effect can be considered a “secondary effect”. It will usually diminish the primary effect. In some cases adaptation leads to an increase in effectiveness. Adaptation takes several different forms:

- **Immediate adaptation based on past learning processes.**
- **Delayed adaptation as a behavioural adjustment process.**
- **Adaptations that modify the exposure to danger.**

These long-term adaptation effects resulting from the introduction of ITS applications make the elaboration of microscopic traffic safety model very challenging.

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**FUTURE WORK**

The following issues will be addressed in the very short future:

- **In-depth problem analysis specialised in a particular area of interest.** This involves the identification and analysis of specific urban area problems. Emphasis is placed on a background study which includes earlier traffic safety related research, accident statistics based on similar or identical traffic situations, direct observation of a number of chosen road traffic sites.

- **Identification of high-potential ITS applications with regards to this problem.** The purpose of this part of the project is to look at a number of existing ITS applications that have the potential to improve some of the urban traffic safety problems identified and analysed earlier. In cases where this potential is not realised in existing systems, it may be possible to identify the need for new ITS-functions.
• **Identifying and selecting relevant safety and performance indicators.** This is the most critical part of the SINDI-project. The indicators that are chosen will eventually have a number of important functions. Together, the indicators must provide adequate sensitivity in order to predict important behavioural and performance-related changes in the driving task at the microscopic level and provide a proxy measure of traffic safety at the societal (i.e. macroscopic) level. These indicators will provide the critical link between the behavioural model and the micro-simulation model that is developed, and also represents a link between different scientific disciplines within the project.

• **Behavioural studies and development of a behavioural model.** The development of the behavioural model is also of vital importance and will be undertaken on the basis of earlier behavioural research in relation to this type of modelling and new information that evolves as a result of a number of experiments performed on the driving simulator at VTI.

• **Building the microscopic traffic safety model.** The microscopic traffic safety model will be based initially on an existing micro-simulation tool that allows sufficient flexibility in adding behavioural modules and the accurate representation of important information from the behavioural model. The model that is developed will be calibrated on the basis of data from existing road environments.

• **Developing safety evaluation procedure.** A safety evaluation procedure will be developed based on the functionality of the behavioural model, the micro-simulation model and the use of different safety and performance indicators. It is intended that this procedure should be general in nature and serve a useful purpose in the safety evaluation of intended ITS applications at an early point in the research and development process, requiring only a minimum of necessary adjustments for different types of ITS and experimental conditions.

**SYNOPSIS**

Associated with the evaluation of new information technology in traffic systems, is the need to identify and describe traffic safety at an early point during the technological development and implementation stages. The relatively new and untried approach proposed in the SINDI-project takes advantage of the available techniques in micro-simulation, driving simulators, specially instrumented vehicles, and behavioural observation techniques, in order to study the safety impact of new ITS functionality from a multi-disciplinary perspective. The primary goal of the project is to develop behavioural and micro-simulation models that communicate the probable safety impact of new or proposed ITS in the form of safety and performance indicators. These safety indicators at the microscopic level should provide proxy measures of changes in the general traffic safety situation existing at the macro-level as a result of newly introduced ITS functionality. Important, secondary goals of this project are to provide a basis for the development of new ITS functions, and promote the level of co-operation between safety related research establishments and different scientific disciplines in Sweden.
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