Transportation Series 7

Evaluation of Intelligent Road Transport Systems

Methods and Results

Edited by Dr. Meng Lu

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Contents

Foreword

We are delighted to have the opportunity to introduce this comprehensive book on the evaluation of Intelligent Road Transport Systems as it fills a serious gap in our knowledge. Intelligent Transport Systems (ITS) use electronics, information and communications technologies to deliver transport improvements instead of extending physical infrastructure, thereby saving money (typically 50%) and reducing environmental impact. ITS are based on a wide variety of information about transport, travellers, and vehicles. They can be deployed on infrastructure to improve road network management and increase productivity; on vehicles to improve safety, reduce journey times and reduce polluting emissions; by travellers to simplify ticketing and payment and deliver better information; and they can connect all three of these sectors to improve mobility and accessibility more generally.

In the overall transport timetable ITS are a relatively recent discipline and we have an incomplete understanding of their costs and benefits compared to the well-established processes for building new, or upgrading, physical infrastructure. In 2010, the European Commission asked a stakeholder expert group, the iMobility Forum, to estimate the potential of ITS to address some of the most important political mobility challenges assuming successful deployment of ITS during the time period 2011–2020. The iMobility Forum estimated 30% reduction in the number of fatalities across Europe, 30% reduction in the number of seriously injured persons across Europe, 15% reduction of road-traffic-related congestion, 20% improvements in energy-efficiency, and 50% increase in availability of real-time traffic and travel information.

Focusing on the aspect of sustainability, especially the environmental dimension, ITS America, ITS Asia-Pacific, ERTICO – ITS Europe together with the global National ITS Associations, have collected in 2015 prior to the COP21 meeting in Paris success stories of ITS implementations specifying the respective positive impact on CO_2 emission reductions.

The ITS Benefits Evaluation Community (IBEC) has pioneered the collection and collation of data on costs and benefits and its sessions during ITS World Congresses have attracted global attention and appreciation. The time is ripe to set down as much as possible of the known wisdom to assist users everywhere. This new book meets that pressing need for a reference source so that practitioners in national or local government, commercial organisations, research centres can quickly find the state of the art for a range of ITS activities worldwide. It is a marvellous example of the principles that have enabled IBEC to thrive for almost 20 years – finding, documenting, then sharing the best available knowledge.

Albert Einstein is famous for a number of reasons but for us his achievements in mathematical physics are equalled by his practical daily wisdom as shown by the following two quotes:

- “True genius is knowing where to find the answer”
- “Never memorise anything you can look up”

Meng Lu has done an excellent job compiling the book which complements the work ERTICO is doing on an ITS Observatory providing decision-makers and related stakeholders with access to reliable, understandable and coherent information on outcomes (benefits and impacts) of existing and ongoing ITS deployment, supporting them in developing fact-based policy objectives and strategies – both initiatives will help you locate the answers to key questions and both will provide rapid “look it up” services. We welcome “Evaluation of Intelligent Road Transport Systems: Methods and Results” unreservedly.

Hermann Meyer
CEO, ERTICO – ITS Europe, Belgium

Eric Sampson
President, IBEC

Preface

The term Intelligent Road Transport Systems covers a wide range of products and solutions that deploy Information and Communication Technologies (ICT) aiming at improving road safety, driver comfort, transport efficiency, and environmental and energy efficiency. Core technologies are positioning, communication and deployment of various sensors. In the past three decades, development and deployment of Intelligent Transport Systems (ITS) was to a substantial degree supported through many national and international projects and initiatives.

A range of evaluation studies demonstrated sustainable impacts of the deployment of Intelligent Road Transport Systems in terms of, respectively, economic, environmental and societal aspects. However, the evaluation results are often (1) not systematically published; (2) not accessible in different countries and regions; (3) not comparable with each other; and/or (4) not easily applicable to other regions or countries for estimation of impacts. Different evaluation methods were used in the past years, and substantial differences may occur in the way a method is used in different situations. Furthermore, data for doing the evaluation are often not well structured, and certainly not always available, or not available with sufficient detail. In addition, the assumptions made for evaluation are often not clearly and explicitly provided, and an adequate discussion of the shortcomings of an evaluation method and how to best address these, is often lacking in evaluation reports. The various evaluation methods that are used in practice do all have shortcomings and generally lack a strong theoretical basis. Therefore it remains a challenge to define adequate and acceptable approaches to do evaluation to support decision-making, based on current or new (integrated) methods.

In the ITS domain, decision-makers would like to have good insight in investment costs and benefits; researchers are involved in developing adequate approaches for ITS evaluation and assessment methods enabling comparison of results in different countries and regions; industry partners are interested to receive information concerning the state of the art and the trends of ITS development and deployment, especially from the perspective of the cost-effectiveness of potential ITS applications. Therefore all involved have an interest in technical assessment methods and results. Due to these interests and needs, IBEC (ITS Benefits Evaluation Community) was initiated in 1999 by a group of experts (including decision-makers, academia and industry), to enable stakeholders to network and to share their knowledge and experience of ITS evaluation, in order to advance the topic. In the meantime, IBEC has developed to an international forum for the evaluation of ITS development and deployment.

I initiated to prepare this book in 2015, when I was serving as the Chair of IBEC, together with distinguished experts in the ITS domain, to provide an overview of ICT-based Intelligent Road Transport Systems, evaluation methods, and recent evaluation results of ITS development and deployment. I sincerely thank all the authors and co-authors for their excellent contributions to this book.

I also thank all my IBEC colleagues, especially Andrew Somers (Co-Chair IBEC), Glenn Geers (Co-Chair IBEC), Eric Sampson (President IBEC), Tom Kern (VP IBEC), Richard Harris (VP IBEC), Jane Lappin (VP IBEC), Keith Keen (VP IBEC), ERTICO – ITS Europe (IBEC Secretariat), other IBEC Management Committee members, and Kees Wevers (President TN-ITS), as well as various organisations that have substantially contributed to ITS, in particular the European Commission (especially DG CONNECT, DG MOVE and DG RTD), the US DoT (Department of Transportation), the US Congressional Budget Office, ITS America, ITS Australia, ITS Canada, ITS Japan, ITS Korea, ITS China, ITS Taiwan, ITS Singapore, ITS South Africa, ITS UK (especially Jennie Martin), ITS Sweden, ITS Denmark, ITS Norway, ITS Finland, ITS Network Germany, ITS Austria/AustriaTech, TTS Italia, ITS Spain, ITS Portugal, ITS France, ITS Hellas, ITS Ireland, ITS Switzerland, ITS Romania, ITS Polska, ITS Hungary, ITS Bulgaria, ITS Czech Republic, ITS Slovenia, ITS Russia, ITS Belgium and Connekt/ITS The Netherlands.

Last but not least, I sincerely thank IET for providing very kind support and help for the preparation and publication of this book, especially Dr Alan Stevens (TRL, UK; see also Appendix I) and Dr John Walker CPhys FIET (Member, IET ARTS TPN, IET Berkshire LN, Chairman, RTIC 2014 Technical Committee; Honorary Secretary, ITS UK Road User Charging Interest Group; Visiting Senior Research Fellow, Transportation Research Group, University of Southampton).

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1 June 2016

List of acronyms

AADT	Annual Average Daily Traffic
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ACR	Average Crash Rate
AD	Automated Driving, also referred to as Autonomous Driving
ADAS	Advanced Driver Assistance Systems
AEB	Automated Emergency Braking
AHP	Analytic Hierarchy Process
AMDTM	Assessment Method for Demand and Traffic Management
ANPR	Automatic Number Plate Recognition
APA	Administrative Procedure Act
ARGO	Algorithms for Image Processing
ARI	Autofahrer Rundfunk Information
ARTS	Automated Road Transportation Systems
ASTDEV	Average Standard Deviation
ASV	Advanced Safety Vehicle
ATMS	Advanced Traffic Management System
AV	Automated Vehicle(s), also referred to as Autonomous Vehicle(s)
BASt	Bundesanstalt für Straßenwesen
BCR	Benefit–Cost Ratio
BLIS	Blind Spot Information System
BRT	Bus Rapid Transit
CBA	Cost–Benefit Analysis
CC	Cruise Control
CEA	Cost-Effectiveness Analysis
CEN	European Committee for Standardization (Comité Européen de Nor-malisation)
CENELEC	European Committee for Electrotechnical Standardization
CCTV	Closed-Circuit Television

CEF	Connecting Europe Facility
C-ITS	Cooperative Intelligent Transport Systems
COMPANION	COoperative dynamic forMation of Platoons
CPRS	Complacency Potential Rating Scale
CSW	Curve Speed Warning
DARPA	Defense Advanced Research Projects Agency
D-FOT	Detailed FOT
DIRD	Department of Infrastructure and Regional Development
DOT	Department of Transportation
Drive C2X	DRIVing implementation and Evaluation of C2X communication technology in Europe
eCall	Emergency Call
GAM	Goal Achievements Matrix
EC	European Commission
ELECTRE	ÉLimination Et Choix Traduisant la RÉalité
ERTICO	European Road Transport Telematics Implementation Coordination Organisation (ITS Europe)
ESP	Electronic Stability Programme
ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
FB	Fixed Base
FCD	Floating Car Data
FCW	Forward Collision Warning
FEA	Fuel Efficiency Advisor
FOT	Field Operational Test
GD	Green Driving Support
GDOP	Geometric Dilution of Precision
GDP	Gross Domestic Product
GPS	Global Positioning System
HIL	Hardware in the Loop
HMI	Human–Machine Interface
HSWIM	High-Speed Weigh-in-Motion
I2V	Infrastructure-to-Vehicle
IBEC	ITS Benefits Evaluation Community
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers

IRR	Internal Rate of Return
ISA	Intelligent Speed Adaptation
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems (or Intelligent Transportation Systems)
ITSS	Intelligent Transportation Systems Society
IVHS	Intelligent Vehicle Highway Systems
IVIS	In-Vehicle Information Systems
IW	Impairment Warning
JDVS	Joint Driver-Vehicle System
JPO	Joint Programme Office
KPI	Key Performance Indicator
KONVOI	Entwicklung und Untersuchung des Einsatzes von elektronisch gekoppelten Lkw-Konvois
LDW	Lane Departure Warning
L-FOT	Large-scale FOT
LIDAR	Light Detection and Ranging
LKA	Lane Keeping Assistance
LSWIM	Low-Speed Weigh-in-Motion
MCA	Multi-Criteria Analysis
MCS	Motorway Control System(s)
METI	Ministry of Economy, Trade and Industry
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MVKT	Million Vehicle Kilometres Travelled
NAV	Navigation Support
NB	Northbound
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NMS	New Mobility Scheme
NPA	National Police Agency
NPV	Net Present Value
NSW	New South Wales
OD	Origin-Destination
PAD	Personal Digital Assistant
PATH	Partners for Advanced Transit and Highways
PBS	Planning Balance Sheet

PI	Performance Indicator
PIARC	World Road Association
PROMETHEE	Preference Ranking Organisation METHod for Enrichment Evaluations
PROMETHEUS	PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety
PRT	Personal Rapid Transport
RDS	Radio Data System
R&D	Research and Development
RFID	Radio-Frequency Identification
RMS	Road and Maritime Services
RMSE	Root-Mean-Squared-Error
RT	Reaction Time
RTAs	Reduced Road Traffic Accidents
RTLX	Raw Task Load indeX
RSU	Road-Side Unit
RWW	Road Works Warning
SAE	Society of Automotive Engineers
SAGAT	Situation Awareness Global Assessment Technique
SARTRE	Safe Road Trains for the Environment
SAW	Simple Additive Weighting
SB	Southbound
SFS	Subjective Fatigue State
SIP	Cross-Ministerial Strategic Innovation Promotion Program
SL	Speed Limiter
SME	Small and Medium-sized Enterprise
SRS	Speed Regulation System
SSSQ	Short Stress State Questionnaire
SSVS	Super Smart Vehicle Systems
STA	Swedish Transport Administration
SUS	System Usability Scale
TBS	Task-related Boredom Scale
TCC	Traffic Control Centre
TI	Traffic Information
TIC	Traffic Information Centre
TMC	Traffic Message Channel

TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UN	United Nations
US	United States
UTAUT	Unified Theory of Acceptance and Use of Technology
UTMS	Universal Traffic Management System
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VaMoRs	Versuchsfahrzeug für autonome Mobilität und Rechnersehen
VDA	Verband der Automobilindustrie
VICS	Vehicle Information and Communication System
VMC	Vehicle Management Centres
VMS	Variable Message Sign(s)
VMT	Vehicle Miles of Travel
VSL	Variable Speed Limit(s)
VTS	Vehicle Testing Station
VTTI	Virginia Tech Transportation Institute
WIM	Weigh-in-Motion
WTP	Willingness-to-Pay
WWP	M1 Wet Weather Pilot System
xFCD	extended Floating Car Data

Part I

Introduction

Chapter 1

History and deployment of ITS (Intelligent Transport Systems) technologies and an outline of the book chapters

Adrian Zlocki[1], *Felix Fahrenkrog*[2] *and Meng Lu*[3]

1.1 Introduction

Since motorised road transport started to develop, increasing comfort and safety have been important development goals in the transport domain. Over the last century, transport gradually gained more and more importance in a modernising society, with a growing need for individual mobility. The automobile is the embodiment of this need, providing the option of individual and distant transport to every citizen.

Different systems and technologies have been developed for increasing comfort and safety, such as automatic starter, chassis systems and restrain systems. Different ideas and concepts for modern transport were already invented many years ago, but could not be implemented due to technical limitations in the early part of the last century. One of the best examples in the automotive sector is the idea of vehicle automation and automated driving. First visions of automated driving and futuristic vehicle concepts were already developed at the beginning of the twentieth century (cf. 1939 New York World's Fair Futurama as in Reference 1).

Due to the rapid development of electronics, micro-electronics and computer technology in the 1980 measures to provide such a comfortable and safe transportation method became available. These were implemented first on research level by means of demonstrators and proof of concepts. Afterwards a transfer towards market introduction and deployment was implemented. Vehicle technology and intelligence for individual mobility as well as infrastructure-based systems for mass transport (including individual mobility) experienced ever since important achievements such as the introduction of ABS (Anti-lock Braking System), ESP (Electronic Stability Program), routing technology and driverless public transport systems.

Measures to enhance comfort, safety, efficiency and effectiveness of public transport and individual mobility are referred to as ITS (Intelligent Transportation

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Systems). ITS describe a broad range of diverse technologies in the area of transport. These technologies include areas such as sensor technology, communications systems, information processing and control technology. Applications of these technologies are ranging from vehicle manufacturer dependent functions up to large-scale traffic management networks.

ITS are classified into the main areas of vehicle-based (on-board) and infrastructure-based (off board) systems. Examples of vehicle-based ITS are vehicle automation, active safety systems, advanced driver assistance systems (ADAS) including perception and all means of communication system (including e.g. satellite communication, vehicle to vehicle communication and radio communication). Examples of infrastructure-based intelligent road transport systems are tolling, traffic monitoring, traffic control, communication and all backend systems.

The term ITS is fairly generic and used in context of different disciplines such as traffic engineering, automotive engineering and communication engineering. A clear definition of ITS is not available. The following definitions are provided by different stakeholders.

ITS definitions

EU Directive 2010/40/EU (7 July 2010)

"ITS are advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks" [2].

European Telecommunications Standards Institute (ETSI)

"ITS include telematics and all types of communications in vehicles, between vehicles (e.g. car-to-car), and between vehicles and fixed locations (e.g. car-to-infrastructure). However, ITS are not restricted to Road Transport – they also include the use of information and communication technologies (ICT) for rail, water and air transport, including navigation systems" [3].

US Department of Transportation (DOT)

"ITS improves transportation safety and mobility and enhances American productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. Intelligent transportation systems (ITS) encompass a broad range of wireless and wire line communications-based information and electronics technologies" [4].

ITS Japan

"ITS offers a fundamental solution to various issues concerning transportation, which include traffic accidents, congestion and environmental pollution. ITS deals with these issues through the most advanced communications and control technologies. ITS receive and transmit information on humans, roads and automobiles" [5].

In general it can be concluded that ITS are systems or applications that aim to improve (road) traffic and transport by means of smart communications and control technologies.

1.2 Classification of ITS

Different classification schemes can be applied to structure the wide field of ITS available today. A methodical approach for the classification of ITS is a formal description of these systems. In the following box different classification schemes are provided:

ITS classifications

Classification of ITS with regards to system architecture

This classification scheme clusters infrastructure based and vehicle based. The main distinguishing feature for this type of classification is on the architecture dependent collection of ITS relevant information. Examples of infrastructure-based ITS range from traffic management systems, cloud-based systems such as tolling or even to infrastructure guided vehicles. Infrastructure-based autonomous vehicles are self-driving vehicles operated in a dedicated infrastructure such as dedicated lanes or closed areas (e.g. airport taxi, underground rail transport). These vehicles do not need a driver or operator. Vehicle-based ITS are defined according to different automation levels [6] or active safety systems and reply mainly on on-board sensor information. A link between data collected from on-board and off-board sensors is the basis for combined systems. Next to the automation levels also the degree of connectivity is a scale for classification of ITS systems. The range starts at autonomous systems, which are not connected to the environment up to highly connected systems with high data transfer rates.

Classification of ITS with regards to the driving tasks

Based on the three-level model ITS can be classified according to the driving task. The model is divided into the three operating levels navigation, guidance and stabilisation [7]. On navigation level the route inside an existing road network is selected and a course is determined. On guidance level the driver adjusts all relevant control parameters to the selected course in the network and the surrounding traffic. The stabilisation level is characterised by setting all necessary control parameters and changes of those within the chosen driving strategy e.g. steering torque, accelerator pedal position or brake force.

Classification of ITS with regards to the type of support

The level of support provided by ITS can range from pure information, to warning and even extend to an active intervention. Informing ITS support by supplying precisely the information highly important and required in the current situation, e.g. navigation systems, which inform in case a motorway change is necessary at the next junction. Warning systems support by providing acoustical, optical or haptical warnings in critical situations. This can be critical states of a vehicle (e.g. low tyre pressure), of a driver (e.g. drowsiness) or the overall situation (e.g. low distance to target vehicles). Intervening systems take over parts of the driving task and thus support or relieve the driver, e.g. ACC systems (Adaptive Cruise Control) or AEB (Automated Emergency Braking).

Classification of ITS according to the course of traffic

The classification approach [8] results from consideration of the safety improvement of ITS. The main focus is on traffic safety. The classification foresees the levels safe course of traffic (e.g. traffic flow), risk avoidance (minimising risks like small time gaps and high decelerations), collision prevention (e.g. emergency braking), protection of passengers (e.g. active and reversible restrain systems) and partners and rescue management (e.g. eCall).

ITS in passenger vehicles or trucks enable new functions to increase vehicle safety and vehicle automation. C-ITS (Cooperative Intelligent Transportation Systems) focus on the connectivity of each single traffic participants in an overall connected network in order to allow the exchange of messages to increase comfort, safety, traffic and environmental efficiency.

1.3 History of ITS

Ideas for today's ITS have been created since the invention of the automobile as given in Reference 1. A first mechanical implementation of an ITS comfort systems installed to a passenger vehicle was the mechanical cruise control in the Chrysler Imperial as the so-called auto pilot in 1958 [9]. This mechanical system was able to keep a constant set speed and therefore could take over the longitudinal vehicle control on a motorway. This system was designed by means of mechanical components, which could be replaced by a computer controlled unit in the 1980s due to the development in electronics and information technologies [10].

With regards to communication technologies and infrastructure ARI (Autofahrer Rundfunk Information) was one of the first systems active from 1974 to 2008 in Europe [11]. The system was developed by the Germany company "Blaupunkt" together with national radio broadcasting operators. ARI added a special modulated sound ("Hinz-Triller") to radio-based traffic messages, which could be detected by special equipped receivers in order to determine the availability of a radio station sending out traffic messages, a geographic area to determine the relevance of the radio station and finally the traffic message itself, which could be replayed to inform the driver.

Since the introduction of these first systems information and communication technologies (ICTs) have been applied in many fields of road transport. A systematic research of such technologies was started in several research programmes with funding on national or international level. The goal of all programmes was to develop systems and standards with jointed forces independent of one single company.

Such research programmes were implemented in different countries, e.g. (1) PATH (Partners for Advanced Transit and Highways) (USA) and IVHS (Intelligent Vehicle Highway Systems); (2) ARTS (Automated Road Transportation Systems) (Japan) and ITS Japan; and (3) PROMETHEUS (PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety) (Europe).

In 1986 the California PATH program was established. The programme was sponsored by the California Department of Transportation. The aim of PATH was to develop long-term strategies in order to cope with the immense traffic in California. The University of California at Berkeley and other university partners from California are investigating solution to public and private transport involving ITS [12].

Between the seventh and the tenth of August 1997 a vehicle platoon consisting of eight Buick LeSabres vehicles was demonstrated as one output of PATH. The distance between each longitudinal and lateral controlled vehicle was 6.5 m at a velocity of up to 96 km/h. The distance accuracy was measured in range of 10 cm at constant driving and 20 cm at acceleration and deceleration manoeuvres [13].

On national level the IVHS program was authorised by the Intermodal Transport Surface Transportation Efficiency Act of 1991. Within this IVHS program five broad, interrelated areas were addressed: Advanced Traffic Management, Systems, Advanced Traveller Information Systems, Advanced Vehicle Control Systems, Commercial Vehicle, Operations, and Advanced Public Transportation Systems [14]. The programme initiated several IVHS operational tests all over the US.

In Japan funded research in the field of ITS was started in the 1980s by different ministries and agencies. Vehicle oriented projects like SSVS (Super Smart Vehicle Systems) and Energy ITS were sponsored by METI (Ministry of Economy, Trade and

Industry). ASV (Advanced Safety Vehicle) was sponsored by the MLIT (Ministry of Land, Infrastructure, Transport and Tourism) in addition to infrastructure oriented projects like VICS (Vehicle Information and Communication System), ETC (Electronic Toll Collection) or Smartway. The infrastructure oriented project UTMS (Universal Traffic Management System) was sponsored by NPA (National Police Agency) [15].

In 2008 the initiated Energy ITS project was aiming at energy saving and CO_2 emission reduction by means of truck platooning [15]. At the ITS world congress 2013 a platoon of three automated trucks driving at 80 km/h with the gap of 15 m was demonstrated as one result of the project. In 2014 the Japanese government started the Cross-Ministerial Strategic Innovation Promotion Program (SIP), which inter alia the next generation of ITS infrastructure [16]. A main project in this research programme is the SIP-adus project that aims to deploy automated driving in Japan. Within the SIP-adus project research in the field of automated driving related topics (dynamic map, connected vehicle, security, impact assessment, human factors and next-generation transport) is conducted [17].

In Europe the PROMETHEUS project was initiated in 1985, following first research activities of the European automobile industry on automated driving. Within the EUREKA (intergovernmental organisation for pan-European research and development funding and coordination) research initiative PROMETHEUS (1986–1994) was the first cooperation of 14 European vehicle manufacturers and over 100 suppliers that took place independent of their country. The initiative was a direct reaction towards the joined research activities in the US and Japan [18]. The aim of PROMETHEUS was the improvement of traffic safety and traffic management on the three levels of the driving task, navigation, guidance and stabilisation. The PROMETHEUS project consisted of seven sub-projects. Within the sub-project PRO-CAR [19] first advanced driver assistance functions and necessary ICT were developed and demonstrated including new sensor concepts, algorithm for image processing and control functions [19]. First automated driving functions could be implemented for the very first time. Today many of the elaborated ideas and demonstrations are well established and available in vehicles on the market. Prominent examples are integrated navigation support, Adaptive Cruise Control (ACC) and Lane Keeping Assistance (LKA).

The positive results of these first research activities and the resulting market introductions led to continuous research programmes, as well as the founding of organisations such as the IEEE Intelligent Transportation Systems Society (ITSS), ERTICO – ITS Europe (European Road Transport Telematics Implementation Coordination Organisation) and various ITS conferences (e.g. organised by IEEE ITSS; and jointly organised by ERTICO, ITS America and ITS Japan).

Today the European Framework Programmes (currently Horizon2020) provide funding for a number of R&D and demonstration projects for the deployment of ITS. Figure 1.1 provides an overview of some selected ITS projects, which are funded by the European Commission. ITS technology is the major aspect of all these projects.

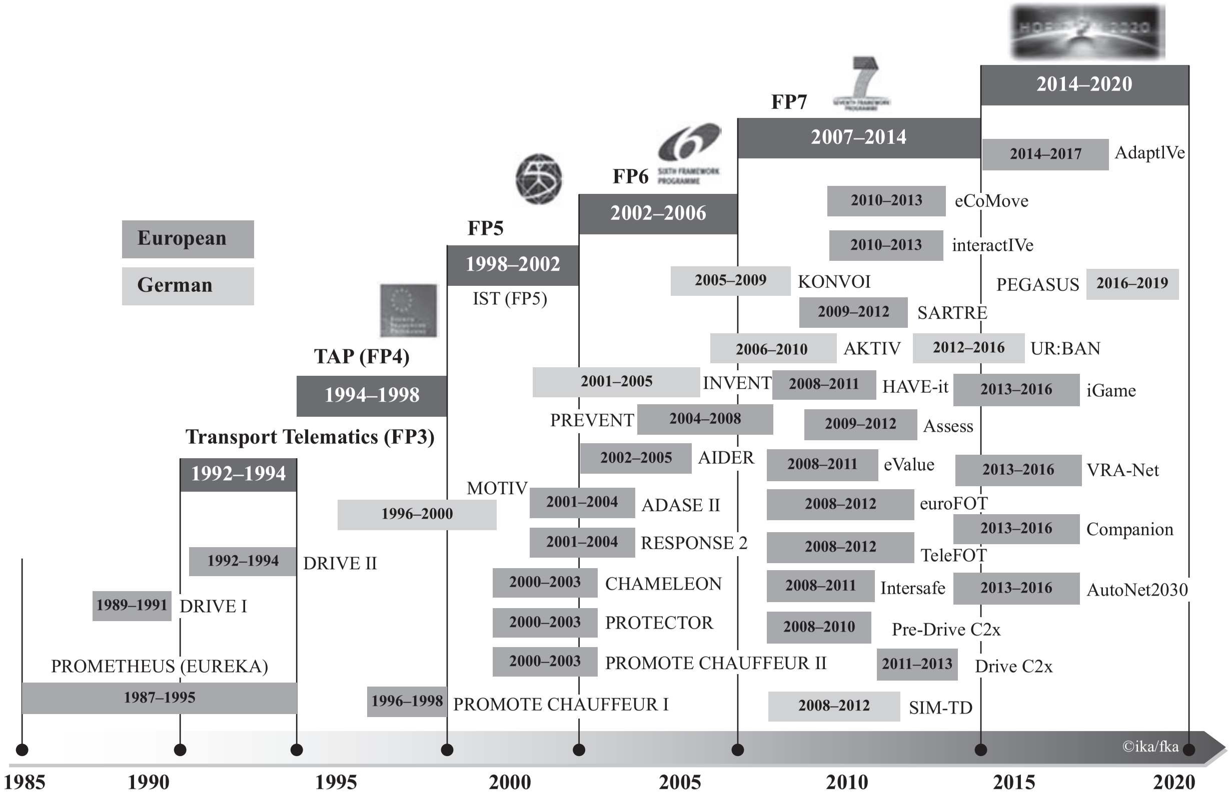


Figure 1.1 *Overview of selected research projects in the European research framework programmes and in Germany*

1.4 Infrastructure-based ITS

Infrastructure-based ITS utilise off-board sensors and communication technology. Due to the wide spread availability of state-of-the-art communication technology the deployment of these systems is increasing.

1.4.1 Emergency vehicle notification systems, eCall

According to the European directive 2007/46/EG the European eCall is to be in operation from 2018 onwards [20]. This decision is the result of a long time struggle on the introduction of an ITS which can determine the exact location in case of an accident and initiate an automated emergency call to the closest rescue team independent of the location in the EU. Due to the ambitions to collect and communicate data, which includes personal information such as location, and the continuous technical progress in communication technology, the introduction of a unified eCall system was discussed and investigated for many years. The eCall system shall be free of charge and uses the international emergency number 112. All location-based data may not be recorded and stored and therefore is not available to third parties. Meanwhile vehicle manufacturer dependent systems are introduced as services, which offer additional comfort for intelligent routing and navigation to points of interest.

1.4.2 Automatic road law enforcement

Since the early twentieth century vehicle speed is measured by law enforcement using ITS technology, such as laser or radar. These speed controls are infrastructure based at selected locations or mobile by means of so-called laser guns. The collected data is transferred to a central server in order to provide tickets to drivers, who violated the traffic rules. Automatic road law enforcement not only is used for the observance of speed limits, but also provides the automated detection of red light runners at crossings.

1.4.2.1 Tolling

Tolls for using certain roads or waterways exist long before the invention of the automobile. The first system for electronic tolling was proposed in 1959. By means of ITS, data are transmitted from transponders to infrastructure. A computer calculates the toll for the vehicle according to the driven distance and the time of day. Electronic toll collection systems rely on four components: automated vehicle identification (mainly by radio-frequency identification via transmitter), automated vehicle classification (classification of vehicle), transaction processing and violation enforcement (e.g. police patrols, physical barriers automatic number plate recognition) [21].

1.4.2.2 Variable speed limits

Standard speed limits signs do not take the given conditions into account. Variable speed limit signs adapt depending on the environmental situation as well as traffic flow and day time. Infrastructure-based ITS in the form of sensors (e.g. cameras, induction loops, laser) measure traffic flow, weather conditions and determines events such as heavy congestions. Data is collected in traffic management centres, which transmit relevant information to the driver by means of radio communication, RDS-TMC (Radio Data System – Traffic Message Channel) or variable (traffic) message signs (VMS).

1.4.2.3 Infrastructure-based automated driving

Infrastructure-based automated driving vehicles provide new mobility concepts. Especially public transportation systems such as trains, buses and PRT (Personal Rapid Transport) are operated on different automation levels even up to driverless transportation systems. Automated trains and transportation systems in dedicated areas (e.g. railways, special driving lanes and closed environments) have been introduced for many years. New modes of automated transportation are PRT. These are fully automated driverless vehicles, which navigate automatically along a network of dedicated guide ways providing on-demand service. Examples of such systems are installed at the airport in Heathrow. The “ULTra” is a four-seater vehicle driving on four rubber-tyred wheels at the size of a small car [22]. Another PRT system in operation is located in Masdar, Abu Dhabi [23].

1.5 Vehicle-based ITS

Since the introduction of research and deployment programmes for ITS, a large number of projects have been conducted. Fundamental results were achieved in these projects with regards to application of ITS technologies in vehicles. Selected projects are mentioned in the following as they define the state-of-the-art of ITS research.

Due to the availability of high resolution perception systems and computational power an increase of automation in vehicle-based ITS can be observed in the recent past. First advance driver assistant systems were focused on the support of the driver by means of comfort, information and warning functions. Active safety system capable to take over either the longitudinal or lateral vehicle control utilised next-generation sensor systems and fusion of different sensor principles. Recent developments (e.g. traffic jam assist) combine longitudinal and lateral control. Today these functions have to be monitored constantly by the driver. However, demonstration and prototype vehicles show already next steps which are possible with available technology.

The level of automation that a vehicle-based ITS can provide has been classified in different ways, e.g. BASt (Bundesanstalt für Straßenwesen) (updated to 5 levels)/VDA (Verband der Automobilindustrie) definition [24]; NHTSA (National Highway Traffic Safety Administration) definition [25]; and SAE (Society of Automotive Engineers) definition [6].

The SAE definition and the updated BASt/VDA definition provide the same number of automation levels with only minor difference. The NHTSA definition is summarising SAE levels 4 and 5 into one single level. In the following the different automation levels according to the SAE definition are described.

1.5.1 Automation level 1 – advance driver assistant systems (ADAS)

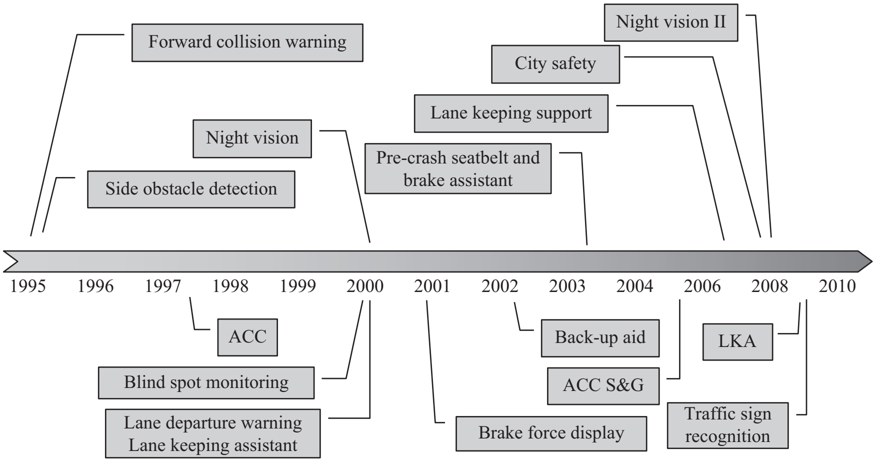
In level 1 ADAS execute the driving mode-specific driving task by means of either steering or acceleration/deceleration using information about the driving environment. The human driver is in the driving loop and monitors the driving environment. Such systems have been introduced in the market since the mid-1990s. An overview on selected research activities in Europe is shown in Figure 1.2.

1.5.2 Automation level 2 – example: traffic jam assist and platooning

Specific for level 2 is the execution of one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment. The driver remains still in the driving loop and needs to monitor the environment. He is supported in lateral and longitudinal vehicle control.

First systems are on the market such as the traffic jam assists, which can be activated in a specific condition (traffic jam) and supports the driver in the dynamic driving task. An overview on available ADAS and the resulting sensor ranges for automation level 2 functions is shown in Figure 1.3.

A concept known from railways is to combine single vehicles into so-called platoons. Research activities like PATH [13], KONVOI (Entwicklung und



ACC − Adaptive cruise control
ACC S&G − Adaptive cruise control stop & go
LKA − Lane keeping assist

Figure 1.2 Market introduction of level 1 driver assistance systems focusing on guidance and navigation level up to 2009

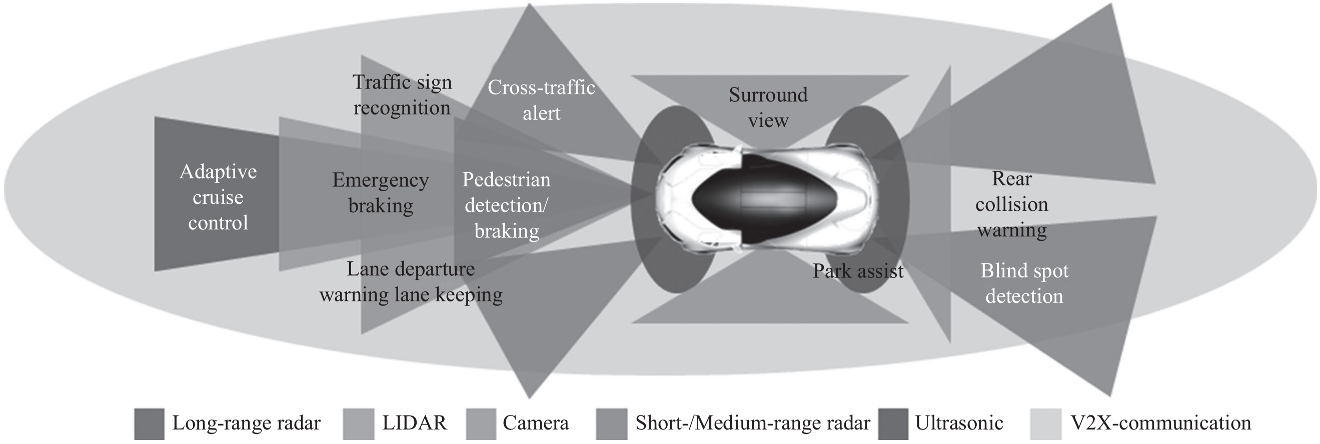


Figure 1.3 Overview of available ADAS and used sensors

Untersuchung des Einsatzes von elektronisch gekoppelten Lkw-Konvois) [26], Energy ITS Japan [15], SARTRE (Safe Road Trains for the Environment) [27] or COMPANION (COoperative dynamic forMation of Platoons) [28] develop and demonstrate these platoons. Within the SARTRE project a platoon of five vehicles (two trucks and three passenger vehicles) was built up and demonstrated on public road. Currently the logistics on how platoons are created during a trip is under research [28].

1.5.3 Automation level 3 – example: highway pilot

Starting in automation level 3 the system monitors the driving environment. The system performs the driving mode-specific driving task in all aspects. The human driver will respond appropriately to a request to intervene, if necessary. Such systems are yet not legal to be operated on public roads except for test vehicles driven by driver with test permissions. One of the first systems to be introduced is the Highway Pilot. Due to the controlled environment on highways (pedestrians and bicyclists are not allowed on Europe highways) the Highway Pilot takes of longitudinal and lateral vehicle control even in higher speeds using state-of-the-art environmental sensors. The driver shall be able to focus on secondary tasks next to the driving task for a limited time duration.

1.5.4 Automation levels 4 and 5

In level 4 all aspects of the dynamic driving task is performed by an automated driving system. Even if a human driver does not respond appropriately to a request to intervene, the system needs to be able to solve the situation. The driver is not to be foreseen as a fallback for the performance of the driving task.

In level 5, also called autonomous driving, the full-time performance of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver is taken over by the automated system. The driver does not need to be available. These systems can act fully autonomous, but can also provide high connectivity to other vehicles or the infrastructure.

For these automation levels different demonstrations and research activities have been initiated in the last 25 years. In Europe the first test drive of a level 4 system was undertaken in the VAMP activity at the end of the PROMETHEUS project. A journey of approximately 1,600 km from Munich (Germany) to Odense (Denmark) took place in 1995 in which most of the driving was performed by the VaMoRs (Versuchsfahrzeug für autonome Mobilität und Rechnersehen) system [29]. In Italy the ARGO (Algorithms for Image Processing) project demonstrated vehicle automation on a journey of approximately 2,000 km in the MilleMiglia tour (Italy) in 1998 [30].

A new mobility concept in terms of “Cybercars” was created, which uses the advantages of automobiles combined with ITS technology. The idea of Cybercars was developed in the European funded research project “Cybermove” [31]. Cybercars are slow moving automated driving vehicles on existing road infrastructure. The first systems have been put in operation in the Netherlands at the end of 1997 and have been running successfully 24 hours a day. Several other systems have been implemented in European research projects on this topic (see Cybermove project from 2004, Cybercars project from 2006 and CityMobil (Cities demonstrating automated road passenger transport) projects 1 and 2 from 2011 and 2016).

In the US demonstrations like the NavLab 5, a journey of approximately 4,587 km from Pittsburgh (USA) to San Diego (USA) was conducted also in 1995 [30]. The groundwork for many of today's driverless vehicle activities of different companies/institutions was laid by the DARPA (Defense Advanced Research Projects Agency) Grand Challenges. The DARPA Grand Challenge 1 was conducted in 2004, followed by the DARPA Grand Challenge 2 in 2005. Two years later in 2007 the DARPA Urban Challenge took place in an urban environment. In all three challenges robot vehicles have to complete a test track (in the desert and in an urban city scenario) without any human interaction or control [32].

Shortly after the DARPA Grand Challenges Google announced its self-driving car programme. Ever since different vehicle manufacturers have shown milestones of vehicle automation such as the VW Golf 53+1, the BMW Track Trainer, the Daimler Berta Benz drive, Audi's Jack, and Delphi's Coast to Coast drive [33]. Nowadays experience and data are collected in large-scale field tests and vehicle automation is part of every development roadmap in the transportation sector.

1.6 Deployment of ITS

Large-scale deployment with high penetration rates is desirable in order to maximise impact of ITS. Especially in the recent years, implementation and deployment has been the focus of funding activities due to a high level of maturity of ITS technology. For a successful deployment cross-border and cross-company standards are a prerequisite. Standards pave the way for market introduction.

1.6.1 Standardisation

Standardisation of new technologies in the field of transport enables the safe operation of systems and exchange of information independent of the design and manufacturer. Different institutions are involved in standardisation of ITS.

CEN (European Committee for Standardization/Comité Européen de Normalisation) was established in 1974. The Technical Committee for Transport Telematics and Road Traffic TC 278 (Road Transport and Traffic Telematics) was established in 1992 and consists in 2016 of 10 active working groups with over 300 nominated experts. ITS revenant standards in Europe are managed in CEN TC278 [34].

ETSI (European Telecommunications Standards Institute) is a non-profit organisation, which was formed on 29 March 1988. It is the European equivalent of IEEE (Institute of Electrical and Electronics Engineers) of the US. In 2016, ETSI is listing 85 standards related to ITS [35].

At an international level the ISO (International Organization for Standardization) TC204 (overall system and infrastructure aspects of ITS) is responsible for the overall system and infrastructure aspects of ITS. TC204 oversees the coordination of the ISO program in this field, which includes setting the schedule for standards development and taking into account the work of existing international standardisation bodies. Work in ISO TC204 includes standardisation of information, communication and control systems in the field of urban and rural surface transportation, traveller's information, traffic management, public transport, commercial transport and emergency and commercial services [36].

Furthermore standardisation work in CENELEC (European Committee for Electro technical Standardization), IEEE on ITS communication, SAE on vehicle automation and other national institutions as well as standardisation from robotics, industrial automation and communication are relevant in the field of ITS.

1.6.2 Testing and demonstration

Following the design and development of ITS the final steps before market introduction are testing and development. Next to track tests and field tests an important method is field operational tests on public roads. Field operational tests, in which the developed and available technologies are analysed in the target environment, are conducted at manufacturers and/or dedicated projects. ITS technologies have been investigated in field operational tests for many years. Important test activities such as the 100 car study performed by VTTI (Virginia Tech Transportation Institute) in the US [37], the European projects euroFOT (which was the first large-scale European Field Operational Test) [38], Drive C2X (DRIVing implementation and Evaluation of C2X communication technology in Europe) [39] and others are shown in Figure 1.4.

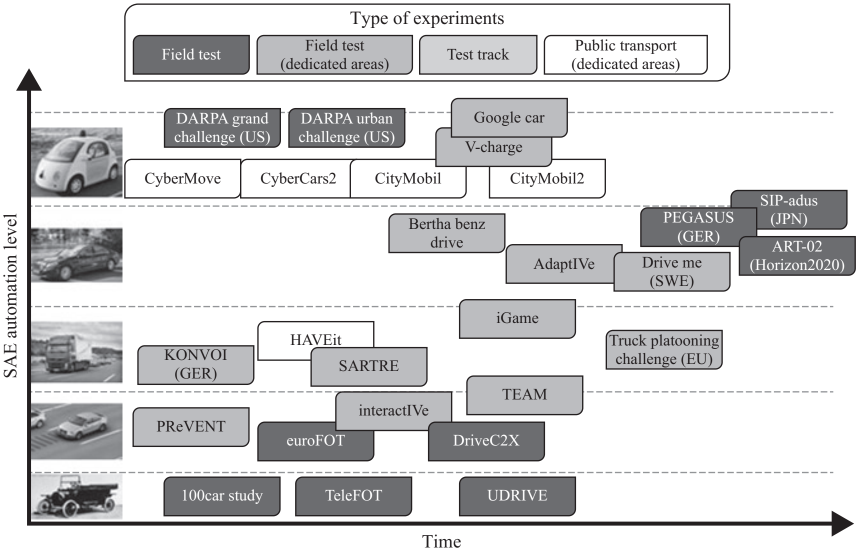


Figure 1.4 Overview of selected tests and demonstration activities in the field of automated road transportation at different SAE automation levels

Furthermore test permits can be obtained by system manufacturers in order to perform evaluation and market readiness sign-off data collection. Especially tests of vehicle automation level 3 and higher have been in focus of recent activities. Test licenses are provided to different companies in some states of the USA. In Europe a call for proposals is issued in the ART-02 (Automated Road Transportation) Horizon2020 program to demonstrate level 3 or 4 systems cross-border on European roads.

1.6.3 Market introduction

A successful market introduction is the last step of deployment. In order to maximise the impact of a technology, a high penetration rate is desirable. For market introduction different approaches need to be distinguished:

1. A technology is introduced for new infrastructure or vehicles as an option. In this case it depends on the customer, whether this opinion is chosen. It can be expected that the customer will go for the opinion in case a benefit (monetary, comfort, safety) from the system is expected. Typically to this approach is the slow increase of the penetration rate, since only new infrastructure or vehicles are equipped. This implies that existing infrastructure or vehicles are not involved and need to be replaced over time.
2. A technology is introduced for new infrastructure or vehicles as an option and a retrofitting of the existing infrastructure or vehicles is possible. Similar as in the first approach it is up to the customer, whether a technology is successful or not. In contrast to the previous approach, at least theoretically, higher penetration rates can be reached faster.
3. A technology is introduced for new infrastructure or vehicles as standard equipment. This could happen, for instance, due to a change in a law that requests a certain technology. In this case the customer cannot choose and the penetration rate entirely depends on the market introduction of the new infrastructure or vehicles. Due to the enforced introduction of the technology it can be hard to charge the customer more.

An overview on the penetration of different vehicle-based ITS in Germany is given in Table 1.1 [40]. The penetration rates of the systems were derived on the basis of 5,070 interviews and vehicle inspections of ordinary drivers.

1.7 Outlook

Today ITS technologies have already a long history and are introduced in the transportation sector as a wide range of different systems. Nevertheless the disrupting impact of these technologies is forecasted by the introduction of automated driving technologies for higher automation levels. Currently a step-wise introduction versus a direct introduction of even autonomous vehicles is considered by different companies out of different industry branches.

Table 1.1 Overview of penetration rate of different vehicle-based ITS in Germany in 2013 on the basis of Reference 40

System name	**Penetration rate of fitted vehicles (%)**	**System name**	**Penetration rate of fitted vehicles (%)**
Navigation and driver information		**Lane keeping and lane change assist**	
Navigation device	71	Lane change warning	1
Speed warning	3	Blind spot detection	1
Attention assist	2	Lane departure warning	1
Traffic sign detection	1	Lane change assist	0
Vehicle dynamics and distance control		**Parking system**	
Brake assist	73	Park distance control	27
ESC	68		
Forward collision warning	2	Rear view camera	4
Secondary collision mitigation	2		
AEB up to 30 km/h	1	Park assist	3
AEB above 30 km/h	1		
Cruise Control		**Others**	
Cruise control	35	eCall	3
Speed limiter	14		
ACC (Adaptive Cruise Control)	3	Accident data logger (only company car)	2
Traffic jam assist	0		

Dedicated roadmaps and ITS action plans indicated a further deployment of ITS technology in each upcoming new transport generation independent of vehicle type and manufacturer. Electronics and IT will play the most important role. A shift form hardware to software development is one of the essential transformation, which can be observed in current research and development. The role of large data sets (“Big Data”) provides new opportunities and business models.

1.8 Outline of the book chapters

The book contains four Parts: I Introduction; II. Needs and methods; III. ITS evaluation results; and IV Discussion and conclusions (see Table 1.2). A total of 17 chapters are presented.

Table 1.2 Outline of the book chapters

Part	Chapter	Description
I	1	It provides a technical review of ITS in terms of relevant research programmes, challenges, demonstrations, market introduction; in addition current developments in the domain of automated driving. ITS history, deployment and key technologies (infrastructure based and vehicle based, respectively) are comprehensively addressed.
II	2	It focuses on policy dimensions of evaluation and presents the specific needs for evaluation of the ITS solutions to traffic safety, traffic efficiency, energy efficiency and environmental impacts. An international survey was carried out in 2015–2016, and the results are analysed.
	3	It provides a comprehensive overview of the frameworks and methods for ITS evaluation. It provides definitions of relevant terms and an outline of evaluation issues from practical aspects. In addition, it addresses the key challenges in evaluation of ITS development and deployment.
	4	It provides an overview of the different approaches at European or International level to assess the impact of ITS on mobility. It presents evaluation tools, as well as comparative analysis results of the impacts evaluation of variable speed limits, ramp metering, dynamic lanes, road pricing, information services and journey time.
	5	It presents an ITS evaluation of the US Interstate Highway System from a network perspective. Conventional evaluation, e.g. in North America, focuses on specific investments, which may miss positive synergies from a network of investments. New technology, such as automated driving, offers an opportunity to generate the scale of net benefits.
	6	It targets the evaluation of Field Operational Tests (FOTs). It presents a new approach for addressing user up-take (user acceptance and user adoption) and the impact evaluation of mobility, efficiency, safety and environmental issues.
	7	It proposes a new method of balancing transport measures, including ITS, which is developed in the Netherlands. It especially focuses on the two widely used transport measures: cost–benefit analysis (CBA) and multi-criteria analysis (MCA).
	8	It presents the technical assessment of the performance of in-vehicle systems mainly based on the EU-funded and French projects, such as SAFESPOT and LAVIA. The assessment approach is widely adapted for non-technical evaluation in Field Operational Tests (FOTs) in Europe.
	9	It targets an evolution of ITS – extending to pervasive web-enabled devices. It outlines various types of schemes and examples of real-life implementations, addresses challenges of evaluating new ITS applications for the standard transport evaluation paradigm, and discusses evaluation approaches, strengths, limitations and potential interfaces.
III	10	It presents evaluation results concerning Cooperative ITS (C-ITS), which predict the costs and benefits of a range of C-ITS services, considering the benefits compared with no service or, incrementally, from a non-cooperative service. It introduces a comprehensive evaluation framework.

(Continues)

Table 1.2 (*Continued*)

Part	Chapter	Description
	11	It presents an evolutionary approach towards automated driving. It aims to take stock of existing knowledge concerning (socio-economic) assessment, to review and reconsider it with a view towards automated driving. The results support the view that the functions deliver important benefits to the performance of road transport but in terms of magnitude they cannot yet be considered as being of disruptive nature.
	12	It targets user-related evaluation of ADAS (advanced driver assistance systems) and automated driving. It especially focuses on automation related issues for user-related evaluation, hypotheses, indicators and assessment methods.
	13	It provides a review of the effects and assessments of ITS applications for traffic management in Sweden. It focuses on the CBA application for the evaluation of travel time and incident information, ramp metering, variable speed limits (VSL) and motorway control system (MCS).
	14	It reviews relevant before and after studies, and presents the need for the F3 system (automatically reducing the speed limit on a motorway when raining) in Australia. It also addresses challenges, e.g. limit of measurements and assigning accurate costs and future research.
	15	It presents the state-of-the-art of ITS development Asia. It provides examples of the benefits evaluation of ITS projects in PR China: Bus Rapid Transit (BRT) System in Guanzhou; and Advanced Traffic Management System (ATMS) in Qingdao.
	16	It performs a benefit–cost study of an overloading control centre in South Africa for heavy goods vehicles, incorporating elements such as concept of operations, electronic control and monitoring systems, including weigh-in-motion detectors, traffic situation and various facilities, as well as potential costs.
IV	17	It presents a summary of the evaluation results of intelligent road transport, lessons learned, research needs and challenges. In addition, it discusses the implications of these topics on the industry and on academia and administrations, lists the open research areas, includes suggestions for future work and provides conclusions.

References

[1] Herman, A. (2012) Freedom’s Forge: How American Business Produced Victory in World War II, pp. 58–65, Random House, New York, NY, 2012. ISBN 978-1-4000-6964-4.

[2] Anon. (2016). Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010, http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:207:0001:0013:EN :PDF [Accessed 31 March 2016].

[3] Anon. (2016). ETSI Intelligent Transport, http://www.etsi.org/technologies-clusters/technologies/intelligent-transport [Accessed 31 March 2016].

[4] Anon. (2016). Intelligent Transportation Systems Joint Program Office, http://www.its.dot.gov/faqs.htm [Accessed 31 March 2016].

[5] Anon. (2016). ITS Japan, http://www.its-jp.org/english/about_e/ [Accessed 31 March 2016].

[6] Anon. (2014). Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, SAE Standard J3016, USA.

[7] Donges, E. (1982). Aspekte der aktiven Sicherheit bei der Führung von Personenkraftwagen, Automobil-Industrie, Heft 2.

[8] Eckstein, L. (2014). Automotive Engineering – Active Vehicle Safety and Driver Assistance Systems, Lecture Notes, Institute für Kraftfahrzeuge (ika), RWTH Aachen University, Aachen, Germany.

[9] Rowsome, F. (1958). What It's Like to Drive an Auto-Pilot Car, Popular Science Monthly, USA, April 1958.

[10] Shaout, A., Jarrah, M. A. (1997). Cruise Control Technology Review, *Computers Electric Engineers* Vol. 23, No. 4, pp. 259–271.

[11] Weiskopf, B. (2001). ARI-Technik. UKW/TV-Arbeitskreis der AGDX e. V., Mannheim, February 2001.

[12] Shladover, S. (1992). The California PATH Program of IVHS Research and Its Approach to Vehicle-Highway Automation, IEEE Intelligent Vehicle '92 Symposium, Detroit, USA.

[13] Anon. (1997). PATH Program – Vehicle Platooning and Automated Highways, PATH Fact Sheets, University of California, Berkeley, USA.

[14] Mammano, F.J., Bishop, J.R. (1992). Status of IVHS Technical Developments in the United States, IEEE Vehicular Technology Conference, Denver, USA.

[15] Tsugawa, S. (2011). The Current Trends and Issues on ITS in Japan: Safety, Energy and Environment, IEEE MTT-S International Microwave Workshop Series, Daejeon, South-Korea.

[16] Harayama, Y. (2014). The National Program for Innovation, Cross-Ministerial Strategic Innovation promotion Program (SIP), 1st SIP-adus Workshop on Connected and Automated Driving Systems, Tokyo, Japan.

[17] Kuzumaki, S. (2015). Innovation of Automated Driving for Universal Service (SIP-adus)-Mobility Bringing Everyone a Smile, 2nd SIP-adus Workshop on Connected and Automated Driving Systems, Tokyo, Japan.

[18] Nagel, H. H., (2008). EUREKA-Projekt PROMETHEUS und PRO-ART (1986–1994), Informatikforschung in Deutschland, Springer, pp 151–202.

[19] Hofflinger, B., Conte, G., Esteve, D., Weisglas, P., (1990). Integrated Electronics for Automotive Applications in the EUREKA Program PROMETHEUS, Solid-State Circuits Conference, ESSCIRC '90. Sixteenth European, Vol. 2, pp. 13–17.

[20] Anon. (2015). Regulation (EU) 2015/758 of the European Parliament and of the Council (29 April 2015) Type-Approval Requirements for the Deployment of the eCall In-Vehicle System Based on the 112 Service and Amending, Directive 2007/46/EC.

[21] Kelly, F. (2006). Road Pricing: Addressing Congestion, Pollution and the Financing of Britain's Road. Ingenia (The Royal Academy of Engineering) 39: 36–42.

[22] Bly, P., Lowson, M. (2009). Outline Description of the Heathrow Pilot PRT Scheme, Deliverable D1.2.2.2, CityMobil project.

[23] Anon. (2011). 2getthere Company Information, http://www.new.2getthere.eu [Accessed 31 March 2016].

[24] Gasser, T. M., Arzt, C., Ayoubi, M., *et al.* (2010). Die "Projektgruppe Automatisierung": Rechtsfolgen zunehmender Fahrzeugautomatisierung 11. Braunschweiger Symposium AAET, Proceedings, Publisher: Intelligente Transport- und Verkehrssysteme und –dienste Niedersachsen e.V., Braunschweig, Germany. ISBN 978-3-937655-23-9.

[25] Anon. (2013). Preliminary Statement of Policy Concerning Automated Vehicles, National Highway Traffic Safety Administration (NHTSA).

[26] Deutschle, S. (2008). Das KONVOI Projekt – Entwicklung und Untersuchung des Einsatzes von Lkw-Konvois, Aachener Kolloquium Fahrzeug und Motorentechnik 2008, Aachen, Germany.

[27] Chan, E., Gilhead, P., Jelinek, P., Krejci, P., Robinson, T. (2012). Cooperative Control of SARTRE Automated Platoon Vehicles, in Proceedings of the 19th ITS World Congress, Vienna, Austria.

[28] Farokhi, F., Johansson, K. H. (2015). A Study of Truck Platooning Incentives Using a Congestion Game, *IEEE Transactions on Intelligent Transportation Systems* Vol. 16, No. 2, pp. 581–595.

[29] Maurer, M., Behringer, R., Fürst, S., Thomanek, F., Dickmanns, E.D. (1996). A Compact Vision System for Road Vehicle Guidance, Proceedings of ICRP 1996, IEEE.

[30] Bertozze, M., Broggi, A., Fascioli, A. (2000). Vision-Based Intelligent Vehicles: State of the Art and Perspectives, *Robotics and Autonomous Systems* Vol. 32, p. 10.

[31] Parent, M., Gallais, G. (2002). Intelligent Transportation in Cities with CTS, Proceedings of IEEE 5th International Conference on Intelligent Transportation Systems, ISBN 0-7803-7389-8.

[32] Urmson, C., Anhalt, J., Bagnell, D., *et al.* (2008). Autonomous Driving in Urban Environments: Boss and the Urban Challenge, *Journal of Field Robotics* Vol. 25, No. 8, pp. 425–466 (2008), DOI: 10.1002/rob.20255.

[33] Zlocki, A. (2014). Automated Driving: Encyclopedia of Automotive Engineering, John Wiley & Sons, Ltd., DOI: 10.1002/9781118354179.auto023, ISBN: 978-0-470-97402-5.

[34] CEN/TC278 (2016). http://www.itsstandards.eu/index.php [Accessed 31 March 2016].

[35] ETSI TC 278 (2016). http://www.etsi.org/index.php/technologies-clusters/technologies/intelligent-transport [Accessed 31 March 2016].

[36] ISO TC204 (Overall system and infrastructure aspects of ITS) (2016). http://www.itsa.org/industryforums/isotc204 [Accessed 31 March 2016].

[37] Dingus, T. A., Klauer, S. G., Neale, V. L., *et al.* (2006). The 100-Car Naturalistic Driving Study Phase II – Results of the 100-Car Field Experiment National Highway Traffic Safety Administration, Report Nr. DOT HS 810 593, Washington D.C., USA.

[38] Benmimoun, M., Zlocki, A., Kessler, C., *et al.* (2011). Execution of a Field Operational Test within the euroFOT Project at the German1 Test Site, 18th World Congress on Intelligent Transport Systems, Orlando, USA.

[39] Brakemeier, A. (2012). Co-Operative ITS – Standardization, Improving Road Safety and Traffic Efficiency, 18th European Wireless Conference, Poznan, Poland.

[40] Follmer, R., Geis, A., Gruschwitz, A. Hölscher, J., Raudszus, D., Zlocki, A. (2015). Marktdurchdringung von Fahrzeugsicherheitssystemen, Report of Bundesanstalt für Straßenwesen (BASt), Mensch und Sicherheit, Heft M 258, Bergisch Gladbach, Germany.

Part II

Needs and methods

Chapter 2

ITS evaluation policy – Culture and needs

*Martin Böhm[1], Barbara Flechl[1], Walter Aigner[2]
and Caroline Visser[3]*

2.1 Introduction

Millions of Dollars and Euros are invested each year by transport authorities and network operators for making their countries' transport infrastructure more intelligent. New Traffic Control Centres and Traveller Information Centres are built, new sensors and communication technologies are deployed and more or less innovative traveller information services (from Variable Message Signs via information through navigational devices to Smart Phone Apps) are rolled out. Additionally, high amounts of money are invested for making the rolling stock smarter – starting with 'tracking and tracing' technologies for vehicles via connecting them with the used infrastructure towards automated services. More and more 'intelligent' systems and services are available and promoted under the umbrella of Intelligent Transport Systems (ITS).

As many of these deployments are driven by public authorities, the main drivers are the traditional policy pillars called safety, security, sustainability (including environmental friendliness) and efficiency. Especially in the transport field, all investments need to show a positive impact in at least one of these pillars, but shall ideally cover more than one. Additionally cost efficiency needs to be ensured, which gets more and more important in times of limited financial resources. In principle, all bigger investments done need to be evaluated in this framework.

In parallel, we know that politicians like to open newly built infrastructures and to cut 'red ribbons'. For politicians, who are often the final decision-makers especially for large infrastructure investments, it is highly important to be noticed by the general public in a positive manner to ensure re-election. Their strategies are often based on success stories in daily newspapers about improved infrastructures that help citizens, e.g. opening a new bypass-road that cuts trough-traffic in residential areas.

[1] AustriaTech, Austria
[2] HiTec, Austria
[3] Global Road Links, Switzerland

Often such huge investment in new ‘hardware’ infrastructure makes sense and has a high positive benefits–cost impact. But sometimes the benefit–costs ratio would be even better either by replacing this ‘hardware’ infrastructure by ITS solutions, or at least considering the deployment of smarter ‘soft’ measures as well, thereby having ITS solutions. But such smarter solutions are often not that visible to the general public. In this gap integrated between high visibility and a good benefits–cost ratio decision-making for or against ITS solutions is done at highest authorities’ level.

Based on literature review as well as a questionnaire initiative and several face-to-face interviews, an analysis of the status quo for decision-making towards the implementation of ITS solutions was performed by the authors. The underlying thesis of this chapter can be formulated as follows: ‘ITS evaluation contributes to better informed, evidence-based ITS decision-making’. In this context, it is important to understand first the general principles of ITS evaluation and the expected value by decision-makers. Followed by an analysis of the different decision-making and evaluation cultures around the globe finally the findings of a global survey among ITS practitioners and decision-makers are discussed. At the end recommendations for evaluators to make their work useful for decision-makers are formulated.

2.2 Why evaluation is needed by decision-makers and what it is used for

2.2.1 The importance of evaluation for ITS deployment

In general evaluation can be defined as ‘systematic acquisition and assessment of information to provide useful feedback about some object’ [1]. In particular, ‘the term “evaluation of ITS” is an assessment of the extent to which an ITS scheme has met its objectives’ and ‘provides lessons on improving performance in future’ [2]. The World Road Association PIARC [2] lists six main issues which should be taken into consideration for an ITS evaluation: the reason for an evaluation, the audience for whom the evaluation is intended, the evaluation cycle, the evaluation methods, the budget and the resources that can be made available, and how evaluation and monitoring can improve performance.

The overall goal that authorities and operators aim to achieve with the deployment of ITS is the improvement of road safety, increasing efficiency of road infrastructure (i.e. improved capacity) and reducing the environmental impacts of road traffic. Furthermore, according to Newman-Askins *et al.* [3], the costs of building extra road infrastructure can be reduced by deploying ITS. To verify and quantify those benefits and to further support decision-makers in the justification of investments in ITS systems and applications, it is of utmost importance to use comprehensive evaluation methods. As most of the deployments of ITS solutions are driven by the public sector and hence funded through tax revenues, accountability is always one of the highest priorities. To justify the spending of scarce public funds, evaluation provides a convenient tool for assessing the cost-effectiveness and the documentation of already existing systems. Furthermore, it creates the basis for future implementations and supports the creation of a better understanding and acceptance of ITS measures within the general public.

But it needs to be noticed that the impact evaluation of ITS projects in comparison to conventional road projects is different as stated by Newman-Askins *et al.* [3]. Evaluation activities of ITS comprise various additional factors like customer satisfaction, driver behavioural response or increased comfort. And these factors are difficult to measure or value and they necessitate qualitative assessment methods rather than being measured with quantitative methods only.

Therefore, the role of evaluation for decision-makers is not only the justification of investments. If evaluation is planned thoroughly based on an evaluation plan, an improvement of future ITS implementation processes or an enhancement of the whole ITS system can be ensured by showing if the system works as intended. The EasyWay Evaluation Expert Group [4] recommends that such an evaluation plan should ideally cover several feedback mechanisms, including scientific studies, audits, monitoring, performance measurement, policy analysis, feasibility studies and impact analysis.

Decision-makers like transport authorities, infrastructure operators or funding bodies are interested in the availability, acceptability and the financial feasibility of an existing or planned ITS service or application. Evaluations can support them in verifying whether the expected value of the investment in ITS has been realized and in which areas the benefits exceeded or were below expectations and therefore to get a sense 'about the requirement, design, procurement, deployment and utilisation of ITS systems and how these can be improved in the future' [5].

But an isolated evaluation of ITS is not sufficient. Evaluation needs the commitment and the cooperation of many actors to enable a comparison of ITS implementations. Therefore, certain standards for evaluation need to be created, starting with commonly agreed Key Performance Indicators (KPIs) followed by standardized evaluation methodologies resulting in comparable evaluation results. Such an internationally harmonized evaluation methodology would contribute to improving access to knowledge of ITS implementations and projects, including positive as well as negative examples. It would furthermore enable linking similar ITS deployments to learn from each other, coordinate approaches and to accomplish to similar goals.

2.2.2 From R&D to ITS deployment

The path from research and development (R&D) to deployment can become a long and difficult one, particularly in the case of ITS. Often ITS technologies remain in the research stadium or get stuck in the transfer process to deployment because of deficits in the knowledge about the real abilities of the ITS system or ITS services. Furthermore, the implementation process can take too long, not keeping pace with technology life cycles, and technology becoming obsolete before the implementation of the ITS system is finalized. Additionally the different life cycles of ITS implementations and infrastructure deployments need to be considered. While infrastructure implementations are usually built for long time periods (e.g. a road construction will remain several decades), many ITS systems rely on emerging technologies, including information and communication technologies. To counteract the above mentioned challenges, assistance to policy-making level needs to be made available in form of guidelines or supporting documents based on evaluation evidence in test cycles to support deployment decisions. Sometimes even regulations on national or transnational level are needed.

In Europe, e.g. the European ITS Action Plan [6] and the European ITS Directive [7] were created to accelerate and foster harmonized ITS deployments across Europe. While several research projects have demonstrated the positive impact of ITS systems and services, real-world deployments were sometimes stuck. The ITS Action Plan was established in 2008 to ensure a European approach towards reaching the goals of greening transport, improving transport efficiency and improving road safety and security and in this context to show the European added value of ITS deployment. Two years later, in 2010, the European Parliament and the Council published the ITS Directive followed by delegated acts in which the access to transport related data as well as the deployment of eCall-services is regulated with the goal of fostering and accelerating wide-scale implementations of ITS across Europe in a coordinated way.

The high importance of ITS evaluation is recognized by the United States (US), where the Joint Programme Office (JPO) of the US Department of Transport (DoT) provides guidance for ITS evaluation [8]. Evaluation is seen as an important part towards deployment, both on policy level as well as on a project basis. The two types of evaluation methods, qualitative and quantitative, should in accordance to the US JPO both be applied combined to ‘compare and contrast converging and possibly conflicting evidence’ [8]. Furthermore, it is seen as highly important to define goals and objectives for the evaluation of ITS projects and ensure their measurability.

Similar approaches can be found in Canada, where the Canadian Victoria Transport Policy Institute has published many documents on Evaluation in the transport sector [9]. On global level, three initiatives need to be mentioned: First, the World Bank provides an ITS Toolkit for urban ITS implementations [5] which includes case studies; second, the ITS Benefits Evaluation Community (IBEC) provides training materials for ITS evaluations [10], and third, the World Road Association (PIARC) is concerned with the subject of ITS evaluation as well and has published some supporting guidance documents [2] available on its website.

To show the progress in achieving specific policy targets, evaluation is seen as a helping tool for ITS stakeholders like ITS service providers, transport and infrastructure operators, associations of ITS users, representatives of the manufacturing industry, social partners, professional associations, as well as local, regional and national governments representing the public sector.

The person or entity providing or carrying out the evaluation is another crucial factor to consider. The US DoT, ITS JPO states in this context the importance of an independent evaluator ‘who has no vested interest or stake in the project itself’ [8]. In this respect, the evaluator should neither be with the contracting party nor be with the implementing party to ensure potential neutrality. Even though the evaluator is seen as an independent party an early involvement is necessary. A six-step process for ITS evaluation is recommended by the ITS JPO and was employed successfully by many ITS projects:

1. Form the evaluation
2. Develop the evaluation strategy
3. Develop the evaluation plan
4. Develop one or more test plans
5. Collect and analyse data and information
6. Prepare the final report

Complementary to guidance on how to perform evaluation, the facilitation of harmonized evaluation methods might support the comparability and reliability of evaluation results, supporting the leap from R&D to ITS implementation. Regulations and deployment specifications as sole instruments seem to be insufficient. A thorough understanding on investing in ITS needs to be developed; and evaluation is the most appropriate tool to achieve this target by showing the benefits–cost ratios for single implementations. Evaluation creates a better understanding on the potential of ITS by both, ITS experts and decision-makers. ITS evaluation shows which ITS solutions work and where further improvements are needed. In this context, evaluation provides a kind of 'investment security' by supporting decision-makers to invest money in the most efficient way, preferably based on commonly agreed KPIs underlining the impact of envisaged ITS deployments.

While discussing the positive effect of harmonized evaluation methods, it needs to be noticed that even the commonly agreed KPIs for ITS evaluations do not exist globally. It is exactly this field of the development of commonly agreed KPIs where a lot of activities are going on in Europe. At the beginning of 2015, an European Commission (EC)-funded study was carried out by AECOM on 'Key Performance Indicators for Intelligent Transport Systems', initiated by the need for European common KPIs for ITS. The goal was to provide KPIs that 'deliver a minimum standard' for ITS deployment and to 'support future investment and deployment' [11]. With a state of the art review, a stakeholder survey and a stakeholder workshop, a list of 98 commonly used KPIs for ITS deployments was identified. These were divided into two sections: deployment KPIs, which relate directly to ITS deployment (e.g. number of kilometres on the road network equipped with ITS) and benefit KPIs, which show the benefit of an ITS implementation, like increased safety impacts of ITS. On this basis, a shortlist of 11 KPIs has been created where the EC expects evaluation results provided by the single Member States. This can be seen as a starting point for harmonizing the evaluation KPIs in Europe.

To conclude evaluation is seen on policy level as an important tool for decision-makers, particularly in the public sector where public funds are involved, to plan and assess the cost-effectiveness of ITS. Additionally, with the help of evaluation, the benefits of ITS implementation can be made visible to the public.

Nevertheless, many transport administrations and operators do not evaluate the particular ITS implementation properly, as evaluation is often done 'in-house' and not by neutral external evaluation experts. Consequently, the potential of some ITS solutions cannot be fully tapped, resulting in money being spent in an ineffective way.

2.3 Evaluation policy and how it influences ITS evaluation

Evaluation has been seen differently in various policy traditions, research traditions, as well as from a more general conception of the sociology of knowledge. This section is intended to stimulate some reflective thoughts and to raise awareness on potential risks from implicitly assuming that we are all looking at the same phenomenon. We frankly admit, this is based mainly on personal observations and on perusing hundreds of ITS evaluation reports and presentations (with a bias towards documents from Europe and European eyes) as well as from mostly low key hints or hidden hints in some of the more recent policy analysis books. Unfortunately, the issue of differing expectations, cultures and context has hardly been reflected or made explicit when ITS evaluation results are presented at international ITS conferences or published in reports.

We start by dissecting the quoted expectation, then will hint towards some cultural training differences on evaluation report writing and then reflect on consequences from a general tendency to self-reference in culture, projects and policy. Finally, we list some candidates for culturally different expectations from newly emerging cultural contexts for ITS evaluation policy (open innovation perspective, democratizing innovation; living labs, social labs).

We tend to reframe the expectation (‘I would expect rather unbiased clear answers, guided by objectivity’) as naive because this framing itself is heavily biased towards relevance or one concept of relevance. This issue has been discussed for decades under the dichotomy rigor versus relevance. The implicit assumption that ITS evaluation results are relevant for the local transport administration when they consider rolling-out an ITS service seems to prevail in several ITS deployment related discussions. This implicitness seems to hinder many of us in reflecting or speculating on cultural or other contextual differences. In explicit terms, it is perhaps rather rare to find ITS evaluation reports that really are targeted towards potential buyers or interested transport authorities and deployment experts; and if a report is visibly targeted towards future buyers or take-up for deployment many of us will tend to suspiciously look for the guiding marketing hand of, e.g. a service provider and ITS manufacturer. It is certainly a process of mutual learning and in some parts of the globe this process perhaps started earlier.

Some readers from the United States and more generally from outside Europe might take for granted that ITS evaluation is done by independent professionals and these experts are fully committed to serving a governmental agency or transport authority. On top of these expectations one might take for granted that these evaluations are attractively paid, are being involved at the right time and basically have the purpose to let others – outside in the world – know, what works, what does not work and who should consider taking-up what has been tested in his city, region or field of application. From a European perspective – some of these elements seem to be implemented as a standard procedure with many DoT-funded ITS evaluation reports. At least for Europe we have seen a variety of different ITS evaluation contexts and sub-cultures. Most often in Europe evaluation is done within joint-industry-university ITS research and development consortia.

With many local ITS programmes it has become a key expectation to grow local ITS knowledge as well as growing knowledge-intensive jobs by involving local (research and educational) institutions in ITS evaluation projects. This practice comes at a price; similarly to your local hospital's specific knowledge on rare cases or yet emerging phenomena. However, there have been several initiatives studying alternative options or triggering something like self-regulatory processes by means of publishing ITS evaluation results in easy to use databases.

Throughout Europe by far most evaluations of ITS R&D are done by staff from research institutions or by individuals who feel somehow linked to the research sphere even when they currently do not have employment status with a research institution. Those who typically consider themselves at the upper end of a fictitious one-dimensional quality scale, try to adhere to scientific standards and to what had been acceptable or without negative reaction from the funding bodies. Although ITS evaluation during the past 15 years has become a significant funding element for all types of traditional and entirely new research institutions, this has not changed these communities' guiding principles towards the relevance end.

More often than not these evaluation team works as part of the research project consortium where an ITS service or product is developed and tested. In blunt terms, they are involved from early on, however the evaluation researchers are neither in the driver seat (in terms of project design) nor will the staff that finally does the evaluation be identical to who was part of the project in the beginning. On top of this, ambitious large-scale ITS research and development projects often evolve in their ITS service focus. The evaluation methodology design team may find itself forced into rough guesses onto what will be tested due too many loose ends and unspecified elements into what the 'box' actually will deliver. As a consequence, evaluation is often framed independently from the flagship projects' evolving vision and project roadmap: Additionally, it is either the core of an academic thesis or similar academic exercise or one of a series of scientific publications that have to be done to qualify for the next 2-year contract or – and this is the most disturbing context, the ITS evaluation exercise has to be done for funding reasons but actually steals away precious time from other academic research activities. Rigor is not only a context factor but also a result from an attempt to escape from playing in two cultures or risking one's scientific standing from giving in towards pragmatic constraints or cooperating with consultants or government administration.

Evaluation communities have demonstrated significant hesitation to cooperate with state power; it is considered inappropriate to work on an evaluation focus or research question set by somebody who is not the researcher itself. At least in several (European) evaluation traditions [12] supporting the decision-makers or governments and operators has been challenged. This strong self-selection and self-confirmation mechanism certainly hinders ITS evaluation gaining momentum. Novec's [13] discussion on smartening the state by linking experts and public administration and reframe the future of governing does not integrate this strand sufficiently.

When the ITS evaluation report is the message: On top of this, a reader of an ITS evaluation report most probably will see the written report as a valid representation of the underlying phenomenon, research result or ITS innovation project outcome.

Many evaluation teams are unaware of significant differences in report writing benchmarks, skills and training traditions as well as their own poor practice. However, only the best analysts manage to shift significant time from collecting information into writing the report. A recent analysis on emerging trends with industry analysts comes to rather similar observations. Pollock [14] also elaborates on why many social scientists have ignored the proliferation of these new forms of management and technical expertise. He somehow seems to suggest an effort to shift resources from collecting information towards writing the report will further increase the difference between the highly professional commercial groups from the rest of the world.

ITS evaluation is content in a culture of self-reference. Who has not seen the scenario: We are the project. Key outcomes are some videos on the longitudinal highlights and the final event. Evaluation is often expected to be part of this self-reference frame and becomes part of the success story. Ideally, a success story about the evaluation process itself and about the media-related impact of evaluation processes. It has become a learnt benchmark for several policy layers and ITS policy at least throughout Europe. The outcome is that we had a project and that we are looking for continued funding. Maybe evaluation is a legacy conception and does not fit into what the future will bring or what some people consider good practices. ITS evaluation policy cannot possibly separate itself from this cultural discourse.

From voices mainly in the United States, there have been hints towards standard evaluation being part of an outdated policy or management paradigm. In blunt terms, the claim is made that the new key is that decision-makers are not in control or they better admit that they act on the basis of non-knowledge [15, 16]. It is not entirely clear how the sociology of knowledge's conception of a growing blind spot impacts the question of what can be known and anticipated when ITS evaluation budgets are significantly increased or reduced [17, 18]. However we suggest, even under such a context and guiding narrative, ITS evaluation can have a specific role in the form of informal policy [19].

As a reaction to several challenges, there is significant risk that the role of experts and evidence-based ITS evaluation will be eroded. For the United States, Novec [13] from her specific agenda of eroding status of experts within a megatrend of Democratizing Innovation comes to her rather polemic conclusion that informal policy or even what she terms smarter government may be illegal. Several regulations on the federal level 'forbid robust citizen engagement. … Notice-and-comment rulemaking under the Administrative Procedure Act (APA) limits outside comments on already formulated regulations through a highly technocratic process. It attracts substantive participation from only a small number of inside-the-Beltway professionals.' The role of experts is dynamically evolving and so does the planning paradigm (democratizing innovation activities, informal interaction of governing bodies with the broad public…). Under some newly emerging policy expectations, there seems to be the claim that ITS deployment has to focus all citizens equally or even ITS evaluation should study primarily impacts on populations who do not use the ITS services and technologies. Such guiding elements from a differentiated view on acceptance and success of innovations, ITS might face a new culture under this democratizing innovation thread. For more than 50 years, adoption of innovation as a theory and concept in studying innovation has shown that successful deployment depends on success within certain subgroups. This makes assessment of risks as well as one-shot evaluation of ITS-impacts significantly more difficult. It has proven crucial to explaining failure and success with new behaviour. This theory seems to be significantly wider accepted in the United States than in Europe [20].

A closely related phenomenon has become open innovation. As Chesbrough [21] in his more recent public lectures has shown it can have significant value to start research from what others have considered failures. How would ITS evaluation look like, when not the proven, documented and deployable successes are the main outcome? Other project teams could probably gain a lot more from true failures as well as from 'false positives'.

This brings us back to the question how evaluation policy influences ITS evaluation. We can distinguish between direct and indirect influence on policy. ITS evaluation can sensitise policy makers to new issues and outdated solutions by providing vocabulary or conceptual frameworks [22]. Perhaps one consequence from certain types of evaluation sub-cultures is learnt irrelevance or learnt helplessness towards this perceived irrelevance. It is certainly interesting to read some of the survey results under this frame. Some people in governmental agencies and with decision teams on ITS deployment would agree that learnt helplessness qualifies as an appropriate label for the dominant ITS evaluation context in Europe [12]. This probably is resulting from the pendulum being on one extreme end of the rigor versus relevance dichotomy.

2.4 Surveying the use of ITS evaluation evidence

2.4.1 Background

2.4.1.1 Aim and context of a survey on the use of ITS evaluation evidence

Being aware of the different policy frameworks and the current changes in the evaluation culture described in the last chapter, an online survey containing 24 questions was carried out during August and September 2015, disseminated through mass e-mailings and social media announcements in ITS and transport related target groups. The aim of the survey, designed by the IBEC and Global Road Links, with support from AustriaTech, was to better understand the current decision-making practice concerning deployments of and investment in ITS in different parts of the world. The focus of the survey was on the characteristics and quality of data and information that are needed for and used to support these processes.

While the authors do not claim the survey to be of sufficient academic significance, due to the survey method and the response sample of 42 completed responses from respondents in 20 different countries around the globe,[1] the topic is little researched and some valuable insights emerged from the survey. This section will address those insights and formulate some recommendations for further research.

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[1] Covering all continents, including Africa, Asia, Australia, Europe, North America, and South America

Table 2.1 Breakdown of survey respondents' affiliation

Respondents' affiliation	Percentage of total respondents
1. Transnational governmental policy maker/decision-maker (e.g. EU/World Bank/UN Agencies)	1.5
2. National governmental policy maker/decision-maker (including federal level)	12.3
3. Regional governmental policy maker/decision-maker (including state level)	10.8
4. Local governmental policy maker/decision-maker (including city level)	1.5
5. Coordinator or leadership within a transnational organization supporting transport policy development and implementation	3.1
6. Coordinator or leadership within a national organization supporting transport policy development and implementation	10.8
7. Provider of transport solutions (e.g. transport supplier, operator, consultancy)	32.3
8. Academic, research or capacity building	23.1
9. Others	4.6

Table 2.1 illustrates what organizations the survey respondents work at; 26.1 per cent of the respondents work at a government agency, either at international, national/federal, region or local levels; 13.9 per cent of the respondents work at a national or international body that supports transport policy development, such as a national ITS association; 32.3 per cent of the respondents come from the private sector, providing transport or ITS solutions and 23.1 per cent work in the research or education sector.

To draw some conclusions as to parallels or differences between public and private sector responses, the respondents coming from organizations in categories 1–4 are considered public sector respondents. Respondents coming from organizations in categories 5–7 are considered private sector respondents.

2.4.1.2 Scope of the survey

The survey covered a number of issues related to ITS investment decision-making. The first part of the survey addressed the context for decision-making, such as the typical value of investments concerned, the characteristics of and stages in the decision-making process, and who signs off on the final decision. The second part of the survey looked more in detail at what data are used to underwrite ITS investment decisions, where these data are obtained, familiarity with and use of existing ITS evaluation databases and more specifically at how alternative investment options are weighted and compared. The final part of the survey aimed at extracting a qualitative assessment of barriers to evaluation-based ITS decision-making and recommendations for improvement.

2.4.1.3 Limitations of the survey

Although 117 people started filling in the survey, only 42 (i.e. slightly more than one third), made it through the full questionnaire. The high drop-out rate could be explained as follows: The survey was targeted at people in positions with regular and actual experience in deciding about the purchase, maintenance or operation of ITS. Only 5 out of the 42 survey respondents indicated that they were responsible for ITS decision-making within their organization, and 3 out of those 5 only up to a certain investment threshold. With questions geared towards the decision-making responsibility, other respondents might have felt discouraged to continue filling out the survey. All respondents provided feedback on the decision-making process within their organisations, despite the majority indicating they were not the final decision-making person.

Although the survey was aimed at a global audience and responses from all over the globe were received, the vast majority of respondents who completed the survey were from Europe. Hence it is difficult to draw conclusions on parallels or differences in ITS decision-making between different global regions as discussed in section 2.3.

2.4.2 What makes for a decision-making process on ITS investments?

Decision-making processes within organizations vary, due to structure, culture and other factors such as vision and mission, complexity of the issue to be resolved, data availability and estimated impacts of alternative solutions. The survey included a number of questions related to the decision-making processes in the respondents' organizations.

The average size of ITS investment projects dealt with by the respondents' organizations is depicted in Figure. 2.1.

85 per cent of the respondents' investments considered in the survey fall within the range of up to 5 million USD in terms of capital costs. These are small amounts in comparison to the costs of road infrastructure construction, rehabilitation or maintenance.

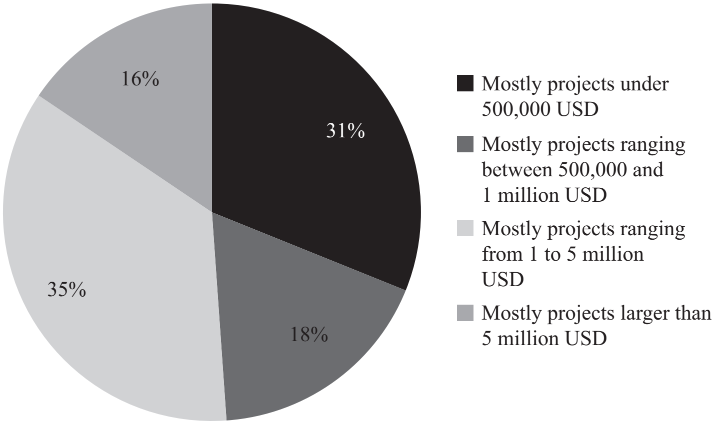

Figure 2.1 Average size of ITS investment projects considered in the survey (in USD)

Of the respondent's organizations, 38 per cent are responsible for decisions both on investments in new ITS applications and services as well as in maintenance of ITS. 3.6 per cent of the respondents indicated that their organization was only responsible for new investments; an equal part indicated their organization to be only responsible for ITS maintenance investments.

According to 68 per cent of the survey respondents, decisions about ITS investment are taken in a wider context of infrastructure investments, such as the construction of new infrastructure or rehabilitation of existing infrastructure. 16 per cent of the respondents indicated that the decision is stand-alone and another 16 per cent said that it depended on the circumstances. A number of respondents indicated that ITS was often applied at a later stage to existing (road) infrastructure, e.g. measures to improve traffic safety. The responses from the private sector to this question showed significantly more variety than the response from the public sector. Eighty-seven per cent of the public sector respondents indicated that ITS decisions are taken in a wider context. In the private sector this percentage was much lower, at 57 per cent, with the remaining 43 per cent equally spread between having ITS investments as a separate decision and a mixed decision process somewhere between separate decision and decision in a wider context depending on the circumstances.

In terms of fitting in with vision and mission, ITS decisions seem to be rather strongly embedded in higher-level strategies of the organizations. This was indicated by 78 per cent of the respondents. Typical higher-level strategies include innovation strategies, business strategies, national ITS strategies, congestion relief policies, national/federal ITS architectures, mobility policies and strategic long-term transport plans.

2.4.3 Phases in the decision-making process and the use of ITS evaluation evidence

Following the survey response, ITS investment decision-making processes in the respondents' organization can be characterized as follows:

- Very to moderately structured according to 62 per cent: This indicates that in the majority of cases decisions are reached after undergoing some sort of preparation and following a pre-set process rather than ad hoc;
- Neither predominantly top-down nor bottom-up: This indicates that ITS investment decisions are neither predominantly imposed by the top of organizations nor pushed from the work floor;
- Often to very often involves multiple actors (62 per cent): This indicates that in the majority of cases decisions are not taken stand-alone by a single actor;
- More based on practical experience (55 per cent) than on policy-theory (20 per cent): Practical experience with ITS systems and applications seem to be leading in influencing the choice for certain ITS investments. Policy-theory or a theory of change plays a significantly less important role;
- Both problem driven (46 per cent) and solution driven (35 per cent).

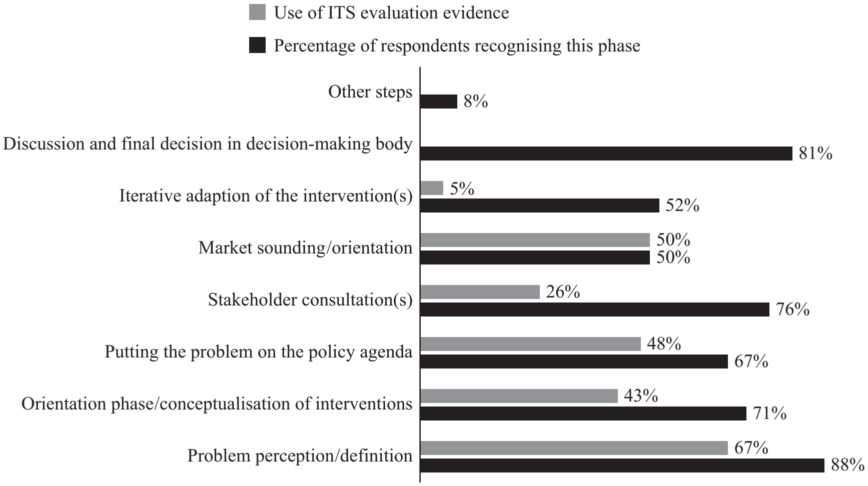

Figure 2.2 Recognized phases in the decision-making process and the use of ITS evaluation evidence (percentage of respondents)

The following phases in the decision-making process were recognized by the survey respondents as part of the processes in their own organization, starting with the problem definition and ending up with the final decision by the decision-making body.

Following Figure 2.2 a market sounding or orientation phase does not seem to be a very common step in the preparation of an ITS investment decision, whereas a meeting with the industry at an early stage in the process could provide useful insights and directions about possible solutions and technical and economic feasibility.

In addition to the phases in the survey, the preparation of an ex-ante cost–benefit analysis (CBA) or business case was mentioned by a small minority of survey respondents as a step in the process. This step would usually occur between the stakeholder consultation phase and the final decision. It is assumed that to prepare an ex-ante CBA or business case, there exists a particular need for relevant, up to date ITS evaluation evidence.

Figure 2.2 equally shows in which phase(s) of the decision-making process ITS evaluation evidence is used. Although no strong relationship is proven through the survey responses, ITS evidence seems to play a more important role in the early stages of the decision-making process and in particular during the problem definition stage.

2.4.4 How to reach a decision: data needs, data use

An assumption in the survey is that the need for ITS evaluation evidence stems most clearly from the way alternative options of ITS investment are compiled and assessed. The survey therefore addressed what methodologies are used to weigh different options and what evaluation data is needed and used to feed into this assessment.

2.4.4.1 Data needs

From the survey it appeared that the three most important factors taken into account when assessing ITS investment options are efficiency of the solution (e.g. its impact on traffic flow compared to pre-set targets) (85 per cent), cost and expenditures (83 per cent) and traffic safety related factors (83 per cent). Other factors, such as social (50 per cent), environmental (55 per cent) and security (45 per cent) related aspects were deemed of less importance.

When looking at the difference between public sector and private sector respondents, the percentages are generally higher for public sector respondents on all factors than the percentages for private sector respondents. This could be explained by the multi-objective orientation that drives public sector operators in their decision-making, whereas private sector decision-making is generally motivated by continuity and profit.

The implications for data needs derived from this would be that data on (life cycle) costs, efficiency and in particular traffic safety effects are of particular interest to ITS investment decision-making. An interesting issue is with security issues, as these are currently not seen of that high importance. It can be expected, that this factor will receive more importance in future due to automation initiatives.

The respondents indicated that the most common methods used to compare alternative ITS investment options are CBA, cost-effectiveness analysis and the presentation of various alternatives in overview tables (Figure 2.3).

The implications for the data needs derived from the response on the methods used would be that data on (life cycle) costs, benefits and effectiveness are most sought after. From the analysis of the factors that are deemed important and the

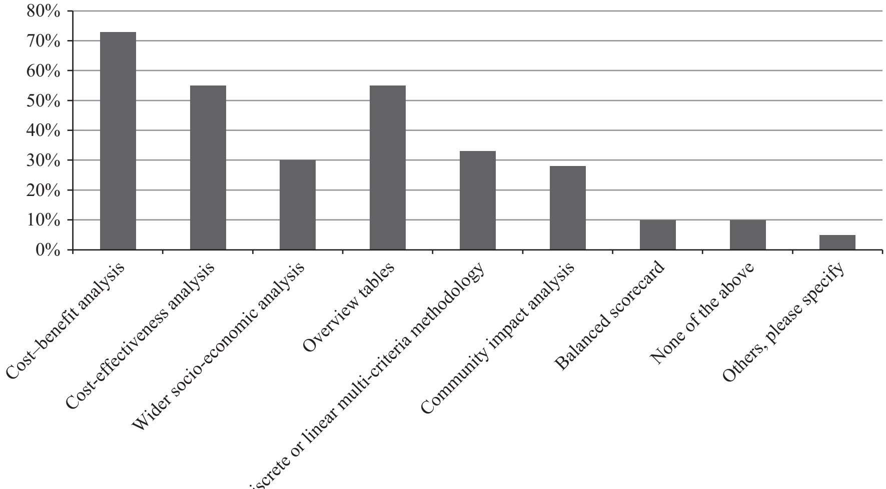

Figure 2.3 Use of methodology to compare and weigh alternative ITS investment decision options (percentage of respondents)

methodologies used to compare investment alternatives, the following data needs are derived (in order of priority):

1. (Life cycle) cost data
2. Data on the effects and benefits of the investment
3. In particular effects and benefits related to traffic safety

According to the survey response wider socio-economic analysis, multi-criteria analysis or community impact analysis is only used in around 30 per cent or the organizations the respondents represent.

2.4.4.2 Data use

The actual data use indicated by the respondents shows that the most used is cost data, which are in line with the identified data needs, followed by data on lessons learnt (including unsuccessful deployment or failed implementation) and international best practice/success stories. Figure 2.4 shows the type of data used in support of ITS investment decision-making.

The lessons learnt and international best practices are rather unspecified sources of information; it does not provide much insight into what specific data the respondents are after. One could argue that respondents are content with any information, albeit unspecified, about positive and negative experiences with ITS systems and applications elsewhere. Transferability of these experiences often hampers, however, the use of the evidence in ITS decision-making.

2.4.5 Sources of ITS evaluation evidence

The data are obtained from the following sources, in order of importance:

1. Meeting with industry at international fairs (85 per cent)
2. Desk research of international evaluation studies (60 per cent)

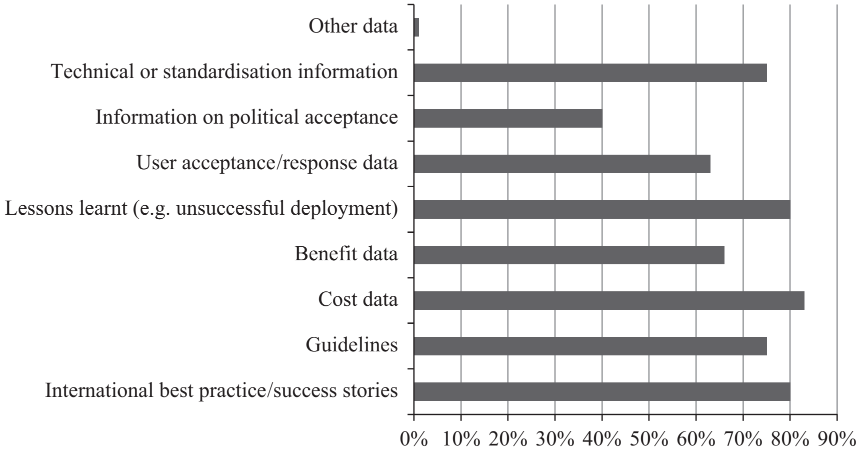

Figure 2.4 Type of data used to support ITS investment decision-making

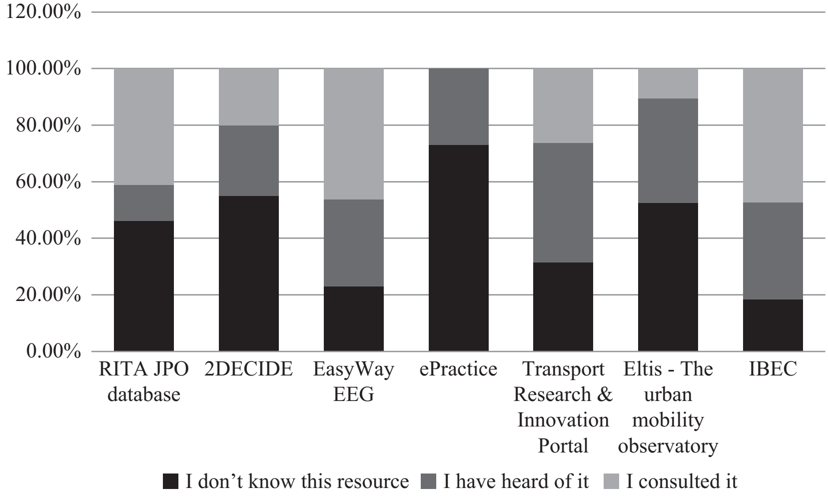

Figure 2.5 Awareness about existing ITS evaluation resources

3. Study tours to visit neighbouring systems (53 per cent)
4. International peer network (50 per cent)
5. Own research department (45 per cent)
6. Other: national working groups, national research institutes, national standards and guidelines (20 per cent)

A number of online resources on ITS evaluation evidence are available to the public. Of these, the IBEC, the EasyWay Evaluation Expert Group, and the Transport Research & Innovation Portal were best known and/or consulted by the respondents as can be seen in Figure 2.5. ePractice, a knowledge-sharing community initiated by the EC offering services for the professional community of eGovernment, eInclusion and eHealth practitioners, was the least known among the respondents.

Other resources mentioned by the respondents (but not surveyed) included UK Web Transport Analysis Guidance (Tag), the ITS Manual of ITS America, the iMobility Effects Database, national reports and vendor/supplier documentation.

2.4.6 Barriers to evidence-based ITS investment decision-making

When asked about the obstacles to evidence-based ITS investment decision-making, remarkably, there was not a single respondent that indicated that he/she did *not* see any obstacle. This seems to indicate that obtaining useful evidence for solid decisions is perceived to be rather difficult.

The most important barriers that were identified by the respondents included:

1. The lack of cost–benefits information (55 per cent)
2. The lack of *impartial* information (53 per cent)
3. Legal obstacles or lack of political acceptance or awareness (53 per cent)

In particular it was perceived that *objective* information about benefits was difficult to obtain; cost data is easier to get – or easier to estimate with a certain level of accuracy. A specific comment made about cost data was that often there is little information available about the *operation and maintenance costs*, with data about the capital cost of installation of an ITS system or application more readily available.

A small number of respondents raised the point of a lack of information on *vendor/supplier performance*.

Other obstacles mentioned by the respondents included:

- Transferability of results/outcomes is questionable;
- Lack of resources: Financial, time and competence, including skills to develop a business case;
- Inconsistent procurement practices, evolving requirements and objectives;
- Increasing complexity and interrelated systems;
- Cultural: ITS as a toy rather than part of transport system delivery.

As to the way forward, an interesting comment was made by one of the respondents who addressed the communication gap between ITS practitioners and decision-makers. In particular, the respondent referred to the ability (or lack) of ITS practitioners to demonstrate the business case (in the wide sense of the word) to ‘technology-agnostic’ decision-makers. In a similar way, one respondent recommended a shift for ITS practitioners from a supply mind-set, offering a technically sound solution, to a buyer’s mind-set that is oriented towards providing a solution that meets costs, reliability and sustainability requirements.

2.5 Conclusions

Although this chapter was based on the thesis *ITS evaluation contributes to better informed, evidence-based ITS decision-making*, we recognized, that the policy framework across the globe concerning evaluation based ITS decision-making is fragmented. While especially in the United States we are currently approaching an age where public administrations are reducing their linking with external ITS experts, we see especially in Europe a close linking in the field of decision driven evaluation with experts that are fully committed to serve a governmental agency or transport authority resulting in sugar-coated evaluation results. Independent evaluation results provided by independent experts are only sporadically available. But by taking these policy framework conditions into consideration, evaluation is highly relevant for achieving policy decisions.

Having a look at the ITS field in detail, it can be recognized, that most ITS decisions are not seen as standalone decisions, but are integrated in a wider context and strongly embedded in higher-level strategies of administrations and organizations. And decision-makers like to deploy things they have practical experience with. Especially in the field of ITS, where new technologies, services and other solutions are rapidly evolving – one just needs to think of recent developments in the field of vehicle automation – that fact of having deployments based on practical experience is often slowing down or even hindering technical evolution.

But even when ITS evidence is needed, which especially plays an important role in the early stages of the decision-making process and in particular during the problem definition stage, a big problem identified is with different KPIs describing the benefit of an ITS solution. As it is highly difficult to generate evidence by comparing pears and apples, administrations started to work towards harmonized KPIs. The US JPO of the US DoT provides guidance for ITS evaluation; in Canada, the Canadian Victoria Transport Policy Institute has published many documents on Evaluation in the transport sector. In Europe, the EC started with the definition of commonly agreed KPIs to be used within ITS deployments across Europe.

But KPIs are for sure not enough. Currently no internationally harmonized evaluation methodology for ITS evaluation exists. Such an harmonized evaluation methodology would contribute to generating evidence on ITS solutions including the improved access to knowledge of ITS implementations and projects. In this respect it is important to the authors to state that such evaluation evidence needs to include both positive as well as negative examples. But unfortunately failing (having no success) of a project is no option. Therefore most evaluation results are presented in a positive manner.

That was also recognized by the survey respondents, where a clear result showed that obtaining objective information about benefits in the field of ITS is highly difficult. Much easier is the collection of cost data, or at least easy to estimate with a certain level of accuracy. However for deployment decisions often only the investment costs are available. Much more difficult, is the collection of the operation and maintenance costs.

Finally, coming to the real needs of decision-makers and summarizing the questionnaire results, based on the analysis of methodologies used to compare and weigh alternative ITS investment options and the factors that are deemed important in the assessment of alternatives, the following data needs are derived (in order of priority):

1. (Life cycle) cost data;
2. Data on the effects and benefits of the investment;
3. In particular effects and benefits related to traffic safety.

The data most used in ITS decision-making are cost data, lessons learnt (including unsuccessful deployment or failed implementation) and international best practice/success stories. This data is often found at meetings with the industry at international events, through desk research and through international study tours.

On the other hand the questionnaire showed, that even though this information is highly requested, a lack of cost-benefits information, a lack of impartial information, and legal obstacles or lack of political acceptance or awareness are seen as the main barrier to the use of ITS evaluation evidence.

The conclusions emphasize the need stated in the introduction of the chapter to continue investing in (open access) repositories, whether national or international, where ITS evaluation studies can be accessed. However, this would only be helpful if the studies contain the information that is most sought after, namely costs, benefits and in particular safety related benefits. The transferability and impartiality of results and outcomes of evaluation studies is a concern. Standardized evaluation study methodologies and formats would help addressing this issue.

The third barrier, however, would need to be addressed differently. As one of the respondents indicated, decision-makers, especially those in the field of politics, are generally ‘technology-agnostic’. Translating the ITS evaluation evidence into a language that is understood by decision-makers and geared towards their motives, is key to raising the awareness of the potential contribution of ITS to today’s transport challenges.

References

[1] Trochim W. *Research Methods Knowledge Base*. [online]. 2006. Available from: http://www.socialresearchmethods.net/kb/ [Accessed 15 March 2016]

[2] PIARC World Road Association. *Road Network Operations & Intelligent Transport Systems*. [online]. Available from: http://rno-its.piarc.org/en/planning-and-deployment-monitoring-and-evaluation/what-evaluation [Accessed March 2016]

[3] Newman-Askins R., Ferreira L., Bunker J. *Intelligent transport systems evaluation: from theory to practice*. In Jaeger, V., Eds. *Proceedings of 21st ARRB and 11th REAAA Conference*, Cairns. 2003.

[4] EasyWay Evaluation Expert Group (EEG). *EasyWay Handbook on Evaluation Best Practice*. [online]. 2012. Available from: https://www.its-platform.eu/filedepot/folder/1077 [Accessed 4 July 2016]

[5] The World Bank. *Toolkit on Intelligent Transport Systems for Urban Transport*. [online]. 2011. Available from: http://www.ssatp.org/sites/ssatp/files/publications/Toolkits/ITS%20Toolkit%20content/guidance/evaluation/evaluation.html [Accessed 15 March 2016]

[6] European Commission. *Action Plan for the Deployment of Intelligent Transport Systems in Europe*. [online]. 2008. Available from: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52008DC0886 [Accessed 4 July 2016]

[7] European Parliament. Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the Framework for the Deployment of Intelligent Transport Systems in the Field of Road Transport and for Interfaces with Other Modes of Transport. In: *Official Journal of the European Union*. Brussels, Belgium. 2010.

[8] United States Department of Transportation, Intelligent Transportation Systems Joint Program Office. *ITS Evaluation Guidelines – ITS Evaluation Resource Guide.* [online]. 2015. Available from: http://www.its.dot.gov/evaluation/eguide_resource.htm [Accessed March 2015]

[9] Victoria Transport Policy Institute. *Evaluation Impacts and Problems*. [online]. 2015. Available from: http://www.vtpi.org/documents/evaluation.php [Accessed 15 March 2016]

[10] ITS Benefits Evaluation Community. *The ITS Benefits Evaluation Community (IBEC)*. [online]. Available from: http://ibec-its.com/ [Accessed April 2016]

[11] AECOM Limited. *Study on Key Performance Indicators for Intelligent Transport Systems*. [online]. 2015. Available from: http://ec.europa.eu/transport/themes/its/studies/its_en.htm [Accessed 4 July 2016]

[12] Lodge M., Wegrich K. (eds.). *The Problem-Solving Capacity of the Modern State. Governance Challenges and Administrative Capacities*. Hertie School of Governance. Oxford: Oxford University Press; 2014.

[13] Novec B. S. *Smart Cities, Smarter State. The Technologies of Expertise and the Future of Governing*. Cambridge: Harvard University Press; 2015.

[14] Pollock N., Williams R. *How Industry Analysts Shape the Digital Future.* Oxford: Oxford University Press; 2016.

[15] Ross A. *The Industries of the Future. How the Next 10 Years of Innovation Will Transform Our Lives at Work and Home*. New York City: Simon & Schuster; 2016.

[16] Malik F. *Navigating into the Unknown: A New Way for Management, Governance and Leadership*. Campus Verlag: Frankfurt/Main; 2016.

[17] Brüsemeister T., Eubel K.-D. (eds.). *Evaluationsbasierte Steuerung, Wissen und Nichtwissen – Einführung in die Thematik Evaluation, Wissen und Nichtwissen*. Wiesbaden: VS Verlag für Sozialwissenschaften; 2008.

[18] Wehling P. (ed.). *Vom Nutzen des Nichtwissens: Sozial- und kulturwissenschaftliche Perspektiven (Sozialtheorie)*. Bielefeld: Transcript; 2015.

[19] Bröchler S., Grunden T. (eds.). *Informelle Politik. Konzepte, Akteure und Prozesse*. Wiesbaden: VS Verlag für Sozialwissenschaften; 2014.

[20] Brem A., Viardot E. (eds.). *Adoption of Innovation. Balancing Internal and External Stakeholders in the Marketing of Innovation*. Switzerland: Springer International Publishing; 2015.

[21] Chesbrough H. *Managing Open Innovation*. Lecture 10 December 2015. Unpublished Presentation to WU Institute for Strategy, Technology and Organization. Vienna; 2015.

[22] Spotswood F. (ed.). *Beyond Behaviour Change: Key Issues, Interdisciplinary Approaches and Future Directions*. Bristol, UK: Policy Press; 2016.

Chapter 3

Frameworks and methods for ITS evaluation

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3.1 Description of Intelligent Transport Systems (ITS)

ITS encompass all the systems and applications that make use of Information and Communication Technologies (ICT) in the transport sector. ITS can be implemented both on any kind of transport infrastructure and on any type of vehicle. The first ITS applications appeared when transportation engineers began to utilize technological solutions to control road traffic in a more robust and efficient way. Traffic signal control systems are considered to be the first developed ITS. Since then, many new technologies have been applied in the transport sector and ITS cover a wide spectrum of applications with a potential to deal with most of the challenges that modern Transportation Engineering faces nowadays.

The technological background of ITS is based on ‘telematics’. Telematics are widely utilized in the transport sector both for urban and intercity transport services through communication technologies (i.e. Internet, mobile communications, etc.) as well as information technologies (e.g. CCTV cameras, sensor loops). Apart from telematics, integral part of ITS implementation is the use of various software related to routing algorithms, statistical analyses, traffic assignment, etc.

With respect to ITS classification, there are many ways of categorizing ITS in literature depending on the scope of each classification. For example, there are classifications based on the mode of transport for which ITS are implemented, or on the technology used, or on the type of service provided, etc. One of the widely accepted classifications of ITS includes the following [1]:

- ITS for Traffic and Travel Information
- ITS for Traffic and Public Transport Management
- ITS for Navigation Services
- ITS for Smart Ticketing and Pricing
- ITS for Safety and Security
- ITS for Freight Transport and Logistics

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- ITS for Intelligent Mobility and Co-modality Services
- ITS for Environmental and Energy Efficiency

3.2 Why is the evaluation of ITS essential?

The vision for ITS is to set the foundations for 'intelligent mobility towards fully informed people, zero accidents, zero delays, with reduced impacts on the environment, where services are affordable and seamless, with privacy respected and security provided' [2]. It becomes obvious that ITS can have significant benefits for both providers and users. Moreover, wider use of such services could create additional benefits for the whole society by reducing the negative economic, environmental and societal impacts of transport. US DOT has established the following six goals for ITS deployment [3]:

1. Increase transportation system efficiency and capacity
2. Enhance mobility
3. Improve safety
4. Reduce energy consumption and environmental costs
5. Increase economic productivity
6. Create an environment for an ITS market

It is therefore a necessity to develop evaluation methodologies that could assess ITS in a holistic manner, to understand the impacts of the systems, to quantify the benefits, to facilitate future investment decisions and to optimize existing systems design and operation [4].

However, taking into account the variety of technologies used for the development and operation of the subsystems of each ITS application, the evaluation process can become quite challenging. Thus for every ITS a comprehensive evaluation framework should be developed that could identify the specific goals, objectives and potential impacts of the system and then develop measures to estimate these impacts [5].

3.3 What to be evaluated?

Two strategies about 'what' the evaluation is going to examine are the following.

3.3.1 IT-system as such

In this strategy, the researcher studies the system by considering explicitly its users. So it is clear that the researcher must have full knowledge of the system, because the result of the evaluation depends on that.

3.3.2 IT-system in use

In this case, the researcher observes the system in a real functional environment, because system's users are now part of the process. Regarding this approach interviews with users and questionnaires are necessary, but data collection becomes significantly easier.

3.4 What is the process of evaluation?

It has been widely suggested that the evaluation processes used for ITS projects and traditional road projects should differ. It has been stated that existing evaluation methodologies may be inadequate, since the comprehension of the mechanisms with which ITS impacts are created is confined [6]. The implication of this latter statement is that estimated impacts from one site may not be easily transferred to other potential applications, as there is limited statistical confidence regarding the way parameters of each scenario and the ITS application may interact to generate the project effects.

Relationships between cause and effect in ITS projects are deemed to be more convoluted than in ordinary road projects. The effects of single components are less significant compared to the impacts of the interactions and synergy between multiple components [7]. To address this inherent complexity of ITS projects, an ITS evaluation methodology should be able to evaluate both the impacts of individual components of the project, and the combined effect of the various components. Additionally, a number of ITS projects induce an insignificant upgrade in capacity opposite to conventional road projects [8]. Therefore, the level of detail and sensitivity of the utilized ITS evaluation methodology should be higher compared to existing evaluation models and ensure that ITS impacts are not shadowed by the temporal fluctuations of traffic impacts.

The degree of technological risk involved in ITS projects is rather high, since ITS implementations generally rely on electronics and communications. The probability of technical failure is significant and ITS must be designed flexible to remain adaptable to future innovations in technology. Despite the substantial efforts to evaluate and monetize the costs and benefits of ITS projects, there is still significant variance regarding the projected benefits and costs of ITS projects. As a result of the high risk and the short life expectancy of ITS projects, it is essential that the evaluation processes should encompass extensive risk and sensitivity analysis.

The behavioural traits of drivers towards the ITS applications play an important role in their successful operation [9]. For example, a proposed detour displayed on a variable message sign (VMS) will have very less effect on mitigating congestion if drivers fail to understand and react to the message. User behaviour is mainly affected by past experience, familiarity with the network, the behaviour of other drivers, as well as the availability and quality of the ITS equipment [8]. Driver behavioural traits should become a key aspect of the evaluation process of ITS projects, in contrast to conventional road project evaluation where they are not a critical factor.

The evaluation process mainly aims to comprehend the impacts of a system and to quantify its benefits in various aspects. Concurrently a secondary or indirect objective of the evaluation is the optimization and fine tuning of the system operation and design itself. Both objectives can be integrated in the agile approach for the design and development of a system or product. The quantitative and qualitative comprehension of the impacts of the system and its benefits is fundamental for acquiring a solid understanding of the conditions under which the system performance could become optimized.

Evaluation activities represent an important portion of the undertaken work, when developing and deploying new products and services. The effort decreases as the product deployment materializes, as it is presented in Figure 3.1. The evaluation

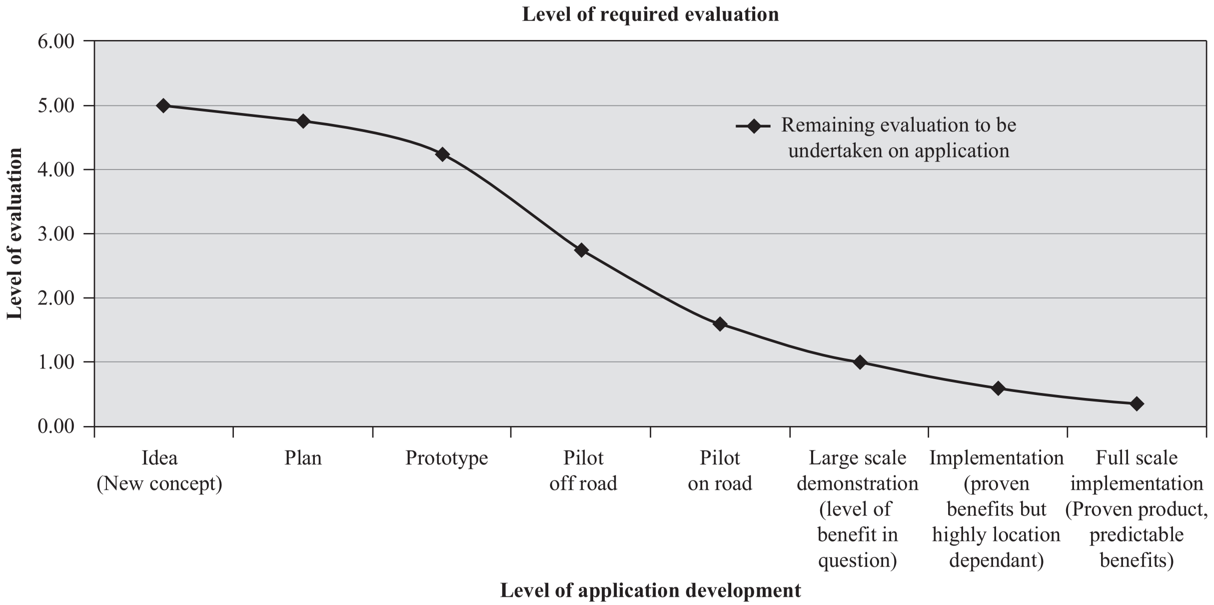

Figure 3.1 Level of evaluation required at each stage of the new services development, Adapted from Reference [10]

of the first steps is related to technical and functional issues while, at the last steps, the evaluation is basically related to the socio-economic and environmental impacts of the system when deployed at large scale.

3.5 Traditional and commonly used evaluation methods

A balance between the complexity and the cost of the evaluation and the cost of a prospective project is necessary for the selection of the appropriate evaluation method for ITS projects. The level of complexity of the evaluation method is determined according to the scope of the evaluation results. The degree of complexity necessary for estimating the social welfare of a project is much higher than for assessing its performance [4]. A critical issue regarding ITS evaluation is the rich data sets required irrespective of the evaluation method. The amount and resolution of this data is still not sufficient despite the growing deployment of ITS projects. ITS projects are normally improvements to the existing transport systems, and they are not deemed to be projects of paramount influence to the economy. Thus, a full economic impact analysis is rarely justified in the case of ITS projects evaluation [11]. The assessment of the impacts of ITS projects can be adequately conducted through a socio-economic analysis such as cost–benefit analysis (BCA) or multi-criteria analysis. BCA comprises one of the most widely used methods for evaluating ITS projects. However, it is critical to be stressed that the monetization of benefits relies on several assumptions. The integration of the benefit–cost ratio into a goal-based evaluation framework such as multi-criteria analysis as one of several evaluation indicators has been suggested as a solution to the aforementioned issue [12]. This solution ensures that no project impacts are going to be excluded, but special attention is needed to avoid double counting of specific impacts that might have been taken into account in cost benefit ratio and the multi-criteria analysis.

BCA and cost-effectiveness analysis are methods that have been frequently used for the evaluation of ITS projects [13]. Cost-effectiveness analysis has been mainly applied in cases that benefits could not be easily quantified or on top of BCA as a means of sensitivity analysis [9]. Within the context of cost-effectiveness analysis a comparison among alternative projects is conducted on the premise of the project cost and a single quantifiable project impact. It has been recommended by the European Union EVA ITS evaluation manual that the use of BCA is warranted in cases that monetary values are available, multi-criteria analysis in cases that monetary values are not available for major impacts and cost effectiveness analysis in cases that monetary values are available only for costs and a specific impact is realized [9].

Capacity analysis has been conducted within the context of previous ITS evaluation frameworks based on traffic volumes, road geometry and signal parameters to define a level of service [12]. It has been indicated that these capacity analyses cannot fully capture the benefits of ITS and it has been suggested that cost-effectiveness analysis should be used instead, accounting for measures of effectiveness such as congestion mitigation, safety improvements or energy savings [12]. However, it has been also stated that instead of incorporating social costs in a cost-effectiveness analysis, it is preferable to conduct a complete BCA along with risk and sensitivity analysis [14].

3.5.1 BCA

BCA is a broadly used method to estimate the profits of different types of investments in the transport sector. From the early deployment of ITS, agencies have developed instructions regarding road transport sector investment calculations and the values that should be used to calculate user costs. These instructions were subsequently adopted by other transport modes, in which the user costs are related to time, vehicle, accident, emissions and noise costs. With respect to the construction of new road infrastructure, user costs are expected to drop and benefit society. A comparison between the present values of investment costs and the generated benefits in terms of a benefit–cost ratio determines the profitability of the investment. Typically, the most crucial factor determining the profitability of a project is travel time savings [15].

The Evaluation Process for Road Transport Telematics study (EVA study) developed a handbook to provide instructions regarding the road transport informatics evaluation methods. This handbook could also be used more widely to assess different types of ITS applications. EVA suggested guidelines for the BCA evaluation method, indicated the costs and benefit elements that should be considered in the BCA, and gave recommendations on the monetization of these elements [16]. Specialized guidelines pertaining to the evaluation of specific ITS applications, like urban traffic management and information or in-vehicle information systems, were later developed through the CORD project [17].

BCA can be performed in two distinct levels of analysis. The first one pertains to systems or subsystems, such as road weather information systems within a country or region. The second one pertains to specific projects, like the deployment of a weather-controlled speed limit system on a portion of a road. Most of the known international ITS BCA examine the operation of different ITS applications as a unified system, and not as specific investment objects. Lind [18] has estimated the possible effects and benefit–cost ratios of certain ITS subsystems in the Gothenburg region based on two different scenarios for the year 2020. In the United Kingdom, a BCA of ITS applications from eight application areas was performed during a review of the potential benefits of road transport telematics projects [19]. Relatively similar BCAs have also been performed in Canada [20] and Australia [21].

3.5.2 Multi-criteria analysis

Multi-criteria analysis encompasses several distinct and different evaluation and decision techniques. Their common characteristic is their ability to deal with two or more criteria measured in different units. The adoption of multi-criteria analysis for the evaluation of ITS projects is justified by three main reasons:

1. Many of the benefits of ITS investments cannot be directly monetized (e.g. service to drivers, comfort, environmental benefits).

2. The pitfalls of traditional BCA can be overcome, so that the results of the comparison process reflect the preferences of decision-makers.
3. Criteria, such as a significant difference in necessary capital expenses between ITS and road construction investments and risks related to the investments, can be taken into account in the comparison.

The EVA manual provides guidelines for applying multi-criteria analysis in the ITS project evaluation domain. Although the EVA manual includes several MCA techniques and EVA offers recommendations regarding the conduct of MCA comparison and assignment of priorities to the criteria, it does not recommend any specific MCA method [16]. Analytical hierarchy process (AHP) is a multi-criteria analysis method that has been used for the comparison of telematics solutions with each other and with road building investments [22]. AHP is based on the development of a hierarchical tree, which relates main objectives to sub-objectives in several layers of detail. Subsequently, the decision-makers assign a weight to the criteria and the alternatives in the tree based on the numerical facts or their own intuition [23].

3.5.3 Design science theory

An alternative classification of evaluation methods is proposed by the design science theory, where the completeness and effectiveness of a system are tested in the following categories: functionality, completeness, consistency and usability. The design science theory proposes the design evaluation methods presented in Table 3.1.

Table 3.1 Design evaluation methods

Observational	Case study: Study system in depth in business environment Field study: Monitor use of system in multiple projects
Analytical	Static analysis: Examine structure of system for static qualities (e.g. complexity) Architecture analysis: Study fit of system into technical architecture Optimization: Demonstrate inherent optimal properties of system or provide optimality bounds on system behaviour Dynamic analysis: Study system in use for dynamic qualities (e.g. performance)
Experimental	Controlled experiment: Study system in controlled environment for qualities (e.g. usability) Simulation: Execute system with artificial data
Testing	Functional (black box) testing: Execute system interfaces to discover failures and identify defects Structural (white box) testing: Perform coverage testing of some metric (e.g. execution paths) in the system implementation
Descriptive	Informed argument: Use information from the knowledge base (e.g. relevant research) to build a convincing argument for the system's utility Scenarios: Construct detailed scenarios around the system to demonstrate its utility

3.6 Evaluation strategies for ITS Projects

Different evaluation strategies have been developed in the design science field regarding the following questions: 'How to evaluate an ITS project?' Three strategies about 'how' the evaluation can be conducted are explained in the following sections.

3.6.1 Goal-based strategy

The most generic strategy for evaluating complex transportation systems is the goal-based evaluation [4]. During this evaluation strategy, goals and the general frame of the evaluated objective are taken into account. The basic idea is to measure the progress or contribution of a system against predefined goals and objectives. The system's goals are drawn from organizational content. The methodology includes a four-step approach divided in to two parts, the evaluation framework and the evaluation plan. The four steps are presented in Table 3.2.

It becomes obvious that the goal-based evaluation method is a project specific method as the definition of the goals as well as the available evaluation measures and data are highly dependent on the nature of each system and the scope of its implementation.

3.6.2 Goal-free strategy

Opposite to the more practical goal-based approach, this one seeks a deeper understanding of the nature of what is about to be evaluated. The involvement of a stakeholders group is deemed crucial for the successful implementation of this strategy. During the evaluation, avoidance of all rhetoric related to the programme goals is attempted; no discussion about the goals is held with staff; no proposals are studied; only the programmes outcomes and measurable effects are considered. Only the countable results of the programme are tested. The goal of the evaluation is to:

- Avoid the risk of studying narrowly defined programmes and thereby missing important unanticipated results.
- Remove the negative impacts that are attached to the discovery of an unwanted effect.

Table 3.2 Evaluation framework and plan within the goal-based strategy

Evaluation framework	**Evaluation plan**
1. Definitions of goals and objectives (i.e. accessibility, mobility, protection of the environment, etc.)	2. Selection of evaluation measures (i.e. travel time savings, crash rate, etc.)
2. Determination and listing of evaluation measures (i.e. travel time savings, crash rate, etc.)	3. Determination of evaluation data items (i.e. value of time, travel time records) 4. Determination of data collection and analysis methods (i.e. traffic simulation, field data from loop detectors, etc.)

- Eliminate the perceptual biases introduced in the evaluation through knowledge and goals.
- Maintain objectivity and independence in conclusions, in terms of the evaluator's view.

3.6.3 Criteria-based strategy

In this strategy, explicit criteria are used as points of reference for the evaluation. The difference compared to the goal-based strategy is that the criteria are not focused on organizational content, but are more general. It can be said, that criteria are a superset of the goals taken into account in the first strategy.

3.7 Field Operational Tests (FOTs)

The most common type of tests for evaluating the performance of ITS when deployed at large scale are the FOTs, which are the fourth and fifth (pilot tests and large-scale demo) steps of the deployment of a new concept or idea. Figure 3.2 shows the traditional steps followed between the conception of an idea and the full-scale implementation and commercialization of the final product or service.

A FOT is defined by the FESTA Handbook as 'a study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods', while the EC officials define FOT as 'large-scale testing programmes aiming at a comprehensive assessment of the efficiency, quality, robustness and acceptance of ICT solutions used for smarter, safer, cleaner and more comfortable transport solutions, such as

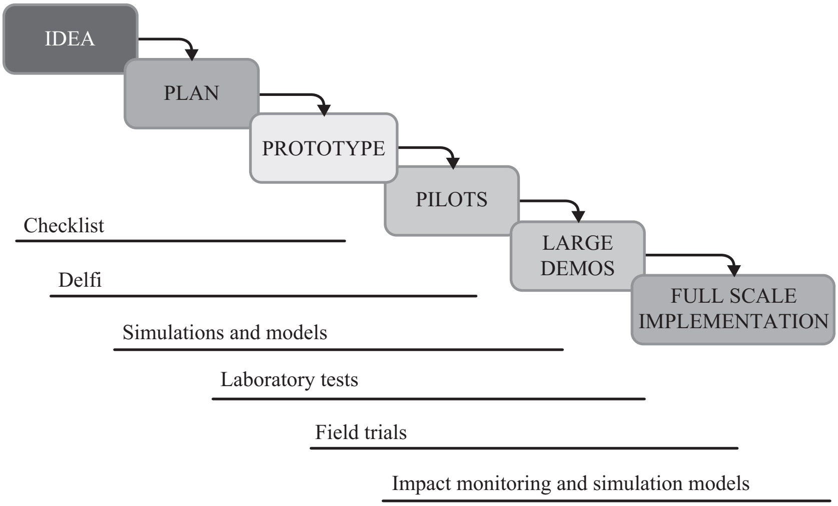

Figure 3.2 Steps of the development of an ITS solution, Adapted from Reference [24]

navigation and traffic information, advanced driver assistance and cooperative systems'. The EasyWay project proposes the following classification of FOTs [10]:

- Pilot project: technical focus on meeting the specifications on a wide area.
- Implementation project: evaluation of socio-economic impacts of the proposed solution.
- Demonstration project: focus on scalability combining the aforementioned categories.

The evaluation methodology of FOTs has been improved along various projects, such as EVA 1991, CONVERGE 1998, MAESTRO 2001 or FESTA 2008. The mentioned projects are briefly presented as follows:

- EVA 1991: Evaluation process for road transport informatics, EVA Manual [16].
- CONVERGE 1998: Guidebook for Assessment of Transport Telematics Applications [6].
- MAESTRO 2001: Monitoring Assessment and Evaluation of Transport Policy Options in Europe – General guidelines for evaluating transport pilot and demonstration projects.
- FESTA 2008: Field operational test support action Handbook for Developing and Assessing Field Operational Tests [25].

FESTA is the result of a joint effort of several research institutes, original equipment manufacturers (OEMs) and other stakeholders from across Europe. The project aimed at supporting the FOTs with the provision of a handbook of good practices, covering aspects such as the timeline and the administration of a FOT or the integration of the acquired data and estimation of socio-economic benefits. The FESTA Handbook was developed under the 7th Framework Programme to offer a common methodology for the performance of FOTs in Europe. It describes the entire process of planning, preparing, executing, analysing and reporting a FOT. It also gives information about aspects that differ substantially in different European countries and are especially relevant for a study of this magnitude, such as administrative, logistical, legal and ethical issues even though many traffic parameters. The methodology proposed within the first FESTA project in 2008 has been updated in 2014. The current evaluation steps in a FOT proposed by FESTA are presented in Figure 3.3.

The left side of the V-scheme contains the preparation activities for setting up the test; the bottom part represents the data acquisition during the use of the systems; the right side represents the data analyses and the interpretation of results.

The preparation phase follows a research-oriented approach. First, the functions to be tested are defined, the use cases are described and the related research questions listed. The use cases should describe daily situations where the system is expected to respond according to the specific functions while the research questions should be statistically testable and evaluate the performance of the systems within the use cases. Second, hypothesis, performance qualitative or quantitative indicators and measures and sensors should be defined. The hypothesis should answer the research questions through direct measures or indirect estimations/calculations of

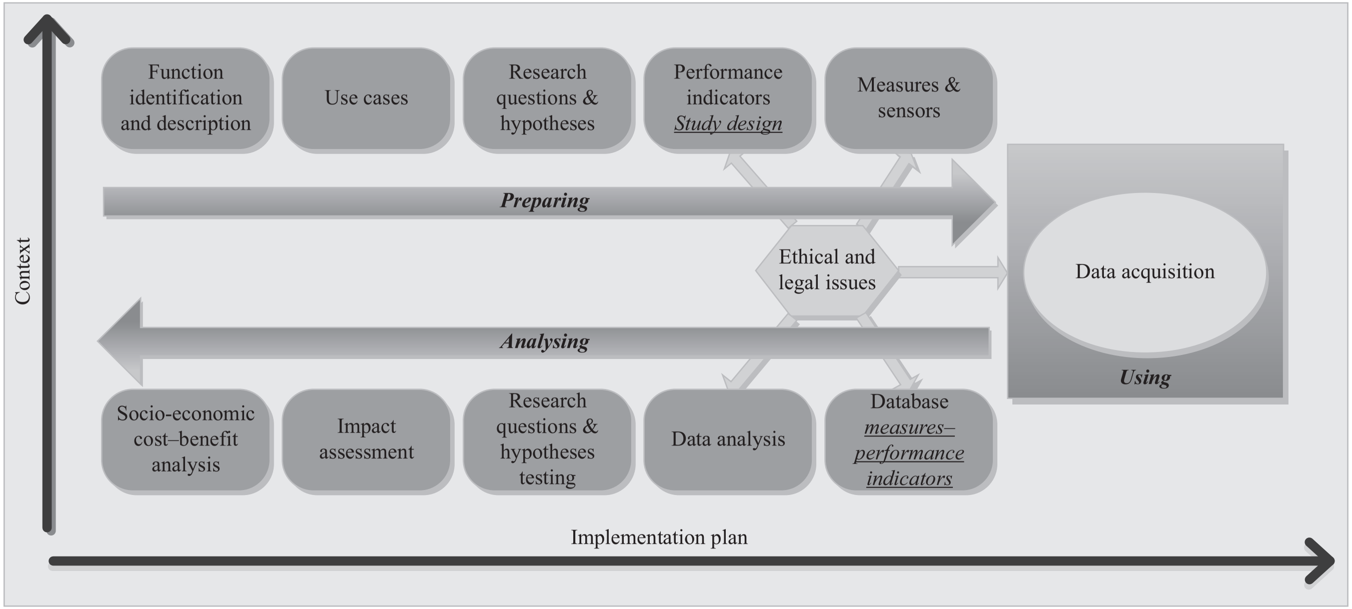

Figure 3.3 Evaluation methodology proposed by the FESTA Handbook, Adapted from Reference [26]

the related indicators. The questions that FOTs aim to answer are quite general and the answers should be supported by the specific and testable hypothesis. Hypotheses are tentative to explain behaviours, phenomena or events. In general, hypotheses should:

- State expectations about a relationship between variables.
- Be refinements of a study problem and specific statements to the problem.
- State what the outcome of the study will be.

Gay [27] defines a good hypothesis as 'stating as clearly and concisely as possible the expected relationship (or difference) between two variables and defines those variables in operational, measurable terms'. It is important also to clearly state and define a hypothesis because it 'must be testable' [27]. It should be possible to support or not support the hypotheses by collecting and analysing data [27].

The analysing phase should estimate values of the indicators to accept or reject the hypothesis and therefore answer the research questions. The results are usually scaled up to assess socio-economic impacts of the system for the whole region if further deployed.

Various components are needed during the aforementioned phases. Sensors measure all the transport-related values which will be used for the calculation of the indicators. They can be individual values of each vehicle, network performance values (through TMCs or simulation) or users' acceptance values (through questionnaires). Measurements are the values measured by the sensors and recorded by the data loggers. The characteristics of the measurements (exact definition, frequency, units) should be clearly defined within the evaluation framework activity. Data loggers record the measurements of the sensors in a specific and harmonized format defined within the evaluation framework.

Databases handle the data recorded by the data loggers. The data management issues (both physical and operational) should be also defined within the evaluation framework. Processing tools are responsible for the development of the methodologies to be used for the calculation of the indicators and the estimations. Estimation tools provide the estimation methodologies for the calculation of secondary transport-related values based on the measurements. Indicator tools develop the methodologies for the calculation of the Key Performance Indicators (KPIs) based on the measurements and the estimations. Impact tools define the impacts to be evaluated by using the calculated indicators.

3.8 Ex-ante and ex-post evaluation

The evaluation framework proposed in the MAESTRO guidelines is composed by three project phases and three evaluation phases and is depicted in Figure 3.4. They are the following:

- Define the objectives.
- Project phase 1: Site selection and Pre-design.

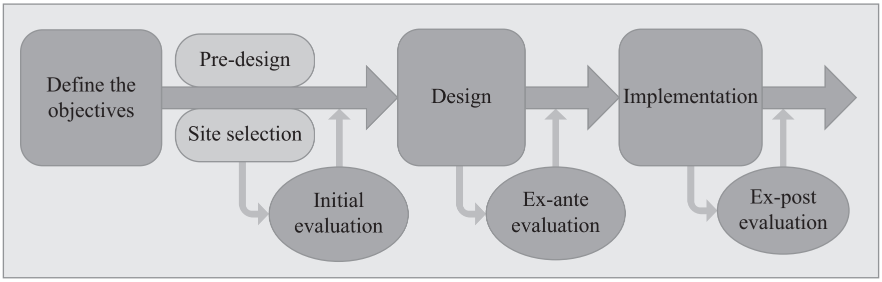

Figure 3.4 Ex-ante and ex-post evaluation framework, Adapted from Reference [28]

- Evaluation phase 1: Initial evaluation (definition of expected impacts based on pre-design).
- Project phase 2: Design.
- Evaluation phase 2: Ex-ante evaluation (estimation of impacts based on design).
- Estimation tools are responsible for providing the estimation methodologies for the calculation of secondary transport-related values based on the measurements.
- Project phase 3: Implementation.
- Evaluation phase 3: Ex-post evaluation (actual impacts from implementation).

The ex-ante evaluation tries to estimate the benefits that the system might have in theory, while the ex-post evaluation measures the benefits that the system has in reality.

The ex-post evaluation methodology is composed of six stages according to EVA (1991) and CONVERGE (1996):

- Identify the final users of the services. The final users of the service are usually private/public fleet operators or individuals.
- Select the most relevant KPI. These indicators should be related to and significant for the final users identified in the first stage.
- Define the methodology for collecting and analysing the data. The data can be collected by direct measurements, simulations or questionnaires. Statistical analyses should be done to guarantee that the results of the sample are representative.
- Define the data needs to calculate the KPI. Various data sources must be taken into account: the fleet, the traffic management centres, the fleet management centres and local sensors.
- Prepare the analysis and monitoring tools. These tools should be ready before starting the implementation works to define extra tasks to be done during the installations. If more data are needed for the tools, they should be introduced during the installations, and not after them.

- Collect data, monitor the demonstration, perform the analyses and evaluate the results. Monitoring of the demonstration performance is a fundamental task to early detect possible malfunctions but also low participation of the users, which could have negative impact in the evaluation of the results.

3.9 Socio-economic evaluation

3.9.1 Impacts assessment

ITS investment schemes need to be evaluated both on the basis of quantitative and qualitative elements. Travel time savings that can be directly estimated in numerical values are quantitative impacts. On the other hand, effects on safety, mobility and the environment cannot be expressed in measurable values immediately constitute qualitative impacts. It has to be mentioned that some elements of the qualitative impacts can partially be estimated, while others cannot be currently measured at all.

Impacts are also categorized into direct and indirect or higher order. Direct impacts (e.g. improved speeds) are generated by the immediate deployment of ITS, while indirect (e.g. benefits for non-users due to the improved system efficiency) are consequences of the direct impacts. Direct impacts have a significant effect on the short run, while indirect impacts affect the transport system and the economy in the longer term. Long-term effects should not be neglected as they constitute important features of the feasibility and cost effectiveness studies.

For the estimation of the impacts of ITS projects, both statistical analyses and simulation-based techniques have been utilized. Simulation analyses occasionally demand extensive workload and might become rather time consuming. To explore the impact of different parameters on performance measurement, researchers need to conduct a large number of experiments (depending on the number of coefficients and the number of the levels these coefficients are divided) [29]. The different variables that may affect the performance of the service should be identified and based on the categorization of these variables the set of scenarios to be tested are going to be generated. For example, in case of five factors each being described by three levels the number of total experiments to have a full factorial design is 243 experiments. This is a very large number of experiments that in most occasions cannot be fully examined.

Thus, methodologies have been developed to conclude to a smaller experimental framework that would still contain a certain amount of information required to derive the effect of each individual factor/parameter to the performance measurement. Experimental design is a scientific field by itself and several methods are being developed to extrapolate information regarding the variance and covariance of the parameters examined. This can be safely conducted place when third degree or higher order interactions between parameters can be ignored [29]. In case of no interactions between the parameters orthogonal arrays can be used to achieve a minimum number of runs for the experiment.

3.9.2 Evaluation of deployment

3.9.2.1 Technical assessment

The elements of an ITS system that should be taken into consideration during its technical feasibility evaluation are presented in Table 3.3. Breakthrough technology is applied in most of the new development systems, but its functions have not been extensively tested in the field. The risks connected with this condition must be explicitly stated during pre-evaluation. A sequential implementation of a project in discrete phases eliminates the risks associated with the project's technical feasibility. When a project evolves in phases, the malfunctioning solutions can be replaced prior to excessive waste of the investment budget. Technical feasibility risks are immediately affected by a project's dependence on the presence and operation of other systems.

Researchers should analyse data pertaining to the users' willingness to pay for a specific service to assess the prospective profitability of an ITS system.

However, it is noteworthy that the suggested willingness to pay could be very doubtful. The transferability of results from one occasion to another should be dealt with great scepticism. The willingness to pay can be used though for comparison of the different services under evaluation.

Occasionally, the goal of an ITS project is to reform the users' attitudes towards a transport service's (e.g. public transport) quality standard, or generally the image of a transport service. Surveys based on user interviews are conducted for the evaluation of the accomplishment of this goal. Questions can, for instance, be asked regarding the users' perception about the characteristics of alternate transport modes and the differences before and after the project implementation. The users' attitudes towards an ITS system or service can also be asked directly. Penttinen *et al.* [31] have designed guidelines for carrying out user interviews in connection with traffic information services. The number of users of a service is a measurable indicator that accurately depicts the users' valuations about the service.

Table 3.3 Elements of evaluation regarding technical feasibility, Source: [30]

Matter under examination	**Example**
Risks associated with technical solutions	Compatibility of equipment from different vendors
Compatibility and common system architecture	Interchangeability of subsystems, the need to rely on standards
Availability and development stage of necessary technology	Do sufficiently reliable sensors exist and are more developed models currently coming on the market?
Dependence on other systems	Does the project call for the implementation of other projects or can it be implemented independently?
Implementation in phases	Can a pilot project be carried out first as part of a larger system?
Risks associated with commitment	Does the implementation bind the operator to a specific system vendor?

Technical feasibility risks (pertaining, but not limited to compatibility, expendability, modularity) raise significantly when a specific form of technology is utilized or commitment to a specific equipment vendor is selected. It is preferable if the implementation of ITS systems is based on the premises of modular design and subsystems remain compatible. This requires solutions that comply with the commonly accepted system architecture. During the early stages of evaluation, compatibility is one of the key aspects of the ITS systems that should cautiously be taken into account.

3.9.2.2 Market assessment

Market evaluation heavily relies on the information collected through the analysis of the behaviour of service users towards an ITS service (e.g. when the objective is to improve a company's position with respect to competition by improving the quality of the provided services). To collect this information it is necessary that comprehensive data are obtained through market research and user surveys. Special focus and attention should be given to specific user groups, such as the elderly and the disabled. The elements that should be checked when conducting a market evaluation are presented in Table 3.4.

The size of the market can be evaluated from the point of view of an equipment vendor or operator. The equipment vendor's goal is to predict the cumulative demand for a system or a piece of equipment and to adjust his investments according to the expected sales. On the other hand, the operator is interested in the magnitude of the necessary investments for the development of a valuable service.

The exploration and determination of the market frequently demands the examination of several new solutions. Moreover, competitiveness is beneficial to

Table 3.4 Market evaluation checklist, Source: [30]

Matter under examination	Example
Estimation of market size (demand)	Overall demand for warning systems
Market development	Does the project create new market opportunities
Satisfying the user needs	Need for system and requirements of system characteristics indicated by market research or user survey
Taking notice of the needs of special groups	Possibilities for the disabled to use the system
Encouraging competition	The risk of the creation of a monopoly as the project is implemented
Improving footing as regards competition	The impact of developed information services on the competitiveness of public transport services
Staying in touch with technological developments	Creation of facilities associated with the development of company operations
Taking care of information services	Information service plan
Exploiting the results	Result exploitation plan

be promoted, especially when implementing projects in the public sector, so that no advantage is given to any single company or the public sector. Finally, the systematic management of information services and analysis of the relevant results is substantial and essential for a project's full exploitation.

3.10 Conclusions

In this chapter, an overview of the currently available evaluation methods and frameworks has been presented. It has been stressed that the level of detail of the utilized evaluation methodology is a function of the desired outcome of the evaluation. For example, in the case of the estimation of the actual economic impacts of an ITS project to the society, it is essential that a comprehensive and large-scale evaluation of the project is undertaken. On the contrary, the examination of the annual progress of an ITS project towards its goals requires a more simplistic evaluation scheme. A critical factor for the determination of the level of detail of the evaluation framework is also the available budget for the implementation of the evaluation.

The advantages and shortcomings of traditional evaluation methods (i.e. BCA, multi-criteria analysis) have been thoroughly analysed. BCA has been widely applied for the evaluation of investments in the transport sector, but several of the impacts induced by ITS projects can hardly be monetized (e.g. environmental improvements). Thus, several techniques have been developed within the context of multi-criteria analysis that facilitate the assessment of qualitative indicators based on experts' intuition. However, it is important to keep in mind that double counting of several impacts might occur during the application of multi-criteria analysis. The credibility of the evaluation results relies on the exclusion of the double effect of these impacts.

Several ITS project evaluation strategies have been developed based on the type and nature of the defined goals within the context of the evaluation framework. According to the depth of the assessment, these goals can shift from rigid to abstract. FOTs are implemented for the evaluation of ITS services prior to their full-scale implementation in the real world environment. The evaluation frameworks are also categorized according to the time point of their deployment. Ex-ante evaluations are conducted during the design phase of ITS projects, while ex-post evaluations after their implementation so as to assess their socio-economic impacts. When conducting a socio-economic evaluation of a ITS project, it is essential to quantify its impacts on society and assess it both from a technical and market point of view. It is apparent that evaluation methods can be classified based on several different criteria (i.e. time, space, detail of evaluation).

The development, refinement and enhancement of the evaluation methodologies for ITS projects are a necessary process to ensure the effective operation and performance of ITS services. We need to evaluate ITS projects, so that new systems can be innovatively designed, current systems can be fine tuned and improved, and future investments on the ITS sector become even more productive. The visions regarding the ITS deployment can be attained through valid, scientifically solid and tested evaluation methodologies.

References

[1] G. Giannopoulos, E. Mitsakis, and J. Salanova, "Overview of Intelligent Transport Systems (ITS) developments in and across transport modes," *EUR – Scientific and Technical Research Reports*. Publications Office of the European Union, 2011.

[2] "ERTICO," Available from: http://www.ertico.com, accessed 15 March 2016

[3] "US DOT," Available from: https://www.transportation.gov/, accessed 15 March 2016.

[4] S. Turner and W. R. Stockton, "A proposed ITS evaluation framework for Texas," Texas Transportation Institute, Texas A&M University System, Tech. Rep., 1999.

[5] T. Lomax, S. Vadali, and W. Eisele, "Evaluating intelligent transportation system impacts: a framework for broader analysis," Tech. Rep., 2000.

[6] X. Zhang, P. Kompfner, C. White, and B. Sexton, "Guidebook for assessment of transport telematics applications," Tech. Rep., 1998.

[7] R. Harris, R. Staats, and R. Bailey, "ITS evaluation: a new framework," in *International Symposium on Automotive Technology & Automation (29th: 1996: Florence, Italy). Global deployment of advanced transportation telematics/ITS*, 1996.

[8] S. E. Underwood and S. G. Gehring, Framework for evaluating intelligent vehicle-highway systems, 1994, no. 1453.

[9] A. Bristow, A. Pearman, and J. Shires, "An assessment of advanced transport telematics evaluation procedures," *Transport Reviews*, vol. 17, no. 3, pp. 177–205, 1997.

[10] "EasyWay," Available from: http://www.easyway-its.eu, accessed 15 March 2016.

[11] D. Gillen, J. Li, J. Dahlgren, and E. Chang, "Assessing the benefits and costs of ITS projects: volume 1 methodology," *California Partners for Advanced Transit and Highways (PATH)*, 1999.

[12] S. Turner, W. R. Stockton, S. James, T. Rother, and C. M. Walton, "ITS benefits: review of evaluation methods and reported benefits," Texas Transportation Institute, Texas A&M University System, Tech. Rep., 1998.

[13] H. Baum and W. Schulz, "Economic evaluation of chauffeur," in *Mobility for Everyone. 4th World Congress on Intelligent Transport Systems, 21–24 October 1997, Berlin. (Paper No. 2349)*, 1997.

[14] D. Gillen and J. Li, "Evaluation methodologies for ITS applications," *California Partners for Advanced Transit and Highways (PATH)*, 1999.

[15] P. Leviäkangas and J. Lähesmaa, "Profitability evaluation of intelligent transport system investments," *Journal of Transportation Engineering*, vol. 128, no. 3, pp. 276–286, 2002.

[16] R. Bobinger, A. Flowerdew, A. Hammond, *et al.*, "EVA – manual, evaluation process for road transport informatics," Final report, DRIVE Project, Vol. 1036, 1991.

[17] X. Zhang and P. Kompfner, "Common guidelines for assessment of ATT pilots," CORD (V2056) DELIVERABLE AC02-PART 6, 1993.

[18] G. Lind, "Test-site-oriented scenario assessment: Possible effects of transport telematics in the Göteborg region: TOSCA II final report," KFB report; 1996: 13, 1996.

[19] K. Perrett, "Review of the potential benefits of road transport telematics," TRL report; 220, 1996.

[20] R. Zavergiu, *"Intelligent Transportation Systems: An Approach to Benefit–Cost Studies,"* Monograph. National Technical Information Service, 1996.

[21] B. A. Hamilton Ltd, "Intelligent transport solutions for Australia. Technical Rep." Booz Allen Hamilton Ltd, Sydney, Australia, Tech. Rep., 1998.

[22] J. Lahesmaa, A. Schirokoff, and P. Portaankorva, "Kaakkois-suomen tiepiirin liikenteen telematiikkaselvitys [comprehensive approach to implement rural area small scale telematic solutions]," *Tielaitoksen selvityksia*, vol. 42, 1998.

[23] T. Saaty and K. Kearns, "*Analytic Planning – The Organization of Systems, International Series in Modern Applied Mathematics and Computer Science*," Vol. 7, 1985.

[24] R. Kulmala, Assessment methods in ITS lifecycle. PowerPoint picture. Finnish Transport Agency, 12 March 2013 (revised based on the draft version of Kumala R. in 2004).

[25] F. Consortium, "FESTA Handbook," *FESTA Support Action. Field opEra-tional teSt supporT Action. D*, Vol. 6, 2008.

[26] *FESTA Handbook, Version 4*, Schneider Electric, 2011.

[27] L. R. Gay, *Educational Research: Competences for Analysis and Application*. Upper Saddle River, NJ: Prentice Hall, 1998.

[28] MAESTRO, "Monitoring assessment and evaluation of transport policy options in Europe," Tech. Rep., 2002.

[29] J. Antony, "2 fundamentals of design of experiments," in *Design of Experiments for Engineers and Scientists*. Oxford: Butterworth-Heinemann, 2003, pp. 6–16. [Online]. Available from: http://www.sciencedirect.com/science/article/pii/B978075064709050003X.

[30] R. Kulmala, J. Luoma, J. Lahesmaa, *et al.*, "Guidelines for the evaluation of ITS projects," Ministry of Transport and Communications, Tech. Rep., 2002.

[31] M. Penttinen, P. Rama, and V. Harjula, "Assessment of Finnra's traffic information services survey questionnaires and instructions," Helsinki Finnish Road Administration, Tech. Rep., 1998.

Chapter 4

Evaluation of the impact of ITS

Luca Studer[1] and Giovanna Marchionni[1]

4.1 Overview of the Diffusion of Intelligent Transport Systems (ITS) in Europe

The evaluation of ITS begins and takes root within a European policy focused on the diffusion and enhancement of ITS. This section briefly introduces the history of the European policies and actions supporting these technologies to describe their scope in Europe.

ITS apply information and communication technologies to make the transport of people and goods easy and flowing.

The potential of ITS was expressly mentioned in several White Papers of the European Commission (EC), which considers them as a way to reduce congestion and bottlenecks. The implementation of traffic management plans, information services before and during the journey, goods management services, assistance and emergency services in case of emergency as well as electronic fee systems is therefore a priority and shall contribute to reduce the saturation of the road network.

To support the extension of services in Europe, the European Community supports ITS in the road sector by co-financing several projects. Community policies for the development of the Trans-European Road Network (TERN) aim at establishing the interconnection, the interoperability and the continuity of services, above all on long-distance corridors and at borders.

Traffic management advanced systems were implemented before 2001 in many European areas. National and regional ITS services were never coordinated, thus resulting in a fragmented mosaic. Aiming at a wide diffusion of ITS services all over Europe, the EC launched the programme Trans-European intelligent transport systeMs PrOjects (TEMPO) in 2001–2006.

The key objective of the programme TEMPO on ITS in the road sector was to promote a harmonious and coordinated development of ITS in the member states of the Union, as well as the cooperation among the several countries, and the safety and quality of the service on the TERN network thanks to the cooperation between bordering regions by means of the so-called Euroregional projects. The programme

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TEMPO 2001–2006 includes six projects: ARTS, CENTRICO, CORVETTE, SERTI, VIKING and STREETWISE. The project CONNECT and the project ITHACA were added to the six projects, thus covering the whole Europe (see Figure 4.1).

The EC, together with the Member States, identified a limited number of key objectives as a priority for the programme TEMPO:

- Enhancement of the use of the road capacity and of goods and passengers traffic flows;
- Improvements of road safety by preventing accidents and reducing their effects;
- Mitigation of environmental damages by reducing traffic congestion.

To avoid the fragmentation of resources, nine *application domains* were identified:

1. Implementation of a high quality road monitoring facility with reliable ITS;
2. Definition of a European network of traffic control centres (TCC);

Figure 4.1 Euroregional projects

3. Removal of traffic jams and fluidization of traffic by means of traffic control and management measures;
4. Implementation of easy accesses to high quality traffic information services, also interfacing with other means of transport;
5. Increase in the safety and efficiency of goods transport by means of fleet and goods management systems;
6. Development of easy and efficient electronic fees payment systems;
7. Enhancement of efficiency and road safety by means of accidents and emergencies management;
8. Promotion of actions aimed at evaluating the impact of all the applications (horizontal activities, as they concern all the previous domains), the coordination at European level and between bordering countries as well as the sharing of the results;
9. Management of the projects.

The EC therefore decided to keep financing road traffic management projects on a European scale.

At European level, the Ministry of Transport and the stakeholders, together with the other Institutes and Road Operators, developed a single programme called EasyWay for 2007–2013.

To carry on the cooperation initiated within the programme TEMPO, EasyWay incorporated the 8 Euroregions to ease the integration of all the new member states. The cooperation among the countries involved was reinforced, thus providing a new integrated overview with clear objectives.

The programme EasyWay 2007–2013 highlights the following priorities for ITS on roads, at European level:

- Traffic information and travelling services
- Traffic services management
- Goods and logistics

Projects shall enhance co-modality by promoting the concept of connected passengers as well as connected intelligent technologies, and emphasize the cross-border cooperation and the continuity of the service.

The objectives of EasyWay for 2020 are (see Figure 4.2):

- Reducing road accidents by 25%
- Reducing traffic congestion by 25%
- Reducing CO_2 emissions by 10%.

A large scale programme such as EasyWay needs a strong and adequate organization. In particular, it includes the following management committees:

- The EasyWay Supervisory Programme Board (SPB);
- The EasyWay Steering Committee, which is composed of 8 Euroregions and of representatives of the European Community. The EasyWay Secretariat;
- The Technical Coordination Team (TCT);

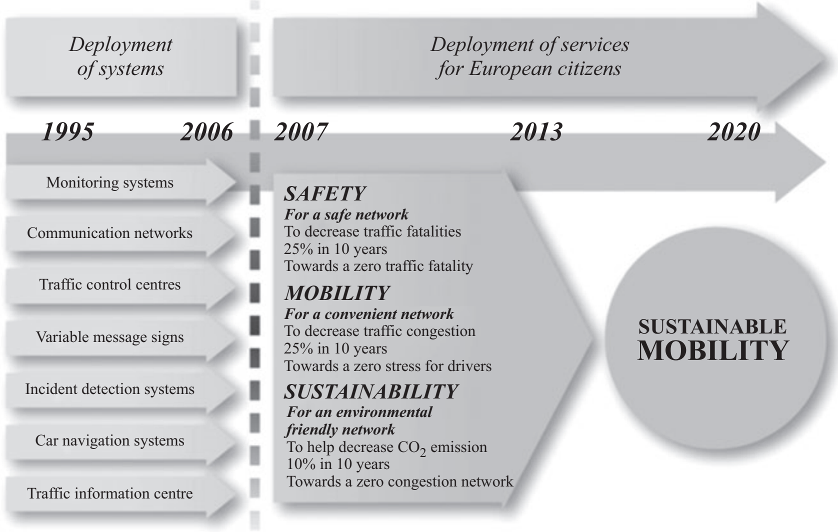

Figure 4.2 Objectives of the programme EasyWay

- The Evaluation Expert Group (EEG), which is independent of EasyWay. It is composed of representatives of each Euroregion plus a leader and a vice. The EEG is responsible for the development of evaluation procedures aimed at collecting and processing the results of evaluation studies within EasyWay. Data and information specified by EEG, which are provided by partners on a regional base, are used to structure the evaluations of the projects based on proper indicators;
- The Communication Team.

The action plan includes six priority sectors, which are connected with each other, as shown in Figure 4.3.

The deployment activities A1–A4 are the core of the project. Regional operating plans were developed for these activities. They focus on the needs of regions and cross-border corridors with respect to the objectives set within the programme EasyWay.

A key element of EasyWay is the definition of 16 ‘Deployment Guidelines (DGs)’ for the several ITS to promote the development, the harmonization and the continuity of services in Europe.

Following the completion of the EasyWay Phase II project which supported the development of DGs, EU Member States expressed the need and the willingness to continue the existing cooperation improving cross-border coordination, exchange of knowledge and sharing of ITS best practices for harmonized future deployment of continuity ITS services across EU road network.

At present the follow-up of the EasyWay Project and the most important EU Project regarding road ITS is the European ITS Platform+ (EIP+).

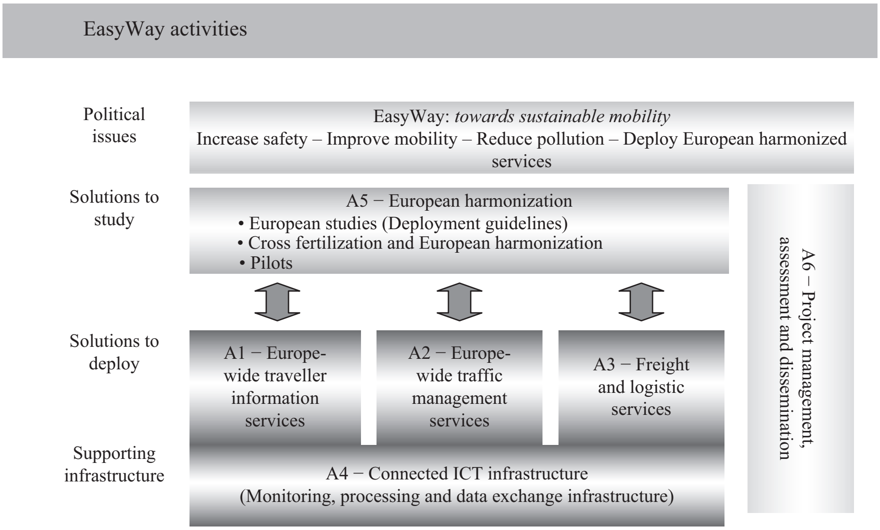

Figure 4.3 Priority sectors of the programme EasyWay

4.1.1 EIP+[1]

Within the framework of the EasyWay programme 2007–2020, seen as Global Project, fostering the development of ITS services along transport corridors, in EIP+ there are 5 Corridors covering almost all Europe: Arc Atlantique, Crocodile, Med TIS, Next-ITS and Ursa Major. The EIP+ has been co-funded by the EC under the EC ITS Call 2012.

Furthermore, the ‘EIP+’ has a strong interface with the ‘Corridor’ projects that are co-funded under the EC 2013 ITS Call, by monitoring their technical progress on ITS services implementation that will be performed, as well as collecting and elaborating their results. One more important task will be the dissemination of knowledge and experiences both inside and outside the partnership of the ‘EIP+’ to make available best practices for the future ITS Service deployments.

Within the ‘EIP+’, it is also important to ensure that evaluations, that will be carried out by each Corridor project, will be of the highest quality, following relevant evaluation guidance, to enable conclusions about the overall levels of benefits being realized by the Corridor projects.

The establishment of the EIP+ should contribute to the following objectives:

- Ensure the harmonized and interoperable deployment of ITS on the TEN-T road network and relevant network nodes that connect the TEN-T road network to other road networks and/or other modes of transport, especially via

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[1] https://www.its-platform.eu/ [Accessed 31 March 2016].

well-established links to Member State Corridor deployment projects applications in the scope of the 2013 EC MAP ITS Call.
- Facilitate the ITS policy level cooperation of Member States and to map policy level decisions on the European level to the EasyWay DGs for ITS and other required technical elements on the operational level, particularly with regard to the priority actions and priority areas of the ITS Directive 2010/40/EU.
- Ensure a wide harmonization of ITS deployment across the TEN-T road network by collecting, processing and promoting best practices on the practical deployment of ITS Core Services through active and committed Member State cooperation in the EIP+.
- Complete the EasyWay DG framework of the Member States to complement European ITS EC Specifications to provide a consistent and coherent framework for future ITS deployments.
- A continuous monitoring and collection of feedback on the application of the DGs in the context of national projects within the Corridor projects (Works) and to consolidate reporting of the results, lessons learned and best practices concerning the DGs requirements at a European scale.
- The evaluation of the impacts of implementation on the Corridor deployments projects; including a definition of key performance indicators (KPIs), methods and procedures to be used, in cooperation with relevant implementation projects.

Moreover, the attention of the 'EIP+' activities is also focused on some specific emerging technologies; in fact different ITS systems and services show different level of maturity and the need to link different networks and modes of transport is continuously increasing. The 'EIP+' include also specific activities that aim to support ITS harmonization within new and growing areas like 'cooperative systems' and 'new and improved monitoring technologies'.

The EIP+ aims to demonstrate operational gains in terms of continuity of service across borders and networks interfaces in a joint effort to ensure the creation of a proper environment for harmonizing existing and future ITS services.

4.2 The Evaluation of ITS

The evaluation of ITS implementations begins with the Euroregional projects to assess and control the progress of several activities.

The evaluation was required for the Euroregional projects to:

- Account for the investments made by the European Community,
- Show the benefits of the single implementations,
- Show the benefits of ITS implementations as a whole,
- Show the benefits of the higher sharing of information among the several projects.

A common method of evaluation not only allows to control the progress of the projects and their compliance with the objectives, but makes it easier to compare the results of similar ITS projects that are implemented in different areas, thus increasing the value of the single projects.

The management of the programme TEMPO established the EEG, which is coordinated by STREETWISE, a group of experts coming from the several countries involved in the programme. They were to discuss the problem of evaluation and of the several methods that had already been developed in every single country. A common approach was to be found to harmonize the several methods of evaluation, as well as a common standard to represent the results, thus making it easy to assess the expected results and to compare the effects obtained from the implementations developed in different areas.

For this reason, guidelines were defined to evaluate the projects, to make a summary of the comparison and of the considerations emerging from the group of experts gathered by the European Community.

The term evaluation covers a wide scope. The evaluation generally depends on:

- The reason for the implementation;
- The objectives of the project;
- The institutional reasons behind the project;
- The expected results.

Once the project is implemented, the evaluation shall assess whether the results set have been reached and identify any secondary effect, both positive and negative, following the implementation of the ITS.

Here are the main aspects to follow to develop the method for a correct evaluation process:

- The applicability to all types of ITS both at study and at implementation level;
- The ease of understanding;
- The compliance with the aims and nature of the objectives associated to the projects at all levels.

4.2.1 General principles of evaluation

The evaluation process must take into consideration some general principles to highlight the most important aspects of each phase of development of the ITS projects analysed.

First, the reasons for the evaluation must be clear, e.g. the description of the performances of the ITS under consideration, showing the benefits obtained to national administrations and to the European Community, the evaluation of the positive aspects of the applications, accounting for the financing made. Above all, the possibility for those who want to adopt similar techniques or need to handle similar problems, to be provided with analyses that allow to evaluate the objectives that were actually reached, and to modify or correct the technologies used.

Second, the evaluation before the implementation (ex-ante) allows to control that the expected results are achieved, and guarantees the creation of a database for the evaluation after the implementation (ex-post).

The clearer the objectives set by the project under consideration, the more effective an evaluation will be; this setting allows to focus on the level of achievement of the objectives.

In general, an evaluation must include:

- A clear description of the place and context where the ITS application is developed to make it easy to spread the results and to compare it with other similar ITS implementations;
- An explicit description of the method and the survey techniques that are used to make it easy to read the results obtained;
- A set of indicators that are defined and clearly recognized at European level to assess the impacts and improve the comparability of the results both at national and European level;
- The indication of the level of statistical significance of the results.

4.2.2 The European guidelines

In general, the results of the evaluation must be easy to understand for every reader, both at national and at European level. There ought to be the possibility to spread the results to similar ITS projects that are implemented in other countries, or to receive useful indications for the implementation of the same project in several areas.

A standard method of representation of the evaluation results of the Euro-regional projects was developed by the EEG and then adopted by the TEMPO, EasyWay and EIP+ Projects with few changes. It describes extremely precise sections that are described in Table 4.1.

The first section summarizes the main results of the evaluation; it is a short summary of the results obtained from the project and allows a first overview of the objectives achieved by the system.

The problem that is dealt with is then described; in particular, the context of application, the place of implementation and the themes to deal with.

The third section describes the ITS project. Particular attention is paid to the objectives set, to the systems and technologies used, to users involved; furthermore, the status of the project at the evaluation is defined. The evaluation can be made before, during or after the implementation.

The first three sections aim at characterizing the ITS project, at identifying the problems that are dealt with and the context of the application.

The fourth section regards the method of the evaluation. First of all, the type of evaluation is defined (whether before or after the implementation) as well as the time schedule; then, the objectives of the evaluation and the impacts to measure. Particular attention is paid to the following aspects (*in italic* the additional aspects mentioned in the TEMPO Project):

- Safety;
- Efficiency;
- Environment;
- *Users acceptance*;
- *Integration*;
- *Accessibility*.

Table 4.1 Chart of the sections described in the guidelines of the EEG

Sections (referred to the EIP+ scheme)	**Subsections**
Key evaluation results	Impact on traffic flow Impact on safety Impact on environment Other key results
Description of the problem	Site Issues addressed
Description of the ITS project	Service area Keywords Objectives Systems and technologies applied Costs Status of the project
Evaluation planned	Timing and type of evaluation Objectives for the evaluation Research questions Study area for the evaluation Expected impacts Expected methods
The impact of the project – results	Technical performance Results Reliability of the results Research questions answered Overall assessment (safety, efficiency, environment)
European dimension – transferability of the results	

It is important to underline that these aspects may not be all relevant to every ITS application. Their evaluation must be taken into consideration only when a project has a real effect on the specified scopes.

This section specifies the method used for the evaluation. Particular attention is paid to the choice of the indicators for each objective, on the selection of data (in the cases when not all the data collected is used in the analysis, the reprocessing of missing or wrong data, etc.), on technical analyses and statistics applied (including the statistical tests used, the level of aggregation of the data used in the analysis, the reliability of the techniques applied).

The choice of the most proper indicators was widely discussed within the EEG. The most delicate problem regards the impossibility to specify proper indicators for a wide range of projects. Indicators should be aimed at each specific project. The EEG reminds that particular attention must be paid to the choice of the level of aggregation of data. A highly detailed level may only imply an increase in evaluation costs without ensuring a greater accuracy of the results. In light of the above, the group of experts suggests a list of proper indicators for ITS (see Table 4.2), however leaving a

Table 4.2 Summary of the main indicators suggested by the EEG

Objectives	**Indicators**
Network and costs (economy)	Variations of the use of the network based on vehicles – km Variations of the journey time when the demand exceeds the capacity Variations of the average speed during rush hours Number of accidents caused by the insufficient capacity of the network Time wasted because of the insufficient capacity of the network
Time and forecast (economy)	Journey time (average and standard deviation) Additional journey time caused by accidents Instantaneous speed (average and instantaneous deviations) Vehicles – km covered with congestion passengers – km, vehicles – km ton – km, etc. Stability of the traffic flow (number of speed changes) Perceived fluidity of the traffic flow Success of information services
Safety	Number of accidents Number of accidents with injured people Number of fatal accidents Vehicles – km covered Number of offences against traffic laws Safety perceived by the user
Emissions of noise and energy (environment)	Number of people subject to traffic noise Number of people exposed to exhaust gases Tons – km of goods transported Tons – km of dangerous goods transported Impact of transport facilities on the environment
Evaluations and comfort	Willingness to pay (mobility) Willingness to pay (services) Number of services users

wide margin to the people responsible for evaluation. The lack of common indicators makes it difficult to immediately compare the results of similar ITS applications. Nevertheless, a detailed description of the method used, as set in the guidelines, somehow allows comparing the result.

The EIP+ project suggested in March 2015 the following benefit KPIs [1]:

- Congestion
  - Lost vehicle hours/time saving
  - Re-routing (traffic management)
  - Difference in-vehicle km driven
  - Journey time
  - Journey time variability at key points

- Safety
    - Number or % change in fatalities/injuries
    - Change in speed

- Environment
    - Reduction of CO_2 emissions
    - Noise reduction
    - Modal split

The fifth section evaluates the impacts of the project under consideration. First of all, they underline the technical performance of the system and the conclusions on the influence on the impacts identified. Results are then proposed in terms of measurement of the indicators, statistical analyses made, global evaluation, which consists in a summary of the main results in terms of impact on the above-mentioned European objectives.

The last section highlights the transferability of the results. In particular, it underlines the way in which evaluation results may be applicable to similar implementations in the same or in other nations, pointing out at the same time the local, external or experimental peculiarities that could have affected the results. If several evaluation reports were produced for similar projects, this section of the report may be used to present comparative analyses and considerations on the transferability of the results.

4.2.3 Study on KPIs for ITS

The study was commissioned in 2015 by DG MOVE to establish a set of common KPIs for road ITS, with supporting guidance on their application, presentation and reporting.

The study process commenced with a state of the art review of current degree of application of KPIs within the EU, as well as reviewing examples of good practices through a review of publically available data sets. The state of the art review and stakeholder questionnaire collectively identified 228 indicators currently in use within the EU, although a number of these were considered to fall short of true KPIs. These KPIs were divided into deployment and benefit KPIs, the former monitoring the extent to which ITS have been installed and/or made available to the public, while the later monitoring their impact on the main aspects of transport (such as journey times, accidents).

This list was assessed and refined to produce an emerging long list of 38 KPIs providing coverage across the ITS taxonomy and linked to the ITS Priority Areas of the ITS Directive and policy goals (see Tables 4.3 and 4.4). This list was consulted on as part of the stakeholder workshop and homework pack, providing feedback from EU experts on the identified list and their preferences. Feedback from the various consultation activities and the wider study findings has allowed this list to be refined further down to a list of 15 recommended KPIs.

Table 4.3 Emerging long list of deployment KPIs

1. Optimal use of road traffic and travel data

- % National transport network covered by websites offering comprehensive traveller information (e.g. journey planning, traffic information)
- % Public transport ticket transactions that utilize electronic payment technologies
- % Public transport stops with dynamic traveller information available to public
- % TEN-T network covered by traffic advisory radio and/or mobile network reception and offering appropriate information services
- Number of visits to websites and portals offering traveller information (e.g. journey planning, traffic information)
- % Bus routes equipped with Automatic Vehicle Location
- % Demand responsive vehicles that operate under Computer Aided Dispatch

2. Continuity of traffic and freight management ITS Services

- % Road toll revenue collected by electronic toll collection (ETC) systems
- % Compliance with the Directive on the interoperability of electronic toll road systems (EETS)
- % Urban intersections controlled using adaptive traffic control
- % Urban public transport network interchanges that are equipped with PT priority signals
- % TEN-T network covered by a minimum level of information infrastructures (e.g. traffic, weather and environmental conditions monitoring, CCTV or traffic information and control centres)
- % TEN-T network with a minimum level of traffic management and control (e.g. Dynamic lane management, ramp metering, variable message sign – VMS)
- Number of intelligent truck parking facilities per km of TEN-T network

3. ITS road safety and security applications

- % Vehicles sold featuring intelligent vehicle services (vision enhancement, safety readiness, automated operation, cooperative systems)
- % Hazardous/abnormal load movements for which ITS has been utilized to facilitate the sharing of information between relevant organizations
- % Emergency vehicle dispatches facilitated by computer aided dispatch
- % Hazardous load movements for which information is logged or monitored using ITS
- % TEN-T network covered by incident detection and management algorithms
- % Urban intersections providing safety enhancements for pedestrians and disabled or other vulnerable road users

4. Linking the vehicle with the transport infrastructure

- % TEN-T network supporting cooperative systems (I2V, V2I)
- % Vehicle models currently offered for sale featuring intelligent vehicle services (vision enhancement, safety readiness, automated operation, cooperative systems)

The identified KPI shortlist (see Tables 4.5 and 4.6) of 15 KPIs achieves a relatively even balance between benefit (7 KPIs) and deployment (8 KPIs). The recommended list also seeks to achieve an appropriate balance between the different ITS priority areas of the ITS Action Plan [2] and ITS Directive and wider EU policy goals.

Table 4.4 Emerging long list of benefits KPIs

1. Network efficiency and congestion

- Change in peak hour journey time in conjunction with flow between key points along a route (all vehicles)
- Change in peak hour flow between key points along a route (all vehicles)
- Public Transport journey time reliability – deviation from scheduled timetable
- Journey time variability as measured using standard deviation of journey times between key points along a route (all vehicles)
- Change in Public Transport average daily person flow between key points along a route

2. Improve environmental impacts

- Change in CO_2 emissions per vehicle km
- Change in number of hours where NO_x levels are above threshold
- Change in PM10 emissions per vehicle km
- Change in number of hours where transport noise is above dB threshold

3. Improve road safety

- Change in number of all reported accidents per vehicle km
- Change in severity of accidents (i.e. numbers killed or serious injured) per number of accidents reported
- Number of near misses (potential accidents) recorded by ITS
- Change in crime reports relating to truck parking

4. Enhance modal integration

- Rail and inland waterway mode share along key corridors (tonne km)
- Public Transport mode share along key corridors (people)
- Active travel mode share (people)

Table 4.5 Recommended shortlist of deployment KPIs

ID	Deployment KPIs
R3	Length and % of road network covered by incident detection and incident management. Report separately by road type or area where possible.
R6	Length and % of road network covered by automated speed detection. Report separately by road type or area where possible.
O1	Length and % of transport/road network covered by websites/over-the-air services offering traffic and travel information. Report separately: 1. Travel information 2. Traffic information 3. Integrated traffic and travel information 4. Freight specific information Report separately by road type or area where.

(*Continues*)

Table 4.5 (*Continued*)

ID	Deployment KPIs
O3	Number and % of urban public transport stops for which dynamic traveller information is made available to the public. Report separately by public transport mode where possible.
O6	Length and % of road network covered by the following. Report separately: 1. Information gathering infrastructures 2. Traffic information services 3. Traffic management plan(s) incl. cross border TMP 4. Traffic management and control measures/equipment 5. Infrastructure or equipment on the network to enable Cooperative-ITS 6. Intelligent safety services for disabled and vulnerable road users 7. Report separately by road type or area where possible.
C4	Number and % of signal controlled road intersections using adaptive traffic control or prioritization. Report separately by road type or area where possible.
S11	Provision of intelligent services on the TENT-T core and comprehensive networks that are compliant with the Delegated Regulations of the ITS Directive: 1. Length and % of TEN-T network covered by real-time traffic information services that are compliant with the requirements of Delegated Regulation xx/2015 2. Length and % of TEN-T network covered by road safety related traffic information services available free of charge to users that are compliant with the requirements of Delegated Regulation 886/2013 3. Length and % of TEN-T network covered by information services for safe and secure parking places for trucks and commercial vehicles that are compliant with the requirements of Delegated Regulation 885/2013.
L3	Number and % of new vehicles including the following intelligent vehicle features: 1. Safety readiness 2. Automated operation 3. Cooperative systems 4. Public (112) systems 5. Private eCall systems Report separately by vehicle types where possible.

4.2.3.1 The calculation of benefit KPIs

To assist practitioners in the implementation of these KPIs, a series of pro-forma have been produced to provide additional details regarding the definition of terms, calculation of metrics and recommended presentation of results. The pro-forma also includes a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis to ensure the identified KPIs maximize the available strengths and opportunities whilst minimizing weaknesses and threats. Additional information is also provided on the rationale and coverage of each KPI and the data requirements in producing each KPI (Figure 4.4).

Table 4.6 Recommended shortlist of benefit KPIs

ID	Benefit KPIs	Linkages to deployment KPIs
N1	% change in peak period journey time along routes where ITS has been implemented. Report by vehicle type where possible.	R3, O6, C3, C4, L3, S11
N2	% change in peak period traffic flow along routes where ITS has been implemented. Report by vehicle type where possible.	R3, O6, C3, C4, L3, S11
N4	% change in journey time variability on routes where ITS has been implemented - as measured by coefficient of variation. Report by vehicle type where possible.	R3, O6, C3, C4, L3, S11
N9	% change in mode share on corridors where ITS has been implemented. Report percentage mode share separately for each mode where possible.	O1, O3, O21
S1	% change in number of reported accidents along routes where ITS has been implemented. Report by accident severity where possible.	R3, R6, L3, L9, S11
E1	% change in annual CO_2 emissions (Tons) on routes where ITS has been implemented.	
L9	Time taken between initiation of public (112) eCall to the presentation of the content of MSD in an intelligible way at the operator's desk in the Public Safety Answering Point.	L3

4.3 US ITS programme overview

The U.S. Department of Transportation (USDOT) ITS Joint Programme Office (ITS JPO) is responsible for conducting research on behalf of the Department and all major modes to advance transportation safety, mobility, and environmental sustainability through electronic and information technology applications, known as ITS.

4.3.1 Mission

The USDOTs ITS programme focuses on intelligent vehicles, intelligent infrastructure and the creation of an intelligent transportation system. The programme supports the overall advancement of ITS through investments in major research initiatives, exploratory studies and a deployment support programme including technology transfer and training.

4.3.2 ITS Strategic Plan

The ITS Strategic Plan 2015–2019 outlines the direction and goals of the USDOTs ITS programme and provides a framework around which the ITS JPO and other Department agencies will conduct ITS research, development and adoption activities to achieve the programme's outcomes and goals.

KPI details: benefits	
Reference number	N1
Short name	Change in journey time
Long name	% change in peak period journey time along routes where ITS has been implemented. Report separately by vehicle type where possible, see breakdown by vehicle classification section.
Definition	● **Peak period**: The period or hour with the highest flow during a weekday. The period used can vary by route, but must be fixed between before and after surveys. ● **Vehicle types**: All (but a disaggregation by vehicle type can also be provided if appropriate, see breakdown by vehicle classification section) ● **Routes where ITS has been implemented**: Member States should specify which routes will be included within this KPI. This could be based upon those outlined in the associated deployment KPIs, but sufficient data is unlikely to be available in all instances. The selection of key points between which the journey time change will be measured should be defined in relation to the nature of the ITS implemented on the route. Typically this would be the journey time between key junctions.
Calculation	KPI = ((Journey time before ITS implementation – Journey time after ITS implementation)/Journey time before ITS implementation) *100
Presentation	Percentage change before and after to be presented alongside list of ITS deployment locations used in the calculation. Time-series data to be presented as a line graph.
SWOT analysis	
Strengths	● Can be assessed using standard transport monitoring methodologies. ● Should allow any journey time benefits resulting from ITS to be quantified.
Weaknesses	● May require additional data collection and associated costs. ● Requires data collection before and after implementation or ITS – this may be an issue where ITS is newly implemented or when past data have not been collected/are not available.
Opportunities	● Alignment with ITS deployment should improve attribution or benefits. ● System generated data may be available to calculate this KPI post-system implementation, though comparing information from different sources may be challenging.
Threats	● Other factors in additional to ITS may influence journey time – e.g. traffic growth and inability to disaggregate impact of ITS may call ITS deployment into question.
Rationale and coverage	
Rationale (contribution to White Paper and ITS Action Plan)	● Measure of network efficiency and congestion.
Constraints in aggregation to EU level	In some instances this will require additional data collection, but there should be no constraints in the aggregation or results at Member State and EU levels.
Road type	All road types where ITS have been implemented
Data requirements	
Source	Journey time survey data – e.g. ANPR or Bluetooth. As technologies develop floating vehicle and crowd sourced data may be available to allow calculation of this KPI without the requirement for specific data collection. Size of sample required to be determined based upon variation in results.
Ownership	Data likely to be owned by roads authority/toll road operator and PT operators.
Frequency	Data to be collected immediately before and after implementation or the ITS improvement with continued monitoring carried out on an annual basis during a neutral month.

Figure 4.4 Example of pro-forma scheme for benefit KPI

The ITS Strategic Plan's framework is built around two key ITS programme priorities – realizing connected vehicle implementation and advancing automation. The priorities reflect stakeholder feedback on the need for the ITS programme not only to conduct research, but also to help with deployment and implementation of specific technologies related to connected vehicles and automation.

4.3.3 The Office of the Assistant Secretary for Research and Technology (OST-R)

The OST-R is part of the Office of the Secretary of Transportation (OST). It comprises all of the programme offices, statistics and research activities previously administered by the Research and Innovative Technology Administration (RITA). In January 2014, the US Congress transferred all RITA programmes into OST to provide opportunities for increased research collaboration and coordination, while upholding the integrity and impartiality of transportation statistical data. This helps to ensure that research activities and budgetary resources across the Department are fully aligned with the Department's strategic goals and key interest areas.

The mission of OST-R is to transform transportation by expanding the base of knowledge to make America's transportation system safer, more competitive and sustainable.

OST-R is a dynamic, world-class transportation resource with broad technical and institutional expertise not replicated elsewhere.

The USDOTs ITS research programme focuses on the overall advancement of ITS through investments in emerging ITS technologies, as well as supporting the evaluation of deployed ITS.

4.3.4 USDOT ITS knowledge resources

To support the deployment of ITS and to address the challenges facing the U.S. transportation system, the JPO has developed a suite of knowledge resources. This collection of Web-based resources provides ready access to information supporting informed decision-making regarding deployment and operation of ITS to improve transportation system performance. The knowledge resources contain over 15 years of summaries of the benefits, costs, lesson learned and deployment status of specific ITS implementations drawn primarily from written sources such as ITS evaluation studies, research synthesis, handbooks, journal articles and conference papers.

The four knowledge resources are the ITS Benefits Database (http://www.itsbenefits.its.dot.gov), ITS Costs Database (http://www.itscosts.its.dot.gov), ITS Deployment Statistics Database (http://www.itsdeployment.its.dot.gov) and the ITS Lessons Learned Knowledge Resource (http://www.itslessons.its.dot.gov).

A fifth Web site, the ITS Applications Overview, provides access to information from each of the knowledge resources using an organization scheme.

As of March 2016, there were a total of 1 756 summaries of ITS benefits, costs and lessons learned in the ITS Knowledge Resources Databases from the United States and around the world, as shown in Table 4.7.

Table 4.7 Summaries in the Knowledge Resources Databases

Summary type	Number of summaries
Benefits	900
Costs	294
Lessons learned	562
Total	1 756

4.3.4.1 The ITS Benefits Database

Benefits measure the effects of ITS on transportation operations according to the six goals identified by the USDOT:

- Safety,
- Mobility,
- Efficiency,
- Productivity,
- Energy and environmental impacts and
- Customer satisfaction.

Within the ITS Benefits Database, findings from ITS evaluations and other sources are presented in a concise summary format. Each benefit summary includes a title in the form of a short statement of the evaluation finding, context narrative and identifying information such as date, location and source, as well as the evaluation details and methodologies that describe how the identified ITS benefit was determined. The ITS Benefits Database documents represent findings of ITS evaluations, regardless of outcome, and includes several findings of neutral impact and a few examples of negative impacts under particular goal areas.

The Web site includes useful search capabilities and also presents findings through several organization schemes including the ITS application areas, the ITS goal areas and by location (Table 4.8).

4.3.4.2 ITS Costs Database

The ITS Costs Database was established as a national repository of cost estimates for ITS deployments. The purpose of the ITS Costs Database is to support informed decision-making of transportation leaders. The ITS Costs Database contains estimates of ITS costs that can be used for developing project cost estimates during the planning process or preliminary design phase, and for policy studies and benefit–cost analysis. Both non-recurring (capital) and recurring or operations and maintenance (O&M) costs are provided where possible.

Three types of cost data are available: unit costs, sample unit costs and system cost summaries. The primary difference in the three types is the level of aggregation. Unit costs are the costs associated with an individual ITS element, such as a video camera for traffic surveillance or a dynamic message sign. Sample unit costs are a compilation of actual or estimated costs of ITS elements on a per project basis and can be related back to the unadjusted unit costs. System cost summaries are the costs of an ITS project or portion of an ITS project such as the cost of expanding a

Table 4.8 Benefit classification scheme and topic areas

Classification	Major topics
ITS applications	Alternative fuels
	Arterial management
	Commercial vehicle operations
	Crash prevention and safety
	Driver assistance
	Electronic payment and pricing
	Emergency management
	Freeway management
	Information management
	Intermodal freight
	Road weather management
	Roadway operations and maintenance
	Transit management
	Transportation management centres
	Traffic incident management
	Traveller information
ITS goal areas	Customer satisfaction
	Efficiency
	Energy and environment
	Mobility
	Productivity
	Safety

state-wide road weather information system or the detailed costs for a signal interconnect project. Each entry describes the background of the project, lists the ITS technologies deployed, and presents the costs and what the costs covered.

4.3.4.3 ITS Deployment Statistics Database

The ITS Deployment Tracking Project collects and disseminates information on the level of deployment and integration of ITS technology nationally. Information is gathered through a series of national surveys, covering metropolitan as well as rural deployment. Data have been collected in a series of national surveys conducted in 1997, 1999, 2000, 2002, 2004, 2005, 2006, 2007, 2010 and 2013.

In the most recent survey, conducted in 2013, nearly 2 100 surveys were distributed to state and local transportation agencies. A total of seven survey types were distributed, targeting the key agencies within a metropolitan transportation infrastructure: freeway management, arterial management, transit management, TMC, ETC, public safety – law enforcement, and public safety – fire/rescue (Figures 4.5 and 4.6).

The deployment statistics database serves as a source of information on ITS deployment for the USDOT, state and local transportation agencies, researchers, vendors and the general public.

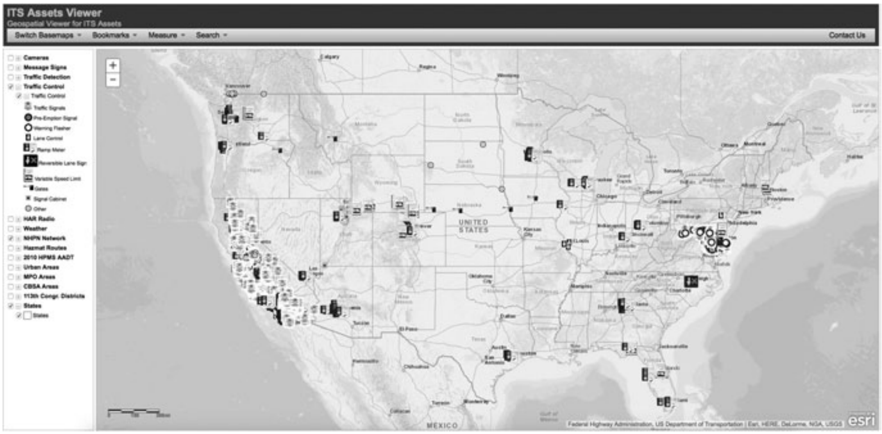
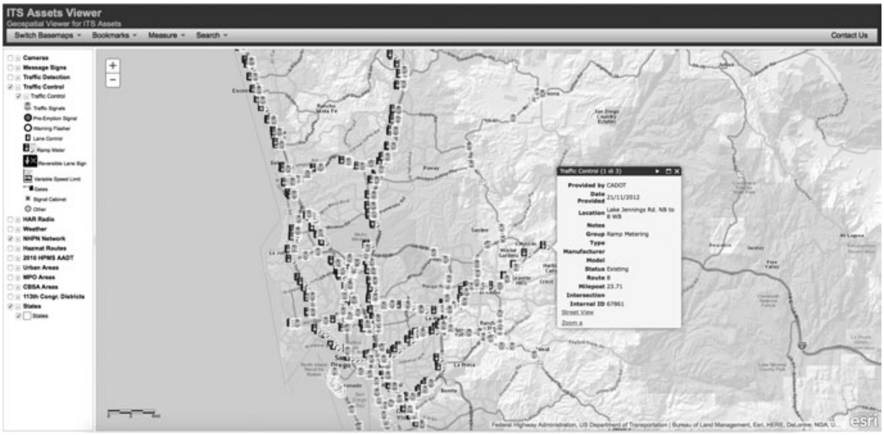


Figure 4.5 Traffic control: ITS assets viewer, Source: http://www.itsassets.its.dot.gov



Provided by CADOT
Date Provided 21/11/2012
Location Lake Jennings Rd. NB to 8 WB
Notes
Group Ramp Metering
Type
Manufacturer
Model
Status Existing
Route 8
Milepost 23.71
Intersection
Internal ID 67861

Figure 4.6 Traffic control: detail of ITS assets viewer, Source: http://www.itsassets.its.dot.gov

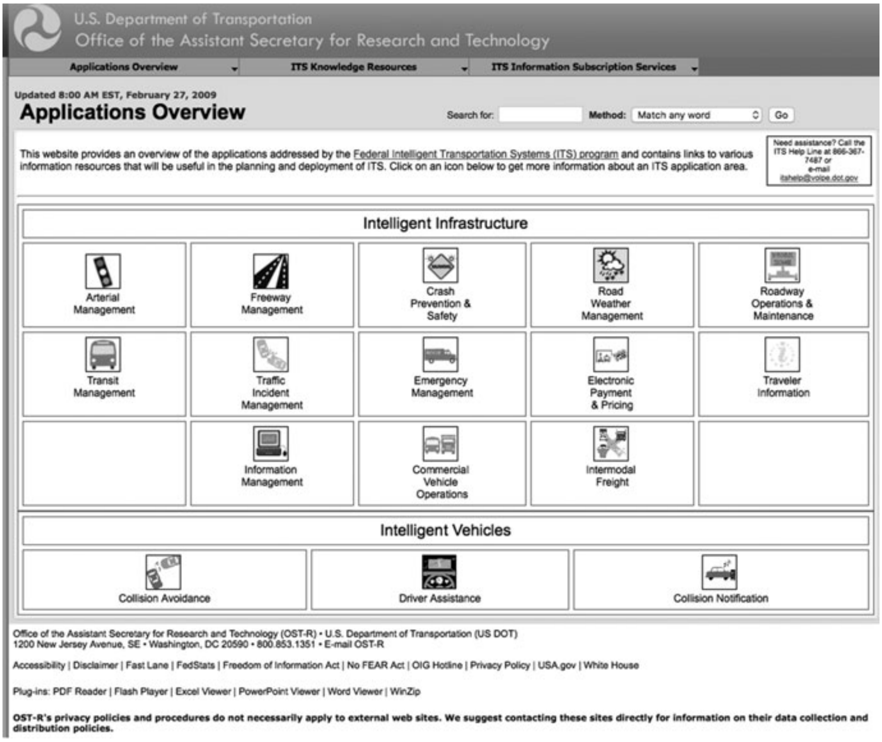
4.3.4.4 ITS Lessons Learned Knowledge Resource

A lesson learned is the knowledge gained through experience or study. It is a reflection on what was done right, what one would do differently and how one could be more effective in the future. The ITS Lessons Learned Knowledge Resource provides the ITS professional community with access to those lessons learned from others' experiences. This knowledge resource serves as a clearing-house to document and share experiences of transportation practitioners in their planning, deployment, operations, maintenance and evaluation of ITS to enable informed decision-making regarding future ITS projects and programmes. ITS lessons are collected primarily from case studies, best practice compendiums, planning and design reviews, and evaluation studies. The National Transportation Library, the Transportation Research Board's Transportation Research Information Services, international transportation literature databases (e.g. transport) and conference proceedings are major sources for the documents that are reviewed. Interviews of subject matter experts are also used as sources of new lessons.

ITS lessons are presented in a number of classification schemes capturing various topics of interest of ITS professionals. Table 4.9 provides a list of major classification schemes and topic areas.

Table 4.9 Lesson classification scheme and topics areas

Classification	**Major topics**
Lesson categories	Design and deployment
	Funding
	Human resources
	Leadership and partnerships
	Legal issues
	Management and operations
	Policy and planning
	Procurement
	Technical integration
ITS applications	Alternative fuels
	Arterial management
	Commercial vehicle operations
	Crash prevention and safety
	Driver assistance
	Electronic payment and pricing
	Emergency management
	Freeway management
	Information Management
	Intermodal freight
	Road weather management
	Roadway operations and maintenance
	Traffic incident management
	Transit management
	TMC
	Traveller information
ITS goal areas	Customer satisfaction
	Efficiency
	Energy and environment
	Mobility
	Productivity
	Safety



Updated 8:00 AM EST, February 27, 2009

Applications Overview

This website provides an overview of the applications addressed by the Federal Intelligent Transportation Systems (ITS) program and contains links to various information resources that will be useful in the planning and deployment of ITS. Click on an icon below to get more information about an ITS application area.

Need assistance? Call the ITS Help Line at 866-367-7487 or e-mail itshelp@volpe.dot.gov

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1200 New Jersey Avenue, SE • Washington, DC 20590 • 800.853.1351 • E-mail OST-R

OST-R's privacy policies and procedures do not necessarily apply to external web sites. We suggest contacting these sites directly for information on their data collection and distribution policies.

Figure 4.7 Overview of the applications addressed by the federal ITS programme, Source: http://www.itsoverview.its.dot.gov

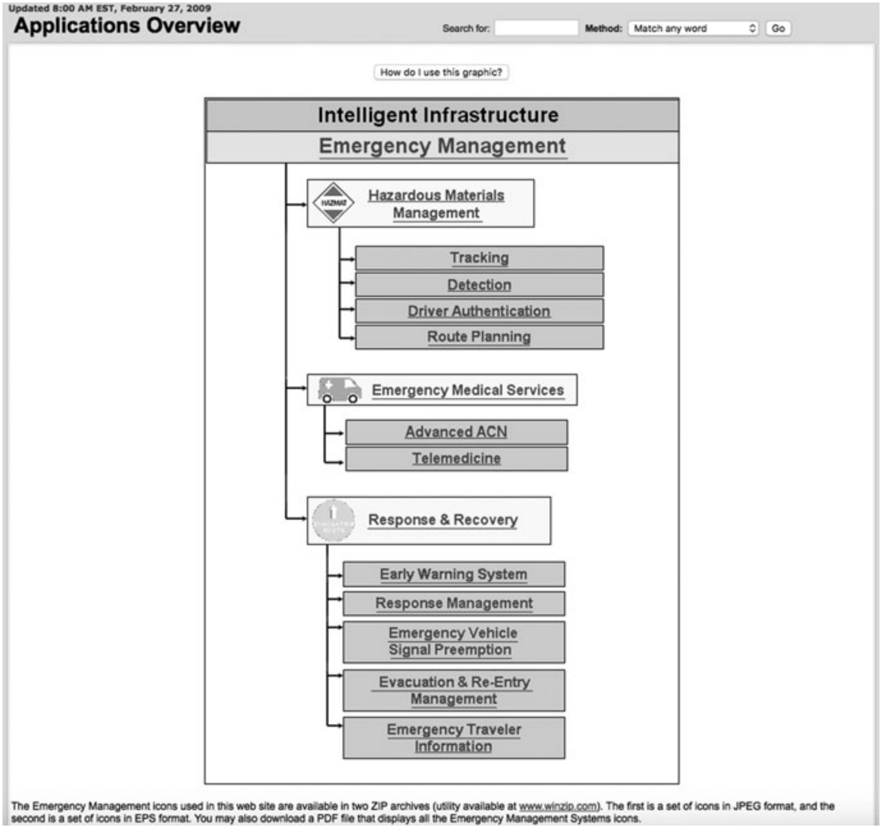
4.3.4.5 ITS Applications Overview

The ITS Applications Overview, available at http://www.itsoverview.its.dot.gov, provides access to each of the four knowledge resources described above, organized by the ITS application areas described in this report (Figures 4.7–4.9). The Web site also provides additional information regarding each ITS application including:

- Evaluation documents available from the ITS JPO
- Related USDOT initiatives and other programme activities
- Other resources available through the JPOs ITS/Operations Resource Guide
- Points of contact within the USDOT.

4.4 The ITS Toolkit and the Project 2DECIDE

To underline the importance given by the EC to the evaluation of ITS and to the generalization of the results and of the experiences made, the European Project



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Method: Match any word

The Emergency Management icons used in this web site are available in two ZIP archives (utility available at www.winzip.com). The first is a set of icons in JPEG format, and the second is a set of icons in EPS format. You may also download a PDF file that displays all the Emergency Management Systems icons.

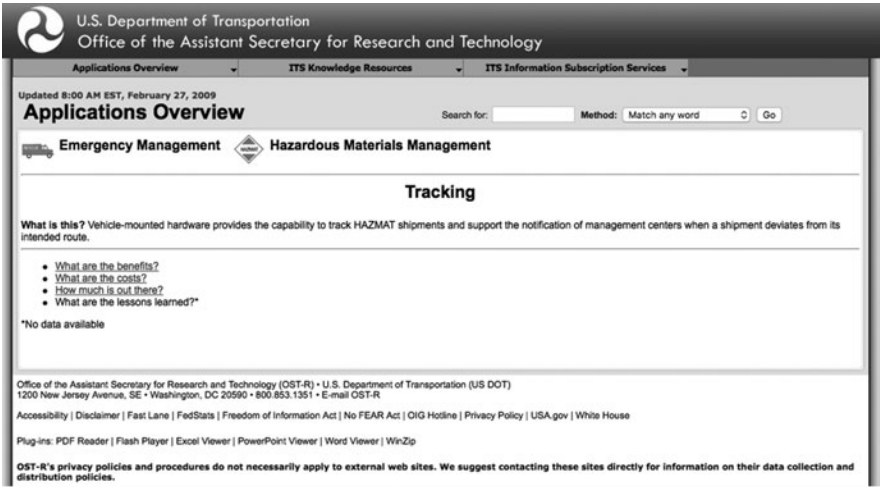
Figure 4.8 Emergency management section in the applications overview, Source: http://www.itsoverview.its.dot.gov

2DECIDE is briefly described together with its instrument, called ITS Toolkit (Figure 4.10).

The ITS Toolkit of 2DECIDE aims at providing a single access point to the European experience on ITS. It is a decision-support online instrument to assist transport organizations in selecting and implementing ITS, to help them handle congestion problems and to steer the objectives of transport policies (Figure 4.11).

The Toolkit is based on a wide database of ITS services, case studies and evaluation reports.

The ITS Toolkit has its roots in the European Action Plan for ITS, which was adopted in December 2008. It provided a political framework to guide the development and the diffusion of ITS for road transport, including the relations with other means of transport.



Updated 8:00 AM EST, February 27, 2009

Applications Overview

Emergency Management **Hazardous Materials Management**

Tracking

What is this? Vehicle-mounted hardware provides the capability to track HAZMAT shipments and support the notification of management centers when a shipment deviates from its intended route.

- What are the benefits?
- What are the costs?
- How much is out there?
- What are the lessons learned?*

*No data available

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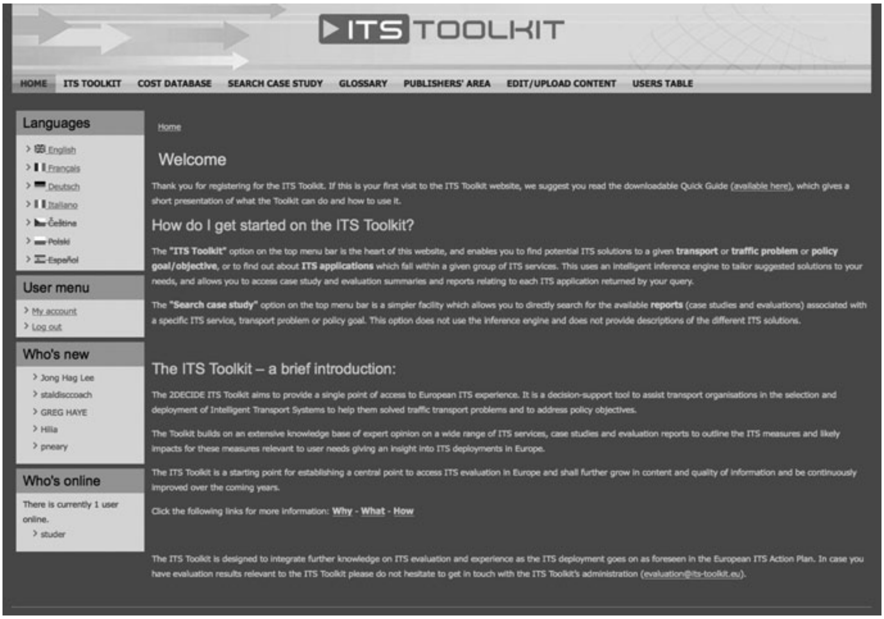
Figure 4.9 Hazardous materials management section in the emergency management area, Source: http://www.itsoverview.its.dot.gov



There is currently 1 user online.
studer

Welcome

Thank you for registering for the ITS Toolkit. If this is your first visit to the ITS Toolkit website, we suggest you read the downloadable Quick Guide (available here), which gives a short presentation of what the Toolkit can do and how to use it.

How do I get started on the ITS Toolkit?

The **"ITS Toolkit"** option on the top menu bar is the heart of this website, and enables you to find potential ITS solutions to a given **transport** or **traffic problem** or **policy goal/objective**, or to find out about **ITS applications** which fall within a given group of ITS services. This uses an intelligent inference engine to tailor suggested solutions to your needs, and allows you to access case study and evaluation summaries and reports relating to each ITS application returned by your query.

The **"Search case study"** option on the top menu bar is a simpler facility which allows you to directly search for the available **reports** (case studies and evaluations) associated with a specific ITS service, transport problem or policy goal. This option does not use the inference engine and does not provide descriptions of the different ITS solutions.

The ITS Toolkit – a brief introduction:

The 2DECIDE ITS Toolkit aims to provide a single point of access to European ITS experience. It is a decision-support tool to assist transport organisations in the selection and deployment of Intelligent Transport Systems to help them solved traffic transport problems and to address policy objectives.

The Toolkit builds on an extensive knowledge base of expert opinion on a wide range of ITS services, case studies and evaluation reports to outline the ITS measures and likely impacts for these measures relevant to user needs giving an insight into ITS deployments in Europe.

The ITS Toolkit is a starting point for establishing a central point to access ITS evaluation in Europe and shall further grow in content and quality of information and be continuously improved over the coming years.

Click the following links for more information: **Why** - **What** - **How**

The ITS Toolkit is designed to integrate further knowledge on ITS evaluation and experience as the ITS deployment goes on as foreseen in the European ITS Action Plan. In case you have evaluation results relevant to the ITS Toolkit please do not hesitate to get in touch with the ITS Toolkit's administration (evaluation@its-toolkit.eu).

Figure 4.10 Home page of the ITS Toolkit, Source: http://www.its-toolkit.eu/2decide

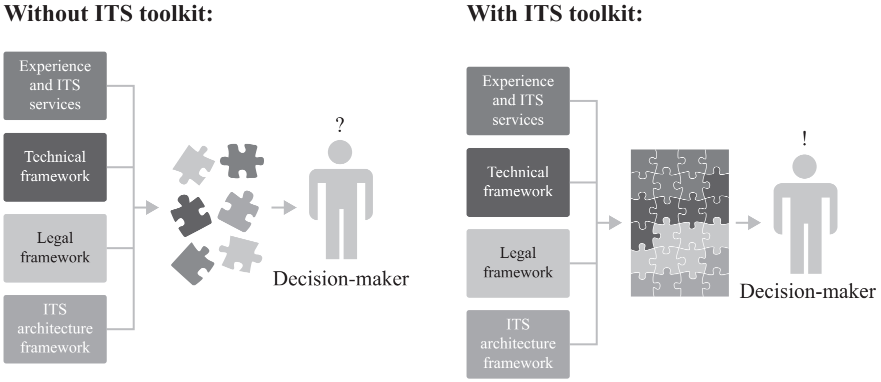


Figure 4.11 Objectives of the ITS Toolkit

One of the measures proposed within the Priority Sector 6 of the plan ‘Cooperation and coordination for European ITS’ is the creation of a online decision support system. The main purpose is to help public corporations, operators and transport infrastructure managers to make more effective and informed decisions on investments in ITS, to solve transport problems and attain the objectives of transport policies. This purpose was achieved with the project 2DECIDE (ended in November 2011), funded within the Seventh Framework Programme for Research and Development in the European Union (FP7), which developed the ITS Toolkit.

This 2-year project collected the existing results of evaluations of ITS services carried out at local, national and community level, as well as case studies and good practices. Algorithms of research and analysis were also developed.

The ITS Toolkit aims at helping users find and know ITS applications and technologies that are suitable for a specific situation and context. The ITS Toolkit gives a general description for each ITS service, its features and technologies to define the typical requirements of each ITS solution. Beside the correspondence with the context (e.g. the type of road, the geographical scope and/or problems and objectives), the ITS Toolkit gives an estimate of the possible values of the impacts experienced in similar conditions. At the end of each research with the ITS Toolkit, the user obtains the most relevant study reports (if available free of charge), thus giving the possibility to analyse in deeper detail the most interesting experiences.

Evaluation studies and case study reports, which are the main content of the Toolkit, were collected from a series of European projects, from national and local implementations and from other sources, such as specialized reviews.

The ITS Toolkit addresses a wide public involved in all the sectors of transport planning and management, as well as in correlated areas, e.g. environmental, safety, accessibility aspects. It therefore addresses not only experts, but also those who have little or no knowledge on ITS.

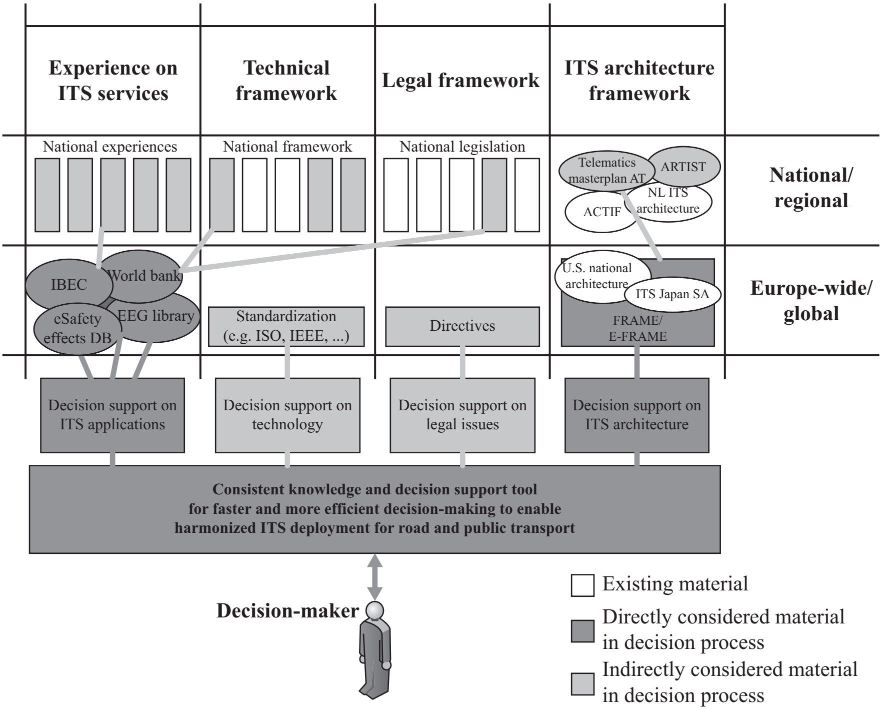


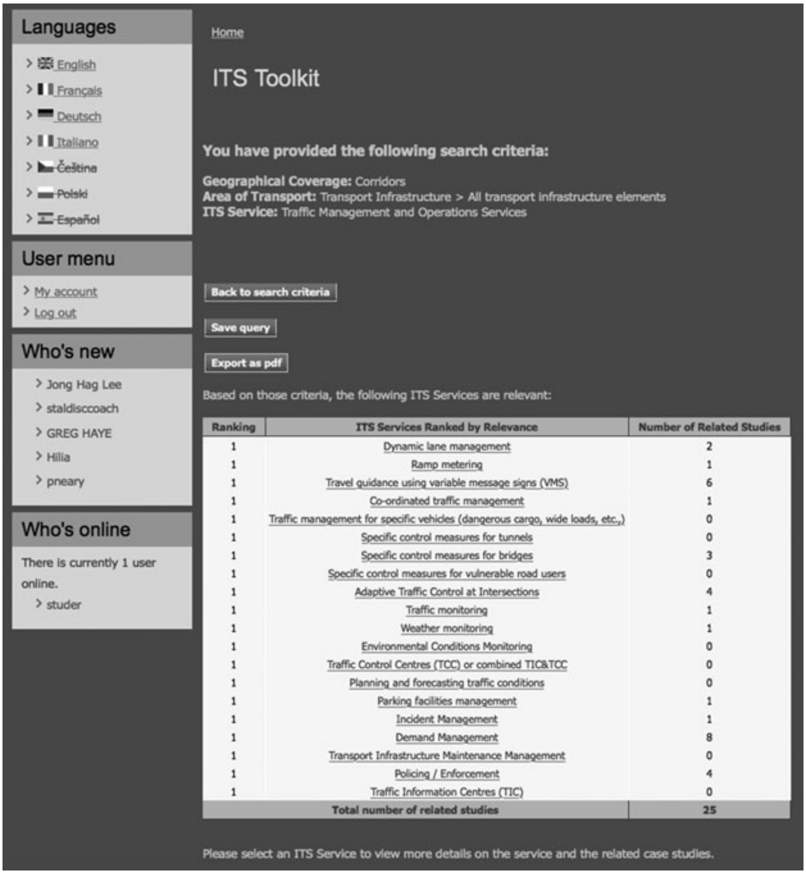
Figure 4.12 Sources the ITS Toolkit is based on sources of the ITS Toolkit

In technical terms, the ITS Toolkit consists in the ‘knowledge base’ – a database where all the information on ITS services is saved with their evaluation reports. The database is analysed by the inference engine that relates the user’s input (the context, the problem/objective, the ITS service) to data saved by means of an advanced search mechanism and a specific algorithm. The inference engine allows users to identify the ITS services (and their descriptions) that are relevant to the requirements. It provides an indication on the impacts – expressed through values or assessments – that can be expected in a context. Moreover, the ITS Toolkit contains information on the aspects of feasibility (technical, legal, organizational aspects) and on the acceptance on the part of users. Except for the general part of the results of the ITS Toolkit, all the information was derived from the existing evaluation reports.

The Toolkit includes ITS for the road network and public transport in Europe (the scope of application of the European Action Plan on ITS). It does not cover specific systems such as air, railway, river or sea transport (Figure 4.12).

4.4.1 ITS Toolkit in action

The toolkit provides two main tool: the ITS Toolkit and the cost database.



There is currently 1 user online.
studer

ITS Toolkit

You have provided the following search criteria:

Geographical Coverage: Corridors
Area of Transport: Transport Infrastructure > All transport infrastructure elements
ITS Service: Traffic Management and Operations Services

Based on those criteria, the following ITS Services are relevant:

Ranking	ITS Services Ranked by Relevance	Number of Related Studies
1	Dynamic lane management	2
1	Ramp metering	1
1	Travel guidance using variable message signs (VMS)	6
1	Co-ordinated traffic management	1
1	Traffic management for specific vehicles (dangerous cargo, wide loads, etc.,)	0
1	Specific control measures for tunnels	0
1	Specific control measures for bridges	3
1	Specific control measures for vulnerable road users	0
1	Adaptive Traffic Control at Intersections	4
1	Traffic monitoring	1
1	Weather monitoring	1
1	Environmental Conditions Monitoring	0
1	Traffic Control Centres (TCC) or combined TIC&TCC	0
1	Planning and forecasting traffic conditions	0
1	Parking facilities management	1
1	Incident Management	1
1	Demand Management	8
1	Transport Infrastructure Maintenance Management	0
1	Policing / Enforcement	4
1	Traffic Information Centres (TIC)	0
Total number of related studies		**25**

Please select an ITS Service to view more details on the service and the related case studies.

Figure 4.13 Example of ITS services ranked by relevance on the provided criteria (geographical coverage: corridors; area of transport: transport infrastructure; ITS services: traffic management and Operations services), Source: http://www.its-toolkit.eu/2decide

4.4.1.1 The ITS Toolkit

The ITS Toolkit aims to help you find and learn about suitable ITS service applications and deployments for a given situation and context.

Fields that must be selected are both Geographical Coverage (the scope of coverage of the context you want to assess) and Area of Transport (the transport sector of your case classified by people/passengers, freight or infrastructure elements) (Figure 4.13).

In addition, one of the following needs to be selected:

- ITS Service or
- a Problem or
- an Objective.

The Toolkit will return the following information:

Step 1: Data entry for user input
Step 2: ITS services ranked by relevance to the criteria provided
Step 3: Information on selected ITS services and case studies
Step 4: Information on selected studies

4.4.1.2 The cost database

The purpose of the cost database is to provide cost estimates for ITS applications. The cost database is meant to provide useful information especially in cases in which the studies included in the knowledge base provide no information on the costs of the application or in which the cost data provided in the knowledge base is incomplete. The cost values mentioned in the database are estimates for typical or probable cost of implementation and operation of the application. Cost elements provided in the database are not directly related in any particular deployment case and they cannot be used as a substitute for cost estimates to be obtained with a proper feasibility study. The database will be updated with improved and more current data as well as new applications by the Toolkit manager(s), when such become available.

The cost database included in the ITS Toolkit provides cost estimates for most of the applications included in the toolkit. For each application, the cost database provides estimated initial investment needed to realize the application, annual operating and maintenance costs and annualized total cost. Annualized total cost of the application was estimated because the initial investment may consist of components with different length of economic life.

Most cost estimates present in the database are based on assumptions related to the application and cost values obtained from US ITS costs database, expert opinion or documented experiences with some known implementation of the application in question.

4.5 Comparison and evaluation of the impacts of ITS on roads

4.5.1 Objectives

This section analyses and compares the impacts on mobility for some categories of ITS on roads. The objective is to draw general conclusions from the results emerging in numerous evaluations that were carried out both at national and at international level.[2]

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[2] The results were developed starting from the thesis written by Mr. Matteo Lodola "ITS in ambito stradale: analisi critica degli impatti a livello internazionale" (ITS on roads: critical analysis of their impacts at international level), supervisor Prof. Luca Studer.

Reference intervals are defined for the variation of values of ITS services evaluation indicators, based on the analysis and generalization of the experiences studied and evaluated. It allows to fully understand the potentials of each ITS service up to the estimate of the impact to be expected from new installations or implementations.

This approach is important as it allows to forecast the impact on mobility of an ITS, to quantify at best the potential benefits or to choose the most proper ITS solution to handle the criticalities of mobility that the parties involved record on their network.

It is clearly necessary to pay particular attention during the generalization of the results (statistical analyses were therefore used), and the transferability of the impacts to situations, which may be very different in terms of local background and users' reaction.

To achieve this result a database was created to enter a significant number of evaluations, which the several global authorities carried out on the effects produced by installing ITS (see Figures 4.4 and 4.5). The past years were taken into consideration to collect a significant sample of cases.

This document includes summary tables that report the most significant numerical values. They are representative of the characteristics of the installations, of their context and their effects.

The aggregated numerical values formed the base for a numerical analysis, which was useful to define reference intervals. Information was catalogued and analysed. Particular attention was paid to the results and to the methods applied for the evaluation. To achieve 'generalizable' results, the statistical analysis was referred to. The average of values was calculated, as well as the first and third quartile that represent the intervals including half of the cases analysed.

For all the types of ITS, the analysis focuses on

- Ramp metering,
- Road pricing in urban areas,
- Dynamic lanes,
- Variable speed limits.

An analysis, which was rather orientated to the acceptance by and the impacts on users and therefore on rather qualitative aspects, focused on:

- Information systems via Internet,
- Information systems over journey time.

The choice, which is clearly partial, was determined by the need to have enough samples to make statistics.

4.5.2 Comparison between evaluations

The results of the comparisons between ITS installations, which are the subject of the analysed evaluations, are described below.

For each type of ITS analysed, the following is reported:

Indicators: the parameters chosen to describe and measure the effectiveness of the systems are described; this list is also useful to highlight the most commonly used performance indicators for a specific ITS;
Data: they are a very brief summary of the information collected. Several tables identify all the installations analysed and their numerical values. Statistical analyses on data are also reported;
Results: a critical analysis on the results is carried out for each case.

4.5.2.1 Variable speed limits

This system imposes speed limits that may vary based on several factors, such as weather conditions, the presence of congestion or accidents, roadwork. Data are processed in real time to calculate the ideal speed, which is communicated to users by means of VMSs along the section.

The system may have several objectives, e.g. in most cases reducing the effects of congestion on motorways, maximizing the capacity of sections, preventing the formation of impacts and enhancing the use of a road.

Another objective may be a reduction in the average speed because of adverse weather conditions.

Indicators

The following indicators were taken into consideration to analyse the systems that use variable speed limits:

- *Traffic volume*: it indicates the variation of the traffic average flow after the implementation of the system. The increase or the decrease may be unrelated to the presence of the system, or they may be due to a greater use of the road capacity thanks to the system.
- *Flow speed with active system*: it indicates the variation of the average speed obtained with variable limits. This variation may be positive or negative based on the purpose of the system. Some systems aim at reducing the speed of vehicles (e.g. at junctions), and others at regulating the flow of vehicles, thus avoiding traffic waves and start and stop phenomena.
- *Observance of speed limits*: the observance of the speed limits imposed by the system is evaluated. This parameter also evaluates the effectiveness of the system, i.e. to what extent users accept the indications given.
- *Headway:* it measures the time between two vehicles of the same traffic current at the corresponding points. It is one of the indicators under consideration because it is strictly related to vehicle density, to the traffic volume travelling on a given section and to safety. For the latter low headways are considered a cause of potential accidents, as vehicles keeping a short distance are more subject to the risk of collision.

- *Journey time*: the journey time necessary to cover a given distance is taken into consideration. According to the purpose of the system, it may vary based on the reduction in start and stop phenomena or in the average speed imposed by the system.
- *Speed standard deviation*: the standard deviation measures the dispersion of data about an expected value. By calculating the standard deviation of speed on a given road section, it is however possible to calculate its difference from the flow average speed. In other words, this value gives an indication on the uniformity of speed of a traffic flow that travels on a given section. In particular, the possible effects of congestion may be pointed out, as high levels of congestion notoriously correspond to a low level of service, with start and stop phenomena and a following increase in the standard deviation.

- *Safety*: as far as safety is concerned, these are the quantitative indicators to take into consideration [3]:
  - *Number of accidents:* the Vienna Convention of 1968 defines road accidents as an event involving still or moving vehicles and resulting in casualties.
  - *Number of wounded people*: people who were wounded in an accident.
  - *Number of dead people*: people who died instantly or before the thirtieth day from an accident (until 1998 deaths were considered only before 7 days from the accident).

- *Impact on the environment:* the impact on the environment of a road facility concerns many aspects. However, two parameters are mostly considered:
  - *Emissions*: indicators showing the variation of harmful substances that are given out in the atmosphere by vehicles after the implementation of ITS. The parameter that is measured generally relates to CO_2 emissions.
  - *Noise pollution*: the variation of the noise is measured, which is caused by vehicles after the installation of the system.

- *Economic aspects*: in the case of variable speed limits, a price can be defined for the values concerned, starting from the costs that include the implementation of the system and the updated cost of maintenance. Benefits are the time saved (hours per vehicle) thanks to the installation of the system, social costs that were avoided thanks to the reduction in the number of accidents and all the benefits that may be directly calculated. These two values are then compared and related (benefits/costs ratio – BCR).
- *Impact on users:* it indicates the way the system is perceived, if it is appreciated and understood by users. This evaluation is usually carried out by means of interviews and surveys.

Data (4.1)

Country	**Finland**	**Finland**	**France**	**Germany**	**United Kingdom**	**United Kingdom**	**Italy**	**Sweden**	**Sweden**	**Sweden**	**Sweden**	**Holland**
Site	Selkäharju (6/13)	E18	Orange-Valence (A7)	Bremen (A1)	Birmingham (M42)	Uxbridge – Byfleet (M25)	Mestre (beltway)	Fogdarp	Göteborg (E6-E18)	Åryd – Ronneby	Skottorp – Heberg	Apeldoorn – Deventer (A1)
Context	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway	Motorway
Intervention range	Junction	14 km	90 km	34 km	17.4 km	31 km	42 km	Junction	–	17 km	55 km	14 km
Activation of the system	Traffic conditions	Weather conditions	Traffic conditions	Traffic conditions	Traffic conditions	Traffic conditions	Traffic conditions	Traffic conditions	Traffic conditions	Weather conditions	Weather conditions	Traffic conditions
Flow (V/g)	–	–	115 000	86 800	134 000	–	170 000	12 000	–	–	–	55 200
Traffic volume	Increase	–	+10%	–	+7.5%	+1.5%	+6.4%	–	+4%	−3.5%	–	−11%
Flow speed with active system	−5.5 km/h	−4.3 km/h	−10 km/h	–	–	–	+11.5 km/h	−17 km/h	Increase	−14 km/h	−20 km/h	–
Journey time with active system	–	Increase	−10%	–	−16.5%	Unchanged	–	Unchanged	−15%	−1.3%	−1.4%	0%
Observance of limits	–	–	80% respects the limits	–	89% respects the limits	+5%	–	Increase	Increase	Increase	Increase	–
Headway	Unchanged	Unchanged	–	–	–	–	–	–	–	–	–	–
Congestion	–	–	−16%	Decrease	−7%	−6%	–	–	Decrease	–	–	−29%
Speed standard deviation	–	−3.8%	−4.8%	–	−31.5%	Decrease	−21.65%	–	Decrease	–	–	–
Accidents	Decrease	–	−48%	−5.1%	−64%	–	−53.4%	Decrease	−20%	Unchanged	Unchanged	–
Wounded	–	−8%	–	−11.7%	−25%	−15%	–	–	–	−40%	+4%	–
Dead	–	–	–	−86%	–	–	–	–	–	−40%	+4%	–
Emissions	–	–	–	–	−5%	−5%	Decrease	–	+5%	+2%	+0.4%	–
Noise pollution	–	–	–	–	−1.6 dB	−0.7 dB	Decrease	–	Unchanged	–	–	–
Costs (thousand €)	–	–	700	969	–	57 000	–	320	3 600	–	–	–
Benefits (thousand €)	–	–	13 000	2 257	–	370 000	–	731	38 000	–	–	–
BCR	–	–	18.57	2.33	–	6.5	–	2.28	10.56	1.3	1.6	–
Satisfaction	–	95%	87%	–	30%	60%	–	–	50%	70%	90%	–

Results

Under consideration of the great number of types of installations using variable speed limits and their several purposes, the analysis was only used for installations that:

- Are found on motorways,
- Activate based on traffic conditions,
- Have a linear extension (crossings excluded).

Intervention range

The range of the systems under analysis is a merely descriptive parameter. The only outlier was excluded (the section Orange-Valence) to provide a better overview over the length of the sections analysed. It is on average between 17 and 34 km.

Average daily flow

This parameter is descriptive, too. It aims at quantifying traffic on the section under consideration. Daily flows at the installations analysed show values between 87 000 and 134 000 vehicles per day (first and third quartile).

Variation of the average daily flow

After the implementation of the system, almost all the cases showed an increase in the average daily flow, except for the section Apeldoorn–Deventer that showed a counter-trend and was therefore excluded from the analysis.

After the implementation of the system, flows increased on average by 4.3% and half of the values analysed is between 2.1% and 7.2% (first and third quartile).

Variation of the journey time

The analysis of the journey time shows that the use of variable speed limits has a positive impact. The sections Apeldoorn–Deventer and Uxbridge–Byfleet show null values, while the other cases show near values. After an accurate analysis of the evaluations, data on the two sections mentioned above were excluded.

The result is an average interval of reduction in the journey time of 8.8%, and values of the first and third quartile of 1.4% and 15%, respectively.

Variation of the congestion time

The values of the variation of the congestion time show how efficient the variable speed limits system is. Analysed data are quite near, except for the section Apeldoorn–Deventer, which cannot however be considered an outlier.

The average reduction is 14.5%. The interval between the first and the third quartile indicates a reduction in the congestion time between 6.8% and 19.3%.

Speed standard deviation

The standard deviation of speed, in the cases where it was measured, decreases with the activation of the system. Recorded variations range between 4% and 32%.

Accidents

Results are extremely positive also as far as the reduction in accidents is concerned. Samples show that the average reduction is 38.1%, while with reference to the first and the third quartile accidents decreased between 20% and 53.4%.

Number of wounded in accidents

Similarly to accidents, the number of wounded also decreases. The average variation resulting from the cases is 16% (first and the third quartile 8.9% and 22.5%).

Variation of air and noise pollution

Sample data on the variation of pollutant emissions shows opposite values, i.e. the interval of variation ranges from a decrease of 5% to an increase of 5%.

Data on the reduction in noise pollution show a decrease from 0 to 1.6 dB. Also in this case, the sample is not representative enough to draw any conclusion.

Observance of speed limits

The observance of speed limits shows quite high values between 80% and 90%. These data are not representative, as they should be correlated with the presence of speed automatic control systems. The reduced number of values available would nullify such an operation.

Costs and benefits

The values of the costs of installations and of the benefits were analysed. Nevertheless, absolute values do not provide any particularly significant information. The only indicative information that can be derived concerns the average cost of implementation of the installations, where the interval between the first and the third quartile is between 1 and 17 million EUR.

BCR

The situation is different as far as the BCR of the installations is concerned. These values show that, from the economic point of view, the impact of variable speed limits is extremely positive. With reference to the first and third quartile, the ratio ranges from 1.9 to 8.5 with an average of 6.2.

Even if the BCR analyses were carried out with variable criteria based on the authority that made them, the BCR concerning variable speed limits show positive values.

Satisfaction of users

As far as the opinion of users on the system in use is concerned, samples show values that vary from 30% to 90% with an average value of 68.9%.

4.5.2.2 Ramp metering

Thanks to a traffic light placed on acceleration lanes, the ramp metering system allows to regulate the flow entering the main traffic current. Data collected by sensors (generally inductive loops), which are placed on the main road and on the entry ramp, are processed by a computer. With specific algorithms, it identifies the best moment for vehicles to enter the main flow between groups of vehicles.

In this way, a part of the traffic is temporarily left waiting on the ramps, thus avoiding a critical flow/capacity ratio.

The quantity of vehicles that can pass without leading to a critical situation is therefore maximized.

Indicators

The system aims at improving flow conditions on the main road by regulating flows on minor roads entering the major. The following is evaluated:

Variation of the main flow: the variation of the flow on the main road is evaluated after the installation of the system. Since the system aims at improving traffic fluidity, the value is expected to increase.

Main flow speed: in this case the variation of the average speed of the vehicles belonging to the main current is taken into consideration. An increase in the average value is expected.

Journey time on a main road: the variation of the journey time on the main road is calculated. A reduction is expected after the installation of the system.

Journey time on ramps: opposite to the main road, vehicles travelling on the entry ramp must wait for the green light. The indicator evaluates the inevitable increase in their journey time.

Safety: the impact of the system is evaluated as far as road safety is concerned (variation of the number of accidents).

Economic aspects: economic aspects mainly concern the costs paid for the construction of the system and its benefits. In this case the main benefits are obtained by defining a price for the overall time saved by users thanks to the ramp metering system.

Junction capacity: this value indicates the variation of the junction capacity, i.e. the traffic increase that the junction can handle without going beyond the critical threshold of congestion.

Accidents: it evaluates the variation of the number of accidents after the installation of the system.

Data (4.2)

Country	Site	Number of ramps	Main flow		Journey time		Accidents	BCR	ROI (years)	Junction capacity	Congestion
			Variation	Speed	Main road	Ramp (s)					
Australia	Melbourne (Monash)	–	+6.5%	–	−42%	–	–	–	–	–	–
France	Paris south (A6)	5	–	+11.2%	−4.6%	–	–	–	1.5	–	−17%
Germany	Munich (A94)	1	–	–	−7.1%	–	–	–	–	–	–
Germany	Grefeld (A57)	2	–	+8.75%	–	–	–	–	–	–	–
Israel	Tel Aviv (Ayalon Highway)	16	–	–	−6.7%	–	–	7.6	–	+3.3%	–
New Zealand	Auckland	3	–	+28.6%	–	–	–	–	–	+4%	–
Holland	Zoetemeer	9	+3%	+15%	−13%	+20	−38%	–	–	–	–
Holland	Coentunnel	–	–	+20%	–	–	–	–	–	+1.5%	–
Holland	Delft-Zuid	–	–		–	–	–	–	–	+4%	–
Holland	Schiedam-Noord	–	–	+16.6%	−6%	–	–	–	–		0
Holland	Barendrecht	–	–	+16.6%	−10%	–	–	–	–	+5%	0
Holland	Kolkweg	–	–	+3%	−3%	–	–	–	–	0	0
Holland	Vianen	–	–	+4.1%	0	–	–	–	–	+5%	0
Holland	Utrecht (A2-A28)	18	–	–	−5.8%	–	–	–	–	–	–
United Kingdom	Birmingham (M6)	7	+4%	–	–	+45	−5%	4	–	+3.2%	–
United Kingdom	Glasgow (M8)	2	+6%	+5.3%	−13%	–	−7%	–	–	+6%	−14%
United Kingdom	Sheffield (M1)	–	+3%	–	−9.1%	–	–	5	–	–	–
United Kingdom	Birchwood (M6-M62)	4	+5.8%	+32.2%	−29.75%	+63	–	–	5	–	–
United Kingdom	Haidock (M6)	3	+1%	+3.9%	−4.9%	+15	–	–	7.1	–	–

(*Continues*)

(*Continued*)

Country	Site	Number of ramps	Main flow		Journey time		Accidents	BCR	ROI (years)	Junction capacity	Congestion
			Variation	Speed	Main road	Ramp (s)					
United Kingdom	Wakefield (M1)	3	+3%	+10.3%	−10.5%	+56	–	–	2.6	–	–
United Kingdom	Roterhan (M1)	3	+5%	+11.6%	−10.7%	+50	–	–	3.1	–	–
United Kingdom	Walsall (M6) north	2	+0.5%	+7.85%	−8%	+6	–	–	7.1	–	–
United Kingdom	Walsall (M6) south	2	+19%	−10.7%	−15.7%	–	–	–	–	–	–
United States	Twin Cities	431	+11.5%	+11%	−22%	–	−26%	0	–	–	–
United States	Abilene	–	–	+22%	−13%	–	–	2	–	–	–
United States	Arlington	5	–	–	−10%	–	–	–	–	–	–
United States	Atlanta	5	–	–	−10%	–	–	2	–	–	–
United States	Austin	3	+7.9%	+60%	−37.5%	–	–	–	–	–	–
United States	Denver	28	+19%	+46.7%	−31.8%	–	−27.5%	–	–	–	–
United States	Detroit	28	+14%	+8%	−7.4%	–	−50%	–	–	–	–
United States	Houston	–	–	+29%	−22%	–	–	–	–	–	–
United States	Long Island	60	+3.5%	+15%	−16.5%	–	−15%	–	–	–	–
United States	Los Angeles	259	–	+23%	−13%	–	−20%	–	–	–	–
United States	Milwaukee	6	+22%	+19%	–	–	–	–	–	–	–
United States	Minn-St. Paul	–	+24%	+37%	−20.1%	+73	−26.5%	0.3	–	–	–
United States	Phoenix	9	+15%	+7.5%	–	–	–	0.5	–	–	–
United States	Portland	16	+25%	+81.2%	−23.2%	–	–	–	–	–	–
United States	Sacramento	9	+4%	–	–	–	−43%	–	–	–	–
United States	Seattle	22	+74%	+22.5%	−69.3%	–	−50%	0	–	–	–
United States	Renton	9	–	+17.8%	−11%	–	–	–	–	–	–

Results

Number of ramps

This purely descriptive parameter indicates that half of the installations has an average number of ramps between 3 and 9. The installation in Long Island, Los Angeles and Twin Cities were not considered as their analyses referred to systems having a great number of ramps (between 60 and 430) on different roads, which made them very different from the others.

Main flow speed

The benefits of ramp metering are immediately understood by analysing how the average speed of the main flow varies by using this system. With reference to the first and third quartile of data, the increase in the average speed, in half cases, is between 8.2% and 22.9%, with an average of nearly 19.5%.

These values show that ramp metering has a definitely positive impact on one of its primary objectives, i.e. the increase in efficiency.

Variation of the main flow

The variation of the flow on the main road increases on average by 12.6% where the first quartile is 3.6% and the third 18%. Also in this case, the results are satisfying.

Journey time on a main road

Similarly to the above, the value of journey time on a main road decreases on average by 15.8% with the first and third quartile between 7.3% and 20.6%, respectively.

Congestion index

The congestion index, considered as the time when the ratio between flow and capacity goes beyond a given value, was only measured in two of the cases under analysis.

The only two values that are different from zero are taken into consideration, which indicate a positive result although little significant.

Journey time on ramps

Ramp metering has the ‘side effect’ of increasing the waiting time for vehicles waiting on ramps. The increase in this value was measured in seconds.

Measured values show an average of 41 s, with an interval between the first and the third quartile from 19 to 58 s.

Accidents

The reduction of accidents by using ramp metering is rather high, with an average of 28% and half data between 17.5% and 40.5% (first and third quartile).

Given the high number of cases analysed, this result can be considered reliable.

Junction capacity

In the installations under consideration, the junction capacity increases on average by 3.6%, with half cases between 3.2% and 5%.

BCR and time for the return on investment

Ramp metering has good results from the economic point of view.

Excluding the only outlier (clearly too much above the average), the BCR shows an average value above 8, with the interval for the first and third quartile between 6.7 and 10.

In the cases when the years for the return on investment were estimated, half values are between 2.7 and 6.6 years, with an average of 4.4.

4.5.2.3 Dynamic lanes

A dynamic lanes system allows a flexible management of the lanes available, thus giving infrastructure managers the possibility to open or close specific lanes to traffic based on its needs. A typical example of this system is the possibility to open to traffic the emergency lane on motorways in case of congestion, thus making queues flow more quickly. Other types of dynamic lanes are reversible lanes, which are more commonly used in the United States, where the direction changes based on the direction of the higher traffic flow.

Indicators

The following indicators were chosen to compare the cases:

Number of lanes: it indicates the number of accessible lanes when the system is activated.

Average linear density of vehicles: it indicates the average density, meant as vehicles per km per lane.

Distribution of traffic on lanes: it evaluates the way vehicle flows are distributed on the lanes that are open to traffic. One of the objectives of the system is to enhance the distribution by making it as even as possible.

Speed standard deviation: this indicator measures the variability of speed, and therefore of the journey time on the section under consideration.

Journey time: the average journey time is evaluated on the sections under consideration to reduce it by reducing congestion.

Accidents: evaluations did not consider the number of wounded and dead, but only the number of accidents (therefore with physical injuries to people).

Observance of limits: this parameter indicates to what extent users observe the indications given by the system.

Congestion in rush hours: this indicator measures the time variation needed to go beyond a critical threshold, i.e. when the linear density of a given section is greater than a given value.

Traffic volume: when the system is activated, the road capacity will increase. The traffic variation that the road can handle without congestion is therefore evaluated (beyond the critical threshold).

Emissions: the variation of pollutant emissions is evaluated after the installation of the system.

Noise pollution: the noise variation, which is produced by vehicles travelling on a section, is evaluated.

Data (4.3)

Site	Country	Speed std deviation	Journey time	Accidents	Limits observance	Congestion in rush hours	Average flow variation	Flow speed	Emissions	Noise pollution (dB)	Accessible lanes (system active)	Inter-vention range (km)	Flow (V/d)	Average linear density of vehicles	Distribution of traffic on lanes
Uxbridge – Byfleet (M25)	United Kingdom	–	Decrease	−20%	5%	−9%	1.50%	–	−5%	−1.5	4	31	–	–	Improved
Mestre (beltway)	Italy	−25.50%	Decrease	−53.30%	89%	−9.40%	7.70%	+15.3 km/h	Decrease	–	3	42	170 000	−36%	Improved
Birmingham (M42)	United Kingdom	−22%	−16.50%	−78%	14%	−7%	7%	–	−5%	−2.1	4	17.4	134 000	–	Improved
Paris (A4/A86)	France	–	−35%	Decrease	–	−15%	10%	9%	−4.25%	Decrease	5	4	280 000	–	Improved
Everdingen (A2)	Holland	–	–	–	–	−18%	–	0.60%	–	–	3	3.2	–	–	–
Rotterdam – Terbregseplein (A20)	Holland	–	−4.20%	–	–	−12.80%	0.50%	–	–	–	5	3.4	–	–	–
Gorinchem – Noordeloos (A27)	Holland	–	−2.48%	–	–	32.85%	5.60%	–	–	–	4	6	–	–	–
Zestienhoven – Delft Zuid (A13)	Holland	–	−5.30%	–	–	−10.20%	1.30%	–	–	–	4	5.4	–	–	–
Zaandam – Purmerend (A7)	Holland	–	−12.30%	–	–	−71.40%	6.45%	–	–	–	3	10.2	–	–	–
Hoevelaken – Barneveld (A1)	Holland	–	−4.45%	–	–	−8.05%	2.10%	–	–	–	3	10	–	–	–
Friedberg – Frankfurt North West (A5)	Germany	–	–	–	–	−63%	21%	–	–	–	4	18	120 000	–	–
Offenbach – Obertshausen (A3)	Germany	–	–	−48.50%	–	–	–	–	–	–	4	17	130 000	–	–

Results

Accessible lanes

When the system is active and all the lanes are open, the number of accessible lanes is three or four in all the cases, except for the installation in Paris.

Intervention range

The range of the sections with dynamic lanes is quite limited. The Mestre beltway is an exception with its 42 km. All the other installations show values between 3.2 and 31 km, with an average of 14 km.

Average daily flow

The daily flow, which is recorded on the sections under consideration, shows an average value of 138 500 vehicles per day and a maximum value of 170 000, except for the case of Paris with 280 000 vehicles per day. This value was excluded as it refers to the only system with five accessible lanes.

Variation of the journey time

In all the cases, there is a reduction in the average journey time of sections with an average value of 11.5%. With reference to the first and third quartile, reductions are between 4.3% and 14.4%.

In terms of efficiency, dynamic lanes achieve the objectives set.

Accidents

In terms of accidents results are extremely positive, too, with an average reduction in accidents of 50%, with a peak of 78% and a minimum value not lower than 20%. The first and the third quartile are between 41.4% and 59.5%. Available data therefore give a positive indication with respect to the objective of safety. With these interventions the safety equipment is decisively enhanced to allow traffic to travel without the emergency lane.

Congestion in rush hours

One of the parameters, which better shows the improvement in terms of efficiency, is the variation of congestion in rush hours, i.e. with the active system.

In this case, analysed data show three outliers, two showing values well over the average and one showing a counter-trend (Gorinchem). Since there is much data available, these values were excluded from the analysis to have a more even evaluation.

A limited range therefore results between the first and the third quartile, equal to 8.8% and 13.4%, with an average value of 11.2%.

This result can be considered positive, above all under consideration of the increases in the average flows of traffic with the system implementation.

Variation of the average flow
As mentioned above, a reduction in congestion corresponds to an increase in average flows on the sections analysed, with an average value of 6.3% and a central interval (with reference to quartiles) between 1.7% and 7.5%.

The system records a good functioning in terms of efficiency.

Air and noise pollution
Data on pollution are very limited. However, in the case of air pollution, recorded values are very near, showing an average reduction in emissions of 4.8%.

Noise pollution decreases on average by 1.8 dB.

Observance of speed limits
The limited number of data available and its poor uniformity do not allow to draw any conclusion.

4.5.2.4 Road pricing in urban areas

Road pricing is a system to increase the cost of travelling for users in a given period or within a congested area to reduce traffic flows. Road pricing usually works by creating a paid-access area (generally the centre of a town). Access is allowed through gates, which are equipped with automatic number plate recognition systems. The payment of the toll is associated with a number plate, and a central processor can therefore ascertain whether the user paid the right sum to enter the restricted traffic area.

Indicators

To compare the evaluations, the cases of road pricing in urban areas were chosen. Indicators included the public's satisfaction and its evolution. Here are the indicators that were taken into consideration:

- *Population*: the indicator of the resident population of the urban area under consideration provides an overview of the operating context.
- *Interested area*: urban toll collection systems are characterized by a cordon structure. This cordon contains a given area. This indicator, too, provides information on the context where the system is implemented.
- *Number of gates*: it indicates the number of gates for vehicles to enter and exit the restricted traffic area.
- *Hours of operation*: it indicates the hours when the installation is operating during the week, with a distinction between working days and holidays.
- *Dates of beginning and end*: it indicates the date when the system is activated and, if the installation is no longer active, the date when it stopped working.
- *Reference period*: it indicates the year which the data in the table refer to.
- *Passages through gates*: it indicates the difference between vehicles that passed through gates before and after the implementation of the system.

- *Daily passages through gates*: it indicates in absolute value the number of average daily passages through entry and exit gates.
- *Average toll*: it is the cost that a small car has to pay to enter the area contained by the cordon for 1 day.
- *Traffic variation*: it indicates the variation of traffic inside the toll area. This value is processed based on the passages to and from gates.
- *Congestion index*: this index is based on the flow/capacity ratio, i.e. by considering the quantity of time when the ratio goes beyond a critical threshold.
- *Accidents variation*: data on accidents before and after the implementation of the system are compared.
- *Costs/benefits analysis*: the indicators included in this sector quantify the impact of the system from the economic point of view:
  - *Toll revenues*: it indicates the annual revenues deriving from the payment of the entry fee;
  - *Revenues from fines*: it indicates the annual revenues deriving from the fines given to offenders;
  - *Benefits from the time saved*: they correspond to the price defined for the total time saved by users;
  - *Benefits from minor accidents*: also in this case, the social saving deriving from the reduction in accidents in the area is calculated.
  - *Environmental and health benefits*: the social saving, which derives from health conditions that are improved by reducing pollution, is quantified and a price is defined for it;
  - *Annual maintenance cost*: it indicates the annual cost to maintain the installation in operation;
  - *Years of return on investment*: it indicates the years necessary to amortize the investment for implementing the installation.

- *Variation of CO_2 emissions:* it indicates the variation of CO_2 emissions in the area enclosed within the gates.
- *Public opinion:* this part evaluates the residents' opinion on the installation. In particular, data on their satisfaction during the first year of implementation are searched for to compare it with their current satisfaction.

Data (4.4)

Country		Italy	Italy	Italy	Italy	Norway	Norway	Norway	Norway	Sweden	United Kingdom	United Kingdom	Singapore
Site		Milan	Rome	Bologna	Genoa	Bergen	Oslo	Trondheim	Nord-Jæren	Stockholm	London	Durham	Singapore
Population		1 300 000	2 700 000	380 000	610 000	168 000	570 000	168 000	250 000	818 000	7 550 000	43 000	4 500 000
Interested area (km^2)		8.2	4.2	3.2	1.5	18	64	50	–	29.5	20	–	7.25
Number of gates		43	23	10	11	7	19	24	21	18	170	–	50
Hours of operation	Monday–Friday	7.30–19.30	Variable	7.00–20.00	0.00–24.00	6.00–22.00	0.00–24.00	6.00–17.00	0.00–24.00	6.30–18–30	7.00–18.00	10.00–16.00	7.00–20.00
	Saturday–Sunday	–	Variable	Sun. 7.00–20.00	0.00–24.01	6.00–22.00	0.00–24.01	–	0.00–24.01	–	–	Sat. 10.00–16.00	7.00–20.00
Passages through gates		–31.1%	−18%	−23%	–	–	–	–	–	−22%	−16%	−85%	–
Passages/day through gates		93 500	2 400	–	–	73 000	244 000	71 000	115 000	221 000	–	550	290 000
Average toll (€/day)		5	1.5	5	7.8	1.25	2.48	1.86	1.2	1.5	11.5	3.2	2
Traffic variation		−31.1%	−15%	–	–	−6.50%	−3.50%	−10%	–	−22.50%	−21%	−85%	−13%
Variation of the congestion index		−16.2%	–	–	–	–	–	–	–	−33%	−30%	–	–
Average vehicle speed		11.80%	4%	–	–	–	–	–	–	40%	37%	–	22%
Accidents variation		−21.30%	–	–	–	–	–	–	–	–	–	–	–
Costs/benefits analysis	Revenues from toll (M€/year)	20.30	15	1.05	–	8.68	109.15	15.63	–	71.26	170	–	41
	Revenues from fines (M€/year)	–	74.8	–	–	–	–	–	–	–	120	–	–
	Benefits from the time saved (M€/year)	9.3	–	–	–	–	–	–	–	60.65	182	–	–
	Benefits from minor accidents (M€/year)	8.4	–	–	–	–	–	–	–	12.33	21	–	–
	Benefits health/environment (M€/year)	3.3	–	–	–	–	–	–	–	9.25	4.35	–	–
	Cost of maintenance (M€/year)	–	0.155	–	–	–	–	–	–	22.62	130	–	8.4
	Years of ROI	–	–	–	–	–	–	–	–	4	–	–	–
Variation of emissions in the area (CO$_2$)		−9%		–	–	–	–	–	–	−12%	−16%	–	–
Public opinion	Favourable at the beginning	–	–	–	–	13%	30%	7%	–	31%	40%	–	–
	Opposite at the beginning	–	–	–	–	54%	70%	72%	–	62%	40%	–	–
	Favourable at the end	–	87%	–	–	50%	57.50%	14%	–	52%	48%	–	–
	Opposite at the end	–	–	–	–	37%	42.50%	57%	–	40%	35%	–	–

Results

To obtain as likely an analysis as possible for the results that can be achieved from a road pricing system, the cases of Genoa, Rome and Durham were excluded.

Number of gates

The number of gates of the systems varies from 7 to 50 (except for London which has more than 150 gates), with an average of 28.

Passages/day through gates

The values of average daily passages through gates provide an overview of the dimensions of the installation. The average value is 115 000 vehicles per day, with a central interval between 72 400 and 232 000.

Average daily toll

The average daily toll for a small car shows quite similar values (all of the same magnitude), except for London, where the value of 11.50 € is considered an outlier.

The average value is 2.18 €, with the central interval of data (first and third quartile) between 1.38 and 2.24 €.

Variation of daily passages through gates

Notwithstanding the different characteristics of the road pricing systems, the variation of the daily passages through gates shows rather similar values.

The average decrease obtained is near 18.6%, with a range between the minimum and the maximum value from 14% to 31%.

Variation of traffic in the area

Similarly to the variation of passages through gates (in some evaluations data are coinciding), traffic within the charging area decreases on average by 13.2%, with the central half of data between 9.1% and 16.50%.

The systems therefore have positive results on efficiency.

Congestion index

There are unfortunately few data on the congestion index that have different values, although all of them show a decrease. Values range from 5% to 33%, with an average of 22.6%.

Variations of pollutant emissions (CO_2)

Also in this case, there is not much data available.

There are three quite near values, with reductions between 9% and 16%, an average of 12.3%, and the first and third quartile of 10.5% and 14%.

Average vehicle speed

Another parameter, which is useful to measure the efficiency of the system, is the increase in the vehicle average speed that is achieved by using the system. The average value is 21.9%, with an interval of half values (first and third quartile) between 6.7% and 37%.

This indicator, too, provides positive indications on efficiency, which is one of the primary objectives of road pricing.

Public opinion
Considering the peculiar nature of road pricing installations, it will be interesting to know how the public opinion changed with respect to the presence of charging zones.

As shown in Figures 4.14 and 4.15, in all the cases the number of people that oppose the road pricing system decreases, while favourable opinions increase.

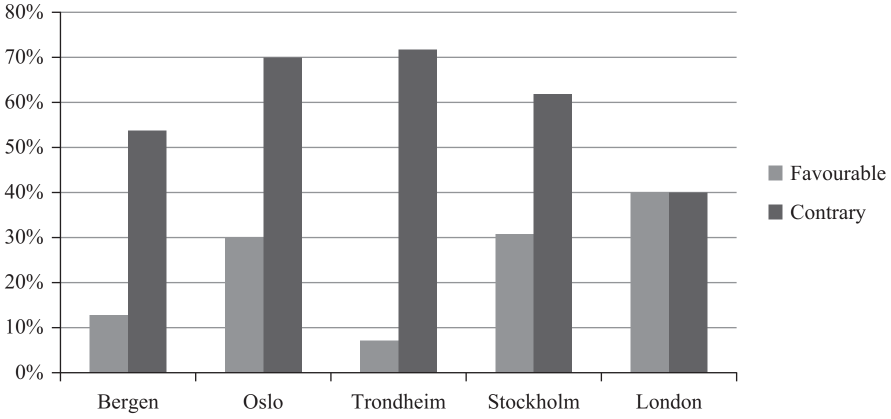

Figure 4.14 Public opinion before the implementation

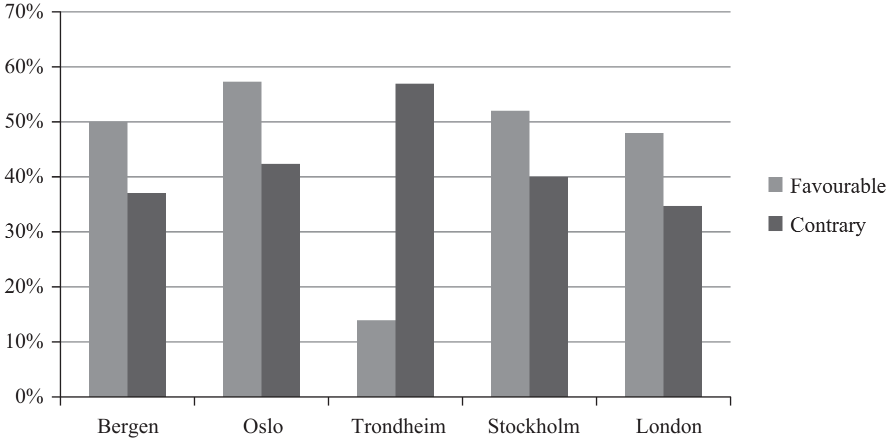

Figure 4.15 Public opinion after the implementation

Except for Trondheim, in all the cases the number of favourable people, which is a minority at the beginning, becomes the majority.

4.5.2.5 Information services via Internet

Via dedicated web sites, users can be informed in real time on traffic conditions. Further information can also be provided such as weather conditions, the images of the most critical sections, the expected journey time, the presence of roadwork.

Indicators

Given the variety of the cases, the scopes under consideration until now were not evaluated (environmental impact, safety, financial aspects, etc.), because almost no evaluation considered them. The evaluations often take into consideration general assessments that are more qualitative than quantitative. These are the indicators chosen to make a comparison:

Information offered: the information provided to users by the information system analysed is listed here (traffic conditions, weather, the possibility to see real-time images of the most critical sections).

Number of visitors: it indicates the number of users who used the web information service in a given time interval.

Increase in visits in critical situations: this parameter gives an indication on how systematically the service is used, i.e. to what extent users rely on it to plan a journey or to receive useful information for that time.

Satisfaction of users: it indicates the satisfaction of users with respect to the service offered.

Users who modify their journey: it evaluates the number of users who modify their journey after receiving the information from the system. It allows to understand the extent to which the service may affect users' behaviour, with possible benefits on traffic conditions.

Data (4.5)

Country		**Denmark**	**Denmark**	**France**	**Italy**	**United Kingdom**	**United Kingdom**	**United Kingdom**	**United Kingdom**
Site		Copenhagen (area)	Funen (E20)	–	Savona – Ventimiglia (A10)	Berkshire	Bristol (M5/49)	Scotland	Scotland
Context		Urban area	Motorway	Motorway	Motorway	Urban area	Motorway	Motorway	Motorway
Visitors per month		22 000	2 100	–	8 000	10 000	5 600	1 100	–
Satisfaction of users		81%	80%	53%	–	–	54%	High	80%
Increase in visits in critical situations		–	–	–	High in summer months	In the hours 9–11/16–19	+25% in summer	–	–
Users who modify their journey	Route	72%	–	–	–	72%	–	–	82%
	Hours	63%	–	–	–	51%	–	–	57%
	Means of transport	6%	–	–	–	11%	–	–	6%
Information given	Webcam	•	•		•	•	•	•	•
	Traffic conditions	•	•		•	•	•	•	•
	Weather	•	•		•		•	•	•
	Journey time		•	•				•	•
	Parking areas					•			•
	Presence of roadwork	•	•		•				•

Results

The most relevant data emerging from the cases, even though with little data available, regards users who modify their journeys based on the information received from web sites:

- Users who change the hours to travel range between 72% and 82%,
- Those who change the departure time range between 51% and 63%,
- Those who change the means of transport range between 6% and 11%.

It is also interesting to observe that the number of visitors is between 1 100 and 10 000 each month in extra-urban areas, while the 22 000 visitors per month in the area of Copenhagen refer to a rather urban context.

4.5.2.6 Indication of the journey time

Being aware of the journey time for a given destination reduces stress for users, above all in case of congestion. By means of an automatic vehicle recognition system (which reads number plates or detects on-board devices, e.g. ETC), which is implemented on two sites, one upstream and one downstream on the section, it is possible to calculate the time needed to cover a given road section. Road users are then informed on the time needed to reach a given exit. Time can be communicated via VMS or other information services.

Indicators

These indicators are considered:

Mode: it indicates the mode to communicate the journey time to users, therefore via VMS, web sites or radio.

Accuracy of information: for this type of system, the accuracy of the time reported must be high. In most evaluations, it was assessed by means of on-field surveys.

Satisfaction of users: it evaluates users' satisfaction with respect to the service offered.

Users who modify their journey: similarly to information services via Internet, it evaluates the number of users who modify their journey based on the journey time calculated.

Safety and emissions: it approximately expresses any possible effects in terms of variation of road safety and pollutant emissions.

Data (4.6)

Country		**Denmark**	**Denmark**	**France**	**France**	**France**	**United Kingdom**	**United Kingdom**	**United Kingdom**
Site		Copenhagen (E20/E47/E55)	Funen (E20)	–	Oisan valley	ASF network	Glasgow (M8)	Scotland	Edinburgh (M90/A90)
Mode	Internet		•	•		•		•	
	FM radio		•	•		•			
	SMS					•			
	VMS	•		•	•	•	•		•
Accuracy of information		–	Good	93%	85%	65%	84%	86%	70%
Satisfaction of users		80%	80%	73%	54%	70%	75%	Good	Good
Users who modify their journey		13%	–	–	–	40%	45%	–	–
Safety		Decrease	–	Increase	–	–	Increase	Increase	Increase
Emissions		–	–	Reduction	–	–	–	–	Reduction

Results

This is the information emerging from the data available:

- The level of reliability of the systems indicating the journey time is high (the lowest level recorded is 65%, with an average over 80%).
- Users' satisfaction for this type of service is high (with an average value of 72%).
- The number of users who modify their journey based on the information given is significant but not high, even if for this indicator there is little data available.

Bibliography

[1] Cullern D., Marsili F., White J., *et al.* "*Definition of Evaluation KPI for ITS Deployment*".

[2] Website http://ec.europa.eu/transport/themes/its/road/action_plan/ [Accessed 31 March 2016]

[3] ISTAT, "*Road accidents in 2007 – Methodological Note*". 2007.

[4] Bankosegger D., Kulmala R., Marchionni G., Studer L., "State of the Art in Europeans ITS Evaluation Research – Where Europe Has Blind Spots". ITS Europe Congress, Lyon, June 2011.

[5] Bunch J., Burnier C., Greer E., *et al.*, "Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference: 2011 Update [online]". 2011. Available at http://www.its.dot.gov/index.htm [Accessed 1 April 2016]

[6] Cambridge Systematics, Inc., "*Twin Cities Ramp Meter Evaluation – Final Report*".

[7] Cohen S., "*A Cost Benefit Assessment of a Variable Speed Limits Operation*". September 2009.

[8] Cohen S., "*Impact of a Peak Hour Lane on Traffic Efficiency and Pollution*". June 2008.

[9] Commissione delle Comunità Europee, Comunicazione 886/2008, "*Piano d'azione per la diffusione di sistemi di trasporto intelligenti in Europa*". December 2008.

[10] Comune di Milano, "*Monitoraggio Ecopass Gennaio – Dicembre 2008, Indicatori Sintetici*". February 2009.

[11] Congestion Charging Division of Transport for London, "*Impacts Monitoring – First Annual Report*". 2004.

[12] CURACAO, "*Case Study Results Report*". 2009.

[13] Dalla Chiara B., Barabino B., Bifulco G. N., *et al.*, "*ITS nei trasporti stradali*". 2013. Egaf.

[14] Department for Transport, "*Understanding the Benefits and Costs of Intelligent Transport Systems: A Toolkit Approach*".

[15] Desnouailles C., "*Managed Lanes: A French Project to Reduce Congestion on Motorways*". 2007.

[16] Dirección General de Tráfico, "*Evaluación del Proyecto: Señalización dinámica y gestión del tráfico de los accesos a Cádiz*". 2009.

[17] Durham City Council, "*Saddler Street Road User Charge Scheme – Monitoring Scheme*". September 2003.

[18] EasyWay Evaluation Expert Group, "*Multi-modal Traveller Information Service, Trafikken.dk Hovedstaden, Denmark*". June 2009.

[19] EasyWay Evaluation Expert Group, "*Own Language Information System*". April 2009.

[20] EasyWay Evaluation Expert Group Document – EEG/11/7 (2011), "*EasyWay Template for Reporting Evaluation Results – Final Version*". April 2011.

[21] Easyway Secretariat, "*Core European ITS Services and Actions*". December 2008.

[22] Easyway Secretariat, "*Easyway Template for Reporting Evaluation Results*". May 2009.

[23] Easyway Secretariat, "*Evaluation approach*". October 2008.

[24] Easyway Secretariat, "*Handbook on Evaluation Best Practice*". June 2008.

[25] European Ramp Metering Project, "*Evaluation Results*". March 2004.

[26] Federal Highway Administration, "*International Urban Road Pricing – Final Report*". June 2006.

[27] Federal Highway Administration, "*Lessons Learned from International Experience in PROGRESS, – Main Project Report*". July 2004.

[28] Geistefeldt J., "*Temporary Hard Shoulder Use in Hesse – Effects on Traffic Flow and Road Safety*". 2008.

[29] Gould C., Rayman N., "*Ramp Metering Development in a UK Context*". 2004.

[30] Van Der Loop H., "*Ex-Post Evaluation of Policy Programmes on Traffic Congestion*". 2004.

[31] Stoelhorst H., Schreuder M., "*Dynamic Speed Limits Pilot Programme*". 2009.

[32] Highway Agency, "*Ramp Metering – Summary report*". November 2007.

[33] Highways Agency, "*Integrated Traffic Management at Junction 33 of the M1 – Evaluation Report*". July 2008.

[34] Highways Agency, "4-*Lane Variable Mandatory Speed Limits – 12 Month Report*". June 2008.

[35] Highways Agency, "*Ramp Metering – Operational Assessment*". July 2008.

[36] Hungarian Roads Public Co., "*TEMPO Evaluation of a traffic monitoring pilot project on Hungarian motorway M7 – CONNECT Evaluation results report*". November 2009.

[37] Ieromonachou P., Potter S., Warren, J. P., "*Norway's urban toll rings: evolving towards congestion charging?*" 2004.

[38] ITS America, "*National Intelligent Transportation Systems Program Plan: A Ten-Year Vision*". January 2002.

[39] Jenstav M., "*Congestion Charging in Stockholm – Impact and Lessons Learnt*".

[40] Land Transport Authority Singapore, "*Road Pricing Singapore's Experience*". October 2002.

[41] Marchionni G., Studer L., Maja R., Ponti M., Veronesi E., "*Valutazione di un sistema integrato ITS in ambito autostradale*". 2007. Trasporti e Territorio.

[42] Opus International Consultants, "*SH20 Mahunga Drive Easy Merge (Ramp Metering) Signal*". 2005.

[43] PIARC, "*Australia: Regaining best use of Melbourne Motorways Monash-Citylink-West Gate Upgrade Freeway Management System*". 2009. Available at http://www.piarc.org

[44] Rämä P., "*Effects of Weather-Controlled Variable Message Signing on Driver Behaviour*". October 2001.

[45] Studer L., Gandini P., Borghetti F., Iuliano R., Pastorelli G., "Assessment of areas exposed to damage by dangerous goods transportation: application of analytic hierarchy process method for land covers weighing". 2015. *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, October, 2015, pp. 2551–2556, DOI:10.1109/ITSC.2015.410.

[46] Giacone M. O., Bratta F., Gandini P., Studer, L., "Dangerous goods transportation by road: a risk analysis model and a global integrated information system to monitor hazardous materials land transportation in order to protect territory". *Chemical Engineering Transactions*, 2012, 26, 579–584, DOI:10.3303/CET1226097.

[47] Reading Borough Council, "*Reading UTMC 29B Evaluation Results*". June 2004.

[48] In't Veld R., "*Monitoring the Main Effects of Rush Hour Lanes in the Netherlands*". 2009.

[49] SERTI Secretariat, "*Informed drivers and efficient traffic management through high performance travel times on the ASF network*". June 2006.

[50] SERTI Secretariat, "*Travel Time in the Oisans Valley*". May 2006.

[51] Societé des AutoRoute Paris – Normandie, "*Evaluation de l'expérimentation d'un panneau d'information sur la disponibilité en places de parking PL des aires d'autoroute – Rapport*". 2008.

[52] Streetwise project, "*Evaluation – Streetwise Guidelines version April 2003*". 2003.

[53] Studer L., Böhm M., Mans D., "Toolkit for sustainable decision making in ITS deployment". 2010. *17th ITS World Congress*, Busan, Korea, 25–29 October 2010.

[54] Studer, L., Cecchetto, M., Marchionni, G., Ponti, M., "Evaluation of dynamic speed control on the Venice-Mestre beltway". 2009. *16th ITS World Congress*, Stockholm.

[55] Studer L., Marchionni G., Ponti M., Veronesi E., "Evaluation of 3 Italian its projects". 2006. *13th World Congress on Intelligent Transport Systems and Services*, 9–12 October 2006, London.

[56] Studer L., Ponti M., Maja R., Arditi R., "Dynamic traffic management plans in North-Western Italy". 2007. *6th European Congress and Exhibition on Intelligent Transport Systems and Services*, Aalborg, 2007.

[57] Swedish Road Administration, "*Variable Speed Limits – In a Nutshell*". August 2008.

[58] Swedish Road Administration, "*Variable Speed Limits on E22 in Blekinge – Final Report*". December 2007.

[59] Taale H., "*Evaluation of Intelligent Transport Systems in The Netherlands*". 2002.

[60] Taale H., "*Analysing Loop Data for Quick Evaluation of Traffic Management Measure*". 2006.

[61] Taale H., Middelham F., "*Ten Years of Ramp Metering in the Netherlands*". 2000.

[62] TEMPO Evaluation Expert Group, "*Traffic controlled variable speed limits, Sweden*". April 2009.

[63] TEMPO Programme – Evaluation Expert Group (EEG), "*Handbook on evaluation best practice*". June 2008.

[64] TEMPO Secretariat, "*Analysis of the red light driving on ramp metering systems on the motorway A40*". January 2007.

[65] TEMPO Secretariat, "*ARENA: A System for Reporting Road Accidents*". October 2005.

[66] TEMPO Secretariat, "*Automatic Incident Detection and Fast Alert Evaluation Report*". May 2006.

[67] TEMPO Secretariat, "*Design, Setting Up and Installation of Ramp Metering on Motorways Intersections*". June 2009.

[68] TEMPO Secretariat, "*Euro Regional Evaluation Guidelines*". April 2005.

[69] TEMPO Secretariat, "*Evaluation of Cross-Border Management between Eindhoven and Köln*". February 2004.

[70] TEMPO Secretariat, "*Evaluation of Cross-Border Management between Rotterdam and Antwerp*". February 2004.

[71] TEMPO Secretariat, "*Impacts of an automatic emergency call system on accident consequences*". January 2006.

[72] TEMPO Secretariat, "*Impacts of an Automatic Emergency Call System on Accident Consequences*". January 2006.

[73] TEMPO Secretariat, "*Intelligent Road Evaluation*". September 2005.

[74] TEMPO Secretariat, "*Local Journey Time System Evaluation*", August 2005,

[75] TEMPO Secretariat, "*M25 Controlled Motorway Summary Report*", February 2006.

[76] TEMPO Secretariat, "*M4 Newport Controlled Motorway Scheme, Wales*", February 2009.

[77] TEMPO Secretariat, "*Mobile Journey Time System*", November 2006.

[78] TEMPO Secretariat, "*MS4 On-Road Trial Final Appraisal Report*", February 2006.

[79] TEMPO Secretariat, "*NADICS Journey Time Planner – STREETWISE Evaluation Results Report*". June 2004.

[80] TEMPO Secretariat, "*Probe IT Evaluation Report*". July 2004.

[81] TEMPO Secretariat, "*Queue Warning System on the E6 – Gothenburg, Sweden*". November 2009.

[82] TEMPO Secretariat, "*Road weather controlled variable speed limits, Sweden*". January 2009.

[83] TEMPO Secretariat, "*Special Operation Paso del Estrecho*". March 2006.

[84] TEMPO Secretariat, "*Speed Control Evaluation on the Autoroute du Soleil*". May 2005.

[85] TEMPO Secretariat, "*Telematics-Controlled Truck Parking at the Motorway A3 Service and Rest Area Montabaur*". December 2008.

[86] TEMPO Secretariat, "*The Road Pricing Experiment in Denmark – User Reaction*". May 2005.

[87] TEMPO Secretariat, "*Traffic Information Kiosks Evaluation*". October 2006.

[88] TEMPO Secretariat, "*Traffic Management Applications on the Køge Bugt Motorway, Denmark*". April 2003.

[89] TEMPO Secretariat, "*Traffic Management Brussels-Beaune*". June 2006.

[90] TEMPO Secretariat, "*Traffic Scotland Web Information Services*". November 2008.

[91] TEMPO Secretariat, "*Travel Times Perception on Variable Message Signs*". June 2006.

[92] TEMPO Secretariat, "*TRIM Travel Time – Funen, Denmark*". December 2004.

[93] TEMPO Secretariat, "*UK-M6 Motorway Ramp Metering (1986–1997)*". February 2004.

[94] TEMPO Secretariat, "*UK-M8 Motorway Ramp Metering (TABASCO project)*". February 2004.

[95] TEMPO Secretariat, "*UK-M90 COMPANION Hazard Warning System (TABASCO project & subsequent Scottish Executive research)*". February 2003.

[96] TEMPO Secretariat, "*UK-TMC Service Evaluation 1998-2001*". February 2003.

[97] TEMPO Secretariat, "*Variable speed limits at intersections, Sweden*". September 2006.

[98] TEMPO Secretariat, "*Variable speed limits at T-junction of highways 6 and 13 in Selkäharju, Finland*". December 2004.

[99] TEMPO Secretariat, "*Video Information Highway Trial – STREETWISE Evaluation Results Report 2 (ST2)*". September 2003.

[100] TEMPO Secretariat, "*Pilot Study into the use of Automatic Traffic Counters for Event Monitoring*". June 2004.

[101] U.S. Department of Transportation, "*ITS benefits: Review of Evaluation Methods and Reported Benefits*". 1998.

[102] U.S. Department of Transportation, "*Application Area Definition*". 2016. Available at http://www.benefitcost.its.dot.gov/its/benecost.nsf/BenefitsHome [Accessed 31 March 2016]

[103] U.S. Department of Transportation, "*National ITS Program Plan*", 1995.

[104] U.S. Department of Transportation, "*Intelligent Transport Systems – Integration Projects*". January 2006.

[105] Fastenrath U., "*Floating Car Data on a Larger Scale*". 2008.

[106] VicRoads Road Safety & Network Access, "*Use of variable Electronic Speed Signs to Improve Safety on Metropolitan Freeways*". May 2009.

[107] VIKING Project, “*VIKING Overview of Evaluations MIP2005*”. April 2006.

[108] Vong V., “*Monash Citylink-West Gate Upgrade Project: Implementing Traffic Management Tools To Mitigate Freeway Congestion*”. 2008.

[109] Washington State Department of Transportation, “*Evaluation of Renton Ramp Meters*”. January 2000.

Chapter 5

ITS evaluation – A network perspective

Richard Mudge[1]

5.1 Traditional approach to ITS evaluation

The benefits of Intelligent Transport Systems (ITS) projects are not as well understood as benefits from more traditional transportation projects. While ITS professionals are well aware of the significant impacts that ITS can have on a transportation network, others, including many decision-makers and the general public, may find it more difficult to understand why, how, or when ITS investments can provide significant benefits.

ITS evaluation frameworks have been in place in the United States and several European countries for more than a decade; however, only one or two efforts have been made to evaluate ITS programs or groups of projects. This focus on individual projects rather than programs of investment is a shortcoming in transportation planning and evaluation in general.

Before considering the specific problems and opportunities involved in program or network-scale investments, there are general problems faced in evaluating ITS.

Review of the general problems in ITS evaluation

Limited data availability

The small size of ITS projects relative to transportation investment in general creates problems:

- The absolute level of ITS benefits is usually quite small relative to the general level of transport benefits. As a result, benefits that can be attributed directly to ITS are difficult to separate from transportation benefits in general.
- Lack of after-the-fact evaluations in particular. That is, while feasibility studies are often done, it is rare to review what really happened. This is also one reason that many forecasts fall short of the mark, often with

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[1] Compass Transportation and Technology Inc., USA

lower travel demand estimates than found in reality. This is part of a general problem of bias in feasibility studies, whether to keep costs low or exaggerate demand and benefits [1].

Difficulties in determining the base case

For projects that have already been implemented, gathering appropriate data for the "before" or "base" case may be extremely difficult. This also can be a problem for ITS projects that are integrated within much larger investments. In recent years, several sources of vehicle probe data (most using GPS-based information) have been developed that describe traffic speed along expressways and major arterials. Several firms also provide historical versions of these data sets that make it possible to develop data that describe speed data on a link-by-link basis after the fact. These data, however, do not have information regarding vehicle type and traffic volumes (while some firms have begun to collect these data for current traffic, other sources are required for historical data and these are not consistent in coverage).

Evaluation process often not started early enough

Often evaluation takes a low priority in the overall picture or is finally desired only after implementation has begun, or even after a system has been activated. In either case, the best opportunities for data collection may have already passed. Evaluation should be considered through all stages of a project, including (and especially) in the early planning phase.

Focus on projects, not programs

For projects with positive synergies, this results in underestimating benefits. This problem is more than a technical issue. Rather, it encourages underinvestment or investment in projects that generate purely local benefits. For example, coordinated traffic signals along a single stretch of roadway will be quite positive, but a coordinated signal system across a metropolitan region would help everyone, not just travellers in a specific location. This chapter focuses on programs or networks of technology investment.

5.2 Brief history of network investments

Transportation stands out as a public service that is used every day by every citizen and resident. Education, health care, welfare, and fire and police services all represent important public expenditures, but most people only use them during portions of their lives.

Transportation is also capital intensive and lasts a long time. The Brooklyn Bridge is still an important part of the transportation network of New York after 132 years. This long life is another reason we tend to take infrastructure for granted.

This section describes a few network-scale investments. These examples serve to show the potential for network-scale investments to change the economic and social aspects of transportation, with positive synergies for overall economic growth. These changes also stimulate structural changes in the national or regional economy, creating new business and industries, and speeding the decline and replacement of other businesses.

The examples described next all come from the United States simply because the author of this chapter knows this region best. None of these have a heavy role for ITS, largely since ITS has been carried out on a piecemeal basis. Exceptions, such as integrated corridor management (ICM) as applied in San Diego, California, and Dallas, Texas, apply only to specific corridors, even though they do involve intensive deployment of technology.

In many ways, the economic history of the United States can be traced through its large-scale infrastructure investments. Every generation or so there has been an investment on a national or regional scale, which has stimulated a burst in economic development and economic change. While these examples involve low-technology according to today's standards, each investment deployed the state of the art technology of its day.

In the earliest decades of the republic, the Army Corps of Engineers was funded to open up the Ohio and Mississippi Rivers. This played a major role in speeding westward expansion – certainly more important than Daniel Boone's Wilderness Road[1] [3]. Previously, these were "wild rivers," but this effort provided access to markets across more than half of the United States at the time and encouraged the rapid expansion of development beyond the Appalachian Mountains.

In the first half of the 19th century, technology shifted first to canals and then to railroads. States, cities, and private entities led the way. The Erie Canal in New York State connected the Great Lakes to the Eastern United States and the resulting growth in trade helped to make New York City the economic centre of the nation.

Transcontinental railroads were a large-scale public–private partnership. The federal and state governments provided financial support mostly in the form of land grants along the proposed rights of way. Railroad access would stimulate economic activity, increasing the value of these properties at the same time that they increased the value of adjacent public lands. The result was a rapid expansion of the network. Passengers and freight could move across the country in a matter of days rather than weeks. This reduced costs and opened new markets – which then reduced costs once again. To help speed deployment, the federal and state

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[1] This strong direct federal role stands out as unique in a time when state's rights were taken seriously and a restrained domestic federal role was reality. This followed the explicit rejection that the federal government should play a lead role in developing the nation's infrastructure (as argued by Albert Gallatin's famous 1808 study for the US Congress: *Report on Roads, Canals, Harbours and Rivers*).

governments gave 8–10 per cent of the continental United States to private railroad companies to help provide financing and to speed construction.[2]

The economic value unleashed by the Interstate Highway System was a prime mover for the nation's economy for at least two decades. The rate of return varies over time, with the highest rates during the 1950s and 1960s when the Interstate Highway System was under construction – but annual rates of return on this investment were well over 50 per cent a year for almost two decades [11]! This was a clear sign of the economic value of building a nationwide network since it stimulated new markets and provided access to new pools of labour and material inputs. It also probably reflects the accumulated underinvestment in civilian capital during and immediately following World War II. During this period, the Interstate investment accounted for fully one-fourth of the nation's overall gains in productivity.

These Interstate Highway related changes occurred very rapidly – as long as one does not count the two decades or so that it took to develop a practical financial plan and for public leadership to emerge from the early planning stages in the 1930s. The combination of a robust financial institution with a national network helped provide far reaching economic benefits and social change. While the Interstate had been authorized in the late 1940s, little was built until the establishment of the Highway Trust Fund in 1956. This financial mechanism provided an assured source of funds (the federal tax on motor fuel was doubled from 2 to 4 cents per gallon in 1960s) combined with a commitment that the federal government would fund at least 90 per cent of construction costs.

In recent years, the rate of return from highway investment has declined (see Table 5.2). This reflects both the natural return to more normal rates after the sea change investment of the original Interstate and the lack of comparable scale investments since then.

Other changes include the introduction of commercial jet aircraft in the 1960s and 1970s and the invention of the intermodal freight container by Malcolm MacLean. The competition unleashed by the deregulation of the airline, rail, and trucking industries in the early 1980s resulted in lower costs, expanded services, and opened new markets on a national scale.

Technology has played an important role in more recent years, with the development of the Internet and wireless telecommunication.

To date ITS investments have been in the form of a local projects. Over time, they may provide coverage for a given technology, but the impacts of individual projects miss the scale possible with a coordinates regional or national deployment. This has begun to change with the development of connected and automated vehicles. The implications of this new network-scale technology will be discussed later in this chapter.

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[2] Land was returned to the federal government if schedules were missed. Also, the federal government continued to reap the rewards of this far-sighted investment through reduced freight rates well into the 20th Century.

5.3 How does a network create economic value?

5.3.1 Key concepts

1. Network scale investments. These have several characteristics:
   - Geographic scale – national or regional versus corridor. This could cover a major metropolitan area – say e.g. London, Paris, and New York.
   - Speed of deployment – incremental change over multiple decades risks not being noticed. Certainty of funding is important. For example, while the Interstate Highway System in the United States was not completed until the early 1970s[3] but the existence of a financial mechanism that was independent of political winds and a clearly defined road map (literally) gave assurance to businesses that the system would be completed in the near future. As a result, the economic impacts appeared well before effective completion of the network.
   - Breadth of impact. That is, the investment should provide services across multiple products or sectors of the economy and society. A specialized network that serves one product or one type of service might not qualify – say e.g. a national police radio network, or perhaps a network of natural gas pipelines (although this last example could be debated).
2. Nonlinear impacts. That is, the economic and social impacts are more than the sum of individual benefits. As discussed later, this implies changes in what goods and service we produce and how this is done. These changes can improve overall economic productivity – less labour and capital are needed to produce a given level of output.

Most analysis of the economic impact of transportation focuses on linear changes – direct benefits to travellers and consumers and indirect benefits from people and industries that depend on these changes. These impacts are important and relatively straightforward to measure. For example, coordinated traffic signals along a given roadway should reduce average travel times, improve safety, and improve overall reliability of travel. The nature and magnitude of these direct personal benefits vary by type of project, but dollar values can be estimated.

Each ITS project will have specific goals or categories of benefits. These differ by type of project. An important step in any evaluation is to identify the most significant benefits. Evaluation efforts can then focus on these benefits. Typically, this work is built around five primary benefit categories:

1. Safety
2. Mobility
3. Efficiency
4. Energy and environment
5. Customer satisfaction

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[3] Technically, some minor segments were not finished until the late 1980s.

Table 5.1 ITS goal areas and common benefit measures[a]

Goal area	**Measure**
Safety	Reduction in the overall rate of crashes Reduction in the rate of crashes resulting in fatalities Reduction in the rate of crashes resulting in injuries Reduction in secondary crashes
Mobility	Reduction in travel time delay Reduction in travel time variability
Efficiency	Increase in freeway and arterial throughput Cost savings for users Cost savings for agency
Energy and environment	Decrease in vehicle emissions Decrease in vehicle energy consumption
Customer satisfaction	Increase in customer satisfaction Link with mobility measures

[a] Adopted from US Federal Highways Administration Performance Measures. http://www.its.dot.gov/evaluation/defs.htm [Accessed 31 March 2016]

An important step is to select specific measures for each category. These measures need to consider relevance or value for the specific project, ability to collect primary measures, and relevance of secondary data from other evaluations. Table 5.1 shows the primary performance measures given by the US Federal Highway Administration for each of the six broad categories.

5.3.2 Economic productivity

More important than linear changes, however, are economic productivity impacts. These involve nonlinear changes as individuals and businesses adjust their practices in response to improved infrastructure. These types of changes are not relevant for projects with a local impact (say adding a lane to an existing highway) but there is a long history of change in response to investments with a national or regional scale impact.

These changes are more than interesting from an academic perspective. Improved economic productivity is a key part of international competitiveness – countries that can improve how much they produce from given resources or improve the quality of what their citizens can produce, will gain a competitive advantage relative to other countries. Improved productivity also makes it possible to increase compensation for labour and capital.

Very simply, productivity gains allow the economy to produce more with less. In the modern economy, both capital and labour are scarce resources, so it is important to maximize their value – that is, to maximize their rate of return to the economy. Productivity gains come from a variety of sources, including new technology (say improved computers and the Internet); improved logistics; better labour skills, and of course, improved access to labour, intermediate goods, and markets.

Productivity is an important part of gross domestic product (GDP) and changes in productivity indicate the likely direction of future GDP levels. At its simplest level, productivity is usually measured as GDP divided by total hours worked during a given time period. Most countries report these results on a regular basis – e.g. in the United States this number is reported four times a year by the Bureau of Labour Statistics.

In sum, growth in labour productivity is the key factor behind the ability to generate long-term growth in a country's standard of living. It also plays a key role in competition between nations. Countries with good growth in productivity of labour and capital will have a competitive advantage over countries with lower rates of growth. Innovation is a key factor in stimulating changes in productivity. Most literature focuses on technology improvements as a driving force, but as summarized above, network-scale transportation improvements play an important role here. This role can be enhanced if technology is part of transportation.

The next section describes the individual parts of these changes, followed by a summary of some of the analytic literature regarding these changes. Most of the examples come from transportation, in large part due to better data.

Three connected stages show how the impacts progress from linear impacts to broader economic changes including gains in productivity and shifts in the structure of the economy.

1. An improved transportation system (either larger in size or higher in the quality of service that it provides) allows industry to produce the same amount of goods and services for less. This can be called a "productivity effect." See example in text box. But the story does not end here.
2. An improved transport system also allows firms and industries to change how much they use of other economic inputs – labour, intermediate goods, and private capital. These changes may result in greater efficiencies as the investment allows firms to substitute for one or more of their traditional economic inputs. Termed "factor demand effects."
3. The cost reductions caused by the first two changes will, in turn, stimulate increased overall demand since individuals and firms can now purchase more goods and services than previously. Called an "output expansion effect" [9]. This is similar to the classic multiplier effect based on increases in economic activity.

Firm-Level Productivity Case Study

Koley's Medical Supply was (in 1990) a wholesale distributor for a coalition of six hospitals in Omaha Nebraska and parts of Iowa that converted to a stockless purchasing system. In the hospital industry, stockless purchasing goes further than just-in-time by offering pick-and-pack operations in addition to frequent deliveries of medical products to hospitals. Koley's packs items in their proper units of issue and delivers them in bins several times a day to user departments in the hospitals.

Transportation is critical to meeting frequent order cycles in a stockless purchasing system. Good access makes frequent (several times a day) delivery efficient costs over the whole hospital materials chain from manufacturer to patient.

One hospital reduced its distribution staff by 12 full time employees and eliminated trucks. Another hospital converted its storeroom to more productive uses.

Source: "Transportation: Key to a Better Future," published by AASHTO [Mudge, 1990].

In effect, in response to transportation investments, industry changes how much it costs to produce goods, then changes how it produces goods (maybe even changing what is produced), and finally changes how much it produces. Of course this last change may also involve another round of changes in how goods are produced as increased demand encourages larger factories and economies of scale come into play.

In sum, when viewed as a network, *transportation stimulates shifts in the demand and supply curves for goods and services*. This is a fancy way of saying that economic productivity improves. These changes can be seen at the firm level as well, although it is harder to quantify the effect precisely. Both Association of State Departments of Transportation in the United States and the Federal Highway Administration published reports that include case studies of how these changes occur at the individual firm level [8].

Even though examples are easier to cite for manufacturing businesses, these changes cover all parts of the economy, including services and the government. Every industry benefits from improved access to labour and customers. Indeed, in the 21st century where businesses depend on labour quality more than in the past, service industries are likely to be more sensitive to improvements in access.

The overall effect from this set of changes is clear – an improved infrastructure creates significant overall increases in economic activity both by reducing costs and by stimulating demand. The result can be positive changes in the economic structure. Similar shifts occur due to technology changes, such as occurred following the introduction of the Internet and of wireless telecommunication.

These types of "network impacts" have been analysed by others. Again, most of the examples come from surface transportation (highways in particular) since there are more and better data here. Each of the quantitative studies are after the fact and are usually based on some form of econometric model to correct for other economic changes (Table 5.2).

Table 5.2 Rates of return on highway investment in the United States

Rates of return	1960–69 (per cent)	1970–79 (per cent)	1980–91 (per cent)	1960–91 (per cent)
Highway capital	54	27	16	32
Private capital	16	18	17	17
Private equity	11	11	12	12
Interest rate	5	8	10	8

Examples of network impacts analysis

Professor Ishaq Nadiri of New York University completed the "most notable" empirical analysis to date to assess the relationship between highway investment and economic growth [5]. Nadiri studied the effects of changes in highway assets from the 1950s through the mid-1990s. He concluded that highway investment in the 1950s and 1960s (the Interstate Era) provided an average 50 to 60 per cent annual rate of return on public investment. More than one-half of these benefits to private industry were realized in services and non-manufacturing sectors—in contrast to the more traditional view that freight, logistics and vehicle manufacturing benefit the most from highway improvements. While the absolute rate of return has dropped significantly in more recent years, these studies still find that the rate of return to public investment can equal or exceed the average rate of return from private investment [10].

The Eddington Transport Study "Transport's role in sustaining the UK productivity and competitiveness" provides a more recent international context for transportation's role in productivity and economic competiveness. The study noted that, on average, a 10 per cent increase in transportation infrastructure investment increases GDP by approximately 2 per cent. The challenges of properly addressing the economic benefits of transportation investment were also addressed, stating that up to 50 per cent of all potential economic benefits of transportation investment go unreported [2].

Remy Prud'homme and Chang-Woon Lee's "Size, Sprawl, Speed and the Efficiency of Cities" compared productivity of European cities, particularly Paris and London. The researchers concluded that, "The efficiency of a city is a function of the effective size of its labour market." The research found that a 10 per cent improvement in access to labour increases productivity, and therefore regional output, by 2.4 per cent [12].

NCHRP Report 463 "The Economic Implications of Congestion" details the importance of congestion reduction to ensure regional economic productivity by providing industry access to a larger labour pool. The research notes that a 10 per cent decrease in congestion for the case studies of Chicago and Philadelphia allows for a larger pool of workers for regional industry. Vehicle miles of travel (VMT) do increase with reduced congestion, but by less than 2 per cent. The result is a net decrease in labour costs since the costs of increased trip lengths are more than offset by the regional productivity gains [13].

Nadiri's system-wide analysis shows that almost every economic sector receives significant economic gains from highway investment. Highways also allow all industries to make more efficient use of labour and intermediate goods. This is due to competitive forces that result from having access to a larger resource pool, access to new or larger markets, and part results from being able to make more efficient use of existing resources [9].

Nadiri uses a set of complex cost-function econometric models that describe the role of highway assets in changing industry costs and outputs. His work examines changes over time and across industries. He corrects for many of the technical criticisms of earlier studies. These include:

1. greater attention to dynamic changes (i.e. highway improvements reduce costs which in turn stimulates demand which then increases costs – although not the same costs affected by highways in the first place),
2. recognition of substitution effects among highways and the other major economic inputs – i.e. businesses use a different mix of labour, private capital, and intermediate goods in response to change in the quality and quantity of transportation,
3. measurement of cause and effect relationships rather than simple correlation,
4. recognition of how highways are financed in the United States – this involves correcting industry costs for highway users fees (benefit taxes), and
5. use of more up to date and more complete estimates of private and public capital stocks (see pp. 15–18 of Reference 10 for a summary of these criticisms and how Nadiri and Mamuneas make adjustments).

5.3.3 General characteristics of network-scale change

The economic (and social) impacts of network-scale investments differ from traditional transportation or technology investments.

Summary of the general characteristics of economic (and social) impacts of network-scale investments

National (or regional) in scale
Generate nonlinear impacts
Improve access to

- labour/jobs;
- markets;
- intermediate goods;
- raw materials.

Stimulate positive shifts in the supply and demand curves. These shifts reflect a new economy and are generated by:

- Economies of scale
- New markets
- New products/services

5.4 Autonomous vehicles: an ITS network to evaluate

Transportation is in the midst of a series of quiet but profound revolutions. Travellers now have choices that go beyond the classic dichotomy of private cars versus bus and rail transit. Many of these changes take advantage of new technology, with some of the most dramatic changes yet to come including self-driving vehicles. New transportation services are now available, including many stimulated by private entrepreneurs. These changes also respond to market forces including increased preferences by some for urban living and a world where mobile communications provide near real-time access to information for business and individuals. The specific impact of these changes on demand for traditional modes, including private cars, transit, walking, biking, taxis, and telecommuting is unknown but will have important implications for how we plan, fund, and operate regional transportation.

While the phrase "autonomous vehicles" is commonly used, there are really three types of self-driving vehicles: *Automated vehicles* operate independently along certain roadways. *Connected vehicles* share real-time information with other vehicles and with others via the infrastructure. *Autonomous vehicles* are both automated and connected. The National Highway Traffic Safety Administration (NHTSA) has a four-stage set of automated levels. The Society of Automotive Engineers (SAE) has a similar five-level categorization.

Table 5.3 shows the role of the drivers for each of the five levels in the SAE system. One way to summarize these is that Level 2 is "feet free – hands remain on

Table 5.3 Driver's role in the autonomous vehicle system

Level	Example systems	Driver roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive *other* function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes – and others)	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus driverless shuttle Driverless valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi (even for children) Car-share repositioning system	No driver needed

Source: Steve Shladover, PATH.

wheel"; Level 3 is "hands free – driver can carry out other functions but needs to stay alert"; and Levels 4 and 5 are "brain free."

While the press tends to focus on full automation, partially autonomous vehicles (NHTSA, Level 2) will be deployed first. Tesla just released a simple version of Level 2 automation in some vehicles. This only works on certain roads (mostly expressways) and in good weather and requires the driver to keep their hand on the wheel or be available to take control of the vehicle in seconds. Other manufacturers plan to include similar systems in some models starting in 2016 and 2017. These offer a key opportunity to test public acceptance and price sensitivity. NHTSA Level 3 vehicles should be available in the next few years – perhaps as soon as 2020. These provide an opportunity for the driver to read or watch video, although they still must stay in the driver's seat.

Fully autonomous (all roads, all weather) is the ultimate goal (NHTSA Level 4 or SAE Level 5 vehicles). Lots of speculation exists about when these vehicles might appear on the market. For example, PATH (research arm of the University of California at Berkeley and Caltrans) says not before 2075.

Autonomous vehicles will create a de facto increase in roadway capacity. This is the key to generating economic productivity gains across the economy. There is considerable active debate regarding how large these impacts on capacity might be, with some estimates as high as a four-fold increase in capacity. Most estimates show gains in the 50–100 per cent range – but debate also continues regarding how large market penetration needs to be before this gains will occur and how rapidly these vehicles will be deployed. What will generate these potential capacity gains?

1. Greatly reduced traffic incidents – alone these account for 25 per cent of traffic congestion.

2. Enable reduced vehicle headways, resulting in an effective increase in roadway capacity. There is controversy over the magnitude of this impact, with some simulations showing a four-fold increase. Google says they believe a doubling is possible. Some analysis (PATH) shows short-term negative impacts on congestion due to interactions between traditional vehicles and autonomous vehicles and the need for connected technology to generate capacity gains. These gains will take time for the vehicle fleet to turn over (or for cost effective retrofit kits to be on the market) and could be quite large if vehicle designs change significantly – perhaps to allow narrower lanes. This has important side effects:
    - Significant environmental benefits due to smoother flow of vehicles
    - Significant drop in energy use
    - Significant decline in the level of funds requested by state and federal transportation agencies
3. Added value from free time while driving. Morgan Stanley puts a $600 billion value on this for just the United States [6]. While they term this effect a productivity gain, the real productivity gains derive from shifts in the structure of the economy. Morgan Stanley also estimates annual benefits once there is full deployment of $1.3 trillion in the United States and more than $5.6 trillion annually worldwide. These estimates do not include the economic productivity effects described above that result from shifts in the supply and demand curves.

Any such increase in roadway capacity has implications for what types of future transport investments will be needed. They also provide significant gains in overall mobility – an effective doubling of roadway capacity could provide a four-fold increase in access to jobs and labour.[4] This has important economic and social implications. Improved access to labour has been shown to have a positive impact on overall economic productivity (see the section on access for a summary of Reference 7). Many key issues have not yet been analysed carefully. What level of market penetration is needed to begin generating these gains? Is 10 per cent ownership enough? 20 per cent? If vehicles cannot communicate directly, might there be a decline in effective capacity – field tests seem to show this.

Will there be a change in car ownership patterns? Is this just a continuation of current trends or a sea change in how we provide transportation? Many of the new players in transportation (e.g. Uber, Lyft, and Google) seem to view autonomous vehicles as a key part of the move towards mobility as a service (MAAS) where most people will buy mobility as needed rather than owning a car that sits idle more than 90 per cent of the time. This could have great impacts on insurance costs, parking demand, and housing footprints and locations. Several simulation models of this MAAS model claim that a fleet 10 per cent the size of current number of vehicles could provide the same or better quality of service. These models may work better in higher density areas.

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[4] The area of a circle is π times r^2 and 2 squared is 4. This assumes that economic-related locations are spread uniformly across a region.

Cost plays a vital role in determining the speed with which the market will grow. Can the costs drop enough to make the new vehicles competitive? The costs of key technology components have already dropped considerably – LIDAR systems from six figures to less than $10,000. Is this enough? How much are people willing to pay for this new technology?

J.D. Power’s survey of drivers found that consumers were willing to pay $800 for traffic jam assist (similar to what Tesla offers now) and $2,500 for limited autonomous driving capabilities. The level of interest in new technology within vehicles showed relatively little variation across age and income groups – although interest was strongest among younger groups [4].

An example of an interesting side effect is that VMT in a world of autonomous vehicles may not be seen as a negative. Smooth vehicle flow has a significant positive impact on energy use and greatly reduces environmental emissions. If autonomous technology allows for lighter vehicles, these positive impacts on energy use may be even larger.

5.5 Possible implications

Improved accessibility has a *broad positive impact on the nation’s economy*. The value of these productivity gains could exceed those generated by the Interstate Highway System and should be larger than the benefits from safety gains alone.

While it is difficult to forecast the specific beneficiaries of this change, past history and recent analysis show the impacts will be very large. For example, a 10 per cent increase in accessibility can generate an additional 2.4 per cent increase in output. This is a small number, but multiplied times a very large number – US GDP is currently about $17 trillion. If roadway capacity improves by 50 per cent this implies a 125 per cent gain in overall accessibility. While the economic gains from this large an increase in access to labour/jobs and markets will be very large, we cannot simply scale the 10 per cent number up for the much larger gain in access.

In addition to technical issues regarding economic evaluation, the topic has a range of policy implications.

Policy implications

Regulations

Safety benefits dominate the debate over the value of autonomous vehicles including the nature of regulations. A macro/network view implies that these benefits underestimate the overall value of full deployment. This has implications for any benefit–cost analysis of potential regulations and can show tangible economic and financial benefits for society. A broader understanding of the full value of autonomous vehicles should encourage regulatory agencies to support rapid deployment of these vehicles.

Change in business and individual location

Reduced congestion will permit individuals to travel longer distances in the same amount of time. This may make it possible for people to decide to live in less expensive (and probably larger) homes on the fringe of urban areas and still have access to a larger pool of potential jobs than at present.

At the same time, autonomous vehicles will make it possible for people to live without owning a car and should make it possible to reuse parking spaces for more productive uses. This may encourage urban lifestyles.

Job impacts

This is a bit tricky since job losses will be easier to identify – e.g. taxi drivers and truck drivers – while job gains will be generated from positive shifts in the supply and demand curves as industries take advantage of improvements in access to labour and markets. These job gains will be real, but also hard to link with the autonomous vehicles. This has been true for past revolutionary changes in transportation or technology.

Outreach

Important to let the public know that there is more to autonomous vehicles than simply saving lives and helping people with mobility problems. These benefits are important, but autonomous vehicles will provide a broad set of benefits that will offset the losses that some industries will experience.

5.6 Unanswered questions

More analysis is needed regarding the impact of autonomous vehicles on roadway capacity.

1. What are realistic numbers for expressways, major arterials, and the roadway network as a whole?
2. How do these estimates change based on market penetration? How important is the "soft spot" when market penetration is low?
3. How do these numbers change based on types of autonomous vehicles? Will significant gains occur before Level 4/5 fully self-driving vehicles are common?

A review of past successful networks shows that predictability regarding completion of the network is important. Assurance is more important than speed of deployment. The Interstate Highway System generated significant economic benefits well before it was completed in large part due to an assured source of funds in the Highway Trust Fund. Three factors are important here:

1. Autonomous vehicles need to be cost-effective to speed deployment.
2. Retrofit kits are practical and low enough in price to attract customers.
3. Regulations should not be a barrier to deployment, but rather recognize the unique nature of this technology.

What is the likely pace of market penetration? How will this vary by type of autonomous vehicles? How much of the economic benefits will be lost if Level 4 (SAE Level 5) vehicles never play a dominant role? What is the impact if capacity gains are found only on expressways, with limited change for arterials?

Will VMT increase or decrease? This may be less of an issue since new VMT is likely to be "better" than old VMT due to reduced energy use, less environmental impacts per VMT and fewer accidents.

Most important, however, how do we translate the productivity gains associated with small (10 per cent) changes in access with the potential for access gains of 100 per cent or more? Fifty years from now we will have enough data to help with an after the fact evaluation – just as Nadiri has done for the Interstate Highway System. What can we say today, while at an early stage of deployment? If a 2.4 per cent gain is on the low end, how much higher makes sense?

References

[1] C. C. Cantarelli, B. Flybjerg, E. J. E. Molin, and B. van Wee (2010). Cost overruns in large-scale transportation infrastructure projects: explanations and their theoretical embeddedness. *European Journal of Transport and Infrastructure Research*, vol. 10, no. 1: pp. 5–18.

[2] R. Eddington (2006). *The Eddington Transport Study: The Case for Action.* HM Treasury, London, UK.

[3] A. Gallatin (1808). *Report on Roads, Canals, Harbours and Rivers. Report to United States Congress*. United States Treasury, Washington, DC.

[4] K. Koolidge (2015). Automated vehicles and public perception. *Proceedings: Automated Vehicle Symposium*. Available at: http://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/2015AV_Symposium/KristinKolodge_JDPowersPublicPerception.pdf (accessed 18 April 2016)

[5] The National Chamber Foundation (2006). *The Transportation Challenge – Moving the U.S. Economy*. United States Chamber of Commerce, Washington, DC.

[6] M. Stanley (2013). *Autonomous Cars: Self Driving the New Auto Industry Paradigm.* Morgan Stanley Blue Paper Report. Morgan Stanley, New York City, NY.

[7] R. Mudge, M. Maggiore, K., and A. Pisarski (2009). *Performance Metrics for the Evaluation of Transportation Programs.* Bipartisan Policy Centre. Washington, DC.

[8] R. Mudge (1990). *Transportation: Key to a Better Future*. The American Association of State Highway and Transportation Officials, Washington, DC.

[9] R. Mudge (2005). *The Rate of Return from Highway Investment. National Cooperative Highway Research Program – NCHRP Project 20-24(28).* Transportation Research Board, Washington, DC.

[10] I. Nadiri and T. Mamuneas (1996). *Contribution of Highway Capital to Industry and National Productivity Growth*. United States Federal Highway Administration, Washington, DC.

[11] I. Nadiri and T. Mamuneas (1998). *Contribution of Highway Capital to Output and Productivity Growth in the United States Economy and Industries.* United States Federal Highway Administration, Washington, DC.

[12] R. Prud'homme, and C.-W. Lee (1999). Size, sprawl, speed and the efficiency of cities. *Urban Studies*, vol. 36, no. 11, pp. 1849–1858.

[13] G. Weisbrod, D. Vary, and G. Treyz (2001). *NCHRP Report 463 Part B: Economic Implications of Congestion*. NCHRP (National Cooperative Highway Research Program), Washington, DC.

Chapter 6

Field Operational Tests (FOTs) – The ultimate answer to impact evaluation?

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6.1 Introduction

During the last 10–15 years, several new functions have been introduced into vehicles, in passenger cars, as well as in trucks and buses. There are functions like collisions warning, lane departure warning (LDW), blind spot warning, adaptive cruise control (ACC), stop-and-go support. Also, functions to help the drivers and other users to manage the traffic situation have been developed. Examples include navigation support, traffic information (TI), and functions that are linked to efficiency and mobility aspects, as well as to eco-driving support. These new functions are often referred to Intelligent Transport Systems (ITS).

The functions had been tested in a rather limited scale in several EU-funded projects and the results were at a first glance very promising. However, the market introduction as well as the use of the functions by ordinary people were very limited. A question was soon raised: Why was the take-up not successful? And some follow-up question: Were the project tests performed to 'small' and not reliable? Were the dissemination efforts applied enough? or Were there other reasons?

6.2 FESTA

In an effort to deal with these issues a project, FESTA, was launched by the Commission in the Seventh Framework Programme of Research. FESTA can be summarized as a methodology to address a larger sample of the potential users (mainly drivers) using the functions 'in real life' over a longer period of time. The ideal set up was a sample size of minimum 100 people and the duration of the test period should be close to a year. The participants involved should drive their own cars as they normally do and there should be a minimum of intervention from any outside experimental body.

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The term Field Operational Test (FOT) was introduced although with a European touch. FOTs have been used before (especially in the United States) but the European approach is somewhat different, the main issue being that the functions tested should be mature, i.e. should have been introduced on the market and already be in use by ordinary people.

A FOT is defined as:

> ‘A *FOT* is a study undertaken to evaluate a function, or functions, under normal operating conditions in road traffic environments typically encountered by the participants using study design so as to identify real world effects and benefits.’

Some more definitions:

> ‘A *system* is defined as a combination of hardware and software enabling one or more functions’ and ‘A *function* is defined as an implementation of a set of rules to achieve a specified goal’.

It must also be possible to compare the effects that the specific function has on traffic with a baseline condition during which the function is not operating. To achieve this, the participants’ control over or interaction with the function(s) has to be manipulated by the research team. ‘Normal operating conditions’ imply that the participants use the systems during their daily routines, that data logging works autonomously and that the participants do not receive special instructions about how and where to drive. Except for some specific occasions, there is no experimenter in the vehicle, and typically the study period extends over at least a large number of weeks. FOTs must, however, consider whether it is still possible to achieve a baseline where all the studied systems are off due to the proliferation of functions in standard vehicles.

6.2.1 The FESTA V

The 11 different steps (Figure 6.1) can be grouped in three phases: preparing, using and analysing. Ethical and legal issues are covered by all phases.

Preparing involves the steps:

- Function identification and (identifying) use cases,
- (Formulation of) research questions & hypotheses,
- (Defining) performance indicators (PI) and study design, and
- (Decisions re) measures & sensors.

Using includes the step:

- Data acquisition and finally

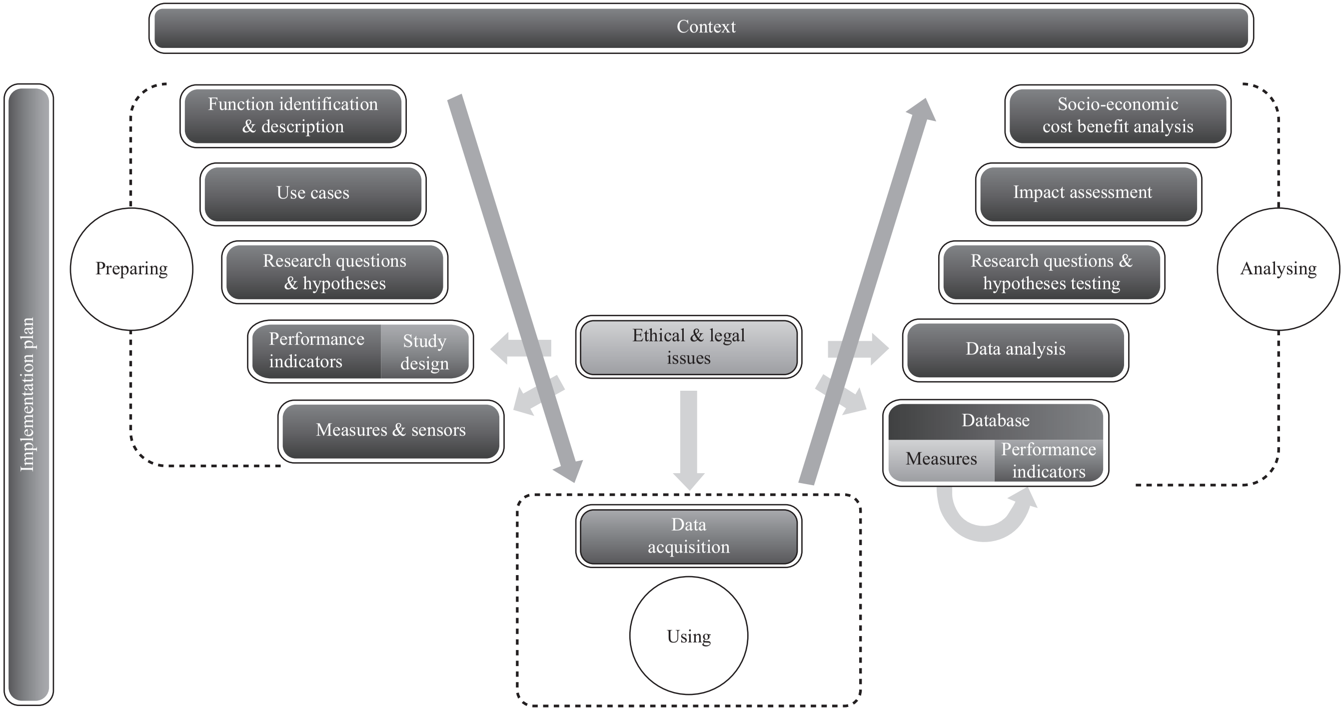

Figure 6.1 *The FESTA V: The steps that typically have to be considered when conducting an FOT. The large arrows indicate the time line [1]. Reprinted with permission from the FESTA/FOT-NET consortia*

Analysing consists of the steps:

- (Creation of) database, data analysis, and
- Research questions & hypotheses testing,
- Impacts assessment, and
- Socio-economic cost–benefit analysis

6.2.2 The FESTA Handbook

FESTA has provided support to evaluators by designing a *Handbook of Good Practice* [1]. The handbook gives applicants to ICT calls in the EU research programs practical guidance to allow them to develop FOT projects. The main effort was devoted to capture the applicability and the everyday use of the new functions that had been developed. The FESTA Handbook covers issues concerning all aspects of the timeline and administration of an FOT. Advice is provided regarding aspects from needs analysis at the commencement of an FOT all the way through to the integration of the acquired data and estimation of socio-economic benefits at the end.

6.3 FOTs

To date, several FOT projects have been conducted in Europe, two of which are euroFOT and TeleFOT. Both projects started in 2008 and ended in 2012 and both followed the methodology described in the FESTA V, although to different degree. A third project DRIVE C2X, finalized in 2014, also applied the FESTA FOT methodology, but with clear limitations as the functions tested were technically mature but were not yet introduced in the market.

6.3.1 euroFOT

The overall aims of the euroFOT project were to evaluate different in-vehicle functions with regard to traffic safety, efficiency and environment, to demonstrate the benefits of the functions and hereby contribute to the deployment of ITS technologies on the market [2].

6.3.1.1 The timeline

The first 2 years of the project were dedicated to preparation, i.e. to specifying functions, designing experimental procedures, formulating hypotheses and deciding on what data should be collected and how. The data acquisition systems were selected, and (if needed) modified or developed for the different vehicles involved [2].

In the third year, the experimentation began. Five so-called Vehicle Management Centres (VMC) in Germany, France, Italy and Sweden were set up and provided general support to eleven Operation Sites (e.g. Gothenburg, Aachen, Munich, Paris and Torino). Together the FOTs involved 980 vehicles, cars as well as trucks, equipped with different types of Advanced Driver Assistance Systems (ADAS) (*see* Table 6.1).

Table 6.1 Overview of number and type of vehicles, and functions tested at the different VMCs

VMCs	**No and type of vehicles**	**Function(s) tested**
Germany – Aachen	100 customer-owned vehicles (cars and trucks) 2 Ford-owned cars	FCW, ACC, LDW, CSW
Germany – Munich	15 leased cars were used by 3 waves of drivers	Safe HMI/navigation system
	15 leased cars were used by 4 waves of drivers	Safe HMI/navigation system
France	40 cars (5 high level equipped + 35 low level equipped)	SRS
Italy	533 cars	LDW
Sweden	100 company cars	FCW, ACC, LDW, BLIS
	30 heavy trucks	FCW, ACC, LDW
	50 heavy trucks	FEA

More specifically the functions tested included:

- Longitudinal control functions: Forward Collision Warning (FCW), ACC, Speed Regulation System (SRS) comprising CC and Speed Limiter (SL);
- Lateral control functions: Blind Spot Information System (BLIS), LDW, Impairment Warning (IW) and
- Advanced applications: Curve Speed Warning (CSW), Fuel Efficiency Advisor (FEA) and Safe Human–Machine Interaction (HMI).

During the FOT, more than 1000 drivers drove their own or leased test vehicles, or took part as professional drivers employed by freight companies.

In the fourth year, the analysis phase was initiated and the methodology decided upon was implemented. Initially, the analysis focused on system performance and user aspects, especially situations that could potentially lead to accidents. This was followed by impact studies on traffic safety, efficiency and environment. A cost–benefit analysis was also completed.

6.3.1.2 A deep dive into the methodology

Regarding the methodology, a common approach was decided upon in the preparation stage but the plan had to be adapted to the local FOTs. For instance, a FOT should typically have lasted 12 months including a 3 months' baseline during which the function was not available and a 9 months 'treatment' phase. However not all FOTs could follow this plan, partly because it was not possible to in all cases switch the system(s) completely off without the drivers having the possibility to switch them on again. The plan also suggested that the recruited drivers should be between 30 and 50 years old to ensure homogeneity, they should drive approx. 15,000 km/year and they should have no prior experience of the functions tested. The recruitment of drivers was not unproblematic, partly because of the need to install data loggers requiring adaptations of the customers' cars, partly because of privacy issues. The age boundaries had to be changed considerably to reach the desired number of participants, few women participated, and it is possible that some (or most) drivers had earlier experience of the functions.

A number of research questions (e.g. Does the FCW increase (traffic) safety?) and related hypotheses were formulated (e.g. H1: An FCW system decreases the number of accidents and H3: FCW system decreases the number of hard-braking), then revised and prioritized. Some research questions concerned user acceptance, usage, trust, etc. as well as how different features influenced acceptance. As a next step more than 100 PI related to the different hypotheses were decided upon describing driving behaviour (e.g. average speed, harsh braking events), driver workload, traffic safety, efficiency and impact on environment. According to the FESTA V also use cases should be defined. In the euroFOT, project use cases were defined by the VMCs and formulated as, for instance 'Driving on route with congestions' provided that the systems were 'on' or 'off'.

Data acquisition techniques ranged from questionnaires to continuous recording of vehicle signals, and also, in some cases, additional instrumentation with video and extra sensors. Some of the data acquisition equipments were common among partners (e.g. the central logging unit and the positioning system), and other equipments were not. The collected data were transmitted wirelessly to a centralized services system to be stored. As there were different kinds of vehicles, as well as different equipment used, pilots were performed to ensure that components as well as processes worked as intended. The importance of these pilots was emphasized.

The impact assessment included hypotheses testing and answering research questions based on PI, situational variables and events. For example, the hypothesis 'ACC decreases the number of incidents' was tested using the PI 'number of incidents' and 'number of incidents' was in turn defined by vehicle speed, distance to forward vehicle, deceleration, etc. The hypothesis testing followed the approach based on the FESTA methodology. User acceptance and user related aspects were also analysed by applying appropriate methodology. In addition, the analysis included an upscaling of impacts from a micro (FOT) level to a macro (EU) level, i.e. to both a larger population and a larger geographical scope. Based on this upscaling, a cost–benefit analysis was carried out for the bundle of ACC and FCW [3].

6.3.1.3 Results

In summary,

- The bundle of ACC and FCW showed a positive impact on driving safety. The average time-headway increased and the relative frequency of harsh braking manoeuvres decreased when driving with the systems compared to when driving without [2, 3]. Based on these results, it was concluded that the combination of ACC and FCW had a positive effect on the number of crashes. The reduction of accidents was calculated to lead to lower incident related delays, which was determined to result in (indirect) positive effects on traffic efficiency. There were also positive effects on environment as fuel consumption was reduced.

- LDW (in combination with IW for cars) resulted in (slightly) improved lateral control and an increase in turn indicator usage. Overall drivers found the LDW to be a useful function but also commented on the many warnings which were perceived as unnecessary.
- Regarding the SRS, the SL function resulted in a reduction in over-speeding and in harsh braking events whereas CC resulted in an increase in over-speeding but a reduction in harsh braking. No safety effects were found but an increase in traffic efficiency was anticipated as an effect of the increase in average speed.
- The impact assessment of the CSW system was based on questionnaire data only. Overall, the drivers had a positive attitude towards the system and felt that it increased safety.
- The same results regarding drivers' attitude applied to BLIS. Any safety impact was not confirmed by the available objective data.
- Regarding FEA the analysis focused on the environmental impact and the system was found to result in a reduction in (truck) fuel consumption. The impact assessment did not consider other possible effects.

6.3.2 TeleFOT

The overall aims of the TeleFOT project (Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles) were to assess the impacts of functions provided by aftermarket and nomadic devices, raise overall awareness of the potential of these devices and hereby contribute to the uptake of ICT systems for driver support.

6.3.2.1 The timeline

As in euroFOT, the first years of the TeleFOT project were devoted to preparing for the FOTs, i.e. identifying the devices to be included in the test, designing a common methodology for the studies, formulating research questions and hypotheses, and deciding on what data should be collected and how.

The trials began in 2011 and consisted of Large-scale FOTs (L-FOTs) and Detailed FOTs (D-FOTs). L-FOTs were the core of the project, intended to investigate normal, everyday use of one or several functions, whereas the D-FOTs investigated the effects of the functions, in particular cockpit activities while driving, in more controlled environments. The FOTs were carried out at eight test sites within the southern, central and northern regions of Europe, more specifically in Finland, Sweden, Germany, Greece, Italy, Spain and the United Kingdom. A special FOT at the French test-site was dedicated to evaluating a nomadic eCall device. Approximately 2800 participants were involved in 11 L-FOTs and an additional 200 in six D-FOTs (*see* Table 6.2).

In the L-FOTs, the main part of the participants drove their own private vehicles. The functions tested included (i) Static and Dynamic Navigation Support (NAV), (ii) Green Driving Support (GD), (iii) Speed Alert (SA), (iv) Speed Limit Information (SI) and (v) TI. In the D-FOTs specially equipped test vehicles were used. In addition to systems already mentioned, the D-FOTs included tests of in-vehicle systems such as ACC and FCW.

Table 6.2 Overview of the locations of L-FOTs and D-FOTs; the number of participants/vehicles and functions tested

	No of participants/vehicles	**Function(s) tested**
L-FOT test site		
Finland	140 drivers, private cars	GD, SI/SA, TI
Greece	148 drivers, private cars	NAV, SI, SA, TI
Italy	168 drivers, private cars	NAV, SI/SA
Spain	120 drivers, private cars	NAV, SI/SA
	132 drivers, private cars	NAV, GD
Sweden	54 drivers, company cars	SA, GD
	96 drivers, private cars	NAV, GD, TI
	554 driver, private cars	TI
United Kingdom	80 drivers, private cars	NAV, SI/SA
D-FOT test site		
Finland	143 drivers, 15 city buses	GD
Germany	9 drivers, specially equipped vehicle	ACC, FCW, GD, NAV, SI/SA
Italy	48 drivers, specially equipped vehicle	GD, (NAV, TI)
Spain	32 drivers, specially equipped vehicle	SI/SA
United Kingdom	40 drivers, specially equipped vehicle	FCW, LDW, GD
	23 drivers, specially equipped vehicle	FCW, LDW

The final year was dedicated to the analysis. In a first step, the data from the respective test sites were analysed and conclusions drawn regarding the effects of single and/or bundles of functions. In a second step, a cross FOT analysis was conducted, searching for patterns for the FOTs where the same type of function had been tested. In a third, step conclusions were drawn on a function as well as on an impact level. Finally, a cost–benefit analysis was completed but from a business point of view [4].

6.3.2.2 A deep dive into the methodology

A common strategy was decided upon regarding the study design of the FOTs [5]. The methodology built on that accomplished in the FESTA project and documented in the FESTA Handbook but, again, had to be adapted to the specific conditions of the FOT. It was for instance decided that each L-FOT should provide a baseline or a control condition. A within-subject design should be used in preference to a between-subject design and the participants should mirror the intended user (or customer) population. The latter was achieved to different degrees. The trials with access to the function(s) should furthermore be long enough to allow for a 'steady state' to be reached, i.e. minimum 6 months, but some trials were shorter even so. In addition, a common design to questionnaires and travel diaries was part of the strategy and several steps were taken to ensure correct translations to/from English.

Regarding the procedure for generating research questions and hypotheses, the TeleFOT project developed a modified and more elaborate procedure by integrating hypotheses developed top-down and bottom-up. Top-down meant that the questions

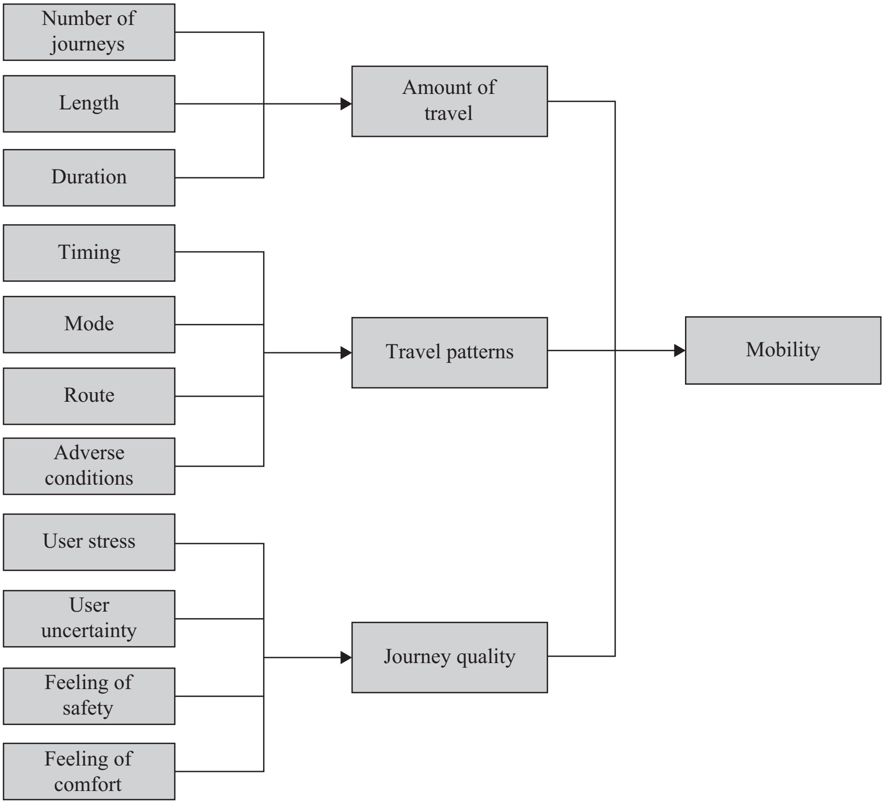

Figure 6.2 TeleFOT mobility model [6]. Reprinted by permission from the TeleFOT consortium

were based on an underlying theoretical framework (see Figure 6.2) here as the bottom-up approach was based on the different functions to be tested use cases, etc.

The research questions finally addressed in the project were then chosen based on three criteria: (i) importance in relation to the context of the impact assessment, (ii) feasibility of collecting PI data and (iii) cost of collecting data to answer research questions and test hypothesis. Once the hypotheses, kept to a minimum, had been formulated, relevant PI, data collection methods, etc. were decided upon.

Data collection included logged data, questionnaires and travel diaries. A limited amount of logged data could be collected in the L-FOTs due to the restricted access to the participants' private vehicles. This was compensated by the D-FOTs, where the specially equipped vehicles provided more detailed data where relevant. All data were transferred to and stored on a web-based server and further enriched by map matching and metadata which provided specific contextual details about each individual test. Before the actual trials, pilot studies were completed for all FOTs, checking the technical function of the data collection system in real driving and operating situations as well as the feasibility of the evaluation process including all data collection methods and tools [7,8].

In the analysis, both L-FOT and D-FOT data were used to answer the research questions and to test the hypotheses. User uptake, being a prerequisite for any impacts, was given considerable attention. The database files, containing FOT data, summary data and related metadata (e.g., detailed description of data formats and contextual information) were used for further processing, analysis and interpretation through use of statistical tools. Before the data were provided for analysis, they were post-processed to create uniform summary tables for each FOT to extract PI. The impact of access to different functions on environment, efficiency, mobility and safety were inferred by answering the specific research questions and related PI.

6.3.2.3 Analysis results

In summary not all functions affected or played the same role in different impact areas [6,9–12]:

- Access to GD was found to have an impact on environment as it resulted in significant decreases in fuel consumption and CO_2 emissions. In some FOTs increased compliance with speed limits could also be observed. Drivers reported increases in perceived safety and comfort as well as decreases in stress and uncertainty.
- Access to NAV had an impact primarily on mobility as journey distances and journey durations (for comparable journeys) were shorter. Participants perceived an increase in the use of rural roads but the logged data showed an increase in city/urban roads, in particular roads with low speed limits. In addition, drivers reported decreases in stress and uncertainty. No changes could be found regarding, for instance, the number of journeys, avoidance of traffic, fuel consumption or speed.
- Access to TI resulted in an increase in the use of rural roads (with potentially higher risks) and a decrease in the use of city roads. At the same time, journey durations (for comparable roads) were shorter, reducing exposure to accidents. TI could thus have an impact on mobility as well as on safety. Drivers reported increases in perceived safety and comfort as well as decreases in stress. No changes were detected regarding number of journeys, transport mode, speed violations, etc. Regards fuel consumption available data were insufficient.
- Access to SI/SA did not result in changes in speed (average speed, speed variation, speed violations, etc.) or in fuel consumption. Drivers reported though increases in perceived safety and comfort as well as in decreases in stress and uncertainty.

All results must be interpreted in the context of the particular systems tested, the participants involved and the degree to which the functions were actually activated and used. In general, the participants used the devices and functions less than expected. A significant portion reported having used the functions for less than 25% of trips made. GD and SI/SA were however used more often than NAV and TI. Overall, NAV and TI were used more in relation to longer and/or unknown journeys whereas GD and SI/SA were beneficial for a larger number of everyday trips.

In general, the participants had high expectations for the devices and function but were initially disappointed, partly because the functions were indeed mature systems. Over time though the assessment changed and became more positive again, emphasizing the importance that tests last for longer periods of time for providing a deeper understanding of user uptake. User uptake was influenced by several factors including perceived usefulness (or benefit), perceived ease of use (related to e.g., design of the user interface), and trust with usefulness being the 'key'.

6.3.3 DRIVE C2X

The European Integrated Project DRIVE C2X started in January 2011 and had its Final Event in July 2014. The project strongly built on previous assessment and technical tests of cooperative systems, which were considered to be mature enough for L-FOTs applying a methodology based on the FESTA V. A consistent Europe-wide testing environment for cooperative systems was created, including seven test sites in Finland, France, Germany, Italy, Netherlands, Spain and Sweden. The project developed the testing methodology and assessed the impacts of cooperative systems on users, environment and society [13].

Cooperative systems are systems that are based on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communication technology. One of the first objectives of V2V, V2I and I2V is to promote road safety. Cooperative systems have also been considered for functions that will influence environmental and efficiency impacts. Cooperative systems differ in several areas from conventional approaches and this will directly influence the FOT planning and operation.

There are few if any cooperative systems available in the market. This implies that the only systems that could be tested are prototype systems installed manually. There will possibly be an initial market for mainly V2I-based applications (functions) and the V2V functions will not be seen until there is a critical mass of equipped cars on the road. The important element is that there is a need for infrastructure installations. Furthermore, the new functions provided by cooperative systems are unknown to the driver. An educational effort is needed. Cooperation means also that either more than one vehicle is present in the communication range or the infrastructure must be equipped with road-side units (RSUs) as part of a communication network.

6.3.3.1 Objectives

The objective of DRIVE C2X was split into four major technical objectives:

- Create a harmonized Europe-wide testing environment for cooperative systems
- Coordinate the tests carried out in parallel throughout the DRIVE C2X community
- Evaluate cooperative systems
- Promote cooperative driving.

Nine functions were selected for the full impact assessment.

Traffic safety-related functions include the following:

- *Road works warning*: vehicles approaching road works are warned in due course before they reach the road works zone. The function is applicable both to stationary road works and moving road works found typically on motorways.
- *Traffic jam ahead warning*: the driver is warned when approaching the end of a traffic jam to avoid running into the last vehicle in the queue.
- *Car breakdown warning*: approaching vehicles are warned before reaching a broken down vehicle to avoid running into that vehicle or endangering people in the vicinity.
- *Weather warning*: information about bad weather conditions ahead is communicated to oncoming vehicles to avoid entering areas with adverse weather conditions at excessive speed.
- *Emergency electronic brake light*: in case of a hard braking manoeuvre following vehicles are warned to avoid rear end collisions and backing up.
- *Approaching emergency vehicle warning*: approaching emergency vehicles warn surrounding drivers about their presence to ensure that they can proceed quickly even in very heavy traffic.
- *Post-crash warning*: in the event of an accident oncoming vehicles are warned to ensure that drivers slow down and do not run into the vehicles involved in the accident.

Traffic efficiency-related functions include the following:

- *In-vehicle signage & regulatory and contextual speed limit*: traffic sign information such as 'ban on passing' is communicated to the vehicles and indicated in the instrument cluster or the head unit. Information on fixed and variable speed limits as well as the recommended optimal speed is communicated to the vehicles and indicated in the instrument cluster or the head unit. This application does in particular address variable message signs.
- *Green-light optimal speed advisory*: signal phases of traffic lights are communicated to vehicles to inform the drivers about the optimal speed to pass traffic lights at green.

6.3.3.2 Results

In total, more than 200 vehicles drove more than 1.5 million km and the faultless performance of system and functions under all relevant traffic and climate conditions proved that the system is mature for Europe-wide deployment. The safety impacts of the DRIVE C2X functions are clearly positive. Drivers react to information and warning signals.

- *IVS Speed limit and weather warning* showed most potential to decrease fatalities: Assuming a 100% penetration rate, *IVS speed limit* that provides continuous information would reduce on average 23% in fatalities and 13% in injuries. *Weather warning* would lead to 6% less fatalities and 5% less injuries.
- It is assumed that the highest penetration rates would be 12% in 2020 and 76% in 2030. For IVS speed limit, this would lead to the reduction in fatalities up to 3% in 2020 and up to 16% in 2030.

- Assuming a 100% penetration rate, *road works warning* would decrease fatalities by 3%, Emergency brake light warning and *traffic jam ahead warning* by 2%. These functions would decrease injuries by 2% assuming all vehicles are equipped.

The safety impacts of the DRIVE C2X functions DRIVE C2X were found to be positive even for functions aimed at relatively infrequent events. Environmental benefits in terms of reduction in fuel consumption ad CO_2 emissions were also achieved for three functions. Based on both user behaviour and preference measurements, the results of the project clearly show the significant potential of cooperative systems [13].

The results also indicate positive impacts on travel comfort. Specifically, journey quality is improved in terms of decreased user uncertainty and stress, and feeling of safety and comfort. Considering the proven safety impact as well as the perceived increase in comfort the promising user acceptance does not come as a surprise.

However, the impacts of forth-coming cooperative functions and services were studied before their market introduction. The aim of cooperative driving applications is to support foresighted driving and early detection of hazards. This is realized by means of a communication-based system that extends the drivers' horizon and warns of potentially dangerous situations ahead. Consequently, the aim of these approaches is to provide drivers with the opportunity to adapt the vehicle speed and also increase headways between vehicles leading to a higher situational awareness of an unforeseen danger. At present, there is a general understanding of the benefits of cooperative systems, but so far they have been tried out in small-scale experiments mostly on closed test tracks. Yet, there is no proof of these benefits with many communicating vehicles used by ordinary people in varying conditions on roads.

For the data collection, DRIVE C2X is aggregating the data that are generated by the national Cooperative FOTs during normal national operations. These data provide the basis for the assessments carried out in DRIVE C2X, but naturally they can only give a rough indication of the impacts cooperative systems will have. These data were assessed for validity, and where possible the results were scaled up for whole Europe. In parallel, DRIVE C2X conducted tests on DRIVE C2X specific functions, which were selected aiming at maximum effectiveness and were expected to yield equal benefit to all member states.

6.4 Driving automation FOTs

There are defined five (or six) levels of driving automation in the context of driving for on-road vehicles. Table 6.3 summarizes SAE International's levels of driving automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein.

The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level.

Table 6.3 The five (or six) levels of driving automation [14]. Reprinted by permission from SAE International

Level	**Name**	**Narrative definition**	**Execution of steering and acceleration/ deceleration**	**Monitoring of driving environment**	**Fallback performance of *dynamic driving task***	**System capability (*driving modes*)**	**BASt level**	**NHTSA level**
***Human driver* monitors the driving environment**			Human driver	Human driver	Human driver	n/a		
0	**No Automation**	The full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems					Driver only	0
1	**Driver Assistance**	The *driving mode*-specific execution by a driver assistance system of either steering or acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	The *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* (‘system’) monitors the driving environment**			System	**System**	Human driver	Some driving modes		
3	**Conditional Automation**	The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*					Highly automated	3
4	**High Automation**	The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	–	

‘System’ refers to the driver assistance system, combination of driver assistance systems or automated driving system, as appropriate.

Table 6.3 also shows how SAEs levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its *Preliminary Statement of Policy Concerning Automated Vehicles* of May 30, 2013.

For the ‘traditional’ FOTs, the problem areas and the policy objectives to be addressed in the study have been chosen beforehand. For vehicle automation, some broader issues like ‘What are the impacts on lifestyle, transportation systems, economy and society at large?’ must also be addressed.

6.4.1 The FESTA approach

Traditionally, the potential system/function impact on DRIVER behaviour (based on Draskoczy *et al.*, 1998) are the following:

1. Direct effects of a system/function on the drivers and driving,
2. Indirect (behavioural adaptation) effects of the system/function on the driver,
3. Indirect (behavioural adaptation) effects of the system/function on the non-user (imitating effect),
4. Modification of interaction between users and non-users (including vulnerable road users),
5. Modifying accident consequences (e.g. by improving rescue), and
6. Effects of combination with other systems/functions.
7. Are there more issues to consider when automated vehicles (AVs) are concerned?

The FESTA methodology is based mainly around *observation and scaling-up*. For the wider impacts of automation, we need an alternative approach around *prediction and scaling-up* [15].

There are new impact areas to cover: Transport demand, value of time, travel cost, mode choice and equity issues are all related to the need for travel and the costs associated with the different mode alternatives. The infrastructure side of automated driving deals with network operation and associated costs. In a wider context, land use and urban planning goes hand in hand and will influence the transport system in the longer term.

Figure 6.3 shows the temporal and spatial resolution when it comes to how the different impact areas that are relevant for automation looks like [16].

Immediate impacts are related to safety (crash avoidance and severity reduction), mobility (closer car following, more efficient intersection performance, increased lane and intersection capacity) and energy/environment (lower tailpipe emissions and energy consumption).

The longer term impacts are related to accessibility (more options for non-drivers), land use (more density, more sprawl), transportation system usage (induced travel) and public health. Economic benefits are due to reduced crash and pollution costs and increased productivity.

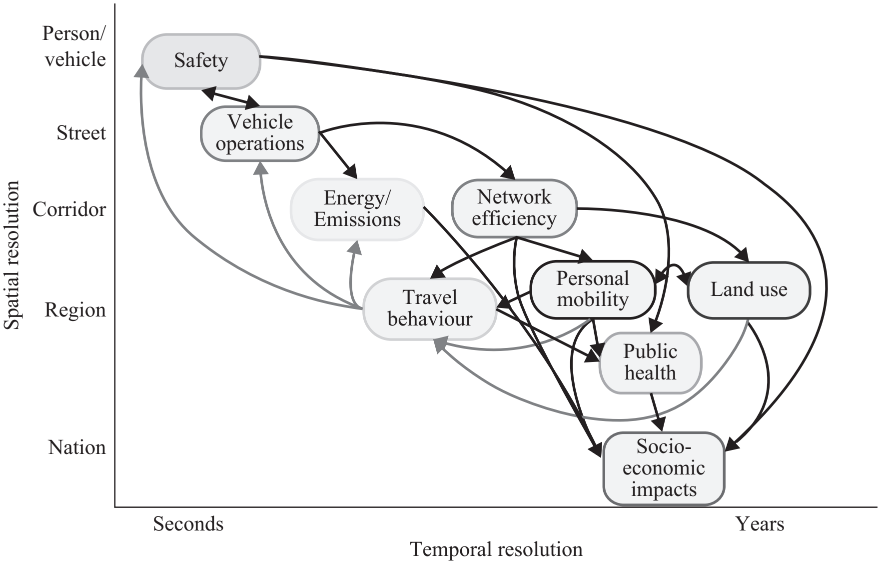

Figure 6.3 Framework elements [16]. Reprinted by the permission from the US DoT Intelligent Transportation Systems Joint Program Office

6.4.2 Transportation system usage

The highest impact from driving automation can be expected on transportation system usage. The *metrics* to be used can be the number of total trips, travel distance and time. Also the average trip duration and speed as well as the modal split (e.g. car, bus, walk, bike) and finally various congestion indices. The following *data* would be needed:

Road and intersection performance (with less than 100% of AV market penetration), network configuration (with existing roads and traffic controls, new managed lanes and ITS infrastructure) and demand for travel (passenger and freight). Data sources are existing regional models as well as supply and demand.

Results from detailed AV modelling provide the following challenges: Many possible future scenarios (the 'baseline' is not current vehicles, levels of automation, market penetration and user response incl. vehicle and trip sharing).

Connecting to existing regional models. The following approach is proposed: assess suitability of existing state-of-art regional models, including land use; identify data sources and automation applications for initial modelling; examine linkages between micro and regional mobility models; develop AV impact models (start with safety, mobility and environment and then continue to other areas); coordinate with US and international evaluation efforts.

6.4.3 Study designs

Referring back to the FESTA methodology, there are several questions that can be raised in the context of driving automation. For example, 'Do we know what PI will be used as new impact areas and research questions will lead to new types of PI?' There will be a wider community of participants in an automation FOT. Apart from the drivers also the monitors in the vehicle, the passengers, other road users and general public, and traffic managers will play a role in the test set up.

The basic question is about what is compared and what is it compared with. One crucial issue is the definition of the baseline. Is the baseline 'no automation' or 'normal driving' according to findings from naturalistic studies? Or furthermore, lower levels of automation or individual driver baseline or different penetration levels of automation. Or, do we really need a baseline? The study design will also be concerned with where the vehicles should be tested and with what indicators would be specific for automation FOTs.

6.4.4 FESTA for driving automation

The original FESTA Handbook has a focus on the system/function to be tested and many practical issues would remain the same, designing and performing a FOT, and analysing the results. A systematic and scientifically based approach should be used to gather sound evidence on the effects of automation.

However, there will be a new focus as the user community is wider, the vehicles operate sometimes without a human intervention, and certainly the context will be different from old style FOTs. Impact questions will get more emphasis as the impact of road automation, is just not about a wide-scale implementation of systems (functions) but the interest is on a wider range of impact questions.

It is important that as much as possible a common methodology is used to be able to study impacts of automation, and by combining all knowledge gathered from different kinds of FOT already performed. First, what minimum data-set would allow for comparison; second, it is important to share experiences, knowledge and data with all actors in the FOT community. For this, the support of the FOT-Net project will be of great value.

6.5 Concluding remarks

Let us go back to the original problems and questions that initiated the FESTA project.

> Why was the take-up not successful? And some follow-up question: Were the project tests performed to 'small' and not reliable? Were the dissemination efforts applied enough? or Were there other reasons?

The ideal set up of an FOT was a sample size of minimum 100 people and the duration of the test period should be close to a year. The participants involved should drive their own cars as they normally do and there should be a minimum of intervention from any outside experimental body. One main issue was that the functions tested should be mature, i.e. should have been introduced on the market and already be in use by ordinary people. Furthermore, it was clearly stated that it must also be possible to compare the effects that the specific function has on traffic with a baseline condition.

The overall aims of the *euroFOT* project were to evaluate different in-vehicle functions (pre-mounted at the factory) with regard to traffic safety, efficiency and environment. In comparison, the overall aims of the *TeleFOT* project were to assess the impacts of functions provided by aftermarket and nomadic devices.

The first 2 years of the two projects were dedicated to preparation, and the plan had to be adapted to the local scenes. The time needed for preparation was often underestimated. The hypothesis testing followed one of the two approaches presented as part of the FESTA methodology. User acceptance and user related aspects were also analysed by applying appropriate methodology.

All results must be interpreted in the context of the particular systems tested, the participants involved, and the degree to which the functions were actually activated and used. In general, the participants used the devices and functions less than expected. In general, the participants had high expectations for the devices and function but were initially disappointed, partly because the functions were indeed mature systems. Over time the assessment changed and became more positive again, emphasizing the importance that tests last for longer periods of time for providing a deeper understanding of user uptake.

DRIVE C2X strongly built on previous assessment and technical tests of *cooperative systems*, which were considered to be mature enough for large-scale field tests applying a methodology based on FESTA. But there are few if any cooperative systems available in the market. This implies that the only systems that could be tested were prototype systems installed manually.

As the impacts of forth-coming cooperative functions and services were studied before their market introduction the results would only give you a rough indication of the impact cooperative systems will have. At present there is a general understanding of the benefits of cooperative systems, but so far they have been tried out only in small-scale experiments mostly on closed test tracks.

The new development in *automated driving* provides new challenges to test the functions, etc. There are defined five (or six) levels of driving automation in the context of driving for on-road vehicles. The most interesting systems are to be found on Levels 4 and 5. For driving automation, some broader issues like ‘What are the impacts on lifestyle, transportation systems, economy and society at large?’ must be addressed and there are new impact areas to cover: Transport demand, value of time, travel cost, mode choice and equity issues are all related to the need for travel and the costs associated with the different mode alternatives.

Referring back to the FESTA methodology, there are several new questions that can be raised in the context of driving automation. For example, ‘Do we know what PI will be used as new impact areas and research questions will lead to new types of PI?’ There will be a wider community of participants in an automation FOT. Apart from the drivers also the monitors in the vehicle, the passengers, other road users and general public, and traffic managers will play a role in the test set up.

The basic question is about what is compared and what is it compared with. One crucial issue is the definition of the baseline. Is the baseline 'no automation' or 'normal driving' according to findings from naturalistic studies? Or furthermore, lower levels of automation or individual driver baseline or different penetration levels of automation. Or do we really need a baseline?

However, there will be a new focus as the user community is wider, the vehicles operate sometimes without a human intervention, and certainly the context will be different from old style FOTs. Impact questions will get more emphasis as the impact of road automation, is just not about a wide-scale implementation of systems and functions, but the interest is on a wider range of impact questions.

A final remark. The FESTA methodology is based on a strictly scientific approach but it cannot cover all aspects of a test set up. The FESTA Handbook gives you a good start when planning a FOT, but the local conditions as well as the systems to be tested will influence the test set up. The new developments in the context of ICT for transport and traffic (or ITS) will bring new challenges to the evaluation community and they have to be addressed properly. For this future endeavours the support of the FOT-Net project will be of utmost importance. The original questions raised when FESTA was initiated are still very relevant.

References

[1] FESTA Handbook (2014), Version 5, 28 February 2014, Revision made by FOT-NET project. Available at: http://www.fot-net.eu/library

[2] Kessler, C., Etemad, A., Alessandretti, G., *et al.* (2012). Deliverable D11.3. Final report. Deliverable to the euroFOT project. Available at: http://www.eurofot-ip.eu/download/library/deliverables/eurofotsp120121212v11dld113_final_report.pdf

[3] Benmomoun, M., Pütz, A., Zlocki, A., and Eckstein, L. (2012). EuroFOT: field operational test and impact assessment of advanced driver assistance systems – final results. In *Proc of the FISITA 2012 World Automotive Congress, Lecture Notes in Electrical Engineering* Vol. 197, pp. 537–547.

[4] Gaitanidou, E., Beklaris, E., Chalkia, E., *et al.* (2010). D5.3.1. Business Cases, Potential New Functions and Technology Implementation Plan. Deliverable to the TeleFOT project.

[5] Karlsson, M., Rämä, P., Alonso, M., *et al.* (2009). D2.2.1. Testing and Evaluation Strategy. Deliverable to the TeleFOT project.

[6] Innamaa, S., Axelson-Fisk, M., Borgarello, L., *et al.* (2013). D4.4.3. Impacts on Mobility – Results and Implications. Deliverable to the TeleFOT project.

[7] Franzén, S., Karlsson, M., Paglé, K., *et al.* (2012). D2.2.2. Testing and Evaluation Strategy II. Deliverable to the TeleFOT project.

[8] Franzén, S., Karlsson, M., Morris, A., *et al.* (2012). Widening the use of the FOT methodology. Development based on experiences from the TeleFOT project. *Procedia – Social and Behavioural Sciences*. 48 s. Available from https://publications.lib.chalmers.se/publication/160537-widening-the-use-of-

the-fot-methodology-development-based-on-experiences-from-the-telefot-project, 1826–1836.

[9] Karlsson, M., Alonso, M., Brignolo, R., *et al.* (2013). D4.7.3. User Uptake – Results and Implications. Deliverable to the TeleFOT project.

[10] Welsh, R., Morris, A., Lenard, J., *et al.* (2011). D4.3.2. Impacts on Safety. Preliminary Results. Deliverable to the TeleFOT project.

[11] Will, D., Schröder, U., Birrell, S., *et al.* (2012). D4.6.3. Impacts on Environment – Results and Implications. Deliverable to the TeleFOT project.

[12] Touliou, K., Brignolo, R., Innamaa, S., Rämä, A., Pagle, K., and Will, D. (2012). D4.5.3. TeleFOT Applications Efficiency Impact. Deliverable to the TeleFOT project.

[13] Schulze, M., Mäkinen, T., Kessel, T., Metsner, S., and Stoyanov, H. (2014). DRIVE-C2X Deliverable D11.6 Final Report (IP-Deliverable). Available at: http://www. drive-c2x.eu/publications

[14] SAE International (2013). Information Report J3016, 2013.

[15] Carsten, O. (2016). Presentation at a FOT-NET Data Workshop on a Common Methodology for Road Automation FOTs and Pilots, 3–4 February, 2016.

[16] Smith S., Bellone, J., Bransfield, S., *et al.* (2015). Benefits Estimation Framework for Automated Vehicle Operations. Final Report FHWA-JPO-16-229, US DoT, August 2015.

Chapter 7

Assessing transport measures using cost–benefit and multi-criteria analysis

Henk Taale[1]*, Jan Kiel*[2] *and Arnoud Muizer*[2]

7.1 Introduction

To assess transport policy measures and putting together packages of measures for implementation, various methods and tools are available in the Netherlands. These methods comprise approaches to achieve packages of transport policy measures at a regional level and which are supported by the stakeholders. The best-known methods in the Netherlands are:

- The Sustainable Traffic Management method (GGB) [1,2]. This nine-step method can be used to compose packages of traffic management measures at a regional level, involving all relevant stakeholders.
- The Accessibility Solutions method [3]. This is a quick scan method, to reach a consensus on a package of solutions for regional accessibility that contains both demand and supply-oriented measures.
- The Assistance for Cost-Effectiveness Analysis (KEA) [4]. This is a guide which shows how regional projects can be developed, balanced and optimised. Cost-effectiveness is an important criterion for deciding on the package of measures.
- The Toekan methodology [5]. This methodology is meant to plan accessibility measures for temporary projects, such as (major) roadworks.

In line with these methods, there are several other studies available that focus on optimising packages of transport policy measures. They are mostly related to one specific policy topic (traffic flow, safety or sustainability) or one specific type of measure (demand management, capacity management). There are also several studies on effects, ratios and cost-effectiveness of measures implemented and available. An overview of the effects of Dutch implementations of traffic management measures is given by Taale and Schuurman [6].

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The existing methods all have their own purpose and function to assess policy packages of measures or individual measures. However, there is a lack of a unified, integrated and comprehensive method to determine the cost-efficiency or to make a (social) cost–benefit analysis for such packages or measures. Currently, on one hand the integration of the different policy objectives and the different types of measures is missing, while on the other hand the uniformity of definitions, data (key figures and costs) and calculation methods is lacking. This chapter tries to fill this gap and describes an integrated and uniform approach, called the *Assessment method for demand and traffic management* (AMDTM).

The method consists of nine steps. In the first step the interaction between measures is determined and after that the costs and benefits. If costs and benefits in terms of money are not known, other quantifiable impacts are investigated. If quantification of impacts is not possible then in the fourth step the qualitative impacts are determined (e.g. impacts on landscape or comfort). Then the goals are prioritised. Goals could be related to accessibility, safety, environment or the interaction between the measures. All the goals receive a weight. With all this information on impacts a multi-criteria analysis is performed, possibly accompanied with a sensitivity analysis. Finally, in the last step the results are discussed with the stakeholders and adjustments can be made.

This chapter discusses the method. The application of the method is illustrated with some case studies, varying from a case assessing alternatives for an infrastructure project to a case to determine suitable transport measures in a region.

7.2 Scope and aspects

7.2.1 Scope

The scope of the AMDTM is ‘accessibility’ in the broadest sense. It may include both regional and national packages of transport measures, aimed at introducing changes in mobility and facilitating mobility. Furthermore, the measures could comprise both passenger and freight transport. It therefore concerns the widest possible scope, both in terms of type of possible actions and type of policy goals. This implies that the assessment method should be usable for a wide range of users, such as policymakers and practitioners in regions. It also implies that the method should be able to weigh different scenarios. In general, it is anticipated that there will be an increasing demand for formulating different scenarios (or variants, or project alternatives) and to weigh these policy scenarios against each other on the basis of cost-effectiveness. Therefore, the method should function as a kind of scale (or balance), which allows packages of traffic management measures to be weighed in a transparent manner, and in this way these measures can be compared with each other with respect to their societal benefits. This allows also to compare, if necessary, different types of projects, such as construction and expansion projects with demand management. Figure 7.1 illustrates this ambition.

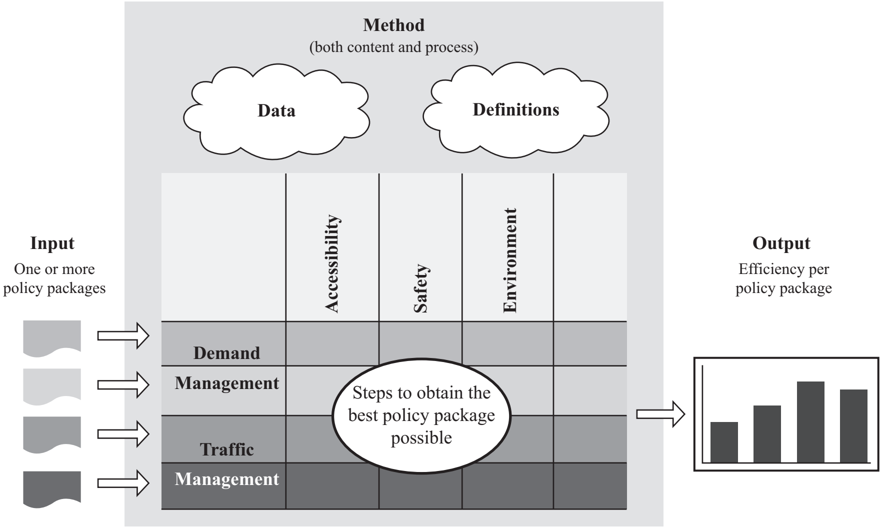

Figure 7.1 Ambition for the assessment method

7.2.2 Basic principles

Based on existing literature and interviews with various evaluation experts, a number of principles for developing the assessment method were formulated. The method should:

- fit in existing processes and existing routines;
- enable an integrated assessment;
- focus as much as possible on monetising impacts;
- focus on the intended effects of measures or packages of measures;
- provide room for qualitative aspects in the considerations;
- provide decision support information;
- make sensitivity analyses possible;
- be robust and accessible.

Most of these principles are obvious. The AMDTM is based on and complements existing methods and in this way adds to a unified and integral method. The existing methods are therefore not replaced, but constitute the base. Basically the AMDTM is a combination of a cost-benefit analysis (CBA) and a multi-criteria analysis (MCA). This combination is not new (for example see for the context of sustainability the work of Sijtsma [7]), but some new elements related to transport and traffic management are added. In the next section, the relation with existing methods is discussed in more detail.

It has already been mentioned that the new method aims at an integrated assessment of accessibility, liveability and safety in a uniform way. These three aspects are complemented by the possibility of interactions between measures and more qualitative aspects. The interaction between the measures involves strengthening or weakening the effects that measures can have. To achieve a particular policy, it is beneficial if measures are mutually reinforcing. In the assessment of the effects this should be made explicit. The qualitative aspects are the ones which are difficult to quantify, such as image, comfort, social cohesion or barrier. The method gives the opportunity to include aspects that may affect the final result, but are difficult to assess. Often these qualitative aspects were mentioned, but not fully taken into account in the assessment and decisions. The aspects are often subjective, but are based as much as possible on opinions and scores of experts and stakeholders (inter-subjective).

7.2.3 Relation with existing methods

In the context of better utilisation of existing infrastructure, already various methods have been developed for putting together measures or packages of measures. Besides the methods previously mentioned in the introduction (GGB and KEA), other examples are the 'Wikken en Wegen' method [8], which helps in deciding on investments in infrastructure related to traffic and transport, and 'CORT & Krachtig' (Short & Powerful) [9], which gives regions concrete guidelines and describes tools that can be used discussing the problem and developing cost-effective solutions. The AMDTM adds to these methods because it is more general and can also be used to anticipate new types of solutions, such as ITS and innovation in the infrastructural programme.

Recently, the Dutch government published the 'General Guidance for Cost-Benefit Analysis' [10], a guide showing step by step how to carry out a CBA for government projects and describing the criteria to be met by the various components of the CBA. In this paragraph the relation with this guideline is described.

The 'General Guidance for CBA' has been developed for the calculation and assessment of the costs and benefits of all kinds of projects, including major infrastructure projects. Within this method impacts on accessibility, the environment and safety are determined and these impacts are monetised as much as possible with available indicators. Concerning the scope and methodology the 'General Guidance for CBA' is a basis for the AMDTM, as well as concerning the calculation of the impacts and the use of indicators. However, the AMDTM focuses on demand and traffic management and the specific aspects that are related with that. Therefore, the following points of interest are important:

- The impacts in terms of accessibility, quality of life and safety should be treated equally in the assessment of packages of measures.
- A CBA may cover large infrastructure projects with a time horizon of several decades. For the measures assessed in the AMDTM this horizon is shorter and will depend on the lifetime of the measures.
- The 'General Guidance for CBA' also accommodates non-quantifiable aspects, such as image and comfort. In the AMDTM we refer to this as 'qualitative aspects'. Often these aspects are mentioned in CBAs (and sometimes scored with a '+', '—' or '?'), but not taken into account. Qualitative elements such as image and comfort, however, can still affect the regional assessment of packages of measures and therefore are considered in the AMDTM.
- The 'General Guidance for CBA' focuses on deciding between project alternatives and a reference case. In the AMDTM the reference case would be the

situation without measures. The project alternatives – which often consist of several measures – are typically composed prior to the use of the AMDTM, using a method like the ones mentioned in the introduction, and are used as a starting point. While in the 'General Guidance for CBA' it is possible to vary within the alternatives afterwards, the AMDTM is more flexible and more focused on 'playing' with the alternatives. For example, this also includes determining the sensitivity of the measure on the results.

7.3 The assessment method in nine steps

7.3.1 Introduction

The AMDTM aims to determine the impacts and the costs and benefits of (packages of) measures, but is not meant for the stage of selecting these measures. Although this is in principle possible, this stage is covered by other methods, such as the aforementioned 'General Guidance for CBA' or the ones mentioned in previous paragraphs (GGB, KEA, etc.). A good CBA can of course contribute to the realisation of a good package of measures. To realise a good set of measures, the first step is to determine the traffic and transport problems and challenges in a region. After that bottlenecks and solution directions for these bottlenecks can be determined. The solutions can be checked and discussed with the stakeholders and can be transformed into specific measures. This set or sets of measures are the starting point for the AMDTM. Stakeholders in a region often comprise different parties, such as local authorities, public transport companies, the regional business community and citizens. The AMDTM aims at the proper assessment of the proposed measures. Involving all stakeholders in the selection and assessment process ensures that the end result will be supported.

In a CBA a base case and project alternatives are used. The impact of a project is defined as the difference between the developments with the project (project alternatives) and without the project (base). The base case is not just do nothing, but the most probable development that would occur without new policies. This may consist of the continuation of the existing policy, but may also contain other choices. In the AMDTM various measures combined in a package form a 'project alternative'. The method aims at weighing the resulting packages of measures against each other. The method also provides the possibility of – in an interactive setting – varying in the composition of the package and to make the choice for the best package, based on the impacts and costs, but also based on underlying choices such as the available budget, objectives and the importance that stakeholders attach to these objectives.

7.3.2 The nine steps

The AMDTM includes nine steps:

1. Determine the interaction between measures;
2. Determine the costs and benefits of the measures;
3. Determine the other quantifiable impacts of the measures;
4. Determine the unquantifiable impacts of the measures;
5. Determine for every measure the priority order of the impacts;

6. Determine the weight for the different aspects;
7. Perform a multi-criteria analysis;
8. Perform a sensitivity analysis;
9. Discuss the results and determine the best packages of measures.

In the remainder of this paragraph these steps are discussed in more detail and illustrated with a fictitious example of a package of different types of measures, including measures for freight and traffic management measures.

7.3.2.1 Step 1 – determine the interaction between the measures

The first step examines to what extent measures influence one another. Practice shows that measures could strengthen or weaken each other. Measures which enforce each other are preferred to measures that weaken each other. Therefore, the interaction of measures must be mapped first, so it can be taken into account in the next steps. For example, a measure introducing a green wave on a route and another measure expanding the capacity on the same route, have both a positive effect on the travel time. The travel time will decrease. Especially if it is a busy route, the interaction between the two measures will be large.

In this step all measures are compared. It concerns the complete list of measures, without having already been combined into packages. The interaction between measures is determined by the stakeholders by assigning scores from −3 to +3, with the score of '3' represents a strong negative correlation and '+3' a strong positive correlation. Table 7.1 shows an example. The scores are subjective, but if all stakeholders fill in the form, a relative clear picture should emerge. The result of this step is taken into account in step 5, and is reflected in the subsequent steps.

7.3.2.2 Step 2 – determine the costs and benefits

For each measure (in a package) the costs and benefits need to be determined. In general, this step will require most of the work, because it requires a lot of information to be collected or calculated. For a uniform assessment the benefits need to be monetised whenever possible. Measures can only be monetised if the effects of the measures can be quantified. That is possible if the impacts can be determined on

Table 7.1 Example of an interaction matrix

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**	**Sum**
Bundle goods	▨	2		1	1			4
Eco-transport	3	▨	1	−1				3
Green wave		1	▨					1
Information	1	−1		▨				0
Measure X					▨	−3		−3
Measure Y						▨		0
Measure Z							▨	0
Sum	4	2	1	0	1	−3	0	5
Relative score on interaction	10	8	7	3	2	1	3	

key indicators such as distance, time and transportation costs and all other indicators that can be derived from the key indicators, such as speed, time losses or emissions. Monetisation can be done using a value-of-time factor. In freight transport it can be done in the same way, but using fixed and variable costs (such as salaries and fuel) is also possible, supplemented with other transportation costs such as tolls or parking. For monetising safety and environmental indicators, conversion factors for emissions, deaths and injuries in traffic can be used. If for some reason it is not acceptable to monetise the variables for the environment or safety, they should be quantified, which is described in the next step.

The costs of the measures should also be determined. The general rule is that all costs should be included, including future maintenance. Furthermore, a time horizon and a discount rate should be observed. The result of step 2 is an overview of the costs and benefits of each measure. An example of step 2 is included in Table 7.2.

7.3.2.3 Step 3 – determine the other quantifiable impacts

If monetisation of the impacts on safety and the environment is not desirable or possible, it can be chosen to quantify these effects. For safety, the number of accidents, deaths and injuries are quantified. For the environmental impacts all types of emissions and noise can be quantified. For safety and the environment the partial effects of each measure are put together in absolute terms. Table 7.3 shows an example where Measure X reduces the number of accidents with 30, the number of casualties with 14 and the number of deaths with 3. For the measures it is clear what the absolute effects are and how they relate to each other. Based on the sum of the absolute effects the measures can be ranked on safety and environment. Apart from summing them also other operators can be used to determine a score for safety.

Table 7.2 Example of matrix with monetised impacts

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Costs per measure	*1000*	*500*	*200*	*200*	*300*	*250*	*0*
Benefits in travel costs (1000 €)	2000		1000	500	25	15	10
Benefits in emissions (1000 €)	15	20	25	2	3	2	1
Benefits in safety (1000 €)	0	1300	900	0	300	0	0
Balance of costs and benefits	1015	820	1725	302	28	–233	11
Relative score on accessibility	10	1	5	3	1	1	1
Relative score on environment	6	8	10	1	2	1	1
Relative score on safety	1	10	7	1	3	1	1
Relative score on balance	7	6	10	3	2	1	2

7.3.2.4 Step 4 – determine the unquantifiable impacts

Basically the different aspects for accessibility, safety and the environment supply a quantitative result, but this is not always the case. For the qualitative effects a separate analysis takes place, which is an addition to steps 2 and 3. Instead of amounts in Euros or absolute values the impacts are described in scores, for example varying from '−5' to '+5', where '0' stands for 'no effect', '+5' for a 'big positive impact' and '−5' for a large negative effect.

This step is more subjective in nature. This could lead to discussions about whether an effect is large or small, positive or negative. Asking multiple stakeholders to score these aspects, an inter-subjective outcome is created. If necessary, the estimated effects can be held up to the light to determine the reason for the major differences.

The required scores are for example filled in a questionnaire. Scoring the effects is carried out by each of the stakeholders. Then the estimated effects of all stakeholders are collected and an average effect is determined. The result of this step is an overview of the average estimated effect for each measure. For example, see Table 7.4.

Table 7.3 Example of matrix with quantified effects

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Reduction emissions (tonnes)	234	345	445	25	30	15	10
Reduction accidents		−20	30		30		
Reduction casualties		−10	16		14		
Reduction deaths		−1	2		3		
Score on environment	234	345	445	25	30	15	10
Score on safety	0	−31	48	0	47	0	0
Relative score on environment	6	8	10	1	1	1	1
Relative score on safety	5	1	10	5	10	5	5

Table 7.4 Example of matrix with qualitative effects

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Comfort	1		2		2	2	
Image		3	3	2	1	1	1
Barriers							
Landscape quality	−3				−2		
Score on perception	−2	3	5	2	1	3	1
Relative score on perception	1	7	10	6	5	7	5

7.3.2.5 Step 5 – determine the priority order of the impacts

From steps 2 to 4 the ranking of the measures for the individual effects can be determined. For each measure, for each aspect (accessibility, environment, safety, quality aspects and interaction) and impact (cost, number of accidents, emissions, image, etc.) it can be examined how the scores of the measures compare to other ones. Within the aspects the scores are totalled so that every aspect turns out to show one score. The choice for the rankings now is that they scale proportionally and therefore are continuous sequences of 1–10. But other choices for ranking are possible and the choice for a proportional scale is something to test in the case studies. Table 7.5 shows an example of the impacts that can be monetised.

The measures all have a certain effect on the aforementioned aspects of accessibility, safety, environment, qualitative aspects and interaction. Some remarks on that:

- For accessibility it concerns an effect on the key variables distance, volume and capacity, travel time, travel costs and revenues. More than these variables are not required for the determination of the effect on the accessibility, because virtually all other indicators can be derived from these. These effects can be monetised.
- Environmental effects involve effects on emissions and noise. These too can be monetised, but this is not necessary per se. A quantification of the amount of emissions (such as NO_x and CO_2) may be sufficient.
- For safety, we look at the impact of measures on the number of accidents, deaths and injuries. In principle these impacts can be monetised, but it is not necessary. There can be ethical reasons which prevent that. If that is the case, it is sufficient to quantify the number of accidents, injuries and deaths.
- Qualitative aspects lead to impacts that cannot be quantified, such as emotion, comfort, image or the quality of the landscape. Sometimes the number of relevant aspects may be large.
- The importance of the interaction between measures (mutual strengthening and weakening of measures) is also included in the assessment of the impacts of measures. Mutual strengthening generates extra points.

Table 7.5 Example of matrix netting monetised impacts

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Costs per measure	1000	500	200	200	300	250	0
Changes in travel costs (1000 €)	2000		1000	500	25	15	10
Changes in emissions (1000 €)	15	20	25	2	3	2	1
Changes in accidents (1000 €)		200	300		100		
Changes in casualties (1000 €)		1000	2000				
Changes in deaths (1000 €)		100	200		200		
Balance	1015	820	3325	302	28	−233	11
Relative score on balance	7	6	10	3	2	1	2

7.3.2.6 Step 6 – determine the weight for the different aspects

Per region, differences in goals and interests could lead to weigh one aspect (accessibility, safety, environment, qualitative aspects or interaction) larger or smaller than the others. Therefore, in the sixth step it is possible to assign weights to the various aspects in order to arrive at a well-balanced package of measures. Furthermore, it provides awareness about the extent in which the five aspects contribute to the end result. The weights can be selected on a scale of 1–100, but of course the sum of the weights should be 100 in total.

7.3.2.7 Step 7 – perform multi-criteria analysis

Once the weights have been determined, a multi-criteria analysis can be performed, including all aspects. With this exercise it becomes clear which measure is the best, based on a weighted average over all aspects, and which one gives the least result. In Table 7.6 the aspects safety and environment are not monetised, but their relative scores are used. It is shown that before weighing the green wave is the best measure, but after weighing the bundling of goods is somewhat better.

If the aspects accessibility, safety and environment are monetised, we can use the relative scores on balance (see Table 7.5). The outcome is shown in Table 7.7. In this case the green wave is the best measure which is due to the lower costs and a better score on safety.

7.3.2.8 Step 8 – perform sensitivity analysis

Given the available budget and the cost per measure, the sensitivity of multiple different packages of measures can be determined. This is done using the results of steps 2 and 5. The cost of a measure can be taken from step 2 and the average rank over all aspects and effects can be used from step 5. Within the available budget, several composed packages of measures are possible. Normally, the budget is exhausted, but obviously there is a chance that the budget is exceeded or under-utilised. In addition, the possibility exists that the optimal package of measures in terms of benefits requires extra funding requirements in access of the original budget. In that case the discussion will focus on the question where extra financial sources can be found.

7.3.2.9 Step 9 – discuss the results and determine the best packages of measures

The final step in the process is a discussion between the stakeholders on the composite packages from step 8 and the weights from step 6. At the start basically every aspect gets the same weight. However, the practice will show that stakeholders attach more value to certain aspects. In step 6, the weights can be adjusted and it is therefore possible that some measures get different ranks as the valuation of the individual aspects changes. Optionally, a second iteration can be done from step 5 to step 8 in order to change the composition of the packets on the basis of the modified weights.

The composite packages show, given the cost and the available budget, what measures can be taken together in one package. Discussion between the stakeholders must give agreement on which package of measures is the best and should be chosen.

Table 7.6 Example of the rankings with and without weighing (without monetisation)

	Bundle goods	Eco-transport	Green wave	Information	Measure X	Measure Y	Measure Z
Accessibility	10.0	1.0	5.5	3.2	1.1	1.0	1.0
Safety	4.5	1.0	10.0	4.5	9.9	4.5	4.5
Environment	5.6	7.9	10.0	1.3	1.4	1.1	1.0
Perception	1.0	7.4	10.0	6.1	4.9	7.4	4.9
Interaction	10.0	7.5	6.7	3.5	1.8	1.0	3.5
Total score	**31.2**	**24.9**	**42.2**	**18.7**	**19.0**	**15.1**	**14.8**

	Weight
Accessibility	50
Safety	15
Environment	15
Perception	10
Interaction	10
Total	**100**

	Bundle goods	Eco-transport	Green wave	Information	Measure X	Measure Y	Measure Z
Accessibility	5.0	0.5	2.7	1.6	0.5	0.5	0.5
Safety	0.7	0.2	1.5	0.7	1.5	0.7	0.7
Environment	0.8	1.2	1.5	0.2	0.2	0.2	0.2
Perception	0.1	0.7	1.0	0.6	0.5	0.7	0.5
Interaction	1.0	0.8	0.7	0.3	0.2	0.1	0.3
Total score	**7.6**	**3.3**	**7.4**	**3.4**	**2.9**	**2.2**	**2.2**

Table 7.7 Example of the rankings with and without weighing (with monetisation)

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Balance	6.7	5.8	10.0	3.5	2.2	1.0	2.1
Perception	1.0	7.4	10.0	6.1	4.9	7.4	4.9
Interaction	10.0	7.5	6.7	3.5	1.8	1.0	3.5
Total score	**17.7**	**20.8**	**26.7**	**13.1**	**8.9**	**9.4**	**10.4**

	Weight
Balance	80
Perception	10
Interaction	10
Total	**100**

	Bundle goods	**Eco-transport**	**Green wave**	**Information**	**Measure X**	**Measure Y**	**Measure Z**
Balance	5.4	4.7	8.0	2.8	1.8	0.8	1.7
Perception	0.1	0.7	1.0	0.6	0.5	0.7	0.5
Interaction	1.0	0.8	0.7	0.3	0.2	0.1	0.3
Total score	**6.5**	**6.2**	**9.7**	**3.7**	**2.4**	**1.6**	**2.5**

7.4 Case studies

The AMDTM has been tested in three case studies. The outcomes of the case studies have been used to further fine tune the method. For the selection of the cases we looked at relevance, data availability and the variety of policy measures. These criteria provided a good view on the applicability of the AMDTM for infrastructural measures and measures for traffic management and the combination of both. The cases chosen were:

- Zoetermeer on the move: A case in which different traffic management measures were adopted and analysed;
- Rijnland connection: A case for a new connection between two motorways (A4 and A44) near Leiden. This case concerns different infrastructural alternatives;
- Region 'A15 River land': A case with several types of policy measures, consisting of a combination of infrastructural and other measures. Due to a lack of cost–benefit input, this case was rather qualitative.

To show how the method works in practice, two of the three cases are used as an example and for these cases the nine steps are described.

7.4.1 The nine steps for 'Zoetermeer on the move'

7.4.1.1 Description of the case

The goal of the project 'Zoetermeer on the move' was to reduce the number of trips by car between Zoetermeer and the Hague, not only on the A12 motorway, but also on other roads connecting the two cities. A feasibility study in 2012 investigated to what extend the business community in and around Zoetermeer could be involved to obtain this goal. As a result of these discussions five projects were implemented in the region:

1. Better use of the available fleet: attract employees of companies to use pool cars for business trips.
2. Bicycle network business parks: improve the attractiveness of bicycle routes to business parks on the aspect of comfort and social safety.
3. Logistics outside peak hours: companies take measures to redistribute logistic trips to periods outside the peak hours.
4. Z(x): work differently; organise mobility management (lease policy, stimulating the use of bicycles, introducing a mobility budget, etc.) within companies.
5. Peak hour avoidance: a programme to avoid car trips on the A12 in peak hours in which participants received a budget to accomplish that.

The projects ran from 2012 to 2014 and results were measured in terms of costs and benefits. Also, some aspects, which were relevant to the business community, were scored by experts. The results are shown in Table 7.8.

7.4.1.2 Interaction between the measures

The interaction between the measures is based on expert judgement. In Table 7.9 it is clear that peak hour avoidance has the highest score and improvement of the bicycle network the lowest.

Table 7.8 Results of the projects within 'Zoetermeer on the move'

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Costs					
Project costs (€)	91,000.00	82,000.00	70,000.00	1,09,500.00	28,00,000.00
Costs per reduced trip (€)	364.00	182.22	5.60	7.30	40.88
Benefits					
Number of reduced trips	250	450	12500	15000	68500
Travel time benefits (€)	557.08	1,002.75	1,33,525.00	1,15,745.00	1,70,542.17
Value of time (€)	9.55	9.55	45.78	33.07	10.67
Qualitative aspects					
Accessibility to companies	2	3	2	4	2
Traffic safety	1	2	2	3	3
Delay reduction in peak hours	2	5	2	5	9
Image of companies	2	8	1	5	5
Health of employees	2	9	1	9	4
Cost reduction for companies	9	3	9	4	2

Table 7.9 Interaction table for 'Zoetermeer on the move'

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**	**Total**
Better fleet management		0	1	2	2	5
Improvement bicycle network	0		0	1	1	2
Logistics outside peak hours	1	0		2	3	6
Z(x) work differently	1	0	1		2	4
Peak hours avoidance	1	0	3	2		6
Total	3	0	5	7	8	23
Relative score on interaction	6	1	8	8	10	

Table 7.10 Costs and benefits for the project period

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Costs per measure (€)	*91,000.00*	*82,000.00*	*70,000.00*	*1,09,500.00*	*28,00,000.00*
Travel time impacts (€)	557.08	1,002.75	1,33,525.00	1,15,745.00	1,70,542.17
Relative score on accessibility	1	1	8	7	10
Relative score on environment					
Relative score on safety					
Balance of costs and benefits (€)	−90,442.92	−80,997.25	63,525.00	6,245.00	−26,29,457.83
Relative score on balance	9	10	10	10	1

7.4.1.3 Costs and benefits

In this step the costs and benefits are determined. For this case no values for environment and safety were available. The results are shown in Table 7.10. Peak hour avoidance has large travel time benefits, but scores low on balance. Better fleet management has the lowest score on impacts. Logistics outside peak hours has the highest score if we look at the balance of costs and benefits.

7.4.1.4 Other quantifiable aspects

Other quantifiable aspects are not evaluated. Also environment and safety are not quantified, but taken into account in a qualitative way.

7.4.1.5 Unquantifiable aspects

Various unquantifiable aspects were scored by the stakeholders and a distinction is made between environment and safety and other aspects. For environment not the traditional aspects are used, but sustainable business and health of employees. The scores are given in Tables 7.11 and 7.12.

Table 7.11 Relative scores for environment and safety

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Sustainable business	2	8	1	5	5
Health of employees	2	9	3	9	4
Traffic safety	1	2	2	3	3
Total score on environment	4	17	4	14	9
Total score on safety	1	2	2	3	3
Relative score on environment	1	10	1	8	4
Relative score on safety	1	6	6	10	10

Table 7.12 Relative scores for other qualitative aspects

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Innovation	5	0	3	3	2
Attractive work climate	1	2	1	5	1
Total score on qualitative aspects	6	2	4	8	3
Relative score on qualitative aspects	7	1	4	10	3

7.4.1.6 Priority order of the impacts

If we take all the scores together for the five different groups of aspects, then we get Table 7.13. From this table we can conclude that ‘Z(x) work differently’ scores the best and ‘Better fleet management’ scores the lowest. However, here accessibility only includes the travel time benefits. If instead we include the balance of costs and benefits (see Table 7.10), then we obtain Table 7.14. Again ‘Z(x) work differently’ scores the best and ‘Better fleet management’ the lowest, but the difference with the other measures is much lower.

7.4.1.7 Multi-criteria analysis

Weighing accessibility with 60 and the other aspects of Table 7.13 with 10 we get the results from Table 7.15. From this table we can conclude that peak hour avoidance is the best measure and better fleet management the worst. But if we include the balance of costs and benefits into the MCA the results change as we can see from Table 7.16 that due to the high costs peak hour avoidance is the measure with the lowest score and Z(x) work differently is now the best measure.

7.4.1.8 Sensitivity analysis

The results are sensitive not only to the aspects that are used as input for the MCA, but also to the weights. If we change the weights for Table 7.15 and give

Table 7.13 Scores per aspect and measure without balance

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Accessibility	1	1	8	7	10
Safety	1	6	6	10	10
Environment	1	10	1	8	4
Qualitative aspects	7	1	4	10	3
Interaction	6	1	8	8	10
Total score	**16**	**19**	**26**	**43**	**37**

Table 7.14 Scores per aspects and measure with balance

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Balance of costs and benefits	9	10	10	10	1
Safety	1	6	6	10	10
Environment	1	10	1	8	4
Qualitative aspects	7	1	4	10	3
Interaction	6	1	8	8	10
Total score	**24**	**27**	**28**	**45**	**28**

Table 7.15 Results from MCA without balance

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Accessibility	0.6	0.6	4.8	4.3	6.0
Safety	0.1	0.6	0.6	1.0	1.0
Environment	0.1	1.0	0.1	0.8	0.4
Qualitative aspects	0.7	0.1	0.4	1.0	0.3
Interaction	0.6	0.1	0.8	0.8	1.0
Total score	**2.1**	**2.4**	**6.6**	**7.8**	**8.7**

Table 7.16 Results for MCA using CBA

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Balance of costs and benefits	5.7	5.7	6.0	5.9	0.6
Safety	0.1	0.6	0.6	1.0	1.0
Environment	0.1	1.0	0.1	0.8	0.4
Qualitative aspects	0.7	0.1	0.4	1.0	0.3
Interaction	0.6	0.1	0.8	0.8	1.0
Total score	**7.1**	**7.5**	**7.8**	**9.5**	**3.3**

Table 7.17 Results from MCA with different weights

	Better fleet management	**Improvement bicycle network**	**Logistics outside peak hours**	**Z(x) work differently**	**Peak hour avoidance**
Accessibility	0.5	0.5	4.0	3.5	5.0
Safety	0.1	0.6	0.6	1.0	1.0
Environment	0.1	1.0	0.1	0.8	0.4
Qualitative aspects	1.4	0.2	0.8	2.0	0.5
Interaction	0.6	0.1	0.8	0.8	1.0
Total score	**2.7**	**2.4**	**6.2**	**8.1**	**7.9**

accessibility a weight of 50, qualitative aspects a weight of 20 and the other aspects a weight of 10, then Table 7.17 emerges. With this set of weights the measure Z(x) work differently scores best.

7.4.1.9 Results and best package of measures

For this case several measures were compared with each other. Suppose the budget was limited to about 200 k€, then the measure peak hour avoidance would not be chosen. However, even if the budget is high enough, the question remains if peak hour avoidance is chosen or that the money would be spent on other projects.

7.4.1.10 Some conclusions from the case 'Zoetermeer on the move'

From the case 'Zoetermeer on the move' several points of interest can be derived from the application of the AMDTM.

- The input was not as expected, because for the environment and safety aspects no quantitative information was available, only some scores on related sub-aspects. We solved this by summing these scores to a total score and use this total score for the MCA.
- Using only the impact on accessibility in the MCA or the balance of costs and benefits for accessibility makes a huge difference. This is due to the high costs of one the measures, which does not influence the impact, but has a large influence on the balance.
- Due to the divergent values for costs, high positive scores can result for measures with a negative balance of costs and benefits (see Table 7.10). This is something to consider in step 2.

The AMDTM gives useful support in deciding on the measures to implement, especially if a budget is limited in comparison with the total costs of the measures. Clearly, the weights in the MCA are important for the results. Playing with them gives insight in the sensitivity of the results.

7.4.2 The nine steps for 'A15 River land'

7.4.2.1 Description of the case

The project 'A15 River land' was carried out with the objective to:

- Make an analysis of the current and future problems on the A15 Motorway from Rotterdam to Germany (more specifically between Gorinchem and Valburg), as well as the underlying road network in this region;
- Provide a broad package of policy measures to overcome these problems.

Different policy measures have been drafted within this project. A selection of these policy measures have served as input for the case study. The location of these measures is shown in Figure 7.2. The inset shows the location of the region 'River land' in the Netherlands. The AMTDM could not be used to a full extent as for most policy measures the costs and benefits of implementation were unknown. Therefore only an MCA could be used. Input for the MCA was collected by means of a workshop with different stakeholders. This section provides an overview of the use of the AMTDM.

7.4.2.2 Interaction between the measures

Some 22 measures were taken into account. Table 7.18 provides an overview of the assumed interaction between the different transport measures.

7.4.2.3 Costs and benefits

The costs are usually given in Euros, but at this stage of the project, most cost data were not available. By means of a discussion and rating tool (Meetingsphere), the

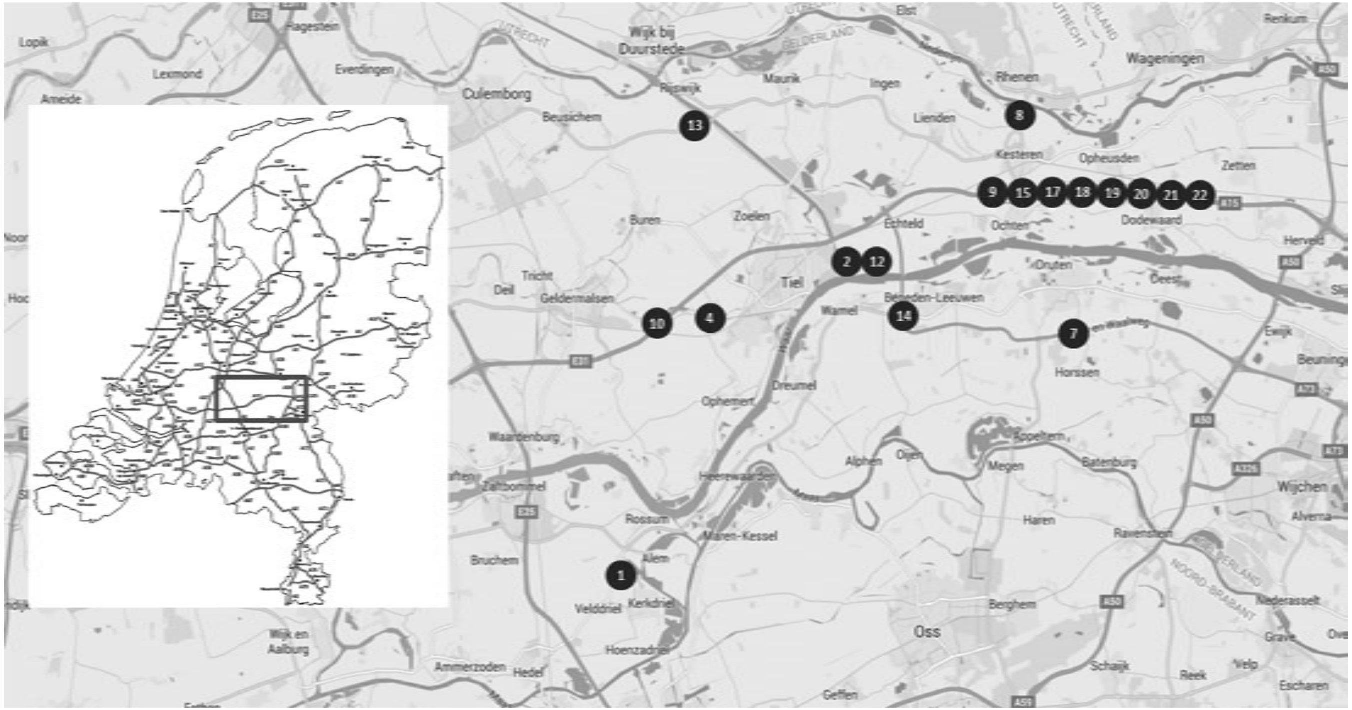

Figure 7.2 Location of 'River land' and its measures

Table 7.18 *Interaction between the measures for ‘A15 River land’*

No.	Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Sum
1	Accessibility Kerkdriel-North																							0
2	Better access logistic hotspot Medel						1						1											2
3	Promotion e-bike				1								1											2
4	Fast bicycle path Geldermalsen-Tiel			2																				2
5	Bundling freight		1				1					1												3
6	Re-scheduling freight transport					1		1																2
7	Improvement traffic flow N322/N323																							0
8	Increase capacity N233 (Kesteren-Rhenen)																							0
9	Extra lane on A15										−2	1							2	−1	−1	1	−1	−1
10	Peak hour lane A15 between Tiel and Deil		1																2	1	1	1	1	7
11	Automated driving								1	1	1		1	1			1				1			7
12	Mobility management Medel		1	1	1																			3
13	Traffic safety N320 (Culemborg-Kesteren)																1							1
14	Safety intersection Maas-Waalweg																1							1
15	No billboards A15																1							1
16	Awareness driving behaviour			1								2	1	1	1			1					1	8
17	Better design curves A15																1							1
18	Ramp metering A15		1							1	2									1	1	1	1	8
19	Usage A15 in off-peak hours									1	1								1				1	4
20	Control traffic A15 using real-time data									1	1	1							1	1		1	1	7
21	Longer acceleration lanes A15									1	1								1				1	4
22	Motorway traffic management system A15									1	1								1	1	1			5
	Total score	0	4	4	2	1	2	1	1	6	5	5	4	2	1	0	5	1	8	3	3	4	5	67
	Relative score	1	4	4	3	3	3	2	2	4	8	8	5	3	2	2	8	2	10	5	7	6	7	

costs were scored, ranging from ‘very low’ to ‘very high’. After that, relative scores were calculated (a high relative score means low costs). Table 7.20 shows the costs. As can be seen, the costs for extra capacity on the motorway were assessed as very high. All other costs were lower and due to the large difference in costs, all other measures do not score very different on this aspect.

7.4.2.4 Unquantifiable impacts

As benefits could not be expressed in quantitative or monetary terms, all benefits were assessed by the stakeholders in a qualitative way. Table 7.19 shows the scores on accessibility, but also on safety, environment and other qualitative aspects. As can be seen the extra capacity on the A15 scores highest on accessibility, while all other measures have a lower score.

7.4.2.5 Priority order of the impacts

The relative scores for the different impacts are put together. For each measure, the scores are summed. In Table 7.19 four transport measures have been marked grey. Motorway traffic management scores best with 35.2 points. Bundling freight flows

Table 7.19 Scores for all aspects without costs

Nr	**Measure**	**Costs**	**Accessibility**	**Environment**	**Safety**	**Quality**	**Interaction**	**Total score**
1	Accessibility Kerkdriel-North		7.4	4.5	5.0	1.9	1.0	19.8
2	Better access logistic hotspot Medel		7.4	6.0	5.0	1.0	4.4	23.8
3	Promotion e-bike		3.6	10.0	1.0	6.8	4.4	25.8
4	Fast bicycle path Geldermalsen-Tiel		4.2	10.0	4.0	9.2	3.3	30.7
5	Bundling freight		5.8	9.5	6.0	7.6	3.3	32.2
6	Re-scheduling freight transport		3.6	7.0	4.5	1.9	3.3	20.3
7	Improvement traffic flow N322/N323		7.9	5.5	4.5	4.7	1.6	24.2
8	Increase capacity N233 (Kesteren-Rhenen)		8.4	2.0	3.5	2.8	1.6	18.3
9	Extra lane on A15		10.0	1.0	5.5	5.1	3.8	25.4
10	Peak hour lane A15 between Tiel and Deil		10.0	3.0	4.0	6.0	7.8	30.8
11	Automated driving		3.9	7.5	6.5	10.0	7.8	35.7
12	Mobility management Medel		4.7	8.5	4.0	5.1	4.9	27.2
13	Traffic safety N320 (Culemborg-Kesteren)		1.0	5.5	9.5	5.6	2.7	24.3
14	Safety intersection Maas-Waalweg		1.0	5.5	10.0	5.6	2.1	24.2
15	No billboards A15		2.1	5.5	6.5	4.7	1.6	20.4
16	Awareness driving behaviour		2.1	7.2	7.5	2.7	8.3	27.8
17	Better design curves A15		2.6	5.5	7.5	1.9	2.1	19.6
18	Ramp metering A15		5.2	6.6	6.9	1.9	10.0	30.6
19	Usage A15 in off-peak hours		4.7	8.0	6.0	4.4	4.9	28.0
20	Control traffic A15 using real-time data		5.8	7.5	6.0	6.8	6.6	32.7
21	Longer acceleration lanes A15		5.8	6.6	7.5	6.8	5.5	32.2
22	Motorway traffic management system A15		5.8	7.5	8.5	6.8	6.6	35.2

scores second best with 32.2 points, followed by peak hour lanes (30.8 points) and the promotion of e-bike (25.8 points).

Table 7.20 also shows the relative scores for the costs of the measures. Adding these does not change the order of the four marked policy measures. The high costs of widening the A15 motorway with an extra lane has the result that the score for costs of most other transport measures do not differ from each other.

7.4.2.6 Weights for the different aspects

The weights for the different measures have been determined by the stakeholders, with and without costs. They are shown in Table 7.21.

7.4.2.7 Multi-criteria analysis

Applying the weights without costs leads to the situation in which the extra capacity of the motorway becomes most attractive. The peak hour lane has the highest score and also the extra lane scores high, because both score well on accessibility which got a high weight. Promotion of e-bike scores lowest as this measure scores low on accessibility. All scores are shown in Table 7.22.

Table 7.20 Score for all aspects including costs

Nr	**Measure**	**Costs**	**Accessibility**	**Environment**	**Safety**	**Quality**	**Interaction**	**Total score**
1	Accessibility Kerkdriel-North	9.5	7.4	4.5	5.0	1.9	1.0	29.3
2	Better access logistic hotspot Medel	10.0	7.4	6.0	5.0	1.0	4.4	33.8
3	Promotion e-bike	10.0	3.6	10.0	1.0	6.8	4.4	35.8
4	Fast bicycle path Geldermalsen-Tiel	10.0	4.2	10.0	4.0	9.2	3.3	40.7
5	Bundling freight	10.0	5.8	9.5	6.0	7.6	3.3	42.2
6	Re-scheduling freight transport	10.0	3.6	7.0	4.5	1.9	3.3	30.3
7	Improvement traffic flow N322/N323	10.0	7.9	5.5	4.5	4.7	1.6	34.2
8	Increase capacity N233 (Kesteren-Rhenen)	9.9	8.4	2.0	3.5	2.8	1.6	28.2
9	Extra lane on A15	1.0	10.0	1.0	5.5	5.1	3.8	26.4
10	Peak hour lane A15 between Tiel and Deil	6.0	10.0	3.0	4.0	6.0	7.8	36.8
11	Automated driving	9.8	3.9	7.5	6.5	10.0	7.8	45.5
12	Mobility management Medel	10.0	4.7	8.5	4.0	5.1	4.9	37.2
13	Traffic safety N320 (Culemborg-Kesteren)	9.9	1.0	5.5	9.5	5.6	2.7	34.2
14	Safety intersection Maas-Waalweg	10.0	1.0	5.5	10.0	5.6	2.1	34.2
15	No billboards A15	10.0	2.1	5.5	6.5	4.7	1.6	30.4
16	Awareness driving behaviour	10.0	2.1	7.2	7.5	2.7	8.3	37.8
17	Better design curves A15	10.0	2.6	5.5	7.5	1.9	2.1	29.6
18	Ramp metering A15	10.0	5.2	6.6	6.9	1.9	10.0	40.6
19	Usage A15 in off-peak hours	10.0	4.7	8.0	6.0	4.4	4.9	38.0
20	Control traffic A15 using real-time data	10.0	5.8	7.5	6.0	6.8	6.6	42.7
21	Longer acceleration lanes A15	10.0	5.8	6.6	7.5	6.8	5.5	42.2
22	Motorway traffic management system A15	9.9	5.8	7.5	8.5	6.8	6.6	45.1

Table 7.21 Two different sets of weights

	Weight		**Weight**
		Costs	44
Accessibility	47	Accessibility	27
Safety	18	Safety	10
Environment	20	Environment	11
Qualitative aspects	9	Qualitative aspects	5
Interaction	6	Interaction	4
Total	**100**		**100**

Table 7.22 Results of MCA without costs

Nr	**Measure**	**Costs**	**Accessibility**	**Environment**	**Safety**	**Quality**	**Interaction**	**Relative score**
1	Accessibility Kerkdriel-North		3.5	0.9	0.9	0.2	0.1	5.5
2	Better access logistic hotspot Medel		3.5	1.2	0.9	0.1	0.3	5.9
3	Promotion e-bike		1.7	2.0	0.2	0.6	0.3	4.7
4	Fast bicycle path Geldermalsen-Tiel		2.0	2.0	0.7	0.8	0.2	5.7
5	Bundling freight		2.7	1.9	1.1	0.7	0.2	6.6
6	Re-scheduling freight transport		1.7	1.4	0.8	0.2	0.2	4.3
7	Improvement traffic flow N322/N323		3.7	1.1	0.8	0.4	0.1	6.1
8	Increase capacity N233 (Kesteren-Rhenen)		3.9	0.4	0.6	0.3	0.1	5.3
9	Extra lane on A15		4.7	0.2	1.0	0.5	0.2	6.6
10	Peak hour lane A15 between Tiel and Deil		4.7	0.6	0.7	0.5	0.5	7.0
11	Automated driving		1.8	1.5	1.2	0.9	0.5	5.9
12	Mobility management Medel		2.2	1.7	0.7	0.5	0.3	5.4
13	Traffic safety N320 (Culemborg-Kesteren)		0.5	1.1	1.7	0.5	0.2	3.9
14	Safety intersection Maas-Waalweg		0.5	1.1	1.8	0.5	0.1	4.0
15	No billboards A15		1.0	1.1	1.2	0.4	0.1	3.8
16	Awareness driving behaviour		1.0	1.4	1.4	0.2	0.5	4.5
17	Better design curves A15		1.2	1.1	1.4	0.2	0.1	4.0
18	Ramp metering A15		2.4	1.3	1.2	0.2	0.6	5.8
19	Usage A15 in off-peak hours		2.2	1.6	1.1	0.4	0.3	5.6
20	Control traffic A15 using real-time data		2.7	1.5	1.1	0.6	0.4	6.3
21	Longer acceleration lanes A15		2.7	1.3	1.4	0.6	0.3	6.3
22	Motorway traffic management system A15		2.7	1.5	1.5	0.6	0.4	6.8

When the costs are taken into account, adding extra capacity drop in the list and now the motorway traffic management scores best. The relative low weight of accessibility and the high weight for the costs are the reasons for this. The relative scores for all measures are given in Table 7.23.

Table 7.23 Results for MCA including costs

Nr	Measure	Costs	Accessibility	Environment	Safety	Quality	Interaction	Relative score
1	Accessibility Kerkdriel-North	4.2	2.0	0.5	0.5	0.1	0.0	7.3
2	Better access logistic hotspot Medel	4.4	2.0	0.7	0.5	0	0.2	7.8
3	Promotion e-bike	4.4	1.0	1.1	0.1	0.3	0.2	7.0
4	Fast bicycle path Geldermalsen-Tiel	4.4	1.1	1.1	0.4	0.4	0.1	7.5
5	Bundling freight	4.4	1.6	1.0	0.6	0.3	0.1	8.0
6	Re-scheduling freight transport	4.4	1.0	0.8	0.5	0.1	0.1	6.8
7	Improvement traffic flow N322/N323	4.4	2.1	0.6	0.5	0.2	0.1	7.8
8	Increase capacity N233 (Kesteren-Rhenen)	4.4	2.3	0.2	0.4	0.1	0.1	7.4
9	Extra lane on A15	0.4	2.7	0.1	0.6	0.2	0.2	4.2
10	Peak hour lane A15 between Tiel and Deil	2.6	2.7	0.3	0.4	0.2	0.3	6.6
11	Automated driving	4.3	1.1	0.8	0.7	0.4	0.3	7.6
12	Mobility management Medel	4.4	1.3	0.9	0.4	0.2	0.2	7.4
13	Traffic safety N320 (Culemborg-Kesteren)	4.4	0.3	0.6	1.0	0.2	0.1	6.5
14	Safety intersection Maas-Waalweg	4.4	0.3	0.6	1.0	0.2	0.1	6.6
15	No billboards A15	4.4	0.6	0.6	0.7	0.2	0.1	6.5
16	Awareness driving behaviour	4.4	0.6	0.8	0.8	0.1	0.3	6.9
17	Better design curves A15	4.4	0.7	0.6	0.8	0.1	0.1	6.6
18	Ramp metering A15	4.4	1.4	0.7	0.7	0.1	0.4	7.7
19	Usage A15 in off-peak hours	4.4	1.3	0.9	0.6	0.2	0.2	7.5
20	Control traffic A15 using real-time data	4.4	1.6	0.8	0.6	0.3	0.3	7.9
21	Longer acceleration lanes A15	4.4	1.6	0.7	0.8	0.3	0.2	7.9
22	Motorway traffic management system A15	4.4	1.6	0.8	0.9	0.3	0.3	8.1

7.4.2.8 Sensitivity analysis

The sensitivity analysis has been carried out in the meeting with the stakeholders. It shows that taking into account the costs at this stage of the project has significant implications for the ranking of the measures.

7.4.2.9 Some conclusions for the case 'A15 River land'

During the meeting with the stakeholders the discussions were determined by the costs of the measures and the scale that was used (5-step scale) and finally who will pay for the measures. The discussion partially influenced the scoring procedure as well as making choices between measures. The assessment method has been developed to weigh the different measures equally. Therefore a focus should be put on the impacts, then ranking the measures based upon their scores and finally look at the scores based upon their (financial) feasibility, support and available information.

Scoring the measures may lead to quick wins of some measures which can be realised on short term. For other more expensive measures the costs need to be determined first. This asks for more information. The amount of investments needs further insight in the financial feasibility of the policy measures before they can be implemented.

Finally, this case shows that it is difficult to take into account transport measures that differ much, such as a parking facility for bikes and extra capacity on a motorway. We conclude that the transport measures should have some relation to each other concerning size and costs.

7.4.3 Conclusions from all cases

Based upon all three cases we came to the following conclusions:

- The assessment method can be applied for the selection of different packages of policy measures, both similar and disparate measures, such as infrastructural projects and traffic management projects
- The AMDTM has added value in an early stage of policymaking. It provides a feeling of the relative impacts of the policy measures. In a later stage the AMDTM can also be applied when more detailed cost–benefit information becomes available.
- When real costs are not available, discussions may arise on the question ‘Who will pay?’ and this may disturb the assignment of scores or the choice between measures.
- Policy measures with high benefits may be rejected in an early stage due to high costs, even though it is not yet clear what the available budget is. Therefore we feel it would be better to put benefits in front of the process instead of costs: a Benefit–Cost analysis in other words.
- In the case of the Rijnland connection, in reality one of the variants was rejected because the benefits were not fully taken into account, simply because of the focus on the costs. The application of the AMDTM showed that the variant could have been valuable, due to a more positive score on the benefits. This shows the merits of the AMDTM.
- The case of A15 River land shows that the policy measures should not diverge too much if only an MCA is carried out. The differences between small and large policy measures, such as parking bikes versus development of a motorway, may hamper a good evaluation of the projects. The projects should be more or less in line with each other. A possible solution is to do the assessment in two steps: one assessment for a package of smaller measures and an assessment for a package of big measures.

The conclusions from the case studies show that the AMDTM is a tool that adds value to policy making process, both at an early stage and in later stage.

7.5 Conclusions

Nowadays the budgets for infrastructural measures and other policy measures are less fixed than it used to be. This is amongst other things due to the possibility of co-finance of policy measures. This gives room to relative expensive measures which are financially feasible because the benefits are rather high. This broadens the public support for these types of measure due to the co-finance possibilities.

The AMDTM keeps the scope as broad as possible and may lead to creative solutions concerning policy packages. This will not be the case if only costs are leading. Instead we need to let the benefits lead, so a BC analysis instead of a CB analysis. The benefits in terms of accessibility, safety, environment and qualitative aspects should come first, then the costs and finally who will pay. This gives room to the selection process in which benefits are equally taken into account.

Giving benefits the lead may imply that for step 2 of the approach only benefits and not the costs are taken into account. Especially this could be helpful in the case when the costs of measures differ strongly and in order to avoid undesired influences of this, the costs could be left out in this step. When discussing the different packages in step 8 the costs are included again, as well as the question how measures can be financed.

This approach helps to show what is most effective, even if the costs are high but financially feasible. This way a choice can be made between measures that can or cannot be taken. And it helps phasing different policy measures, such as quick wins against more elaborated policy measures, by doing this in a transparent way.

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References

[1] Rijkswaterstaat. *Handbook Sustainable Traffic Management*. AVV Transport Research Centre, Rotterdam, the Netherlands, 2003.

[2] Taale, H., Westerman, M., Stoelhorst, H., Van Amelsfort, D. 'Regional and Sustainable Traffic Management in the Netherlands: Methodology and Applications', *Proceedings of the European Transport Conference 2004*, Strasbourg, France, 2004.

[3] Rijkswaterstaat. *Manual for the Accessibility Solutions Method*. RWS Water, Traffic and Environment, Rijswijk, the Netherlands, 2014.

[4] Ecorys. *Assistance for Cost-Effectiveness Analysis*. Report for Rijkswaterstaat, Rotterdam, the Netherlands, 2014.

[5] MuConsult. *Procedure Ex ante CBA Tool Toekan*. Report for Rijkswaterstaat, Amersfoort, the Netherlands, 2011.

[6] Taale, H., Schuurman, H. 'Effects of Traffic Management in the Netherlands – An Overview of 190 Assessments', TrafficQuest, Version 3.3, 2015.

[7] Sijtsma, F.J. *Project Evaluation, Sustainability and Accountability*. PhD Thesis, University of Groningen, 2006.

[8] CROW. Wikken & Wegen [online]. 2014. Available at www.wikken-wegen.nl. [Accessed 29 Mar 2016].
[9] HU and Ministry of Infrastructure and the Environment. *CORT & Krachtig*. 2014.
[10] Romijn, G., Renes, G. *General Guidance for Cost-Benefit Analysis.* CPB Netherlands Bureau for Economic Policy Analysis, PBL Netherlands Environmental Assessment Agency, The Hague, 2013.

Chapter 8

Technical assessment of the performance of in-vehicle systems

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8.1 Introduction

Progress in the application of information and communication technologies in the automotive field is enabling the development of increasingly sophisticated advanced driving assistance systems (ADAS). The recent introduction of 'cooperative systems' opens new horizons for improving road safety by exploiting the possibility of the exchange of data between vehicles, and also between vehicles and the infrastructure to detect potential dangers.

The result, however, is that the complexity of these systems has increased dramatically due to the integration of so many different elements: from the sensing systems themselves, to the communications equipment, the data bases and, above all, the numerous SW modules needed for processing the data. This makes it extremely difficult to trace the cause of malfunctioning once the full system is set up, and means that a well-designed validation procedure is essential so that problems can be resolved at an early stage.

The aim of this chapter is to describe a methodological framework and procedures to be used for the validation of such systems. However, it must not be seen as a rigid framework but rather as an approach that will need to be adapted to the specific needs. Indeed, test and validation is time and resources consuming and therefore it is requested to adapt the method such as to find the best compromise between efficiency, applicability and cost.

The method follows the ISO 9001 procedures, the system engineering V-shaped development process and the experience gained in the PReVAL [1], CONVERGE, APROSYS and SAFESPOT [2, 3] European projects.

Accordingly, this chapter is structured as follows:

- Section 8.2 is a reminder of some fundamental of metrology,
- Section 8.3 investigates the issue of testing complex system,
- Section 8.4 presents the main tools used for test and validation with their advantages and drawbacks,

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[1] IFSTTAR, France

- Section 8.5 is a proposal for a generic template for test and validation,
- Section 8.6 is a case study on an ISA++ driving assistance system: an enhanced ISA[1] system,
- Section 8.7 presents some conclusions.

8.2 Metrology reminder

Before discussing the validation procedures in more detail, it is necessary to give some basic definitions of metrology that will be used for the technical validation.

8.2.1 Range, accuracy and precision

The metrological quality of a measuring device is the set of characteristics that make this measuring device perform the measurements as required by the specifications. These characteristics are: range, accuracy and precision.

- Range is the field of possible variation of the measurement. It is defined by a minimum and maximum value;
- Accuracy is the degree of conformity of a measured or calculated quantity to its actual (true) value. Accuracy is closely related to precision, also called reproducibility or repeatability, the degree to which further measurements or calculations show the same or similar results. However, accuracy is the degree of veracity while precision is the degree of reproducibility;
- Precision is sometimes stratified into:
  - Repeatability: this concerns the variation in measurements taken by a single person or instrument on the same item and under the same conditions. A measurement may be said to be repeatable when this variation is smaller than some agreed limit.
  - Reproducibility: this concerns variability in test results obtained by different operators, with different test apparatus and laboratory locations but the same measurement process. It is often referred as a standard deviation.

8.2.2 Rates: accuracy in binary classification

'Accuracy' is also used as a statistical measure of how well a binary classification test correctly identifies or excludes a condition.

With reference to Table 8.1, the following rates can be defined:

$$\text{True positive:}\quad tp = \frac{a}{a+b} \tag{8.1}$$

$$\text{False negative:}\quad fn = \frac{b}{a+b} \tag{8.2}$$

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[1] ISA: Intelligent Speed Adaptation.

Table 8.1 Accuracy in binary classification

Accuracy in binary classification		**Condition (e.g. obstacle detection)**	
		True	**False**
Test outcome	Positive	True positive (a)	False positive (c)
	Negative	False negative (b)	True negative (d)

$$\text{False positive:} \quad fp = \frac{c}{c+d} \tag{8.3}$$

$$\text{True negative:} \quad tn = \frac{d}{c+d} \tag{8.4}$$

Moreover, the accuracy is the proportion of true results (both true positives and true negatives) in the population:

$$\text{Accuracy:} \quad a = \frac{a+d}{a+b+c+d} \tag{8.5}$$

An accuracy of 100 per cent means that the test never generates false alarm and non-detection.

This is only valid if both the true and false populations are of the same size. Otherwise, the alternative equation would be better:

$$a = \sqrt{\frac{a^2}{(a+c)(b+c)}} \tag{8.6}$$

It should be noted that the concept can be extended to non-binary classifiers. This is possible only if the number of classes is not too high. Indeed, to apply the method to non binary classifier it is necessary to develop as many rates table as there are classes. However, we have proposed to apply such extension, to a fog detector tested in the framework of the European SAFESPOT project.

8.2.3 Sampling size and sampling method

The number of tests performed should be related to the expected level of statistical confidence. For example, if N is the number of tests, f is the observed frequency and p is the probability of the phenomenon, the following statements apply:

$$N = 10, \qquad f = 0.9, \qquad 0.71 < p < 1 \tag{8.7}$$

$$N = 100, \qquad f = 0.9, \qquad 0.84 < p < 0{,}96 \tag{8.8}$$

with 95 per cent significance i.e. 5 per cent probability to be out of the interval (under hypothesis regarding p distribution).

The measurement plan should also guarantee:

- Completeness: concentrating the resources on most important aspects is better than spreading efforts with the consequence of a low statistical significance,
- Insularity: all the influence factors are considered,
- No disturbance of the validation process: no bias except accidental ones introduced in the measurement plan.

This is very challenging, as the performance of the sensors depends on a wide range of factors, such as environmental conditions, positioning and orientation of the sensors with respect to the road, and the traffic environment. At the moment of evaluation not all information on the actual installation (e.g. height and orientation of the sensor with respect to the road) may be available. Another issue is that most of the devices tested are proof-of-concept, and the sensing algorithms may be updated after the first tests to improve the performance.

Moreover, to have statistical significant results, the tests should be able to be completely controllable and repetitive, i.e. all influencing factors are the similar during a block of tests (weather conditions, luminosity, outside temperature). Due to resources limitation, the difficulty of testing the systems in a wide range of environmental conditions (e.g. testing in adverse weather conditions and dense traffic environments may require complex set-ups for protecting the prototype sensors), generating a statistically relevant number of tests is challenging.

Another problem is what is meant with a ‘sample’, in the case of continuous scanning (and if subsequent images are processed independently of each other). Is 1 test = 1 single image, or is 1 test = sequence of images? In the first case, success rate is calculated based on each separate image; in the second case based on events? In the first case, an event corresponds to a block of data (since all influencing parameters are the same).

8.2.4 Sensitivity and operational limits

Every measuring device has a number of limitations. On the one hand, some variable can influence a measurement and on the other hand other variable can determine the operational limits of performance.

The former are quantities that are not being measured but which may affect them, e.g. temperature can affect a far distance measurement.

Operational limitations may include variables that are not subject to the measure or the measured variable itself. For example, a system for measuring a distance of visibility in the fog based on contrast modelling can only work in certain lighting conditions or a measurement device will not operate outside a given or a measuring device will not work outside a given temperature range (e.g. $-20\,^{\circ}\mathrm{C}$ to $+70\,^{\circ}\mathrm{C}$).

8.3 Complex system validation

In a complex system, there are several components (or sub-system) that operate in interaction one from each other. Therefore, all of the system components will be subject to a technical verification whose aim is to verify that each of them satisfies the technical characteristics stated in the technical specifications. Each component may involve hardware (e.g. sensors), software (e.g. data fusion [DF]) or the association of hardware and software seen as a whole (e.g. a closed-circuit television [CCTV] camera connected to an image processing unit). In addition, an important part of the validation concerns the ability of the system to ensure the correct exchange of data between these elements.

8.3.1 System granularity

This highlights the need to define the granularity of the components. For example, if all relevant data regarding a sensor component's performances, in all the conditions where the component will be used, are available from the manufacturer's data sheets, there is no need for validation because these data can be used as a reference. Conversely, a fog sensing module which involves the association of a camera with a processor that runs software for visibility distance estimation must be validated. This example can be generalized to all detection components based on the same association. Further aspects of system hierarchy and granularity will be described below.

8.3.2 Technical validation of sensing modules

The principles of metrology outlined in section 8.2 will be applied to the testing of the sensing modules. The aim of the validation process is to verify that the performance of the modules meets the stated specifications, i.e. their ability to detect the respective object, event or conditions, with an acceptable level of accuracy, precision and reliability, and also:

- in the specified environmental conditions (temperature, daytime, night-time, etc.),
- over the specified distance range (in the case of the sensing of an object),
- with the specified traffic and road conditions (number of lanes, one-way, two-way road, traffic density, vehicle speed, etc.),
- with the correct delivery format, time stamping, geo-referencing (if necessary) and possibly a confidence level.

If there are known conditions in which the system does not work, these must be clarified, e.g. a detector which is guaranteed to operate only within a temperature range of −20 °C to +50 °C.

8.3.3 Technical validation of DF module

To achieve the high reliability level required for driving assistance systems, it is frequently necessary to introduce redundancy at the sensing level. Redundancy can be based on sensors and algorithms similarity or diversity. For example, lateral vehicle control based on lane detection system can make use of redundancy in different manners: vote between two cameras running similar or different detection algorithms or DF from radically different sensors (e.g. a camera and a laser scanner sensor).

In any cases, the objective of the DF process is to increase the quality of the available data. Therefore, the validation must be able to measure this enhancement.

DF of sub-systems exploits data redundancy and/or complementarities from sensing systems:

- It takes advantage of redundancy to increase the confidence in the measurement of some attributes of the object, i.e. it improves its metrological characteristics;
- It takes advantage of complementarities to increase the number of known attributes of the object, i.e. knowledge about the object.

In Figure 8.1, sensor S1 provides attributes a1 and a2 while sensing system S2 delivers a1, a3 and a4, sensor S3 provides a2, and finally S4 provides a1 and a4. All these attributes concern the same object.

The DF methods aim to provide the following benefits:

- An improvement of metrological characteristics of a1, a2 and a4 (the redundancy principle);
- More complete knowledge of the object as the attributes a1, a2, a3 and a4 are combined (the complementarities principle).

To validate a fusion module, it is therefore proposed to use a method based on a comparison, during the same test procedure, with and without fusion. It consists of:

- Comparing to a reference the metrological characteristics of the different attributes at the input and the output of the fusion box;
- Verifying that for new attributes obtained thanks to complementarities, their metrological characteristics have not been degraded by the fusion process.

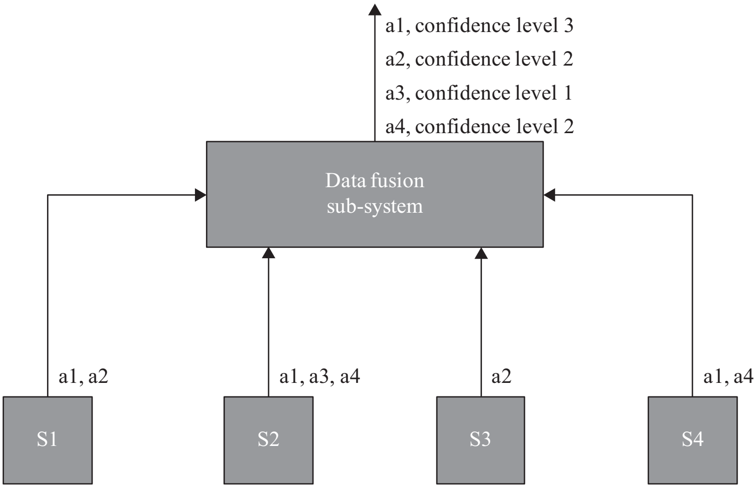

Figure 8.1 Simple fusion architecture

8.3.4 Latency time

Estimation of the latency time of the overall system is very complex. Indeed, action on vehicle actuators (in the case of active system) or warning messages to the driver (in the case of advisory system) is the result of a long chain of elaboration and transmission processes. This can make it difficult to identify the part of the chain responsible, if the latency performance does not meet the constraints.

Up to now, experience shows that overall system latency time is rarely estimated *a priori* but rather measured during test and validation and compared to specification that prescribe an upper limit which must not be exceeded.

To estimate the latency time, it is necessary to make a breakdown of the chain. There are two further factors that make this estimate complex and need to be considered:

- On the one hand, tasks performed at component level sometimes run sequentially and sometimes parallel and asynchronously,
- Secondly, the latency time of some components is non-deterministic (e.g. CAN* Bus messages transmission delay.)

It should be noted that with the emergence of cooperative system (including V2V, V2I) communication, latency time estimation becomes more and more complex due to the fact that the system to be considered in not only *one* vehicle but *two or more*. Indeed, an event detected by a sensing system of a vehicle A can generate a warning message on a vehicle B (e.g. Incident Hazard Warning System).

Therefore, to estimate global latency time, it is necessary to draw up for each event the full data chain from data source to the recipient (i.e. an actuator or an instrument panel).

Figure 8.2 illustrates the data chain principle:

- an event occurs on the road,
- after a time t1 (resp t2), it is detected by the image sensors S1 (resp S2),
- after a time t3 (resp t4), image is sampled by the Image processing component IP1 (resp IP2),

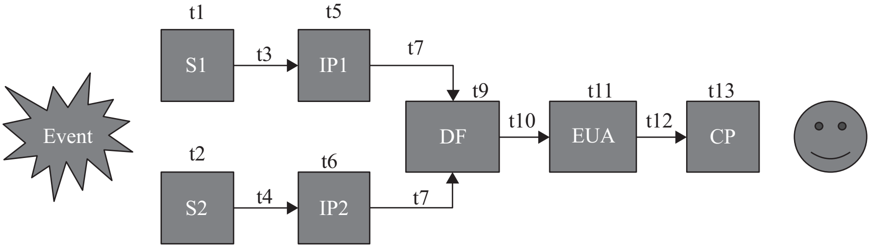

Figure 8.2 Overall system data chain. S1, S2: sensor; IP1, IP2: image processing; DF: data fusion; EUA: end user application; and CP: control panel

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*Controller Area Network

- after a time t5 (resp t6), image processing components deliver a result,
- after a time t7 (resp t8) results are sampled by DF component,
- after a time t9 an enhanced result is provided by DF component,
- after a time t10 this result is sampled by the end user application
- after a time t11 end user application provide a message to be displayed to the dashboard
- after a time t12 the message is sampled by the dashboard
- after a time t13 the message is provided to the driver.

Processing time like t1, t2, t5, t6, t9, t11, t3 are most likely deterministic. Conversely, according to the transmission media used between modules, t3, t4, t7, t10, t12 could be non-deterministic.

To approach latency time estimation, the data chain modelling could be done graphically under the form of data flow or using a hardware description language which after compilation will automatically provide latency time under the form of chronogram. In SAFESPOT project, such modelling was attempted using the VHDL language.

8.4 Test facilities

A variety of facilities and methods is available for carrying out the tests. Each has advantages and disadvantages. None of them is perfect but some have complementarities in relation to others. To carry out exhaustive tests, several different approaches will be used.

8.4.1 Real or virtual approaches

Real testing helps to validate both the hardware and software systems. This includes test beds, test tracks in a protected environment and traffic on public roads. They provide the opportunity to experiment with a great variety of situations. However, environmental conditions are difficult to control, which can make problems, when carrying out tests of repeatability.

Virtual tests are employed to validate the software systems. They include modelling tools, typically, MATLAB®, Simulink, driving simulators and virtual R&D lab, typically VEHIL from TNO [4] or PRO-SIVIC-RECHERCHE (Figure 8.3) from IFSTTAR [5, 6]. Both allow the execution of trials in absolute repeatability conditions. However, the link to reality is not as strong as with real means because the variety of situations is limited. To be representative, the tests require an accurate modelling of hardware components which they replace (sensors, actuators, vehicle dynamics, etc.).

For example, a fog detector can be tested in virtual condition provided there is a model which describes with accuracy the camera used in the detector (including its distortion) and a fog model. Similarly, to test the ice detector, it is necessary to have models for cameras, polarizing filters and ice reflectivity.

An important advantage of virtual tests is that it is not necessary to wait for the occurrence of specific environmental conditions to carry out the tests: fog or ice sensing modules can be validated at any time in summer or winter.

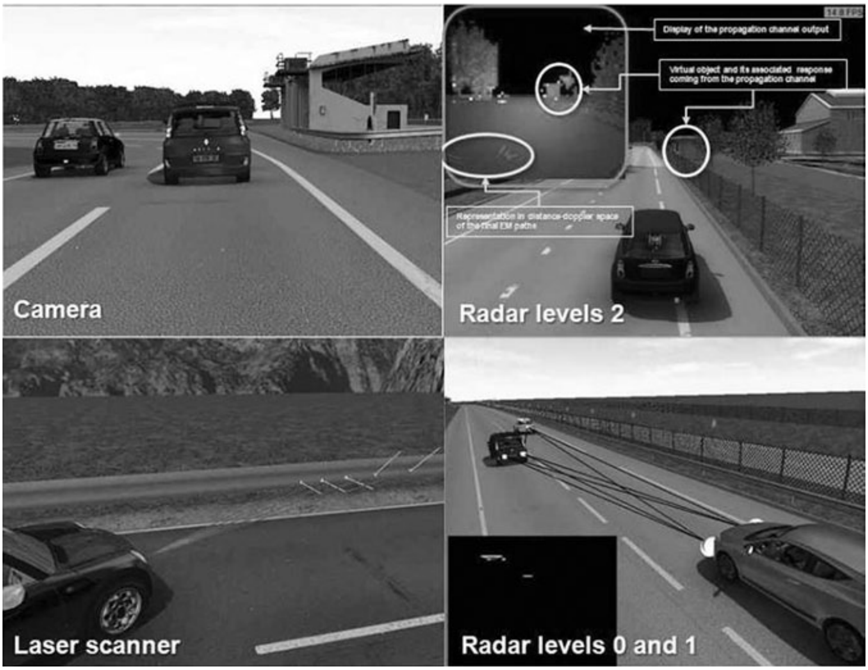


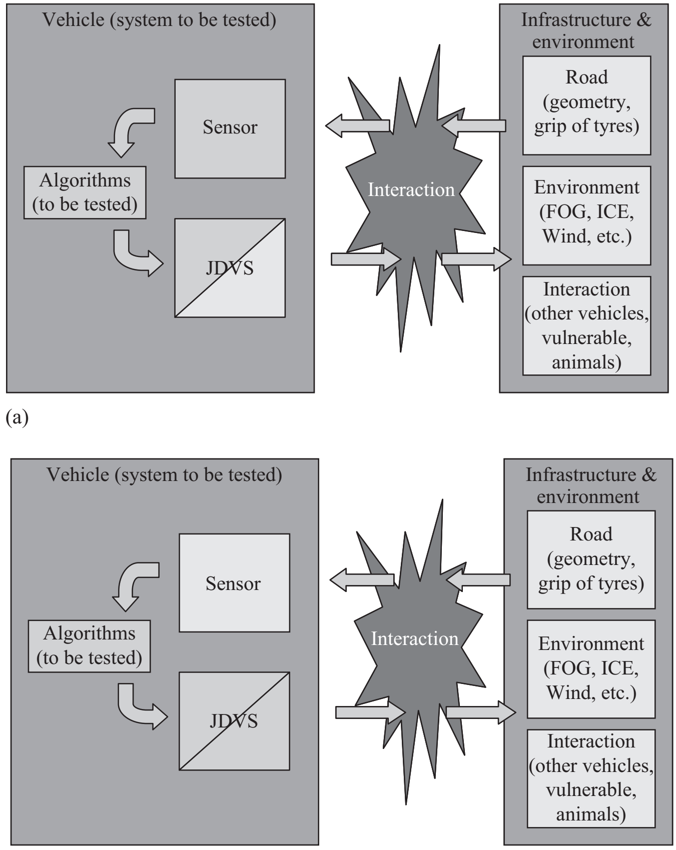
Figure 8.3 Virtual prototyping and testing of in-vehicle systems, namely camera, laser scanner and RADAR based systems, using PRO-SIVIC-RECHERCHE software from IFSTTAR. © 2008 SAFESPOT Consortium. Reprinted with permission from J. Ehrlich et al., Deliverable 2.5.1, SAFESPOT Project, SP2 – INFRASENS Infrastructure Platform – "Plan for testing and validation activities". SAFESPOT Consortium, November 2008

8.4.2 Hardware in the loop (HIL)

Midway between real and virtual is HIL. Figure 8.4 shows HIL model. HIL tests have meaning if there is a component chain including a feedback provided by actuators, by the driver himself or by a combination of both (Joint Driver-Vehicle System [JDVS]).

A typical example concerns the test of a lane-keeping function based on lane marking detection. The vehicle is integrated into the simulator on a treadmill or is raised to release the road-tyres contact. Figure 8.4 shows the distribution of real (medium grey) and virtual elements (light grey):

- A virtual scene is presented to front view cameras whose output signals are applied to a lane marking detection software;
- The software computes a lateral gap and heading and provides alert for the driver and/or correction for actuators;
- Alerts and/or orders are directed towards an HMI or the motor control of the steering wheel. Finally, the effect is to reduce the lateral and heading gaps.



(a)

(b)

Figure 8.4 HIL model for lane keeping. (a) HIL with real sensors and virtual actuators and (b) HIL with virtual sensors and real actuators

In this component chain, cameras or actuators elements can be real or virtual, depending on the kind of test carried out.

HIL test offer a good compromise between control of the test conditions and their representativeness: indeed, in HIL, environmental conditions are simulated therefore perfectly repetitive while sensors and actuators are real, thus avoiding errors due to bias in sensors and actuators models.

8.4.3 Test and validation tools

Table 8.2 draws up a list of test approaches with their benefits, drawbacks and main application domains:

- MATLAB®/Simulink simulation is more a modelling than a test tool. It is used very early in the development process, i.e. in the research phase. It allows the researcher to develop and test models quickly. Like any simulation tool, it has the advantage of offering a very controlled environment but very simple and therefore far from reality. Then it is not a tool well suited to our needs;

Table 8.2 Test tools

Tools	**Benefits**	**Drawback**	**Targets**
Simulation (MATLAB®, Simulink)	Controlled environment	Far from implementation	Mainly for component design
Environment simulator e.g. PRO-SIVIC-RECHERCHE (IFSTTAR), VEHIL (TNO)	Controlled environment	Availability of accurate sensors model	Design, test and validation of component or system
HIL	Controlled environment	Manly suited for ADAS (with actuators)	Test and validation of component or system
Reduced scale test benches	Semi-controlled environment	Scale effects, not totally realistic	Test and validation of component
Real scale test bench	Controlled but realistic	Focused on one situation	Test and validation of component or system
Test tracks	Semi-controlled, realistic and safe	Not totally controlled	Test and validation of component or system
Open road	Realistic, variability	Uncontrolled, random, sometimes dangerous	Test and validation of system

- Virtual labs provide very controlled environments and sensor modelling and therefore are well suited for the components or complete systems validation. However, a major difficulty is to have a realistic model of sensors. Virtual labs may not be sufficient in themselves when the variability of situations is sought or when the scenarios are complex and then must be completed with test on tracks or open road.
- HIL: this is an excellent compromise between representativeness and environmental conditions control. HIL is well suited to test ADAS where feedback is provided by actuators and/or driver;
- Low scale test bench: an example is the LIVIC (IFSTTAR) low scale test bench for fog detection and visibility distance estimation. It is an aquarium with a road inside at 1/20 scale and where it is possible to inject an artificial fog and replicate the lighting. This system offers a fairly good control of environmental conditions but introduces bias due to scale effect. Therefore, it can be used in a development phase of or for demonstrations, but not for testing;
- Real scale test bench: this offers both realistic test conditions and well controlled environmental conditions but little or no situation variability as they are focused generally on one testing scenario. It is therefore well suited for testing components.
- Test tracks: test tracks provide realistic test conditions, good variability but little opportunity to control environmental conditions. Test tracks are well suited for the validation of components or systems, and are a very good complement to a driving simulator or virtual lab.
- Open road: offers hyper realistic test conditions, large situation variability but no control on environmental conditions. As the tests are conducted in traffic, they can present a danger to testers or other road users. Then, they are reserved for the final test systems with high level of reliability.

8.5 A generic template for technical validation

In this section, we propose a generic template for technical validation. It consists of an Excel sheet which is specifically designed to suit the testing of the various system components.

Obviously, a simple Excel sheet is not sufficient to have a clear understanding of how a test must be carried out. Therefore, a test procedure has to be defined for each component with all the necessary information for those responsible for the implementation of the procedures. Such procedure is partially described in Table 8.6.

The proposed template is divided in five sections as described below.

8.5.1 Section 1: indicators, tools and procedures

8.5.1.1 Indicators

In this section, performance indicators to characterize the system are defined. These indicators must be defined to validate the effectiveness of the system with reference to its technical or functional specifications, according to its level in the system hierarchy.

8.5.1.2 Validation procedure

For each indicator, a measurement procedure has to be defined. It should be easy to implement and reproduce under identical conditions such as to have an amount of data statistically representative. It must rely on references deemed to provide value 'correct' indicators that the component is supposed to measure.

Under artificial conditions, this should be possible by equipping a vehicle with special sensors, etc.

Some environment variables can affect the system performance. If defined in the specifications, procedures should be applied in both normal and adverse conditions. At a given moment, only one condition must be changed.

8.5.1.3 Tools

The tools needed for the implementation of the method must be described including:

- Test equipment: simulator, HIL, test bench, test tracks, calibration area, small-scale model,
- References: a standard or an accurate measurement device (e.g. for location, distance, visibility measuring),
- Targets: characterized by their shape, reflectance, temperature, etc.

8.5.2 Section 2: results

This section describes the results achieved through the application procedures. These results are presented with comparison to expected results in reference to the specifications. It concerns range, accuracy and latency time.

The number of repetitions to calculate the accuracy must be specified.

The results will be provided for the so-called normal use conditions as well as for adverse conditions, if they were detailed in specifications.

8.5.3 Section 3: rates for classifier

For discrete variables (Boolean or multi-state variable), we will provide in this section rates tables (TP, TN, FP, FN) as described in § 8.2.2.

In contrast to the previous section, rate is calculated in a context where all environmental conditions of are mixed. Thus, the procedure is achieved on time interval long enough to meet this diversity of situation.

For example, to test an ice sensing module, the measurement campaign should be long enough to meet situations such as dry, wet and icy road, by day and night.

8.5.4 Section 4: system restrictions

In this section, we will indicate restriction of use in term of intervals values of certain variables beyond which the device is supposed no longer to work (temperature, relative humidity, power supply ranges, etc.).

This section does not refer to a particular indicator but rather to the component as a whole. Indeed, we can consider that if one of the indicators is outside expected performances, the whole component is failing.

8.5.5 Section 5: feedback (or link) to specifications

As above, this section deals with the component as a whole and not a specific indicator. This is to verify that the technical and functional specifications are met and this for both normal and adverse conditions.

Beside each specification ID number, and for each environmental conditions considered, the letter Y (yes) or N (no) will indicate whether the specification is satisfied or not satisfied.

8.6 A case study: ISA++

Speed management is a preoccupation for public authority as speed is considered as the main cause of traffic injury accidents. Traditional methods of limiting speed have only been moderately effective. Using driving assistance technology, speed enforcement can be enhanced through vehicle speed management programs, often referred to as Intelligent Speed Adaptation (ISA). An ISA system monitors the location and speed of the vehicle, compares it to a defined (legal) speed limit, and performs corrective action such as advising the driver and/or limiting the effect of the throttle pedal. ISA systems effects on speed reduction and safety improvement are now well known [7, 8].

8.6.1 System analysis

8.6.1.1 System to be tested

From a technical standpoint, most ISA system rely upon a localization system (Global Positioning System (GPS), odometer, gyrometer) that yields absolute vehicle coordinates (Figure 8.5(a)), along with a navigation system associated with a digital map showing these coordinates on a given road segment (Figure 8.5(b)) and a database that enables matching an authorized speed limit with each road segment (Figure 8.5(c)).

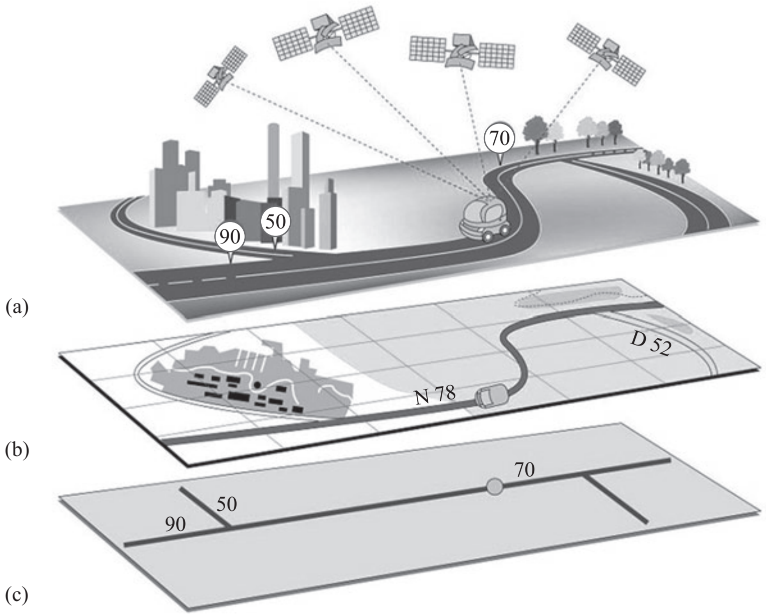


Figure 8.5 ISA basic operation layout. (a) Step 1 – Real world: a vehicle is located on the road thanks to its GPS receiver; (b) Step 2 – Digital Map: then, this vehicle location is plotted on the in-vehicle digital map which in turns delivers the current road segment number where the vehicle is driving; (c) Step 3 – Speed Data Base: the in-vehicle speed data base is then requested with the current road segment number and replies with the current speed limit attached to this segment

In this case study, it is proposed to investigate the test and evaluation of an improved version of ISA, namely ISA++, which is enhanced with two additional technologies: (1) speed limit road sign recognition and (2) visibility distance estimation in fog. To achieve this goal, the vehicle is equipped with two cameras located behind the front vehicle windshield coupled to the following image processing algorithms:

- Two independent road sign recognition algorithms [10], each one being coupled to a camera. Each of them delivers a speed limit value which is introduced into a voting algorithm which provides a legal speed limit if and only if the two algorithms deliver the same result,
- One unique algorithm stereo vision image processing algorithm coupled to both two synchronized cameras which delivers an estimation of the visibility distance in fog [11–13].

Therefore, the final value of the speed limit results on the following computation:

(a) Speed limit resulting from the speed database coupled to the navigation system is combined with the road sign recognition system to deliver a speed limit value with an improved level of confidence.

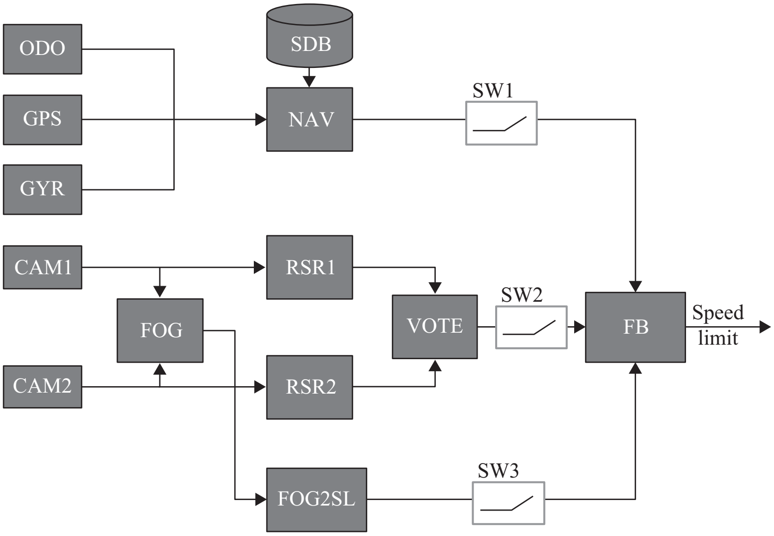


Figure 8.6 ISA++ functional architecture. ODO: odometer (distance sensor); GYR: gyrometer (heading sensor); GPS: GPS receiver (positioning sensor); CAM1 (2): front view camera 1 (and 2); FOG: image processing component for visibility distance estimation in fog; RSR1 (2): image processing component 1 (and 2) for road sign recognition; VOTE: voting algorithm between the two road sign recognition; FOG2SL: speed limit calculation based on visibility distance; FB: fusion box between various speed limit sources; and SW1, SW2, SW3: switches (for test only)

(b) Visibility distance estimation in fog is converted in a speed limit (taking into account time to collision with an obstacle) which can drop the speed limit mentioned in (a).

Figure 8.6 shows the functional architecture of such ISA++ system.

8.6.1.2 System requirements

System evaluation makes sense only if measured key performance indicators are compared to than expected. These are generally provided by the system requirements. Table 8.3 is a simplified form of ISA++ system requirements derived from deliverable DEL22 of Speed Alert Project [9]. However, to limit the scope of this study, we will exclude requirements that are not only driving-situation dependant assuming e.g. a perfect correspondence between the speed data base and the ground truth.

8.6.1.3 Causes of failure

For each requirement above mentioned, it is necessary to identify the possible causes of failure. Table 8.4 presents a simplified failure analysis that focuses only on some driving situation that could cause malfunction and excluding sensors of component failure. The goal is to develop use cases that incorporate such driving situations.

Table 8.3 Simplified ISA++ system requirement

Nr	Requirements
1.	ISA++ must provide 95 per cent of legal speed limit across all road categories.
2.	95 per cent of the speed limit values provided by the system must match the actual speed limit (indicated on road signs)
3.	95 per cent of the differences between the position of the speed limit provided to the driver and the actual position (on the road sign) must be less than 6 m
4.	95 per cent of fog situation where the visibility distance is less than or equal to 50 m must be detected
5.	In 95 per cent of detected situation (see requirement Nr 4) visibility distance must be estimated with relative accuracy better than 10 per cent.
6.	Speed limit must be lowered when visibility distance in fog is lower than 50 m[a]

[a] In France, legal speed for a visibility distance of 50 m is 50 km/h by daytime.

Table 8.4 Simplified failure analysis

Req	Failure	Description
Req 1	F1	GPS failure: GPS do not provide vehicle location to the navigation system. This generally occurs in long 'urban canyon[a]' or tunnels. Short situation are not affected thanks to the fusion with heading and distance sensor.
Req 2	F2	GPS failure: GPS provides the navigation system with a bad location. This generally occurs when relative GPS satellites positions are not optimal and affects the value of the Geometric Dilution of Precision (GDOP) coefficient. It should be noted that GDOP value for a given location can be predicted using sophisticated (but sometimes expensive) simulation tools.
	F3	Map matching failure: the navigation system locates the vehicle on another road because of its close location to the road where it actually runs. This generally occurs on motorway or highway exit interchange, on overpass or underpass crossing or on two close parallel roads.
Req 3	F4	GPS failure: due to inaccurate location caused by F1 (urban canyon or tunnel) or F2.
	F5	Latency time: due to the latency time introduced by the various system components (Figure 8.6), notification of the speed limit happens after the overpassing the road sign. It should be noted that the location difference increases with the vehicle speed.
Req 4	F6	Image processing failure: glare of the camera. This kind of event occurs generally at sunset or sunrise when the sun is low on the horizon.
Req 5	F7	Lack of object of interest (e.g. lane marking) in the field of view of the cameras (within the considered measurement range).
	F8	Lack of horizon line in the image.
Req 6	F9	Due to a bad estimation of visibility distance (F7), the resulting speed limit is erroneous.

[a] An urban canyon is a place where the street is flanked by high height buildings on both sides creating a barrier for GPS wave propagation which results in a temporarily lack of localization.

8.6.1.4 Unitary and integration test

Due to the highly modular architecture of ISA++ it is necessary to carry out tests in a hierarchical approach: unitary tests to validate components followed by integration tests to validate the overall system.

Some important points need to be highlighted:

- When unitary tests are performed on real conditions, the system must provide a mean to disconnect components which could interfere with the tested one. For example, testing the navigation system coupled with its speed database requires neutralizing road sign recognition and fog detection algorithms (switches SW1, SW2, SW3 in Figure 8.6)
- Due to the difficulty to have a realistic GPS simulation including GDOP variations, unitary tests for this function are mainly performed in real driving conditions.
- Conversely, because of the difficulty to have a reference of visibility distance in fog presence under real driving conditions, the unitary tests for this function are mainly carried out on simulators, test chambers, test benches where the visibility distance can be estimated by standard meteorological instruments.

Table 8.5 summarizes unitary tests to carry out for ISA++.

8.6.1.5 Use cases

Based on the requirement and failure analysis above mentioned, it is therefore possible to define use cases. They must include all the situations that have been identified as a possible cause of a system failure.

8.6.2 Example: test and validation of the FOG sensing module

The FOG sensing module combines a camera and an image processing algorithms. Its aim at detecting the presence of fog and at estimating the visibility distance. For the purpose of clarity, this section is limited to the validation of daytime situations.

8.6.2.1 Indicators

The selected indicators are:

- Fog presence: A Boolean which is TRUE if visibility distance is lower than 400 m and otherwise FALSE.
- Visibility distance: an integer in the range 5–400 m
- Visibility range: the fog sensing module provide visibility distance under the form of a class number among 4: class 1: 200–400 m, class 2: 100–200 m, class 3: 50–100 m, class 4: less than 50 m
- Latency time to detect the event occurrence
- Latency time to detect the event disappearance

Table 8.5 Unitary test to carry out for ISA++

Test	Method, tools
Navigation system coupled to speed data base	Test in real driving conditions on various road networks including urban canyons, tunnels, interchange, parallel roads, overpass and under pass crossing, etc.
Road sign recognition algorithm – step 1	Simulator with various road sign positions into the road scene including nightly tests.
Road sign recognition algorithm – step 2	Test in real driving conditions on various road networks including nightly tests.
Visibility distance estimator – step 1: verification	Test on simulator which replays various fog situations based either on synthetic fog images or on video sequences collected in real conditions with unknown visibility distance.
Visibility distance estimator – step 2: quantitative validation restricted to the scale of the fog chamber (i.e. 30 m for the French chamber located in Clermont-Ferrand)	Static test on a artificial fog chamber providing stable and controlled for density
Visibility distance estimator – step 3: validation of the estimated visibility distance in natural fog.	Static test on test bench (Figure 8.7(b)) for test and calibration
Visibility distance estimator – step 4: validation of the estimated visibility distance in fog dissipation situations.	Test on open roads with a static road side unit during a long observation duration (until the occurrence of fog episodes).
Visibility distance estimator – step 5: overall system quantitative validation in various conditions.	Test on open roads with a vehicle driving in fog conditions equipped with a reference sensor and the system to be tested.

8.6.2.2 Tools

Different tools are available to test and validate camera-based fog detection and visibility range estimation algorithms and check if they are able to meet the ISA++ requirements. Each tool has some advantages and inconvenience. Apart from numerical simulation tests, it is difficult to obtain ground truth data, since reference sensors are generally not available. Even in the case when reference optical sensors are available, the variability of the measurements in space and time made the comparison with image-based approaches still very difficult.

- Step 1: Uncalibrated video sequences
  Video sequences with unknown visibility grabbed by daytime at the same urban intersection by different weather conditions have been collected. One hour of fog labelled by human expert and one hour of different other weather conditions (cloudy, sunny, strong shadows, …) were obtained.
- Step 2: PRO-SIVIC-RECHERCHE Virtual Lab
  PRO-SiVIC-RECHERCHE is a real-time simulator which reproduces the behaviour of automotive or video sensors in a virtual 3D world. It helps the

(a) (b) (c)

Figure 8.7 Tools used to test and validate the performance of the fog and validate camera-based fog detection and visibility range estimation algorithms. (a) Artificial fog chamber of Clermont-Ferrland. © 2010 IEICE. Reprinted with permission from Gallen R., Hautière N., Dumont E. "Static Estimation of the Meteorological Visibility Distance in Night Fog with Imagery". Transactions on Information and Systems, E93-D (7): 1780–1787; (b) Calibration test bench. © 2006 IEICE. Reprinted with permission from Hautière N., Labayrade R., Aubert, D. "Estimation of the Visibility Distance by Stereovision: A Generic Approach". Transactions on Information and Systems, E89-D (7): 2084–2091, 2006; and (c) Open road test: static acquisition

system designer to develop ADAS. To test the daytime fog presence algorithm, specific traffic scenarios have been designed, where different fog densities are simulated.

- Step 3: Artificial fog chamber
  The fog chamber of Clermont-Ferrand (France) is 30 m long, 5.5 m wide and 2.7 m high and consists of a small-scale climatic chamber in which water droplets are sprinkled until the air is saturated with fog [14]. The evolution of density of the fog is permanently monitored by a transmissometer with a base of 28 m. Fogs with different droplet size distributions can be produced. For the purpose of the fog component validation, the fog chamber was equipped with artificial light sources, to simulate public lighting installations (Figure 8.7(a)).
- Step 4: Calibration test bench
  To perform a quantitative assessment, a test track was equipped with five large specific targets. The idea is to take pictures of these targets in adverse weather conditions and to estimate the meteorological visibility distance based on the attenuation of their contrast. This static measurement, which uses reference targets, can then be compared on the same images to the results of image processing techniques (Figure 8.7(b)).
- Step 5: Open road tests: static acquisition
  To grab pictures in foggy weather, a van was equipped with a pneumatic pole to install the cameras in the required configuration. An image sequence has been grabbed during a sunrise in fog presence on the test bed of Versailles (4 February 2008). In this sequence, the fog dissipates progressively and the visibility range increases during the sunrise (Figure 8.7(c)).

- Step 6: Open road tests: dynamic acquisition
  Finally, an experimental vehicle was equipped with a camera and a LIDAR prototype, which was dedicated to visibility estimation. In this way, it is possible from a theoretical point of view to compare the estimation from the LIDAR and the estimation from the processing of the camera image. However, since the measurement principles are not the same (the camera measures a global physical property, whereas the LIDAR measures a local property), it is still challenging to compare the performance of the algorithms.

8.6.2.3 Detailed procedures

Table 8.6 summarizes the methods, tools and targets for testing the FOG sensing module.

8.6.2.4 Results

In this section, the performances of the FOG sensing module of the ISA++ system in daytime situation are presented. They are intended to demonstrate, how the procedures presented in the previous section are linked to the requirements of the fog component.

Day fog presence

To assess this component, uncalibrated video sequences of the same urban intersections were used. Very good results were obtained when using the aforementioned video sequences. The results are summarized in Table 8.7. One can see an accuracy of the proposed system equal to 100 per cent meaning that 100 per cent of fog situations labelled by human experts were detected as fog by the system.

Meteorological visibility distance estimation

To evaluate the accuracy of the meteorological visibility estimation method, the test bench was used. For each grabbed image, the reference visibility distance obtained from the targets and the meteorological visibility distance obtained from the image processing are compared. Different error estimations between ground truth and measurements are given in Table 8.8. The accuracy of the proposed methods is better than 10 per cent.

Visibility range estimation

The visibility range estimation algorithm was applied on images acquired during open road tests in static conditions. At the beginning, the visibility distance is less than 100 m (Figure 8.7(c)). After 40 min, the visibility distance is above 400 m, which means that no fog is present anymore. Based on the estimation of the visibility distance, it is possible to deduce the visibility ranges as defined in the requirements of the visibility sensor. They are plotted in Figure 8.8. As one can see, a false classification seems to occur at time $t = 00{:}52{:}00$. This false classification is related to the setting of the expose time of the camera. Since the level of light is increasing during the sunrise, the expose time of the camera is changing as well. At time $t = 00{:}52{:}00$, the image is a little overexposed so that the contrast of distant objects is reduced and a lower visibility range is detected. Later, the camera has

Table 8.6 Methods, tools and target for testing the FOG sensing component

Indicator	Methods	Test conditions	Situational conditions	Tools and targets	Reference
FOG presence	Method 1: only for visibility distance measurement distances less than or equal to 400 m. Method 2: involves a black vehicle at a distance of 400 metres from the camera and verify that the vehicle is detected in the presence of fog when it presents a contrast of 5 per cent. Method 3: uses video sequences acquired with and without fog. Fog density is estimated by experts.	Fog in dissipation phase, offering visibility distances in the range 350–450 m	Day/night. With or without rain	Calibration test bench. Black and white targets. Black car.	Odometer. Reference device for visibility distance measurement.
Visibility distance	The proposed scenario consists in using the test bench on the tracks to estimate the visibility distance by daytime.	Fog in dissipation phase, offering visibility distances in the range 5–400 m	With or without rain	Black car	Odometer. Reference device for visibility distance measurement.

(Continues)

Table 8.6 (*Continued*)

Indicator	Methods	Test conditions	Situational conditions	Tools and targets	Reference
Visibility range	Idem	Idem	Idem	Idem	Idem
Time to detect the event occurrence	Elapsed time between fog/rain/night conditions and the event notification. As it is difficult to determine accurately the time of the event occurrence in real condition, virtual test in a simulated environment seem best suited. The event is simulated at a predefined time and a timer is started at the same time. The timer is stopped as soon as the UDP message is provided for the considered event.	Same condition as above depending on the kind of event tested (fog, rain, day/night)	Nominal conditions	Virtual lab (PRO-SIVIC-RECHERCHE)	Software timer. Event occurrence time stamp. UDP message time stamp.

Table 8.7 Accuracy in binary classification applied to fog detection

		Condition	
		Fog	**No fog**
Test outcome	Fog	25,000	0
	No fog	0	30,000

Table 8.8 Visibility distance accuracy

Average error (m)	6.3
Absolute global error (m)	9.3
Relative global error (per cent)	8

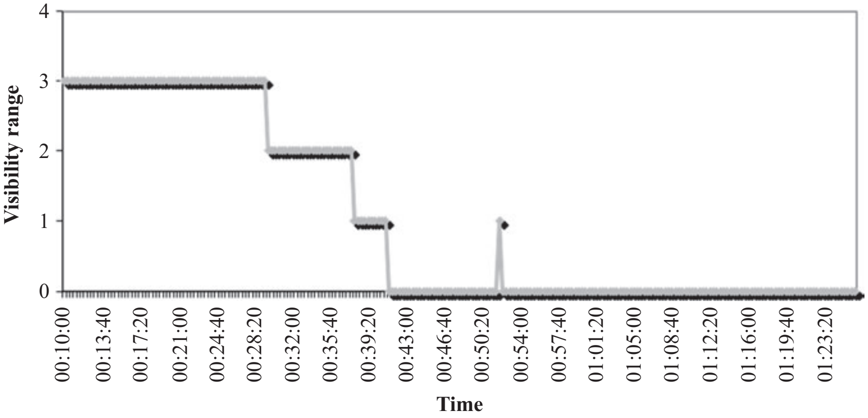


Figure 8.8 Visibility range estimated during morning fog on 4 February 2008

adapted its setting to the new lighting conditions and the visibility range is correctly estimated. Furthermore, the snow on the ground makes the automatic setting of the camera even more difficult since the images are very bright.

Time to detect the event occurrence

To estimate the latency time of the FOG sensing module, the time between the occurrence of the event and its detection must be estimated. However, the fog appearance is a progressive event which makes this measurement difficult in a real environment. So, a simulation was used during which the occurrence of fog was created without transition phase. Thus, the condition immediately moves from a state without fog to a state with fog. Practically, PRO-SiVIC-RECHERCHE was used to test the latency time of the system by switching the simulation from no fog to dense fog. The latency of the system is smaller than 1 s.

The comparison with requirements of the system shows that the FOG sensing module meets the requirements of the system. Nevertheless, a complete testing of the system is still missing – the last step. This is mainly due to a lack of reference data obtained in dynamic situations, which hinders the further development of the ISA++ system.

8.7 Conclusion

In this chapter, a methodological framework and procedures to be used for the validation of in-vehicle complex systems has been presented. This one is based on the V-shaped approach and has been progressively improved through the experiences gained in various European projects. However, this methodology should not be seen as a rigid framework but more as a source of inspiration for future works. To illustrate this one, an original driver assistance system has been designed. The so-called ISA++ system aims at determining the speed limit a driver has to follow based on the speed signs detection, the map-matching of the vehicle and the detection of low visibility distances caused by fog presence. After having defining the requirements of the system, the proposed validation methodology has been applied to the ISA++ system, in particular to the FOG sensing sub-system, which aims at detecting a fog presence and at estimating the visibility distance using cameras located behind the car windshield. Different validation tools at the disposal of the subsystem developer have been presented with their respective advantages and inconvenience. The performances of the sub-system obtained during unary tests have been favourably compared with the requirements, but more realistic tests of the system in dynamic situations are still missing. This last step can still be considered as a chicken-egg problem, since a ground truth sensor is necessary and does not exist yet. In this case, the best perspective is to use fixed meteorological sensors placed along the roadside, which communicate their measurements to passing vehicles using wireless communications. Such complex cooperative systems between vehicles and infrastructure are indeed the key to solve hazardous situations, where the vehicle is not able to act individually. Their technical assessment remains, however, a challenge.

More generally, the validation of driving assistance systems is becoming more and more complex due to the diverse naturalistic driving situations. An open issue that was not addressed in this chapter is that of the representativeness of the test situations. Can we say that the tests which were carried are sufficiently exhaustive to confront the system in all driving situations? What about Google's Car approach which consists in driving hundreds of thousands of kilometres? Once completed, can we consider that the system is reliable? Here is a very challenging field of investigation for researchers of which we can expect very promising and exciting results.

Acknowledgement

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References

[1] J. Sholliers, J.-M. Blosseville, H. Karsten, M. Netto, V. Antilla, S. Leanderson, "D16.3 proposal of procedures for assessment of predictive and active functions", in *PREVENT Consortium, Sixth European Framework Program*, 2007.

[2] J. Ehrlich, A. Spence, N. Hautière, *et al.*, Deliverable 2.5.1, SAFESPOT Project, SP2 – INFRASENS Infrastructure Platform – "Plan for testing and validation activities", November 2008.

[3] J. Ehrlich, A. Spence, N. Hautière, *et al.*, Deliverable 2.5.2, SAFESPOT Project, SP2 – INFRASENS Infrastructure Platform – "Final report: guidelines and best practice for infrastructure sensing", May 2009.

[4] F. Hendriks, M. Tideman, R. Pelders, R. Bours, X. Liu, "Development tools for active safety systems: PreScan and VeHIL", in *2010 IEEE International Conference on Vehicular Electronics and Safety*, QingDao, China, 15–17 July 2010.

[5] D. Gruyer, S. Glaser, R. Gallen, S. Pechberti, N. Hautiere, "Distributed simulation architecture for the design of cooperative ADAS", in *FAST-ZERO (Future Active Safety Technology) 2011*, Tokyo, Japan, September 5–9, 2011.

[6] D. Gruyer, S. Glaser, B. Monnier, "SiVIC, a virtual platform for ADAS and PADAS prototyping, test and evaluation", in *Proceeding of FISITA'10*, Budapest, Hungary, 30 May–4 June 2010.

[7] J. Ehrlich, "Towards ISA deployment in Europe: state of the art, main obstacles and initiatives to go forward", *2009 Road Safety Research, Policing and Education Conference,* Sydney, 10–13 November 2009.

[8] J. Ehrlich, F. Saad, S. Lassarre, S. Romon, "Assessment of LAVIA systems: experimental design and first results on system use and speed behaviour", in *13th World Congress and Exhibition on Intelligent Transport Systems and Services,* London, 8–12 October 2006.

[9] M. Landwehr, W. Kipp, A. Escher, Deliverable 2.2, Speed Alert Project, WP2.2, "System and service requirements", February 2005.

[10] F. Moutarde, A. Bargeton, A. Herbin, L. Chanussot, "Robust on-vehicle real-time visual detection of American and European speed limit signs, with a modular traffic signs recognition system", in *Intelligent Vehicles Symposium, IEEE*, 2007, 1122–1126.

[11] N. Hautière, R. Labayrade, D. Aubert, "Real-time disparity contrast combination for onboard estimation of the visibility distance", *IEEE Transactions on Intelligent Transportation Systems*, 7(2): 201–212, 2006.

[12] N. Hautière, J.-P. Tarel, J. Lavenant, D. Aubert, “Automatic fog detection and estimation of visibility distance through use of an onboard camera”, *Machine Vision and Applications Journal*, 17(1): 8–20, 2006.

[13] N. Hautière, D. Aubert, E. Dumont, J.-P. Tarel, “Experimental validation of dedicated methods to in-vehicle estimation of atmospheric visibility”, *IEEE Transactions on Instrumentation and Measurement*, 57: 2218–2225, 2008.

[14] M. Colomb, K. Hirech, P. Andre, J. Boreux, P. Lacote, J. Dufour, “An innovative artificial fog production device improved in the European project FOG”, *Atmospheric Research*, 87: 242–251, 2008.

Chapter 9

Evaluation of ITS: opportunities and challenges in the era of new pervasive technology

Susan Grant-Muller[1] *and Frances Hodgson*[1]

9.1 Introduction

One of the features of Intelligent Transport Systems (ITS) is the large number of possible configurations that arise in practice, due to the various combinations of connected fixed-based technologies and equipment (ramp metering, variable message signs [VMS], lane marshalling and more). The recent advent of web2.0 enabled pervasive technologies (such as smartphone) has broadened the definition of schemes that can be considered as falling within the family of ITS. These personal technologies and other so-called new generation technologies (such as Bluetooth and connected sensors, the 'Internet of Things') effectively form part of the ITS when they record (or are linked with) individuals' transport choices and/or contribute data to the operation of the transport system. The definition of ITS now includes a legacy system of fixed base infrastructure such as regional traffic control centres with responsibility for a network of managed motorways, plus a network of connected and pervasive technologies such as personal devices, Internet of Things and individuals connected through web-enabled social media (Figure 9.1).

The inclusion of pervasive and connected technology has added to the variety and granularity of data potentially available for the tactical and strategic management of the transport system, and to support more informed choices for the travelling public. However, they also create two different challenges for evaluation methodology:

1. How new data forms can contribute to the evaluation of a variety of established ITS-infrastructure schemes
2. How the impacts of ITS schemes based on new technology can be evaluated – and whether the approach needed is different to that used to evaluate established ITS infrastructure schemes

The first of these challenges arises as new connected technologies provide opportunities to collect data with a different granularity, quality and scope

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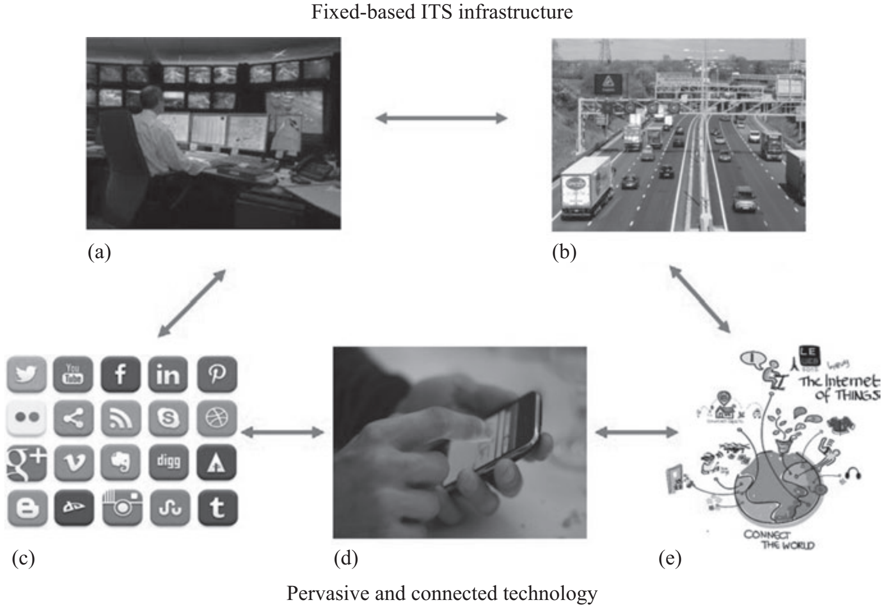

Figure 9.1 Extended scope of ITS with pervasive and connected technology. (a) Traffic control, (b) managed motorways, (c) social media, (d) personal devices and (e) internet of things. Sources: (b) Highways England, (c) Yoel Ben-Avraham, (d) r.g-s and (e) Wilgengebroed

concerning transport choices, traffic conditions and system performance alongside data streams from fixed-based technologies. Examples include social media (Twitter[1]) posts that can rapidly disseminate user-contributed information on incidents and traffic conditions to supplement data from embedded loops and video cameras. This field has had some attention in the literature based on early research. Understanding the strengths, weaknesses and potential of new data forms is key (see, e.g. [1]).

The second challenge is the main focus of this chapter however and is one for which relatively little research has been published to date. A new tranche of transport initiatives and interventions has emerged in recent years. Some of these are based on the ability to detect individuals' location within the transport system and to engage in two-way data exchange and information flow directly with the traveller. This has led to the development of sophisticated and tailored location-based services and persuasive incentivisation to encourage individuals towards behavioural change. Other initiatives have been concerned specifically with the one-way provision of near-real time, dynamic travel information to individuals allowing better informed choices about travel options before and during a journey.

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[1] https://twitter.com/.

A further set of initiatives have been focused on web-enabled social networks and the opportunities for individuals to share their transport related resources (e.g. knowledge of the transport system and vehicles) with other travellers. A better understanding of the impacts of all these new types of schemes is important to being able to justify investment and expenditure on the technology, training staff in key skills areas and on-going ‘maintenance’ costs (such as the cost of provision of incentives for behavioural change). Identifying and enumerating the impacts is also important to policy-makers. Due to the relative novelty of these types of schemes, there is little in the way of established evaluation methodology to demonstrate their impacts or the success of the scheme overall. The goal of this chapter is therefore to summarize the issues in evaluating such schemes, to propose outline evaluation approaches for two main scheme typologies and to provide an overview comparison with established evaluation practice for fixed-based ITS (FB-ITS).

The remainder of the chapter is organized as follows. Section 9.2 describes the main characteristics of the new wave of technology driven pervasive ITS with two particular types (new mobility schemes [NMS] and social innovation [SI] schemes) being selected for further elaboration in Sections 9.3 and 9.4. In these sections, we describe the respective features of these schemes in more detail, highlighting the challenges for evaluation methodology and proposing outline evaluation approaches. In Section 9.5, we provide a comparative overview across evaluation of established FB-ITS, NMS and SI schemes. The chapter concludes with some issues for future consideration regarding the commodification of data arising from new technologies.

9.2 Pervasive technology in the transport sector

ITS is described in the literature (e.g. [2–4]) as an ‘umbrella’ term covering a variety of combinations of Information Communication Technology (ICT) systems and various transport infrastructures to provide ‘intelligent’ services. The intelligence element of ITS is essentially the ability to assist in operational and tactical decision-making concerning parts of the transport system in response to current conditions, typically the highways, although parts of the urban network are also ITS rich. Reference 5 refers to some ITS as discreet invisible agents (services which are not obvious or undetected by the public) due to their role in supplying data for traffic control centres that may be remotely located and therefore not visible to the travelling public. The infrastructures connected by ICT include overhead gantries, roadside VMS, speed indicators, traffic signals, inductive loops, automatic number plate recognition systems, cameras, central control rooms, roadside monitoring stations and many more. Typical examples of ITS schemes are as follows:

1. VMS, where messages are displayed on overhead or roadside gantries providing general traffic information such as estimated travel times to major destinations, incident information or congestion related information.
2. toll collection via an electronic tag installed within the car to pay for road use and parking [6, 7].

3. highway lane marshalling using overhead gantries to separate and direct vehicles into appropriate lanes to avoid last minute lane changing or vehicles performing dangerous manoeuvres around junctions.

These may be categorized as established, FB-ITS. As the main channels of detection and communication are at fixed locations on the transport system, whilst vehicles moving through the system generate data that are detected by the infrastructure. These examples have different operational goals in the transport system (such as informed travellers, congestion charging and operational efficiency) and as a result, the evaluation of their impacts should be expected to cover different impact areas with particular indicators and data needed to capture those impacts.

These FB-ITS form the backdrop infrastructure against which a new set of technologies have emerged and which offer the potential to either work in complement to the existing ITS or offer alternative transport services and functions. These new technologies may be web-enabled, are typically small scale, pervasive and may not have a primary function as part of the transport infrastructure. Examples include (but are not limited to) smartphone, tablet, laptop, Bluetooth, smartcards, electronic tagging (barcode), radio-frequency identification (RFID) and accelerometers. Large volumes of micro-level data are typically collected by the technologies, reflecting the choices, preferences and activity of individuals before, during and after (or not-related to) travel. A distinction can be drawn between those technologies that involve one-directional, passive data flow, such as tap-in-tap-out smartcards and those that are web-2.0 enabled. The latter may include established social media (e.g. Twitter, Facebook and Instagram) or bespoke software applications ('Apps') that may have been specifically designed with transport related functions (such as traveller information) or be unrelated but still reflect individuals' activity patterns (e.g. health/exercise Apps). The contribution that data and information harvested from these new technologies can make towards the tactical, operational and strategic direction of the transport system and towards the evaluation of the success of FB-ITS is outside the scope of this chapter, but the reader is referred to Reference 1 for more discussion.

Aside from the serendipitous contribution of data for ITS evaluation, a new wave of initiatives and interventions has emerged that harness the new technologies and are specifically transport and mobility focused. As with FB-ITS, the numerous technology configurations and functionalities available mean that there is considerable variability in the focus and scope of these initiatives. A broad categorization is as follows:

1. Smarter choices: the provision of travel information, personalized travel planning (e.g. My-Way project in Greece, Germany and Spain, IndiMark and Travelsmart [8], Personal Journey Plans [9]).
2. Purchasing, financial discounts and transactions – packages for Public Transport discount cards, parking and toll charging (e.g. M-ticket, Manchester, UK).
3. NMS – incentivisation to persuade behavioural change – rewards for 'peak avoidance' [10], feedback and self-monitoring, rewards (e.g. SUNSET project in

The Netherlands, the United Kingdom and Sweden [11]). Where incentivisation is accompanied by personal mobility profiling (track and trace functions which indicate the location of the individual as they move on their journey), these are referred to as NMS.

4. SI schemes: walking buses, car share initiatives, peer-to-peer feedback via social networks, information sharing via social networks or dedicated websites (public participation schemes) (e.g. Commute Greener in Belgium, France, Sweden, India, Mexico, the United States and other places).

In practice there is considerable overlap between these categories with many Apps offering several functions and a soft distinction between types – for example, social sharing schemes can also act as positive incentives for behavioural change as individuals are positively encouraged to try a new mode with peer support. The provision of dynamic travel information may also be viewed as a behavioural change initiative. For the purposes of considering the evaluation methodology for the impacts of these schemes, we focus in the remainder of this chapter on two examples: NMS and SI schemes.

Within the transport sector, NMS and SI-based schemes are becoming more widespread; however, there is no established practice in terms of evaluating the impacts of such schemes. This knowledge would be beneficial for practitioners, policy-makers and academics involved in transport sector scheme evaluation and design. Accurate evaluation of these types of new technology schemes would enable practitioners and policy-makers to develop and implement such schemes within transport and across policy sectors to promote policy aims for the improvement of economic development, public health, congestion impacts, carbon and other pollutant emissions.

9.3 Evaluation of technology-enabled NMS

In this section, we focus on the scope of the evaluation framework that is needed for an ICT enabled NMS. First, we outline some of the main features and components of a NMS, identifying illustrative examples. Subsequently, we discuss the evaluation challenges they create and propose the main elements of an evaluation approach.

9.3.1 Components of a NMS

The aim of a NMS is to harness the opportunity offered by pervasive personal devices and two-way communication software applications to encourage individuals to re-think their transport and travel choices. The overall goal may be as broad as the long term sustainability of the transport system, local network efficiency or tactical road/route management. A NMS essentially comprises a combination of ICT enabled technology components, databases and information sources, plus a consortium of transport and other stakeholders who may variously be responsible for providing transport services, incentives, travel timetables and more. The basic technical components of a NMS are as follows:

1. software application (App) based scheme, whereby individuals download software onto a personal device such as a smartphone or tablet. The software may be themed as a travel information/assistant, rewards scheme, game, purchasing facility, activity-challenge, for example. It may also include a social media or social network function and thereby support SI schemes (see Section 9.4).
2. other software held by the transport supplier or transport authority may include an 'operators dashboard' which allows transport operators or city authorities to design and issue transport and travel related messages, challenges, incentives and/or rewards directly to individuals.
3. a mobility monitoring facility, whereby (with permission) individuals' travel choices and movements can be detected using the sensing functionality of the personal device. These travel choices can be converted into whole journeys and mobility profiles, which are anonymized, stored and accessed by the operator of the dashboard to personalize communications and influence future transport choices towards more sustainable modes.

The consortium of stakeholders responsible for providing transport services, incentives, travel timetables and other services is a key element to the scheme, as the technology and software alone will not deliver the ITS. The distinctive feature of these services is that they are 'location based' and often tailored to the individuals profile, for example of past travel choices, home location or other characteristics. An operator is needed to periodically issue communications, a 'helpdesk' may be needed to deal with individuals' queries and a sustainable business model for the provision of dynamic travel information, incentives, and rewards is also needed. In the same way that a traffic control centre is needed for central coordination of managed motorways for example, central coordination is needed for the delivery and effectiveness of a NMS.

9.3.2 Challenges in evaluating a NMS

To understand the challenges in evaluating the success of a NMS, it is important to note that the impacts for this type of scheme are the result of an accumulation of micro-level choices and changes at the level of the individual. Assessing impacts by observing the transport network at macro-level over a period of time (i.e. the traditional approach to assessing many transport infrastructure schemes) is unlikely to detect changes and impacts. The reason for this is that the noise or variation in aggregate traffic indicators such as link travel time, is in general, too large to detect changes which have occurred at the level of the individual traveller.

Impact assessment is therefore based on detecting and monitoring changes in individuals' choices concerning travel time, mode, and route following their agreement to participate in the scheme. These individual changes may be 'scaled up' to population segment sizes or used in estimates (through modelling) of the total scheme impacts in terms of, for example, reduced vehicle kilometres, increased public transport patronage, route changes or others as appropriate to the scheme.

Further challenges exist in capturing the success of the scheme as responses to particular offers, challenges or rewards may be delayed in time from the original time of offering or may result in impacts on parts of the network or transport system that are some geo-distance from the area of focus. For example, an offer of a discounted bus or train ticket may not be responded to immediately where an individual has strong travel habits by private car or responsibility to transport family members. Informational incentives to encourage individuals to avoid a particular route or road segment due to congestion problems, an incident or even a pollution hotspot, may result in choices to divert across a number of other routes. The evaluation challenge is therefore complicated in space and time.

Evaluating the success of the NMS may also entail capturing the flow of costs and benefits to a different set of stakeholders than those traditionally involved in a transport infrastructure scheme and well outside the range of common transport indicators. Third party providers of incentives such as discounted tickets for local entertainment or refreshments, for example, may benefit from longer term and potentially undetected increases in patronage from travellers revisiting their services outside the scheme boundaries.

According to Reference 11, the evaluation framework for a NMS should ideally fulfil the high level requirements.

High level requirements that should be fulfilled by evaluation framework for a NMS

Allow comparability of the scheme with ‘traditional’ ITS or other transport schemes

Captures performance against the specific objectives for the technology configuration

Ability to reflect the dynamic nature of impacts

Ability to reflect long term costs and benefits

Flexibility for different schemes/contexts, particularly given the numerous features possible

Ability to monetize some or all of impacts (to allow comparability with standard evaluation methods)

Disaggregate outputs by stakeholder (considering the different sets of stakeholders involved in this type of scheme)

Ability to reflect ‘intangibles’ and broader socio-economic impacts

Practical with respect to measurability and data demands

The final requirement may act as a determining one on the evaluation approach – whilst the potential presence of a wide range of impacts can be envisaged with a NMS, the ability to measure these in practice and access the necessary data may remain challenging.

9.3.3 Proposal for an evaluation approach for an ICT enabled NMS

As a general proposal (and reflecting the basic high level framework outlined in Section 3.2), we propose the following evaluation approach for a NMS. The approach reflects that adopted in the EU-funded SUNSET project [11], as implemented in The Netherlands, Sweden and the United Kingdom.

An evaluation approach for a NMS

The general structure and main categories may follow those used in the basic evaluation of a FB-ITS scheme and which is also foundational to the evaluation of other types of transport infrastructure schemes. This involves the following categories: costs and financial flows, efficiency, safety, environmental, social, equity and other impacts. Following this structure allows some consistency with the evaluation of other transport schemes.

However, the components in each category will be very different in the case of the NMS. 'Costs' will need to include ICT integration costs for the scheme operator for example, to capture, store and process large volumes of individual mobility data. Incentives will also be a cost component, as may be the provision and training of staff with skills in social media, staff to design and implement incentives packages. Marketing costs may also be accrued as this type of scheme needs proactive individual participation (e.g. by downloading an app) and does not have the same physical 'presence' as a gantry based lane marshalling scheme.

Stakeholder groups, by which both costs and benefits are usually disaggregated, should have an expanded and alternative membership. They should include any third parties involved in the provision of location based information or other services, providers of incentives or rewards, providers of data or ICT services.

Some impact types and indicators that are often included in evaluation may be omitted. The set of tactical highway management indicators related to specific lane use for example, as the NMS may not be able to accurately detect the data needed and the scheme is not directed towards that objective.

Further impact categories are needed that are specific to this type of scheme, including the impacts generated by any social media or social network function in the application (these are discussed further in Section 9.4).

Similarly, impacts concerning changes in perception or attitude to transport choices that have not yet resulted in a tangible outcome, but which have predisposed the individual to future changes should be captured. These represent positive moves along the classic behavioural-change and attitudinal axis.

The evaluation will need to consider the whole journey taken by the individual and aggregate impacts over different stages as appropriate, for example, where an individual walks to a bus terminus then catches a bus and then walks the final stage. This is a different approach to capturing scheme impacts than is the case for FB-ITS where only the instrumented sections of the network are captured, though usually supplemented by social surveys in a broader area.

In summary, the evaluation of a NMS stretches (and in part, extends well beyond) the traditional bounds of the ITS evaluation paradigm. However, that paradigm is foundational to the approach advocated here and we perceive a number of benefits in retaining some common impact categories and structure. Whilst NMS have become far more widely accepted and adopted by cities across Europe and internationally, the ability to determine benefits clearly and in a way that is consistent with the way in which alternative (more traditional) schemes are evaluated is key for public acceptability. A comparison between the evaluation approaches is outlined in Section 9.5.

9.4 Evaluation of technology enabled SI schemes

The aim of this section is to outline an evaluation framework that will overcome some of the challenges inherent in evaluating SI based schemes within the transport sector. We first provide a definition of SI schemes and identify a number of examples. Subsequently, we identify the challenges in evaluating these types of schemes, proposing an evaluation approach.

9.4.1 Definitions of SI in the transport sector

Definitions of SI vary across different fields of study and a number of terms are used interchangeably including, for example, ‘social entrepreneurship’, ‘social enterprise’, ‘shared value creation’ and ‘sharing economy’ resulting in a disjointed and under-researched area [12]. Discussions around SI generally highlight three elements: the first is that it refers to the ‘finding of solutions’, the second element is that the benefit is to society or meeting a social need and the third element refers to social organization. Reference 13 defined SI as ‘innovation activities and services that are motivated by the goal of meeting a social need’ and similarly in 2008 the Stanford Centre for SI coined the following definition: ‘A novel solution to a social problem that is more effective, efficient, sustainable, or just than existing solutions and for which the value created accrues primarily to society as a whole rather than private individuals' [14].

SI schemes within the transport sector necessarily means a focus on 'shared economy', or 'sharing economy' schemes. Largely because these forms of 'collaboration consumption' which has been defined as 'an economic model that emphasizes "access" or "sharing" instead of "ownership"' [15]. Within the transport sector there are a number of examples of these types of schemes including, for example

- Car sharing: Zipcar, COMMUNAUTO, CityCarShare, eGOCarShare
- Peer-to-peer carsharing: Getaround, Relay rides, GoMore
- Ridesharing: Carma (Formerly Avego), Nuride, Carticipate, Piggyback, EnergeticX, Commutr, Zimride, Ville Fluide, GoLoCo, Car2gether, Flinc, Carriva, Covoiturage, Uber
- Bikesharing: Publibike, Citibikes (*see also* www.bikesharingmap.com)
- Other information swapping schemes: Hollerback, Walkit.com, Waze, Harassmap.com
- Other performance sharing schemes: Strava, mapmyrun

These schemes differ in that some are owned and managed by large, sometimes multi-national businesses and others are more small-scale businesses or not for profit businesses. Other, less formal schemes which are much more likely to be small scale or community stimulated and run include: Bike Buddy systems, Travel buddy schemes for more vulnerable travellers and Walking School Buses. This range and diversity of organizational forms is evolving rapidly as new pervasive technologies enable new forms of communication and social organization for example, UBER resulting in an increased interest in innovative business models.

9.4.2 Challenges in evaluating SI schemes in transport

The evaluation of SI schemes in pervasive technology presents a number of challenges. The first challenge is one of resolving how to deal with 'time', that is, finding the 'right' time to evaluate a SI based initiative. This problem can be partially resolved depending on how the SI scheme has been initiated. If it started with a local authority or similar structured organization, then there may well be a clearly identified start date. This would enable a date for evaluation to be identified. Alternatively if the SI scheme has been more organic in development and it is less easy to define the start date, then it is more problematic to set an appropriate date for evaluation.

Similarly with SI based schemes, there is the expectation and possibility that they will change and evolve as they grow and mature. Once again this makes the date of the evaluation less obvious to determine. Obviously, it can be argued that the appropriate date for evaluation could be based on 'exposure'. Using the exposure of the individuals involved in the SI based scheme would require decisions about the definition of exposure and decisions about the level of involvement or participation. In a SI based scheme, an individual could be a long standing participant but also a ‘lurker’ or someone who does not take an active part in the scheme.

This brings us on the second set of challenges associated with SI based schemes, which is that of ‘capturing’ the type of involvement each individual has and how the sum of the individual parts creates social value. As alluded to above some participants may get ‘value’ simply from observing the participation of others for example altruistic feelings towards bikesharing schemes, alternatively they may be able to use information that others generate for example congestion estimates in Waze, without participation or contributing of information themselves. So the challenge in evaluation is to capture the ‘value created’ and the involvement of the participants.

A further challenge is to capture the role of participants in SI based schemes. These can be roles such as influencers, enablers, early adopters, and ‘lurkers’. This is because the actual activities of individual participants and the relations they have between each other may be a determinant of the success or failure of SI based schemes. The challenge is to identify those participants who are most influential, who by their actions or engagement with social media influence others to join a scheme or to engage in particular activities thus generating ‘snowball’ effects and for example, making ridesharing seem a viable alternative to driving into work. A further challenge is to determine the extent of the influence of specific combinations of individual participants and specific actions at influential times. Added to that a challenge is to establish what would constitute a ‘critical mass’ for any SI based scheme particularly if the scheme is part of the ‘sharing economy’. For example, the New York bike share scheme seems to have underestimated the number of casual, one-off users such as visitors to the city.

The technological developments enabling the growth and diversity in SI based schemes in the transport sector that are of most interest are: location based services (LBS), social media use and strategies for building trust. This latter development being an integral key to schemes within the ‘sharing economy’ and policy developments such as ‘mobility as a service’. One of the greatest challenges in evaluation of SI based schemes is the measurement of ‘trust’.

9.4.3 Evaluation proposal for SI schemes in transport

It follows that an evaluation proposal for SI schemes could decide to focus entirely on either outcomes or process indicators or some combination of the two.

1. Outcome indicators would have to focus on travel behaviour and transport related choices. Changes on a before-and-after basis in travel choices (e.g. mode, route and distance by mode) which can then be converted into energy, carbon, equity, health, safety and other impacts for the scheme.
2. A focus on process would be a (productive) focus on identifying those factors that have created success or failure in the schemes. The success of the scheme may be determined by whether the post-scheme’ travel choices involve the sharing of modes or use of communal assets (such as shared bikes) or involvement in buddy/peer support related travel.

Any evaluation framework for SI based schemes within the transport sector will need to exploit LBS in pervasive technology to estimate travel behaviour, for example walking kilometres, passenger kilometres or cycling kilometres.

The specific challenge with SI schemes is to determine when someone is travelling by car but is also ridesharing, or using another car sharing scheme. It is possible to identify a number of ways to refine LBS to identify if car travel is in a carsharing or ridesharing car scheme. The first is to exploit the unique identifiers in Bluetooth and mobile phone technologies to coordinate between cars, and individuals within a carsharing or ridesharing scheme. The aim being to enable the automatic 'track and trace' of cars and individuals within a car and ridesharing scheme. This will enable coordination and identification of use of ride or carshare and vehicle occupancy. The collection of this type of data collection requires a corresponding 'social' element in that individuals need to agree to their movements being recorded and used in subsequent analysis and outputs.

An alternative is more interactive (and potentially invasive) and involves exploiting the social media accounts individual may have, for example Twitter or Instagram or Facebook, to ask the individual how they are travelling. Once again 'track and trace' has to be used, but coordinated and automatic functionality should be explored and utilized so that questions using social media technology are generated by 'track and trace' thresholds and indicators and are sent automatically.

'Track and trace' functionality goes some way to solving the issue of the right 'time' to evaluate in that it allows the generation of data over a period of time with relatively little cost impact or effort burden for the respondent. However, 'track and trace' applications using LBS have to be downloaded by the participant and there has to be active consent to be traced. Nevertheless with sufficient knowledge and foresight it should be possible to sign up a community of scheme users and vehicles or bikes (as appropriate) for the collection of data over the individual's scheme membership lifetime. Such an initiative would have the potential to provide a substantial dataset for evaluation.

There are additional aspects of complexity to consider when using 'track and trace' functionality particularly whether route based information and time stamps are required. There are still errors associated with the geo-location function which should lessen in the future with changes to international controls on global positioning system accuracy allowing greater accuracy in estimation of location to within metres of the actual position of an individual.

Capturing data on participant's actions and roles requires other tools and techniques. For this, we suggest that future evaluation frameworks explore the potential of social media analytic software such as HootSuite or Radian 6. The software focuses on content analysis of textual data from posts on Facebook or Tweets, including sentiment analysis. Sentiment analysis allows some understanding of the 'feeling' behind the content that the individual posts. However, there are fundamental issues with this type of data, including, (a) it is not necessarily contemporaneous; (b) the required understanding of the lexicon including shortened phrases is onerous. In addition, the analytical software available is not yet sufficiently evolved to analyse images and picture, rather than textual data which are a drawback given that an increasing volume of social media content is in the form of images and videos. But the principal problem is that analysis of the social media presence and content, the footprint if you like, of an individual does not necessarily reveal their *actions* within a SI scheme unless the actions are specifically reported. Nor does it reveal much about the link between the individual, the actions and the importance or serendipitous nature of timing unless an individual proactively posts a narrative to reflect this.

Sophisticated data harvesting and analysis techniques are required to reveal an individual's actions within a SI scheme and underpin an evaluation of impacts from the scheme. Existing techniques such as Social Network Analysis could be used to uncover an individual's influence within a social network. Social Network Analysis would be able to demonstrate such factors as density and centrality within a social network highlighting the importance of individual characters. Combinations of 'track and trace', social media content analysis, sentiment analysis and social network analysis could all be undertaken without additional burden on the participant, but would require informed consent and could be quite revealing about the day to day activities of any one individual and therefore a sensitive data stream. However, Social Network Analysis is not an exact way to explore or uncover the role and actions of individual's and it is quite possible that additional social survey methods would be needed.

The final element in the proposal for the evaluation of SI based schemes is to develop new techniques for the gathering of dataset on 'trust'. One approach would be to begin by exploring the potential for using existing data such as the 'rate my driver' or 'rate my passenger' functions such as those used in UBER, using existing social media analytic software, for example, GoogleAnalytics or HootSuite.

In summary then the principal suggestions for the evaluation proposal starts with the identification and exploitation of existing datasets closely followed by principle to use existing 'off-the-shelf' analytical software packages and to combine those with bespoke surveys that fill the gaps. The primary gaps are around the lack of 'social' data: activities, social roles and 'trust'. It follows that an implicit principle is to use a mix of methods allowing quantitative and qualitative dataset generation.

9.5 Overview and summary remarks

The advent of new pervasive technology has enabled a new tranche of ITS schemes to develop, based on personal devices and often employing social functionality alongside functions that are more clearly transport focused. As with established, FB-ITS, the possible permutations of technology configurations and functionality is vast. In this chapter, we have focused on two particular types to illustrate how evaluation methodology should now evolve – NMS and SI schemes.

In Table 9.1, a summary comparison between these two new types of scheme and established ITS is provided, drawing out the main features and areas of difference.

Table 9.1 Comparison of main impact categories for FB-ITS, NMS and SI scheme

Examples of FB-ITS impacts	**Corresponding examples for NMS**	**Corresponding examples for SIS scheme**	**Summary comparison**
Costs: Highways authority/stakeholder investment costs, finance, operating and maintenance costs	Costs: Individual traveller investment in technology, transport authority/third party costs and benefits (e.g. provision of incentives), investment and maintenance of ‘city dashboard’, staff resource for support/Customer Relations Management (CRM)	Costs: Investment to establish and maintain a social forum to facilitate sharing and peer support. Costs of owning and operating particular modes now distributed between individuals or communal owners/consortia	Shift in costs from centralized investment in FB-ITS to individual and local/regional costs for NMS. New business models needed to evaluate the value chain and impacts for third parties, for example in data supply, incentives, establishing a community/social forum.
Efficiency: Travel time, travel time reliability	Efficiency: Individual travel time and travel time reliability. Particular NMS are focused on route change and departure change, implying the need to monitor both over time and in a wide spatial dimension.	Efficiency: Individual travel time and travel time reliability. Particular SI schemes are focused at reducing total travel demand through sharing, reflected by reduced congestion related indicators with large scale uptake	Individuals’ observed departure and arrival time for whole journey possible through mobility profiling with NMS and SI. Efficiency impacts may be distributed/re-distributed over a wider spatial area than directly observed. Observed FB ITS efficiency impacts for instrumented portion of journey and instrumented spatial area only.
Safety: Accidents, speeding/compliance	Safety: Exposure to accidents through mode choice and route choice. Personal security impacts through exposure.	Safety: Exposure to accidents through mode choice and route choice. Personal security impacts through both travel related exposure and sharing of information in community forums.	Bi-directional information flow in NMS allows data collection on contextual perceived safety and low level/unreported security incidents. Exposure through posting personal information on social network forums or through connecting with peers/buddies difficult to assess other than through self-reporting and perceived risk.

(*Continues*)

Table 9.1 (*Continued*)

Examples of FB-ITS impacts	**Corresponding examples for NMS**	**Corresponding examples for SIS scheme**	**Summary comparison**
Environmental: Local environment (emissions) + global (climate change), habitat disruption	Environmental: Individual carbon equivalent, energy + ICT carbon costs/benefits through mode switch	Environmental: Individual carbon equivalent, energy + ICT carbon costs/benefits through mode switch and sharing. Need to assess the level of sharing to enumerate.	FB ITS employs a mixture of observed roadside emissions and modelling from traffic conditions. NMS and SI use modelled/estimated emissions only based on mode choice and either vehicle characteristic assumptions or user input vehicle information.
System/Operation: Throughput, lane behaviour (weaving and swooping), junction hopping, unauthorized hard shoulder running	System/Operation: Unlikely to generate or effectively detect these impacts from NMS	System/Operation: Unlikely to generate or effectively detect these impacts from NMS	Speed impacts may be detectable through location tracking with NMS, however micro lane movements best detected through FB ITS
Social and others: Liveability (residents), driver burden/stress	Social and others: Equity, health, comfort, peer/community standing, community inclusion	Social and others: Equity, health, comfort, peer/community standing, community inclusion	A wide range of additional impacts are possible for NMS and SI depending on the scheme definition and geo-context

This comparison is also intended to highlight the interface with the standard evaluation paradigm (typically a Cost–Benefit approach supplemented by an environmental and safety assessment), the shift in impacts and the ways in which the traditional evaluation approach should be extended.

A final point to consider is that this is a time of growing understanding of the usefulness and commodification of data. The individual is becoming more aware of the ‘value’ in their own data and increasingly sensitive to the ‘sharing’ of data. Increasingly, it is important to include this understanding in any consideration of ethical practice in evaluation research. Any evaluation framework wishing to use datasets generated by recording individuals everyday activities using mobility ‘track and trace’ Apps or social media input, has an obligation to question the extent to which the individual can ‘own’ or use and have access to the dataset generated from their own activities and actions. In addition, there is an obligation to explore the extent to which this ‘sharing’ of the ‘trace’ can form the basis for individual’s to get involved and to participate in research.

References

[1] Grant-Muller, S.M., Gal-Tzur, A., Minkov, E., Kuflik, T., Nocera, S. and Shoor, I. (2014). Enhancing transport data collection through social media sources: methods, challenges and opportunities for textual data. *IET Intelligent Transport Systems*. doi:10.1049/iet-its.2013.0214.

[2] Cottrill, C.D. (2009). Approaches to privacy preservation in intelligent transportation systems and vehicle-infrastructure integration initiative. *Transportation Research Record* 21(29): 9–15.

[3] Žilina, U. (2009). Present and future challenges of ICT for intelligent transportation technologies and services. *2009 1ST International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology*. 112–115.

[4] Lee, W.-H., Tseng, S.-S. and Shieh, W.-Y. (2010). Collaborative real-time traffic information generation and sharing framework for the intelligent transportation system. *Information Sciences* 180(1): 62–70.

[5] Deakin, E., Frick, K. and Skabardonis, A. (2009). *Intelligent transport systems. ACCESS* 34(Spring). 1–126.

[6] Levinson, D. and Chang, E. (2003). A model for optimizing electronic toll collection systems. *Transportation Research Part A: Policy and Practice* 37(4): 293–314.

[7] Boyles, S.D., Kockelman, K.M. and Travis Waller, S. (2010). Congestion pricing under operational, supply-side uncertainty. *Transportation Research Part C: Emerging Technologies* 18(4): 519–535.

[8] Brög, W., Erl, E., Ryle, J. and Wall, R. (2009). Evaluation of voluntary travel behaviour change: experiences from three continents. *Transport Policy* 16: 281–292.

[9] Halden, D. (2008). *Personal Journey Plans – Raising the Benchmark in Travel Information and Provision*. DHC, Edingburgh.

[10] Palm, H. and van der Muelen M. (2014). Reward for avoiding peak period in Rotterdam, Netherlands, 2014, TRB Annual Meeting, USA.

[11] Grant-Muller, S., Thomopoulos, N., Carlson, R., *et al*. (2013). Sustainable social network services for transport deliverable D6.2 evaluation methodology and measurement approach. Available at: http://www.sunset-project.eu/pdf/SUNSET_D6.2_Evaluation_Methodology_and_Measurement_Approach.pdf

[12] Phillips, W., Lee, H., Ghobadian, A., Regan, N. and James , P. (2015). Social innovation and social entrepreneurship: a systematic review, *Group and Organization Management* 40(3): 428–461.

[13] Mulgan, G. (2006). The process of social innovation. *Innovations: Technology, Governance, Globalisation* 1: 145–162.

[14] Phills, J.A. Jr., Deiglmeier, K. and Miller, D.T. (2008). Rediscovering social innovation. *Stanford Social Innovation Review* Fall. Available at: http://ssir.org/articles/entry/rediscovering_social_innovation#sthash.5JWJ5aQc.dpuf

[15] Shaheen, S.A. (2013). Introduction shared-use vehicle services for sustainable transportation: carsharing, bikesharing, and personal vehicle sharing across the globe. *International Journal of Sustainable Transportation* 7(1): 1–4, DOI:10.1080/15568318.2012.660095

Part III

Intelligent road transport systems evaluation results

Chapter 10

Evaluating cooperative ITS

Alan Stevens[1], Simon Ball[1] and Jean Hopkin[1]

10.1 Introduction

10.1.1 Cooperative ITS

Cooperative Intelligent Transport Systems (C-ITS) is a subset of ITS which involves communicating and sharing information between ITS-stations. These ITS-stations comprise personal devices, vehicles, the roadside infrastructure and the back-office. The objective of C-ITS is '... to give advice or facilitate actions to improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems' [1]. C-ITS is also known as 'connected vehicles' and require a substantial value chain to deliver the services and include vehicle manufacturers, in-vehicle product developers, electronics companies, app developers and mobile network operators.

Such systems are now being trialled in cities and corridors with first applications being provision of real-time information and entertainment to the vehicle occupants and collection of position data (floating vehicle data) to assist traffic management. Typically, these are achieved using the connectivity between smartphones and vehicles and through wireless connections such as 3G or 4G, but different services and different technologies are possible so it is important to evaluate the different implementation options and understand their benefits for different stakeholders.

10.1.2 Terminology

The term 'assessment' tends to be used by most authors when forward looking (also called ex-ante) and 'evaluation' is more used when referring to the effects based on actual data rather than forecasts (also called ex-post). Impact is also a general term more used in an ex-post sense.

The European project EVA [2] identified three types of assessment:

1. Operational analysis which is concerned with the technical performance of a system.
2. Socio-economic evaluation which estimates the gains or losses for society resulting from ITS deployment compared with a reference case or other

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options; these typically investigate the impacts of a system for a future time horizon. Such prospective studies make use of an ex-ante impact assessment, often based on literature review, simulation work and expert estimation. They are often comprehensive in scope but they do not involve, or only to a limited extent, data from real-life conditions.

Three types of mainly used socio-economic analysis are: cost–benefit analysis (CBA) in which all the costs and impacts are given a monetary value; cost-effectiveness analysis (CEA) which emphasizes assessment of costs to achieve particular impacts; and multi-criteria analysis (MCA) in which the importance of all relevant impacts are assessed but without assigning monetary values.

3. Strategy assessment which provides a long-term political analysis of entire ITS applications. Impact analysis, or similar terms, may also be used to refer to these strategic assessments (i.e. meaning the use of pre-specified processes, calculations, templates and reports) by governments to prepare evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impacts. The European Commission's (EC) impact analysis is one such approach and is described within this chapter.

10.1.3 Structure and scope

C-ITS is a relatively novel concept so there is a dearth of field trial results on which to base a comprehensive ex-post evaluation of its effects. We do not deal here with technical evaluation of C-ITS performance but concentrate on the more forward-looking aspects of ex-ante assessment and planning of field trials.

The chapter is structured as follows: Section 10.2 provides a brief review of CBA as related to C-ITS; Section 10.3 presents a six-step approach for planning assessment of C-ITS during field trials; Section 10.4 discusses key aspects of data collection, analysis and reporting relevant to C-ITS; Section 10.5 concerns strategic evaluation and assessment of C-ITS; Section 10.6 discusses some challenges and limitations in evaluation of C-ITS.

10.2 CBA

10.2.1 Introduction

CBA is an established methodology for comparing the costs of a measure (in this case, the C-ITS services) with the resource savings such as those arising from increased safety and reduced travel time, fuel consumption and pollution. CBA may be undertaken by individual stakeholders using the costs and benefits that are relevant to them (e.g. to assist development of business cases) but is more usually undertaken at a societal level. Such CBA is based on welfare economics where the resource savings constitute benefits because it is assumed that the resources could be used elsewhere in society with at least the same productivity.

There is a growing body of literature from European projects covering the application of CBA to ITS such as HEATCO [3] and eIMPACT [4]. CBA may be used in advance of C-ITS pilot projects to help determine investment priorities based on relevant data from elsewhere, hypotheses about impacts and estimates suggested by ‘expert judgement’. Ex-ante assessments of C-ITS services have already been carried out by several EU research projects including CODIA [5], eCall [6] and SAFESPOT [7], and additional projects are referred to within the chapter. CBA may also be used in ‘ex-post’ evaluations on implemented projects for comparison with ex-ante estimates and also to provide information to assist future deployment.

10.2.2 CBA methodology

CBA is typically undertaken to compare two alternative future scenarios:

1. A ‘base case’ or ‘do nothing scenario’, which assumes that no C-ITS services are implemented.
2. A ‘with-case’ or ‘do something scenario’, where the (bundle of) C-ITS services are implemented.

CBA may be used to estimate the potential impacts of C-ITS in the road environment over a given period of time. Typically, the impacts (benefits) considered relate to safety, mobility and the environment as these are most readily monetized through the application of standardized cost-unit rates. In addition, the costs of the C-ITS services have to be estimated, e.g. in terms of investment costs, operation costs and maintenance costs. Figure 10.1 provides a general overview of the CBA methodology.

Financial values are estimated for each of the criteria with costs and benefits being calculated over a defined period, such as 10 years. Comparing the economic benefits with the costs can be calculated in several ways, and it is important to be clear how each is calculated and how financial discounting (to take account of the

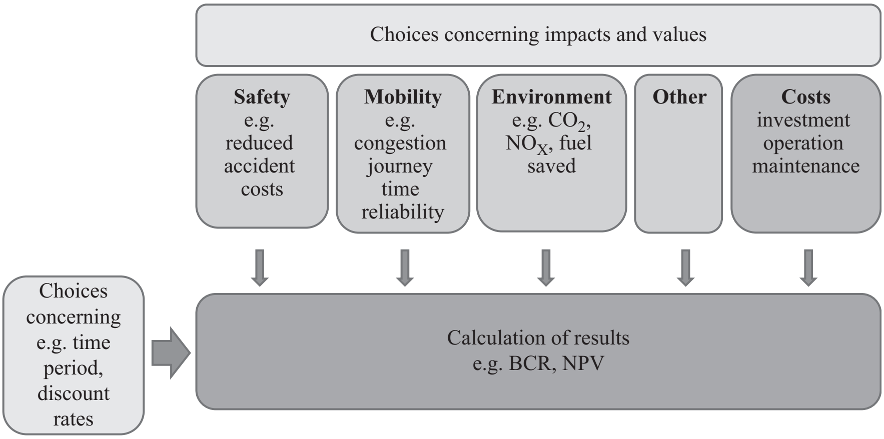

Figure 10.1 Socio-economic evaluation of C-ITS by CBA

future value of benefits and future costs), if any, is applied; this is usually a matter of national financial investment policy. A suitable discount rate for public sector investment in new technology might be higher than the accepted rate for public road infrastructure decisions but considerably lower than the rate that would be used for commercial decisions.

A more complete approach to discounting uses annual values. All the annual costs and benefits considered are summed and then transformed by the discount rate to one actual value of social benefit from the starting data of the C-ITS implementation. This is then expressed as a ratio called the benefit–cost ratio (BCR) or by subtracting the total costs from the total benefits, giving a net present value (NPV). A single service or a bundle of cooperative services can be considered to be beneficial if the BCR is greater than one or if the NPV is positive.

It is also common to preselect one or several target years and to calculate 'snapshot' BCR for these target years. In this case, the costs are transformed to annual values (using the discount rate) and are compared to the target year benefits. Both ways are feasible and represent good practice and which way is preferred depends most notably on information needs.

In many C-ITS studies, particularly if the services are of a generic nature, the simpler approach of snapshot years is often considered appropriate. This reflects the steady state once the whole vehicle fleet has been equipped with the technology, meaning the full annual benefits are achieved, and where the annual fitting costs apply only to new vehicle registrations. It is acknowledged that this will tend to produce higher BCR, for a given evaluation period, than more refined methods that consider the phased implementation over that period. This may to some extent be compensated for, however, by using the current system costs, or estimates of what the initial system costs would be, and not factoring in any reductions in those costs over time.

10.2.3 Sensitivity analysis

A CBA is often complemented by sensitivity analysis which varies important parameters of the CBA calculation (e.g. impact on safety, efficiency, in-vehicle costs, and infrastructure costs). The parameters may be varied by 10% or even 50% depending on the uncertainty of the data. The effect on the reported values such as BCR is also calculated in relative terms and thus reveals the magnitude of its influence.

10.2.4 Cost benefit for major EC projects

The EC has published a guide to CBA for major investment projects [8] and this can be applied at a strategic level to investment in C-ITS services.

The document explains the rationale for undertaking CBA based on the observation that investment decisions taken on the basis of profit motivations and price mechanisms lead, in some circumstances (e.g. market failures such as asymmetry of information, externalities and public goods), to socially undesirable outcomes. However, if inputs, outputs (including intangible ones) and external effects of an investment project are valued at their social opportunity costs, the return calculated is a proper measure of the project’s contribution to social welfare. This also requires a relatively long-term outlook beyond the planning horizon of most individual commercial organisations. The ECs reference period for road projects, e.g., is 25–30 years.

The ECs Connecting Europe Facility (CEF), is a directly managed fund created in 2012 for accelerating cross-border investments in the field of trans-European networks, maximizing the synergies between transport, energy and telecommunications policies, and ensuring funding from both the public and private sectors. It concentrates on projects with a high EU added value, and closely linked to the needs identified in national transport plans based on a rigorous assessment of transport demand (both for passengers and for freight). Although CEF interventions have mainly focused on development of the infrastructure network, projects are also supported which include C-ITS corridors throughout Europe.

CBA compares a scenario with-the-project with a ‘counterfactual’ baseline scenario without-the-project, also called ‘business-as-usual’ and uses a seven-step process.

Seven-step process for major EC projects

- Description of the context
- Definition of objectives
- Identification of the project
- Technical feasibility and environmental sustainability
- Financial analysis
- Economic analysis
- Risk assessment

10.3 Planning for evaluation of C-ITS

This section presents a six-step approach to evaluating C-ITS based on a UK approach for transport interventions [9] and as summarized in Figure 10.2.

10.3.1 Step 1: Clarifying the background to the evaluation

This step involves understanding the requirements of the evaluation and the overall objectives sought. This might include, e.g., measuring specific impacts, introducing specific services or involving specific stakeholders. Four questions may assist the clarification:

1. Who will use the results?

   Identify the stakeholders such as Government, road operators and commercial enterprises.

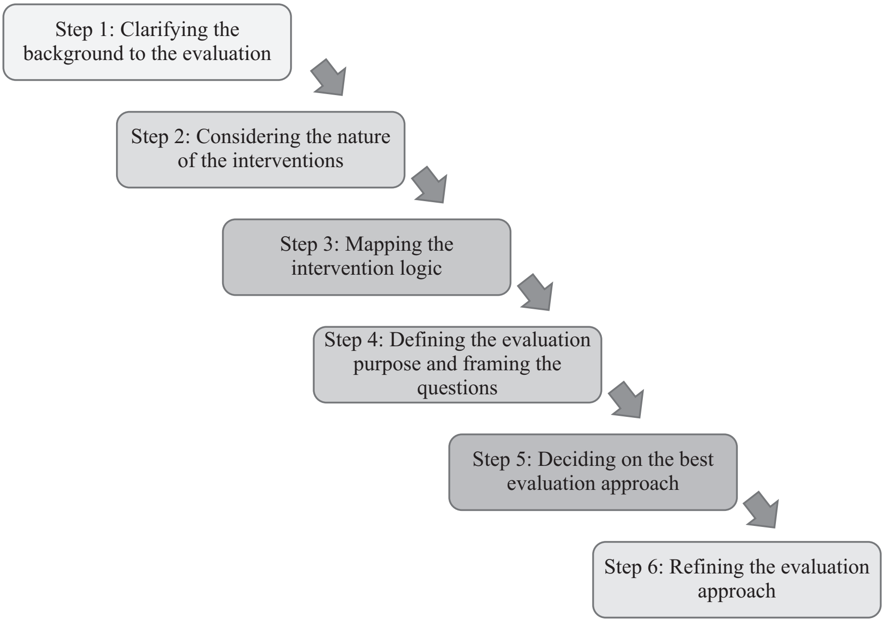

Figure 10.2 Summary of the six-step approach to evaluating C-ITS

2. What are the expectations for the results?

   As C-ITS services are yet to be widely established, there is a dearth of measured data so a full ex-ante CBA is usually impractical. Indeed, the purpose of trialling is often to enabling business cases to be developed for the future roll-out of the services. Therefore, trials need to be well designed and to ensure that the proposed trial methodology will provide the required information it is necessary to identify the potential impacts and their potential scale. It is also be necessary to ensure that metrics that are used can, as far as possible, be monetized consistently and using appropriate local, national or regional values, depending on the context.

   Impacts that are likely to be of greatest importance for C-ITS include reduced road traffic accidents (RTAs); less congestion, journey time savings, behavioural change in drivers, beneficial environmental impacts, including e.g. less noise and lower emissions, societal impacts, and business opportunities for equipment and service providers.

3. What would allow most effective use of the results?

   A particular pilot area or corridor might be chosen as representative to provide robust evidence for estimates of the costs and benefits of the package of interventions and the impacts. The evidence gathered in such a representative study area might enable better decisions to be made should such measures be rolled out in other areas.

4. What resources are available for the evaluation?

   Resources determine, to a large extent, how evaluation can be progressed. Typical categories of resources include: financial resources, e.g. equipped vehicles and roadside units, personnel resources, and other resources including monitoring equipment, e.g. air quality measurement tools, noise monitors and in-vehicle recorders.

10.3.2 Step 2: Considering the nature of the interventions

This step helps to ensure that there is clarity about the C-ITS services that will be provided, their intended benefits, the user groups affected and the likely scale of uptake. As well as selecting the services it is necessary to define them at an adequate level of detail (including their intended benefits and intrinsic limitations). Then, the exact uses which will be considered in the evaluation need to be defined. These 'use cases' are more specific situations where the service is used and help to define the boundary conditions under which a service is intended to be analysed. This is particularly important for C-ITS where different architectural and communication options might be able to deliver the same service.

Although a trial is required to quantify the potential impacts in practice, it is necessary to have some prior understanding of their likely magnitude or scale so that a suitably sensitive evaluation methodology can be designed. As a starting point, modelling can be used with data from the proposed trial site, to estimate the monetized total costs of the main societal impacts of traffic on the pilot site or corridor, which is the starting point for estimating potential savings from the proposed services.

It is important to note that, while crashes can theoretically be reduced to zero, for journey time and fuel consumption in particular, there will be a theoretical baseline value achieved if all vehicles were travelling under free flow conditions at the optimal speed for safety and traffic management, which would not be reduced by C-ITS. The interventions are largely targeting the additional fuel consumption and delays arising from non-optimal traffic flow, so can only influence a small proportion of the total cost. Nonetheless, a 1% reduction in travel time achieved through better traffic management is likely to be worthwhile.

Ideally, the total 'size of the target' i.e. the travel, fuel and emission costs associated with non-free flow (congestion) should be estimated.

10.3.3 Step 3: Mapping the intervention logic

This step involves exploring the causal chain between services provided, their expected outcomes and longer term impacts, identifying both intended and unintended consequences, and how they might be measured. The aim is to build a map of the intervention logic to diagrammatically illustrate the relationship between the intervention and the intended impacts.

The process involves defining the content of four components: (1) **Inputs** – what is being invested in terms of resources and activities; (2) **Outputs** – e.g. target groups reached, in-vehicle units installed, software for message generation;

(3) **Outcomes** – short- and medium-term results, such as changes in traffic flows or speeds at specific points, journey times, reduced driver uncertainty; and (4) **Impacts** – long-term results such as increased safety and environmental benefits.

It is helpful to develop a table and consider the four components in sequence for each service.

10.3.4 Step 4: Defining the evaluation purpose and framing the questions

In this step, the primary and secondary impacts of the use cases specified above are identified and research questions are formulated related to these use cases. The aim is then to identify suitable qualitative and quantitative metrics (also called indicators) and to derive hypotheses associated with the research questions that can be tested using the metrics.

Research questions are relatively general and are to be answered by compiling and testing related specific hypotheses. While research questions are phrased as real questions ending with a question mark, hypotheses are statements which can be either true or false. These can be tested by statistical means.

10.3.5 Step 5: Deciding on the best evaluation approach

This step involves selecting the most appropriate methods for providing a control, or baseline, against which impacts of C-ITS can be compared to ensure that they are real and can be attributed to the interventions.

There are two main approaches although a combination may also be used: (1) Experimental design – This requires setting up of either before and after measurements or comparison of matched areas where C-ITS is implemented in one area only. (2) Theory-based approach – which involves observation and measurement of the effects of C-ITS but without the experimental control. This approach typically has much greater stakeholder involvement and extends over more prolonged time periods.

10.3.6 Step 6: Refining the evaluation approach

This step allows review and finalization of the methodology. If necessary, some changes to the preferred indicators may be required for compatibility with the chosen approach.

10.4 Trials data collection analysis and reporting

10.4.1 Introduction and planning of data collection

Although there are many ways of evaluating C-ITS, the most extensive is through a ‘field operational test (FOT)’. This allows a rigorous assessment of the services in their intended environment by their intended users, on a scale and with duration sufficient enough for statistically robust conclusions.

The data collection methodology is generally developed in detail as part of the trials design. Data required for evaluating C-ITS typically includes quantitative measurements, quantitative assessments (e.g. rating scales) and qualitative data (e.g. feedback from stakeholders and reports of focus groups). From an analysis perspective, key issues are clear naming, labelling and secure storage of data and also following all ethical and legal requirements. As well as the data collected for the C-ITS impact assessment, metadata can be collected including: (1) technical performance of the C-ITS systems (e.g. sensor faults, availability) and (2) monitoring of service delivery and vehicle availability.

To support FOT design, operation and analysis of results, the EC sponsored development of a FOT methodology, called Field opErational TeSt support Action (FESTA). The original FESTA project, completed in August 2008, developed a handbook of best practice for the design and implementation of FOTs in Europe. This has been subsequently updated as a result of project experience [10, 11]. The handbook describes the key issues to be addressed including: (1) planning and running a FOT; (2) legal and ethical issues; selection of functions to be tested, and definition of use cases, research questions and hypotheses relating to those functions; (3) performance indicators; (4) experimental procedures (including participant selection, study design, study environment and pilot testing); (5) data acquisition; (6) databases and analysis tools; (7) data analysis and modelling; and (8) socio-economic impact.

FESTA describes some of the specific issues involved in conducting field trials with C-ITS [12] including: (1) integration of the C-ITS into the vehicles; (2) the need to train drivers in the C-ITS usage; (3) the need to equip vehicles and infrastructure and suitable logging equipment; and (4) ensuring a sufficiently high penetration rate for interaction effects to be observable.

It also provides general advice (not specific to C-ITS) concerning data acquisition, databases and analysis tools, data analysis and modelling.

10.4.2 Data analysis

Collection, initial assessment, aggregation and processing of data from C-ITS trials generally follow the conventional approaches briefly summarized here:

Approaches for data collection, initial assessment, aggregation and processing

Initial data assessment and aggregation

- Dynamic data assessment – ‘sense checks’ on data as it is being collected
- Quality check on data (e.g. completeness, correct units, values in feasible range)
- Aggregate raw data over appropriate time scale
- Combine aggregated data into the previously identified indicators (reporting confidence limits according to standard statistical practice)

Core analysis

- Use traffic modelling and judgement to determine input parameters for estimation and modelling of outcomes (relative to base case)
- Test hypotheses of previously developed intervention logic
- Use modelling, including future traffic flows, accident rates, traffic mix and service penetration to estimate future benefits and costs for refined CBA
- Evaluate risks and sensitivities

Further analysis

- Undertake opportunistic data mining of data sets and make selected data sets available outside of the project
- Evaluate broader outcomes such as impact on other services (legacy services) and modal distribution
- Estimate distributional effects of benefits and outcomes for different stakeholders including industry, road operators and road users
- Use appropriate scaling factors to estimate national benefits of services
- Develop models for sustainability of services using ‘value web’, for mapping of the flows of services, revenues and non-monetized value between the main stakeholders involved in a service (whether as providers or users)
- Undertake financial analysis and stakeholder analysis (e.g. Willingness-to-Pay data which can provide evidence about likely demand) to study business cases for service delivery

10.4.3 Reporting

Broadly, three classes of information are reported from field trials of C-ITS: (1) technical performance of the technology, (2) data description and quality statistics and (3) key outcomes of e.g. safety, traffic flow and environmental improvements.

Consistency in reporting of key indicators would assist wider comparison between trials. Table 10.1 summarizes the indicators reported in one European C-ITS evaluation project COBRA [13], a study for the European C-ITS Platform undertaken by RICARDO [14] and an AECOM report on Key Performance Indicators (KPIs) for road transport ITS [15].

Reporting may need to extend beyond the impacts to make recommendations e.g. for future roll-out, bundling of services, evaluation approach and other services.

Table 10.1 Comparison of C-ITS indicators from three studies

COBRA	EC C-ITS Platform WG1	European KPI report
Road safety – number of fatalities Road safety – number of serious injuries Road safety – number of slight injuries Road safety – damage cost of injury accidents	Safety, i.e. the percentage change in accident rates (classified by fatalities, serious injuries, light injuries and material damages) for a vehicle equipped with C-ITS services.	Percentage change in number of reported accidents along routes where ITS has been implemented. Report by accident severity where possible.
Travel time – the total time spent travelling, which is the sum of the theoretical minimum travel time if all vehicles travelled at the speed limit and the 'lost vehicle hours'		
	Traffic efficiency, i.e. the percentage change in average speed for a vehicle equipped with C-ITS services.	
		Percentage change in peak hour journey time along routes where ITS has been implemented. Report by vehicle type. Percentage change in peak hour traffic flow along routes where ITS has been implemented. Report by vehicle type. Percentage change in journey time variability on routes where ITS has been implemented as measured by coefficient of variation. Report by vehicle type.
Fuel consumption – money spent on petrol (exc tax) Fuel consumption – money spent on petrol (exc tax)	Fuel consumption i.e. the percentage change in fuel consumption for a vehicle equipped with C-ITS services.	
Emissions – CO_2	Polluting emissions i.e. the percentage change in NO_x, CO, VOC and PM emissions for a vehicle equipped with C-ITS services.	Percentage change in annual CO_2 emissions (tons) on routes where ITS has been implemented.
Emissions – NO_x Emissions – $PM_{2.5}$		
		Percentage change in mode share on corridors where ITS has been implemented. Report percentage mode share separately for each mode. Time taken between initiation of public (112) eCall to the presentation of the eCall data in an intelligible way at the operator's desk in the emergency centre.

10.5 Strategic approaches to evaluation and assessment

10.5.1 Introduction

Strategic assessment is more complex than ‘pure’ CBA, and recognizes the diversity of objectives and issues that contribute to appraisal. Qualitative factors included in strategic assessment typically include: (1) distribution and equity, (2) environmental factors, (3) affordability and financial sustainability, and (4) practicality and public acceptability.

Here implicit or explicit deployment scenarios are required. One approach is to present the socio-economic impacts of the C-ITS services at different levels of penetration or at future years with an assumed penetration growth rate. Alternatively, specific alternate futures can be presented with assumptions about technical performance, regulations and costs.

In this section the technique of multi-criteria assessment is first briefly described before summarizing the strategic approaches used in different international forums.

10.5.2 MCA

Multi-criteria assessment uses CBA as just one input in a process that attempts to take the multiple impacts of an ITS project into consideration in a balanced manner. MCA provides a flexible way of dealing with qualitative multidimensional effects of transport projects and can rank projects from the point of view of different stakeholder groups.

There are many variations on MCA, but common in almost all is the need to determine: (1) a set of alternative projects (usually including ‘do-nothing’), (2) a set of criteria to be taken into account in the evaluation and (3) a ranking or weighting of the relative importance of the criteria.

The BCR or other quantitative financial measure may be just one criterion. Alternatively, the costs and benefits may separately contribute to a number of criteria. Within the European ADVISORS project, a hierarchical tree of criteria was constructed [16] to evaluate the benefits of different driver assistance systems. Wider economic impacts include, e.g., legacy systems and replacement, effects on productivity, growth and employment.

Within MCA, the overall desirability of each alternative ITS is evaluated on each criterion giving partial evaluation within a matrix. Additionally, the impacts are weighted depending on their relative importance or priority in terms of meeting different stakeholder objectives. Both the criteria and their importance may be derived from a stakeholder analysis.

MCA can combine individual costs and benefits or separate CBA studies with a range of other relevant impacts that cannot easily be translated into monetary terms. The method of combination allows all impacts, both qualitative and quantitative, to be considered on the same basis and by different stakeholder groups. The main shortcoming of MCA is that one solution rarely dominates for all stakeholder groups so compromise and judgement still needs to be exercised. The development of more robust MCA incorporating costs and benefits is a future challenge in ITS evaluation.

10.5.3 US and UK examples

The US Department of Transport has developed a short list of what it calls the 'Few Good Measures' for evaluating ITS impacts based on its strategic ITS plan [17]. These are: crashes, fatalities and injuries, delay, travel time reliability and customer satisfaction, capacity, cost, emissions and energy consumption.

In the UK, major Government transport projects (including C-ITS) use a national Transport Analysis Guidance approach [18] which involves a spreadsheet summary table (see Table 10.2). The objectives reflect the UK Government's transport objectives. Where possible, quantitative values are included but many factors are rated on a 7-point scale.

10.5.4 EC Impact Appraisal

The latest Better Regulation Guidelines [19] contain guidance on how Commission Services conduct impact assessments and are accompanied by a toolbox [20] which provides complementary guidance for Commission staff on specific impact assessment elements. This guidance would apply to the introduction of regulations around cooperative services and, e.g., an impact assessment was required before the eCall Directives were developed.

Table 10.2 Appraisal summary table based on UK Transport Analysis Guidance

Objective	Sub-objective
Economy	Business users and transport providers
	Reliability impact on business users
	Regeneration
	Wider impacts
Environment	Noise
	Local air quality
	Greenhouse gases
	Landscape
	Townscape
	Heritage of historic resources
	Biodiversity
	Water environment
Social	Commuting and other users
	Reliability impact on commuting and others
	Physical activity
	Journey quality
	Accidents
	Security
	Access to services
	Affordability
	Severance
	Options and non-use
Public accounts	Cost to broad transport budget
	Indirect tax revenues

Impact Assessments (IAs) set out the logical reasoning that links the problem, its underlying drivers, the objectives and a range of policy options to tackle the problem. They present the likely impacts of the options, who will be affected by them and how. An Inception Impact Assessment which describes the problem, subsidiarity related issues, objectives, policy options and an initial consideration of relevant impacts of these policy options, allows stakeholders to provide feedback, and the impact assessment may be used as part of a broader consultation strategy to target relevant stakeholders and evidence.

Impact assessments compare the policy options on the basis of their economic, social and environmental impacts (quantified as far as possible). While impact assessment analysis can be complex, the Impact Assessment Report is for non-expert readers. Generally, the main report comprises 30–40 pages with annexes for more detailed technical material and analyses.

Specific elements contained in an impact assessment report

- A description of the environmental, social and economic impacts and an explicit statement if any of these are not considered significant
- A clear description of who will be affected by the initiative and how
- Impacts on Small- and Medium-sized Enterprises (SMEs)
- Impacts on competitiveness
- A detailed description of the consultation strategy and results

The impact assessment analysis assesses the relevant advantages and disadvantages of the retained policy alternatives (i.e. the options) against the reference of the baseline and identifies how any adverse consequences would be tackled. To do this, it is necessary to identify the changes that a proposal would imply for those affected and, thus, a wide range of possible impacts need to be reviewed across the economic, social and environmental policy areas, going beyond the more obvious consequences and including indirect impacts. All potentially important impacts should be identified regardless of whether or not it will be possible to assess them precisely. EC impact assessments are required, in particular, to examine the impact that options have on fundamental human rights.

Both positive impacts (i.e. the benefits) as well as negative impacts (i.e. the costs or adverse environmental and social impacts) should be identified. A positive impact for one party can be negative for another. It is therefore important to identify who would be specifically affected by each impact.

Particularly relevant for policies involving C-ITS are considerations around information technology (IT) systems and networks to automate business processes, publish/exchange information, and deliver online services via web-based Portals. For C-ITS, it is important to examine the implementation of new systems or the adaptation of existing information and communications technology (ICT) solutions and a ‘digital screening’ tool in the toolbox is provided.

At the end of this analysis, the positive and negative potential impacts are mapped according to their expected magnitude and likelihood and to the specific parties that would be affected.

Classification of potential impacts

- Broad nature: economic, social and environmental
- Specific nature: e.g. changes in business compliance costs, market efficiency, competitiveness, innovation; impacts on health, quality of the environment, combating climate change, levels of education and training, fundamental rights, employment and skills, social inclusion and poverty
- Indirect (or second-round) impacts arising as a result of the behavioural changes prompted by the direct impacts
- Affected parties, groups or regions
- Frequency and certainty: long/short term, one-off, recurrent; certain or likely (risks)

The choice of impacts to be retained for deeper assessment should be clearly justified, taking account of their expected overall magnitude, relevance for specific stakeholders (particularly SME) and compatibility with EC policies.

All relevant impacts should be assessed quantitatively, if possible, as well as qualitatively. Similarly, impacts should be monetized whenever possible. Whenever an assumption is particularly important or uncertain, sensitivity analysis should be used to check whether changing it would lead to significantly different results. The EC Impact Appraisal does not specify a methodological approach to quantify impacts, but expects that the choice is clearly justified and explained in the impact assessment report.

In the case of both quantitative and qualitative analysis, it is important to remember that changes should be assessed relative to the baseline scenario and that appropriate discounting should be used to account for the distribution of costs and benefits over time. An impact assessment assesses impacts from the point of view of society as a whole although distributional effects and cumulative burdens on individual parties are considered but taking care to avoid any double-counting (e.g. when costs are transferred from one stakeholder to another).

Based on the assessment of the various impacts and their distribution across affected stakeholders, the impact assessment should compare the different options with regard to their effectiveness, efficiency and coherence, as well as their compliance with the proportionality principle. CBA, CEA, compliance cost analysis and MCA are the most commonly used methods to compare options.

An impact assessment brings together the results in a clear comparison of the options which is intended to facilitate the identification of the preferred option. It does not need to identify a preferred option, but it should attempt objectively to compare the options against common criteria, in particular: the extent to which different options would achieve the objectives (effectiveness), the benefits versus the costs (efficiency), and the coherence of each option with the overarching objectives of EU policies (coherence).

Having the entire policy cycle in mind, the impact assessment should identify monitoring and ex-post evaluation arrangements to track whether the policy measure actually delivers the intended results and to inform any future revisions of the policy.

10.6 Challenges and limitations

This section identifies some of the challenges and limitations inherent in assessing and evaluating C-ITS. Here we concentrate on issues that are specific or significant for C-ITS beyond those that are challenges in evaluating ITS more generally such as monetary valuation of outcomes and distributional effects of benefits between stakeholders.

10.6.1 Size of the effect

A key challenge in evaluating the impact of C-ITS services is the size of the impact or effect that the C-ITS service is likely to have. Several previous national and European projects have made ex-ante assessments of the potential of C-ITS based on different definitions of services/bundles of services and different methods of evaluation. The ex-ante assessments have been based on sparse data, estimations from relevant sources and expert opinions and then scaled up to estimate national or regional impacts.

The COBRA project [13] investigated three bundles of services each consisting of several cooperative functions:

1. Local dynamic event warnings: Hazardous location notification, road works warning (RWW), traffic jam ahead warning and post-crash warning (eCall)
2. In-vehicle speed and signage: In-vehicle signage, dynamic speed limits and Intelligent Speed Adaptation
3. Travel information and dynamic route guidance: Traffic information and recommended itinerary, multi-modal travel information and truck parking information and guidance.

The results predicted when 100% of vehicles were equipped are shown in Table 10.3.

A study by consultants for the EC, reported in the European C-ITS Platform (WG1) report [14] came to a broadly similar ranges of impacts based on largely the same data and assumptions as COBRA. Hence, we can anticipate that the effect size we are trying to measure (e.g. of travel time or vehicle crashes) is less than 10% and often less than 5% even if all vehicles are benefiting from the cooperative service.

In pilots and field trials, it is typical to equip a few hundred or even a few thousand vehicles in a city or corridor. The total number of vehicles provides a

Table 10.3 Predicted impacts of three service bundles from the COBRA project

Impact indicators		**Bundle 1 (%)**	**Bundle 2 (%)**	**Bundle 3 (%)**
Road safety	Number of fatalities	−7	−7	−4
	Number of non-fatal injuries	−8	−5	−5
	Number of injury accidents	−7	−5	−5
Travel time	Time spent travelling	+0	+4	−11
Fuel consumption	Petrol and diesel	−1	−4	−10
Emissions	CO_2	+2	−4	−9
	NO_x	−10	−9	−5
	$PM_{2.5}$	−1	−10	Not found

'headline' but for evaluation purposes a more important metric is vehicle-km in the area of interest within a defined time period. Any measurable effects will depend on the pilot fleet's usage of the network, and more specifically its density at any one time and place. So, an important question is what density of equipped vehicles is required to 'see' the effect of a C-ITS service bearing in mind that the period over which a C-ITS service is relevant may be limited (e.g. during congestion/incidents) or relevant only at specific points in the network.

An outline calculation illustrates the density requirements on a corridor: The maximum flow achievable is approximately 1,500 vehicles/h/lane but more sustainable 500–1,000 vehicles/h/lane. To achieve, say, a 5% density of equipped vehicles at a quiet time on a single lane part of the network might need 25–50 vehicles/h. Whether this is achievable will depend on the number of vehicles and their distribution over the area of interest. Such a density might be achievable during a focussed and dedicated trial but for many corridors this is unlikely to be achieved naturally by equipping a fleet of vehicles going about their normal routine.

For services providing information to drivers, a change of behaviour would be required to measure effects and it therefore seems very unlikely that flow data typically obtainable from traffic counters (e.g. providing 2-min averaged traffic counts) would 'see' any change at a bulk traffic level. A similar argument could be applied to environmental data and to safety data such as vehicle crashes.

Therefore, to measure an effect, it will be important to monitor the behaviour of individual vehicles/drivers and correlate this with the information provided. This can be achieved through interrogation of the driver (e.g. questionnaires, logs) or interrogation of the vehicle (e.g. by data logging). If and when effects are measured, there needs to be some assumptions and modelling about how the change in behaviour will translate into impacts such as traffic flow and safety. Thus there is a long and, arguably, fragile chain of assumptions between the effects measured and the impacts anticipated.

10.6.2 Bundling the effects of individual services

Impacts may initially be considered (or measured in trials) for individual C-ITS services. Alternatively, a bundle of two or more services may be considered or implemented together. In practice, a likely deployment scenario would involve a bundle of services implemented together, rather than in isolation.

A simple addition of impacts would only be reasonable if the individual functions' impacts did not overlap. For most of the functions within a bundle, this is not the case, e.g. hazardous location warning and traffic jam ahead warning do overlap when a traffic jam originates from a hazardous location. Therefore, in general, it will be necessary to identify overlaps and the combined effects of multiple services during evaluation.

10.6.3 Overlap with existing infrastructure

C-ITS can offer some services that are entirely new so the base case is clear; however, C-ITS can also replace or supplement non-cooperative services so the comparison is more difficult (indeed, C-ITS can completely change some business models so may have wider consequences).

Where the functions of C-ITS overlap with existing technologies, the impacts of these existing technologies also need to be taken into account alongside that of the C-ITS. For example, suppose a section of motorway is already equipped with a Queue Protection system, i.e. where inductive loops are used to detect queues and warn drivers via Variable Message Sign (VMS) that there is a queue ahead. If a cooperative system were to provide the same or similar 'queue ahead' service, its impact would likely be not as great on a section already equipped with the existing infrastructure. It may provide additional benefits, but this would depend on the functions and design of the systems. Some examples are illustrated in Table 10.4.

Another example would be to consider to what extent in-vehicle dynamic route guidance yields additional benefits over roadside routing information. This is challenging, because amongst other things, it introduces the concept

Table 10.4 Potential overlap of C-ITS services with other ITS services

Example C-ITS service	Potential overlap
Floating vehicle data	Loops, Bluetooth, number-plate matching
In-vehicle signage (static and dynamic)	Static signs, variable message signs
Road works warning	Static and dynamic signage, radio reports
Freight lorry parking	Signage, fleet management information systems, radio/phone contact with base or colleagues
Freight slot availability	Fleet management information systems
eCall automatic crash notification	Video surveillance and processing, static vehicle sensors

of whether in-vehicle route guidance is able to give altruistic messages, i.e. where recommendations are optimized so that the recommended route not necessarily the best for the individual driver, but is better for overall traffic efficiency.

10.6.4 'Hotspots' and transferability

As noted above, some C-ITS service may only be relevant at specific points in a network. Similarly, some services may be relevant only to certain types of roads, vehicles, drivers or journey purpose. Therefore, care has to be taken when scaling impacts measured in one region or corridor up to national level. The scaling up will involve obtaining data on benefits achieved, with informed assumptions to make estimates where that data are not available, increasing the fragility of the estimates of effects.

10.6.5 Proportion of equipped vehicles and road network

Deployment variables include the number of equipped vehicles and, for services communicating with road infrastructure, the proportion of road network that is equipped with communications (e.g. cellular or wireless beacons).

For most C-ITS services which receive information from the roadside, it can be assumed that the relationship between deployment level and overall impacts is linear, i.e. each additional equipped vehicle benefits equally. This may not actually be the case; it could be better or worse as two examples illustrate:

1. Road Works Warning (RWW) might cause a large number of vehicles to seek an alternate route whereas, in practice, the better option may be for most to stay on the original road. So, as an information service becomes widespread it needs to take account of the number of vehicles likely to act on the advice.
2. Information services that cause vehicles to slow down (such as RWW or Green Light Optimization) might have the effect of also slowing other traffic, particularly if overtaking opportunities are limited.

For C-ITS services that involve information exchange between vehicles, this relationship certainly would not be linear; it is likely that for very low penetration rates there are no impacts at all and it is only when the number of equipped vehicles reaches a certain threshold that any impacts are received. This threshold depends on the C-ITS service, but also other factors. Similar to the 'hotspots' assumption for existing infrastructure, the number of equipped vehicles within range would be greater in busier traffic conditions.

10.6.6 Driver acceptance and compliance

A vehicle may be equipped with an in-vehicle unit and be travelling along an equipped section of road, but the user may choose to turn off the service. In other cases the user may choose to turn on the service (or it may be permanently on), but then choose to ignore any information from it. This would clearly affect the impact of C-ITS services.

This is an area in which there is relatively little research specific to C-ITS services although there is general consensus on some important issues [21]:

General consensus on driver acceptance and compliance

- Acceptance is a complex construct which has many facets and dependencies.
- Acceptance is based on individual judgements, so a driver-centric view is required to measure or predict acceptance at an individual level (assessing societal acceptance requires an additional broader perspective).
- Two key determinants of acceptance of new technology are usefulness and ease of use.
- Acceptance depends on the individual, so issues such as gender, age, culture and personality are likely to be important.
- The context of use is also important, including the supporting infrastructure (in its widest sense), whether use of the technology is voluntary and also broader social/cultural influences.
- Drivers do not have to actually like a technology/system to be accepting of it (but liking it may increase use of the technology).
- Acceptance should be regarded as a continuous variable, not a binary concept.
- Acceptance is not invariant; it may change (even for one individual) depending on the specific time/context in which the new technology is used and as experience with the technology develops.

10.6.7 Time horizon for evaluation

One of the specific challenges in evaluating C-ITS is deciding on the appropriate time horizon. This is always an issue in evaluation but C-ITS involves three components (of devices, vehicles and infrastructure) with very different time horizons. Road infrastructure has an expected life of perhaps 30 years whereas vehicles are typically replaced in 5–10 years and IT devices, such as mobile phones, have a typical replacement frequency of 1–2 years. So, deciding an appropriate period for a C-ITS service is problematic and depends on the perspective of the stakeholders.

10.7 Closing remarks

There are many challenges in assessing and evaluating C-ITS – from initially defining the service, to measuring effects and expressing meaningful results. In part these challenges occur when introducing any ITS, and more generally with any transport intervention. However, evaluating C-ITS services presents some unique challenges as a result of their relative novelty and the diverse hardware components, system architectures and stakeholders that need to be involved.

Market trends indicate that future vehicles will increasingly be connected and able to exchange information with each other and with devices within the road infrastructure. To understand the implication of this connectivity and hence to manage its development for the benefit of stakeholders, good evaluation is an essential tool and further efforts to refine our understanding and practice of C-ITS evaluation are expected to be worthwhile. This chapter is offered as a contribution to that ongoing process.

References

[1] ISO/TR 17465-1: Intelligent transport systems—terms, definitions and guidelines for Cooperative ITS standards documents—Part 1: terms, definitions and outline guidance for standards documents.

[2] EVA consortium (1991). Evaluation process for road transport informatics. EVA manual. Funded by the Commission of the European Communities DGXIII. Carried out by the EVA consortium Project V1036 Programme DRIVE.

[3] HEATCO (2006). Developing Harmonised European Approaches for Transport Costing and Project Assessment. Contract No. FP6-2002-SSP-1/502481. Available from: http://cordis.europa.eu/result/rcn/45028_en.html [Accessed 29 March 2016]; http://heatco.ier.uni-stuttgart.de/ [Accessed 29 March 2016]

[4] Assing, K., Baum, H., Bühne, J.-A., *et al.*; eIMPACT (2006). Methodological Framework and Database for Socio-Economic Evaluation of Intelligent Vehicles Safety Systems, eIMPACT Deliverable D3.

[5] Kulmala, R., Leviäkangas, P., Sihvola, N., *et al.*; CODIA (2008). CODIA Deliverable 5: Final Study Report. CODIA Co-Operative systems Deployment Impact Assessment. VTT Technical Research Centre of Finland. Submitted to European Commission DG-INFSO. Available from: http://bookshop.europa.eu/en/codia-deliverable-5-pbKK0414583/ [Accessed 29 March 2016]

[6] eCall (2009). Impact assessment on the introduction of the eCall service in all new type-approved vehicles in Europe, including liability/legal issues. Final Report Issue 2. DG-INFSO. SMART 2008/55. Available from: http://bookshop.europa.eu/en/impact-assessment-on-the-introduction-of-the-ecall-service-in-all-new-type-approved-vehicles-in-europe-including-liability-legal-issues-pbKK0214699/ [Accessed 29 March 2016]

[7] SAFESPOT (2010). Report on socio-economic, market and financial assessment. SAFESPOT Integrated Project – IST-4-026963-IP, SP6 – BLADE – Business models, Legal Aspects, and DEployment, Deliverable No. D6.5.1. Version 12, 21/10/2010.

[8] Sartori, D., Catalano, G., Genco, M., *et al.* (2014). Guide to Cost-Benefit Analysis of Investment Projects – Economic appraisal tool for Cohesion Policy 2014–2020. European Commission. Directorate-General for Regional and Urban Policy. Available from: http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf [Accessed 29 March 2016]

[9] Guidance for Transport Impact Evaluations: Choosing an Evaluation Approach to Achieve Better Attribution. The Tavistock Institute. March 2010. Available from: http://www.tavinstitute.org/projects/report-new-guidance-for-evaluation-in-the-transport-sector/ [Accessed 29 March 2016]

[10] FESTA Handbook Version 4 (2011). Available from: http://www.its.leeds.ac.uk/festa/downloads/FESTA_Handbook_V4.pdf [Accessed 29 March 2016]

[11] FESTA Handbook Version 5. Available form: http://wiki.fot-net.eu/index.php/FESTA_Handbook [Accessed 29 March 2016]

[12] Regan, M.A. and Richardson, J.H. (2009). Planning and implementing field operational tests of intelligent transport systems: a checklist derived from the EC FESTA project. IET Intelligent Transport Systems, 3(2), 168–184. DOI: 10.1049/iet-its:20080083, Print ISSN 1751-956X, Online ISSN 1751-9578.

[13] Ball, S., van Noort, M. and Nitsche, P. (2013) Costs and benefits of cooperative ITS for road authorities: the COBRA decision-support tool. Proceedings of the 9th ITS European Congress, Dublin, Ireland, 4–7 June 2013, Paper ID: TP0081. Available from: http://www.itsineurope.com/its9/index.php/programme/proceedings [Accessed 29 March 2016]

[14] C-ITS Platform Final Report January (2016) European Commission (Includes reference to RICARDO study for WG1). Available from: http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf [Accessed 29 March 2016]

[15] Key Performance Indicators for Intelligent Transport Systems Final Report (2015) AECOM Study for European Commission. Available from: http://ec.europa.eu/transport/themes/its/studies/doc/its-kpi-final_report_v7_4.pdf [Accessed 29 March 2016]

[16] Macharis, C., Stevens, A., de Brucker, K. and Verbeke, A. (2006). A multi-criteria approach to the strategic assessment of advanced driver assistance aystems. In: Towards Better Performing Transport Networks, Ed. by: Jourquin, B. Rietveld, P., Westin, K. Routledge: Taylor and Francis. ISBN 0-415-37971-7.

[17] Department of Transportation website on evaluation guidelines ‘few good measures’. Available from: http://www.its.dot.gov/evaluation/eguide_resource.htm [Accessed 29 March 2016]

[18] UK DfT Transport Analysis Guidance (TAG). Available from: http://www.gov.uk/government/publications/webtag-appraisal-tables [Accessed 29 March 2016]

[19] Better Regulation Guidelines (2015). Available from: http://ec.europa.eu/smart-regulation/guidelines/toc_guide_en.htm [Accessed 29 March 2016]

[20] Better Regulation Toolbox (2015). Available from: http://ec.europa.eu/smart-regulation/guidelines/toc_tool_en.htm [Accessed 29 March 2016]

[21] Regan, M., Horberry, T. and Stevens A. (2014). (Eds) Driver Acceptance of New Technology: Theory, Measurement and Optimisation. Farnham: Ashgate. ISBN: 978-1-4094-3984-4.

Chapter 11

The evolution towards automated driving – Classification of impacts, review of assessments of automated driving functions, challenges for evaluation

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11.1 Introduction

In recent years, the concept of automated driving has received substantial interest from various sectors, including the automotive industry and its suppliers, IT and telecom industry, public authorities and road operators. The interest has resulted in various efforts (example references are provided but do not aim for completeness):

- to define research needs for automated driving [1],
- to define cross-sector roadmaps for closing the research gaps [2],
- to carry out the necessary elements of research and to network the projects [3],
- to develop national and European strategies towards automated driving [4–6],
- to set up adequate infrastructure for testing of automated driving functions [7, 8] and
- to form coordinating institutions and arrangements fostering the preparation of implementing first functions of higher automated driving levels [9, 10].

11.2 Levels of automated driving

There are different levels of automated driving. The most frequently used levels are those specified in the SAE classification (Figure 11.1), described in the SAE J3016 Information Report 'Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems' [11]. They correspond to the levels developed by BASt [12].

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SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ('system') monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 11.1 SAE classification for levels of road vehicle automation [11]

Even though Level 0 systems have none of the driving functions automated, they can be equipped with warning systems alerting the driver to hazards enabling the driver to respond earlier and more effectively to those hazards.

Level 1 driver assistance systems may provide automatic speed control or automatic steering of the vehicle, but the driver continues to perform the other control functions. Level 1 systems have been available on the market from late 1990s in the form of electronic stability control (ESC) and adaptive cruise control (ACC).

Level 2 partial automation systems have recently been introduced on high-end vehicles, and will be introduced on premium vehicles from more manufacturers within the next few years. Both Level 1 and 2 systems provide driving comfort and convenience, but they require that the driver continuously monitor the driving environment for hazards and be prepared to resume control immediately when the system encounters situations it cannot handle [13].

Level 3 conditional automation systems will provide higher levels of driver comfort and convenience by allowing the driver to temporarily turn attention away from driving to engage in other activities, but the driver still needs to be available to retake control within a few seconds' notice when the system reaches the limits of its capabilities [13].

Level 4 high automation includes a diverse collection of capabilities that need to be considered individually. These systems can replace drivers completely (not requiring driver interventions). The Level 4 systems would operate only under specific limited conditions, which can vary widely from system to system. These systems include automated valet parking systems, automated buses on special transitways, automated trucks on dedicated truck lanes, automated low-speed shuttles, automated passenger cars on limited-access highways [13].

Level 5 full automation will enable a vehicle to drive itself anywhere and under any conditions in which a normal human driver would be able to drive. This is the concept that captures the public imagination by allowing full 'electronic chauffeur' service [13].

The Level 4 and 5 applications are the ones that could have revolutionary impacts on travel behaviour and urban form by eliminating the disutility of travel time, decoupling parking locations from travellers' origins and destinations, facilitating vehicle-sharing as well as ride-sharing, and breaking down the boundaries between public and private transportation. At Level 4, these impacts are likely to be localized to the zones that are capable of supporting the highest automation capabilities, but at Level 5 they could apply throughout urban regions and even nationally [13].

11.3 Classification of potential impacts of automated driving (stakeholder, timeline)

Automated driving will provide many kinds of benefits – some direct and some indirect. The benefits originate at the individual level, from changes in the behaviour of drivers and travellers with regard to driving and mobility, ending up with benefits at the social level via changes in the whole transport system and society, where many of the current planning and operations paradigms are likely to be transformed by automated driving. There may also be disbenefits, particularly at a social level, for example in intensity of travel which could result in additional congestion and increased use of natural resources. There may also be unintended consequences. For example, we do not know the impacts on public transport: driverless vehicles could provide a means to a lower cost service provision, but the availability of automated cars could lead to more car travel at the expense of collective transport [14].

11.3.1 Near and medium terms

In this period, most of the changes are likely to be evolutionary, with a gradual introduction of higher levels of automation, particularly for privately driven vehicles. Additionally, urban 'pods' may operate in limited and perhaps segregated environments.

11.3.1.1 Benefits

Individual

Access to infotainment and the possibility to work or relax or just be connected while driving is likely to be the major motivation for an individual to go for highly automated driving. This likely results in a major change in their lifestyle and improvement of their quality of life. It could also make long-distance commuting by car more attractive, and thus offer a wider choice of residency location.

According to Reference 15, an average driver spends 235 h driving every year, having to concentrate on driving 100% of the time. In an automated vehicle, this journey time can be safely used however they wish, from working, reading a book, to surfing on the web, watching a film or just chatting face-to-face with other passengers. It has been argued that the freedom to multitask is a significant factor in mode choice [16]. It can be argued that some of the benefit of any such ability flows to an employer rather than just to the individual.

Regulatory change would be needed in some countries to allow the use of infotainment while driving. The interplay between levels of automation and engagement in non-driving-related activities is a specific issue. It is found in Reference 17 that drivers were very willing to engage in non-driving activities, particularly watching videos while driving, even with Level 1 automation that provided only automated lane-keeping. Admittedly, that study was carried out on a driving simulator, but it can certainly be expected that, even at the lower levels of automation (Levels 1 and 2), drivers will wish to exploit the support to use their time in more rewarding manner.

For many individuals, the reduction of the risk of fines related to compliance with traffic rules and regulations may be a meaningful benefit. That would apply also to current rules about using mobile phones and other devices while driving. There can be a need for legislation to change here to accommodate non-driving-related activities, under certain circumstances.

Comfort of driving may be one of the main selling arguments in the near term. Vehicles will be able to offer more and more automation for the boring tasks such as long-distance driving on freeways and other highways supported by lane-keeping combined with ACC.

Another individual benefit could be the potential cost savings due to the increased level of safety offered by the systems linked with reduced premium offers from insurance companies.

Automation could be attractive for elderly people who may adopt it relatively fast unless they find it too complicated to use. It is likely that manufacturers will limit their liability by setting a series of usage restrictions. A major issue is the public acceptance for these systems, which might limit the freedom of the driver with a variety of warnings when they engage in other tasks than driving.

At lower levels of automation, the benefits are still restricted as the driver needs to be prepared at all times to take control of the vehicle.

Safety

Impacts on safety in the transitional period depend on the features of automation, on the penetration of vehicles with automated driving capabilities and on the extent to which the various systems are used. Some crashes on motorways would likely be avoided because of the fast reaction times of highly automated vehicles. Automated vehicles have a potential to address fatigue-related crashes, although on the other hand driver sleepiness may be increased as a result of boredom in driving and of disengagement from vehicle control. However, there is also the possibility of misuse or abuse of automated systems. Examples might be disengagement from driving when supervisory attention is required, e.g. in Level 2 and Level 3 automation, and using an automated system in conditions under which it is not supposed to be used. Good system design should reduce the potential for such problems, but examples have already been reported of such abuse, for example with online videos of Tesla Autopilot being operated from a rear seat.

Level 3/4 vehicles will be equipped with an array of sensors and of crash avoidance systems. Those technologies will also be available to provide driver support and crash avoidance in manual driving and in driving at lower levels of automation (1 and 2). Therefore, it can be expected that these vehicles will be safer in general operation. It can also be expected that the automation aspects provide only a small additional benefit. The general safety effects of driver support systems have been estimated in a number of studies. eIMPACT looked at 12 different driver support systems (ESC, full speed range ACC (FSR-ACC), emergency braking, pre-crash protection of vulnerable road users, lane change assistant (warning), lane-keeping support, NightVisionWarn, driver drowsiness monitoring and warning, eCall, intersection safety, wireless local danger warning and SpeedAlert (i.e. advisory ISA)) and estimated their fatality reduction potential to range from 1.4% to 16.6% [18]. It was estimated that combining all 12 driver support systems together could produce a fatality reduction of about 50%. The overall safety impact of these vehicles would naturally depend on their penetration into the vehicle fleet and their relative usage [14].

Efficiency and capacity

Automated driving is expected to reduce shockwaves and crashes resulting in improvements in capacity and efficiency. On the other hand, there are also factors that could mitigate against this. Long vehicle platoons in the inner or a middle lane may act as an obstacle to lane changing and therefore inhibit overtaking. Long vehicle platoons in the outer lanes may make merging in from an entrance ramp more difficult and could also inhibit access to exit ramps. Dedicated lanes for automated vehicles may reduce capacity for manually operated vehicles. In urban areas, any dedicated space for automated vehicles might be at the expense of other vehicles. If automated vehicles required totally segregated space, pedestrians and cyclists could also be negatively affected through loss of street space. The provision of vehicle-to-vehicle communication could mitigate against negative impacts on non-platooned vehicles, but that would require (a) high penetration of V2V systems into all vehicles and (b) a consensus or set of regulations about operational rules such that platoons could be broken apart to meet requests for road space from other vehicles. There is a potential need also for more general agreement or regulation concerning limitations on the operation of long platoons in weaving sections and especially around exits and entries to the roadway. Other road sections where limitations might be needed are up gradients and places where the number of lanes reduces or is limited [14].

Environment

Any automated driving will be more fuel efficient than manual driving, since automated control is smoother than manual control and is less prone to the very late reactions often exhibited by human drivers, i.e. it will drive in an anticipatory manner which is at the core of eco-driving. Fuel savings will also be incurred by adherence to the speed limit in motorway driving. According to Reference 19, there would be an overall fuel and CO_2 savings of 6% on British motorways with even loose compliance of all cars to the speed limit of 70 mph (112 km/h). It is also possible for vehicles under automated control to be permanently engaged in a more elaborate eco-driving mode. However, environmental benefits are not likely to be substantial at lower levels of penetration and use. There could also be environmental disbenefits from the encouragement of long-distance car journeys and from making long-distance commuting more attractive, since the time spent in such commuting could be used more productively. This could promote urban sprawl, though here again the effects would be small at low levels of penetration [14].

11.3.1.2 Costs

The socio-economic impacts also include costs related to additional investments caused by moving to automation. These costs are presented below on the basis of the stakeholder role in automated driving.

Individual

Especially on the medium levels of automation, additional investments are likely required for driver training and road user education. Changes are required to the education programmes to ensure that people are capable of driving an automated vehicle and fully aware of its limitations, and the consequences that these limitations impose to the drivers. The drivers need to be aware in which circumstances they can give up the control of the vehicle, and when and how they should again regain the control of the vehicle. Special licenses or permits to operate an automated vehicle may be needed, if research, pilots or first use experiences indicate this to be useful.

For instance, Level 3 automation, requiring the driver to resume vehicle control within a specific short time period, could be too demanding for some drivers.

Vehicle owner

For the vehicle owner, automation comes at a cost. The 'technology packages' of today bundling navigation, infotainment and safety (including ACC, lane-keeping assist, blind spot detection and emergency braking) providing the essential elements for Level 2 automation are in the range of $3,000 [20]. Automated systems will require a degree of redundancy of safety-critical systems/components which could increase the price above this range; however, the price to the customer is not easy to predict as it is heavily influenced by market factors.

It is found in Reference 21 that about half of the drivers polled in 2011 were prepared to pay for driver support systems (ESC, blind spot monitoring, lane support system, advanced emergency braking system, speed alert or adaptive headlights). Interestingly, the proportion of people willing to pay for such systems had increased by 4–25 percentage points from 2009. The median value of the willingness to pay for a system ranged from €300 to €500. A focus group study [22] found that consumers were willing to pay a 15% premium for self-driving capability.

Infrastructure owner/operator

Automated driving likely requires investments from the road and information communication technology (ICT) infrastructure owners and operators as discussed below.

Special lanes or roads could be needed for highly and fully automated driving until their full-scale deployment to get the full safety and efficiency benefits from automated driving. If the automated vehicles need to interact with human-operated vehicles and vulnerable road users, the necessary functions to guarantee safety will considerably reduce the mobility of the automated vehicles and the vehicle flow efficiency. In the transition period towards full-scale automation, the building of special roads or lanes, or reservation of special lane space for automated vehicles are bound to lead to higher road investment, operation and maintenance costs. Thereby, such will only be provided if a critical mass of automated vehicles exists. On the other hand, there are dedicated lanes that could be re-purposed or designated for automated vehicle operation during specific time periods.

Road markings and traffic signs are likely required for the safe and efficient operation of automated vehicles. If road markings and signs were globally harmonized to sufficient extent, it would be easier for the vehicles to interpret them correctly. This would cause additional costs related to upgrading the markings and signs as well as the harmonization process itself. The markings and signs should also be always kept in good condition and visible, which will also result in additional costs. For instance, in countries with ice and/or snow covering roads frequently, winter maintenance costs may be doubled in the event automated vehicle use is desired at all times to ensure that road surfaces are clean of ice and snow [23].

Roadside solutions are likely necessary to mark the road line to facilitate automated driving also in cases where the road markings are either non-existent or not visible. This is the case for gravel roads, narrow paved roads, roads temporarily covered with snow, ice, mud, etc., and also in case of poor visibility due to dense fog, smoke, etc.

Even if satellite positioning is quite accurate, it tends to drift. Thereby accurately positioned fixed objects on a digital map could be needed to maintain the accurate position of the vehicle on the road. This means that if the road operator wishes to facilitate automated driving on the road at all times, the road operator could have specific landmarks such as fixed marker posts or poles alongside the road so that these are also accurately marked in digital maps used in the automated vehicles [24]. This corresponds to reflector posts or winter maintenance guidance sticks placed at road sides to provide visual guidance to human drivers in adverse conditions. Naturally, the installation, maintenance and accurate positioning of such landmarks, posts and poles will cause additional costs for the road operator.

I2V and V2I infrastructure would likely improve the traffic efficiency impact of automated driving. The communication infrastructure depends on the communication solution and the road and traffic environment. DSRC beacons should be available at appropriate intervals to ensure full road coverage of a specific section. In urban areas, equipping signal controls at intersections with I2V/V2I communications could be the most cost efficient option as the electric power and I2I communications would already be available. Elsewhere the provision of DSRC could be much more costly, and likely restricted to ‘hotspots’, where traffic problems would require the availability of I2V/V2I communications. Cellular-based I2V/V2I communications could be the basic solution in other parts of the road networks. In the medium term with future 5G cellular networks, there would not be any major changes required in the communication infrastructure, but in the existing and emerging 4G networks, some software and hardware modifications can be necessary [14].

To offset the increased infrastructure costs, cost recovery mechanisms may need to be set up. In case of public infrastructure, this can be done via taxation of vehicle ownership and use or fuel. Different road user charging schemes could also be set up so that these would cover the investment, maintenance and operation costs for the infrastructure-related elements facilitating automated driving using the ‘user-pays’ principle. Paradoxically, for policy reasons it may be wished to impose higher charges on manually driven vehicles to encourage the take-up of automated driving. Dynamic road user charging (via e.g. a distance tax) will be quite cost-efficient to employ as the necessary data collection, recording and communication equipment may be readily available in the automated vehicle. Indeed, one might expect such taxation to be built in to the usage fee, just as it is nowadays for taxi services [14].

Service providers

To cater to the needs of automated driving, various service providers are useful for higher levels of automation such as providers of digital maps. Local dynamic maps are used as central point to collect information for decision. Digital map information used as additional sensor to provide an ‘electronic horizon’ for the automated vehicle, and map information is important in supporting positioning. Hence, highly accurate digital maps including data on fundamental road features (lanes and their widths, physical and painted features), road malformations such as potholes and ruts, information derived from human drivers for human-like automation (median trajectories, average speed profile, median point of first breaking, etc.), specific landmarks in the street to increase positioning accuracy (poles, shape of curbs, speed bumps, etc.) and information to facilitate evasive decisions (nature of the adjacent lanes, guardrails, detours, etc.) would benefit automated driving. This would be complemented by a feedback service from the vehicle to map provider concerning detected discrepancies in the map data [24].

Provision of high-quality real-time traffic information may also add costs. The high quality of such information on especially events, incidents and congestion is needed for extended preview information outside the vehicle sensor range [25]. Automated driving likely calls for much better accuracy of the information provided than in today's traffic information services. This especially concerns event timeliness, event coverage and location accuracy of the messages.

Automotive industry

The costs for vehicle manufacturing can increase due to the provision of the basic elements of automated driving i.e. accurate positioning, V2X connectivity, extended environmental sensing, need to preserve driver/occupant privacy and need to ensure security. These costs may decrease in time with the mass production of automated vehicles, but it is likely that the relative average cost of an automated vehicle increases with increasing automation levels.

In addition, there will be additional costs related to standardization, vehicle dealer training and vehicle servicing at least in the transition period towards full automation. Remote diagnosis and remote software update may be a must before more automation can be introduced. The costs for vehicle servicing are also affected due to automated vehicles' capability of detecting wear, faults and failures. There will be low fault tolerance, which would tend to drive up maintenance costs [14].

There is a concern as to the ability of parties other than franchised dealers to repair automated vehicles, and this is likely to have an impact on the costs of repair. EU legislation regarding access to Repair and Maintenance Information (RMI) requires that manufacturers commit to making repair information available on a non-discriminatory basis to official dealerships and independent repairers alike, and certain minimum information must be included on websites as part of vehicle-type approval. An automated vehicle is likely to be particularly complex and utilize proprietary technology extensively so manufacturers may not wish to permit or enable repair by other parties. They may be concerned that their Intellectual Property will be compromised if they reveal programming code and they might also be concerned with the potential for those of criminal intent to gain knowledge that enables them to hack into vehicles [15].

Currently, as vehicles age, repair of the more complex and expensive systems on board can become uneconomic. If there is a problem with the automation systems, such vehicles may still be able to be used in manual only mode. It is essential that safety is maintained, but at the same time it would be preferable to avoid premature scrapping of vehicles, which harms sustainability and negatively affects those who cannot afford new vehicles [15].

Insurance-related costs are likely to be affected considerably for the vehicle manufacturers, if liability for driving is transferred from the driver/vehicle occupant to the vehicle manufacturer at higher levels of automation starting already from Level 3. Naturally, this will be offset by the change in drivers' insurances. The overall change in insurance costs will primarily depend on the effects that vehicle automation has on the number and severity of crashes, and thereby the related insurance claims made [14].

Authorities

The authorities likely need to set up regulations concerning automated vehicles, and this will require resources and investments on regulation, research and cross-border harmonization.

While the deployment of automated driving may reduce the overall level of risks related to road safety, it likely leads to a major liability shift amongst the stakeholders involved. The most common question raised with respect to automated vehicles is, Who would be held responsible in the event of a collision? There is a range of different people or bodies which may bear or share liability in road accidents, i.e. vehicle drivers, owners, operators, manufacturers and suppliers/importers as well as service providers, data providers and road operators. Each of these parties may be found to be civilly (or in some cases criminally) liable to a greater or lesser extent depending on the exact circumstances of the situation [15]. The settling of the liability issues requires a lot of efforts and related expenditure.

There are also data protection and privacy concerns with automated vehicles. Any processing of data collected by an automated vehicle should, where an individual can be identified, comply with data protection rules. Data are collected by the vehicle's own electronic control units, event data recorders and via the different sensors on a vehicle. This information can potentially be sent from the vehicle via the Internet to remote server storage. To comply with the fair processing requirements of data protection legislation, drivers and the registered keepers of vehicles should be made aware of the data that their vehicle is collecting, and the uses to which it might be put [15].

The ownership of the (big) data produced by automated vehicles needs to be solved quite urgently as these data offer major business opportunities even in the short term.

Theft and security measures are also required to prevent vehicle theft and 'hacking', just as with non-automated vehicles. Given the data that may be collected by a vehicle, such as global positioning system (GPS) data and camera recordings, there may also be concerns that information on the movements of a vehicle or its location could be extracted without authorization. This would have implications for privacy issues, and potentially facilitate criminal activities [15].

Certification and roadworthiness testing should be developed for higher level automated vehicles. In Europe, the vehicles will need type approval, and the framework for that needs to be enhanced to cover automated vehicles of all levels. However, the upgrades and additions of automated driving functionalities as software updates can make the current-type approval process obsolete, requiring changes to the current certification practices.

A vehicle licensing process analogous to the current graduated driver licensing (GDL) systems for novice young drivers to be set up for self-driving vehicles is discussed in [26].

The needs for standardization of vehicle performance (acceleration, braking, time headway, response lag) as well as the warning signals and tones to inform the driver of the need to take back control are issues to be solved. These are proposed to avoid confusion amongst the public when changing from one vehicle to another.

A global agreement of infrastructure requirements would be useful to clearly specify what is required to facilitate automated driving at higher levels.

11.3.2 Long term

In the long term, fully automated vehicles that operate door-to-door can be expected to have full freedom of movement with many of the substantial technological obstacles having been addressed. A wide range of vehicles can be automated – private cars, pods for both personal transport (individual and shared) and goods delivery and public transport vehicles (buses and trams).

11.3.2.1 Transformational potential

As indicated earlier, fully automated driving would constitute a totally new mode of transport, whose impacts are difficult to predict in the same way that the impacts of mass car ownership and large-scale road freight on almost every aspect of social, economic and cultural life could hardly be predicted at the onset of the twentieth century.

Ride-sharing via automated collective transport could secure a substantial reduction in vehicle travel by reducing single-person use. But that presumes that worries about personal security and privacy can be overcome. If not, there could be substantial reluctance to use such services, and the availability of automated door-to-door transport at affordable costs could have substantial negative environmental implications by increasing car use at the expense of walking, cycling and collective public transport. That would also result in a negative impact on public health and even life expectancy. It could have the same perverse effect on journey time that large-scale car use has had in the past in industrialized countries and that motorization is now having in industrializing countries: a reduction in journey times for early adopters followed by an enormous increase in congestion and reduction in travel speeds as vehicle usage in urban areas grows [14].

Means to ensure personal security are increasingly important as sharing unsupervised rides with strangers will likely be unacceptable.

Impacts on logistics could be considerable with driverless vehicles providing a ‘last mile’ service for goods movement and delivery. Both for freight and personal transport, there would be employment impacts. Taxi drivers, delivery drivers and tram and bus drivers may be threatened occupations in the future. In the intermediate term, regulations on driver hours might become less of a restriction on freight operation, with vehicles being used more intensively, perhaps even for 24-h operation. That would almost certainly require some road zones in which full automation was provided [14].

Fully automated vehicles may require dedicated road space in urban areas. This has implications for the space remaining for other modes – cars, bicycles, pedestrians, public transport, etc.

Land required for parking would most likely be reduced due to increased car- and ride-sharing and reduced car ownership allowing more intensive land use in urban areas. It is estimated that currently in the United States there are up to eight parking spaces for each car [27].

Driverless vehicles could provide more accessibility to employment, particularly for low-income families who currently cannot afford a private car (or maybe a second car for the household), and who lack a variety of employment possibilities because of inadequate public transport. This would have positive social effects by reducing unemployment and underemployment. However, there might also be negative environmental impacts in that driverless vehicles might encourage long-distance commuting and hence residential dispersion [14].

Truck platooning and even limited-scale automated driving may reduce road haulage costs and thereby encourage even greater movement of freight by road. This could have wider implications in terms of harmful environmental effects and impact on other modes such as rail.

11.3.2.2 Benefits

Individual

It is hoped that safe ‘driving’ while impaired would be facilitated by automated driving at the highest levels. The impairment may be due to fatigue, illness, medication, alcohol, drugs or other reasons.

The highest levels of automation also provide individual mobility for people without a car or driving licence, or with physical impairments. These include the elderly and children. Others may simply not want to drive or be concerned about their ability to do so [15].

The individual benefits of automation will depend on how frequently the automated functions are switched on. For many drivers enjoying manual driving and demonstrating their skills in it, automated driving may not appeal in normal circumstances. For these individuals, the benefits of automated driving will be limited.

There will be an increased efficiency in time. People will get to places with greater certainty and more directly since, in full automation, there is no need to find parking and to travel then from parking to the actual destination.

Automated driving on the higher levels will bring about various benefits to individual mobility. People likely become less interested in owning a car, and instead subscribe to different on-demand services for car- or ride-sharing. Individual mobility may become more affordable. There may also be an individual preference for procuring mobility as a service and not having to spend time on vehicle purchase, vehicle maintenance, vehicle insurance, etc. Service providers would presumably offer a variety of vehicles, tailored to particular usage (commuting, family holidays, leisure activities, etc.). The per km cost of car use is expected to diminish with increased efficiencies in service provision [14].

For a public transport user, autonomous driverless vehicles and people movers likely provide smoother travel improving possibilities for work and leisure activities during travel. It is also likely that service intervals are shortened due to driverless operation resulting in shorter waiting times at stops and also short travel times. On the other hand, travel times may also increase, if the vehicles are using the same space as vulnerable road users [14].

Use of travel time

With highly automated driving, there are social benefits from the more efficient use of time as time spent while driving for work can be used more productively and without causing a safety risk through distraction. This will have wider implications for the value of time spent in travel, a topic which is already being investigated by transport economists. There may be reduced willingness by travellers to pay for journey time savings in driving as car travel is less costly because the time can be used productively.

Safety

The impacts on road safety are expected to increase with higher levels of automation, and full automation should assist in the elimination of serious road crashes as the main risk factor of human error is excluded totally, although there is significant challenge in being able to deliver interaction with drivers of non-automated vehicles and with vulnerable road users (pedestrians, cyclists and riders of two-wheeled motor vehicles). There is also significant challenge in delivering systems with very low failure rates [14], and in addressing the design challenges in achieving safe cooperation between human operators and automated systems.

In motorway driving, automated vehicles have the advantage of maintaining full attention at all times (they do not get distracted, fatigued or impaired by alcohol and drugs) and of faster reaction times than human drivers. Under automation, vehicles will comply with regulations such as static and dynamic speed limits, and both, car following and lane-keeping will be enhanced because of control that is superior to human performance. Sensor limitations may, however, preclude automatic operation in challenging conditions such as snow [14].

Safety can be further enhanced by [14]:

- Vehicle-to-vehicle communication to deliver cooperative ACC and smart platooning. This will help to eliminate shockwaves and secondary crashes and could help to eliminate crashes in poor visibility conditions such as fog, where currently there are still significant multi-vehicle collisions often resulting in serious injuries and fatalities.
- Assisted lane-changing to overcome failure to detect vehicles in the blind spot. Again, this would be enhanced by cooperative V2V capability to deliver negotiated lane changes.
- Infrastructure to vehicle communication to notify vehicles of downstream events beyond the visible horizon.

Passengers of automated buses assess their traffic safety to have increased due to automation. However, security is one of issues of concern for passengers for automated buses, especially during night time services [28].

However, there also very real design challenges in automotive human–machine interface (HMI) to be overcome. Similar design challenges have been significant even in the highly regulated and professional operating environment of civil aviation. For car driving, they will be harder to overcome. HMI needs to be well-designed, providing appropriate levels of information when needed, and suppressing superfluous information. Operator monitoring by the vehicle is likely to be required, to ascertain driver availability in take-over situations. Mode errors, in which drivers misinterpret the level of automation or misunderstand the functionality or capabilities of the currently engaged system(s) are likely to occur. Confusion may arise when drivers switch vehicles and encounter capabilities and HMIs with which they are unfamiliar. These problems are likely to be aggravated by the insistence of vehicle manufacturers on having brand-specific design themes. Whereas in civil aviation there are only two major manufacturers, in road vehicle production there are dozens and each will want its own idiosyncratic design, thus making learning more difficult and most likely compounding problems.

Efficiency and capacity

The effects on efficiency and road capacity are expected to be very high, but dependent on the following headway length settings. The smaller the headways used, the higher road capacity achieved. At low and medium levels of automation, shorter headways could increase crash risk, since there could be a requirement for very fast driver reaction in takeover situations.

The efficiency and capacity effects also depend on the mix of vehicles at various levels of automation and on whether the automated vehicles are equipped with V2X or not. With V2X, automated driving carries much less risk of shock waves and shorter headways can be used. In Reference 29 it is stated, perhaps somewhat optimistically: ‘A fully automated automobile fleet can potentially increase highway capacity five-fold.’ However, there could be negative effects at lower levels of automation and in interaction with manually driven vehicles. For example, the ability of manually driven vehicles to change lane (e.g. to overtake slow moving trucks) could be impeded by automated vehicles driving in platoons with short headways. This implies a potential need to ‘manage’ the behaviour of automated control and provide vehicle-to-vehicle communication to enable lane changing by non-automated vehicles. Entrance and exit ramps might have to be managed in a similar manner, so that platoons do not block intended manoeuvres [14].

Better lane-keeping facilitated by automation would enable the use of narrower lanes for automated vehicles and fitting more lanes on the same carriageway, increasing road capacity. However, this is only achievable with dedicated lanes for automated driving. Interaction with motorcycle riders would have to be considered, since filtering between such narrow lanes would not be possible.

Better efficiency will also result, if the increased use of vehicle-sharing results in reductions in vehicle miles/kilometres travelled. That would reduce congestion and help to counteract the effect of population growth on travel demand. There is also a large potential for vehicles to be used more intensively. This point is made in Reference 26. They argue that analysis of US travel data indicates reveals that there is a considerable potential for vehicle-sharing within households because trips do not overlap in location in time. Thus, if vehicles had a ‘return-to-home’ capability, there would be less need for multiple vehicles within households. They conclude that ownership rates per household could be reduced by 43% and individual vehicle travel (vehicle km/year) be increased by 75%.

There is also the potential for operational efficiencies. The use of driverless buses and trams could lower public transport costs and thus act as a counterbalance to the usage of low-occupancy door-to-door vehicles. Similarly the costs of freight transport could be lowered with the advent of long-distance road trains (which should lead to labour efficiencies) and the use of automated pods for local delivery [14].

Environment

Vehicles operating under automated control can be expected to save energy and emissions because of smoother driving, i.e. fewer harsh accelerations and decelerations and cruising with less flutter in accelerator control than in manual driving. The maximization of such effects depends on manufacturers’ vehicle control algorithms, on how willing those manufacturers are to design systems that maximize energy savings as opposed to maximizing performance, and on how tolerant users of the vehicles are of eco-driving. Vehicle standards could provide a means to ensure such benefits. There is also the potential to use I2V communication to actively manage energy consumption and emissions, along the lines of programmes for active emissions management already implemented on Dutch motorways. V2V communication is likely to enhance energy savings. Accident reductions would also result in energy savings by reducing network congestion from incidents.

Vehicle-sharing would result in substantial energy savings, by reducing energy consumed in manufacture. It could also reduce the land space allocated to parking since with fewer vehicles being owned, there would be less need for parking in residential areas. However, some of that savings would be cancelled out by the movement of empty vehicles around the network to cater to different demand patterns over the day and the week. The need to shuttle empty ‘vehicles’ around has been noted in urban shared bicycle schemes in cities such as London and Paris.

The International Transport Forum estimated [30] that due to fully automated ‘TaxiBots’, nearly the same mobility can be delivered with 10% of the cars while the overall volume of car travel will likely increase as a TaxiBot system with high-capacity public transport will result in 6% more car-kilometres travelled than today as also bus services would be replaced. Reduced parking needs will free up significant public and private space.

All in all, it is found [31] that the environmental benefits due to the combined effects of energy savings per vehicle, platooning, individual mobility changes, vehicle-sharing and other factors to be positive.

Service providers

Overall, as consumption of vehicle travel changes into use of services, as opposed to ownership on one or more vehicles, huge economic opportunities are likely to open up for new service providers. Services such as those offered by Uber may be the precursors to that change. Other kinds of new services will likely emerge. We have already seen the interest of some big players such as Google, Apple and

HERE in this potential. Software services for connected and automated vehicles, including the provision of infotainment, could constitute a very large market. That may in part explain the interest of Google and Apple. The provision of the software that sits on top of the basic vehicle platform, particularly for driverless vehicles such as urban pods, may be another huge market.

11.3.2.3 Costs

The socio-economic impacts also include costs related to additional investments caused by moving to automation. These costs are presented below on the basis of the stakeholder role in automated driving.

Individual

When highest levels of automation are available and used, drivers of non-automated vehicles, bicyclist, pedestrians and other travellers outside automated vehicles would be better off if they were aware of the behaviour of automated vehicles. Information campaigns and awareness measures may also be required to ensure user acceptance and uptake as well as non-user acceptance.

Vehicle owner

The price of a fully automated vehicle could be much higher than that of a manually driven vehicle. However, costs of vehicle use are likely to diminish with increased sharing of vehicles and higher intensity of use. Indeed, it is likely that there will be less actual ownership and more purchasing of vehicle use as a service. Shared ownership will likely impose some additional costs for managing the use, parking and maintaining of the vehicles. Another possible option is that automated vehicles could be leased rather than sold to the public, thus allowing the manufacturer to retain control and specify conditions, such as requiring repairs or servicing to be performed only by the manufacturer themselves, or other parties that they specify [15]. This would likely increase the costs for ‘owning’ the vehicle.

In the long run, if all or most vehicles are fully automated, the urban robot cars or pods will likely be much lighter and perhaps also simpler than today’s cars, resulting in lower costs of vehicle ownership and use [14].

Infrastructure owner/operator

Automated driving may require considerable investments from the road and ICT infrastructure owners and operators. The investments due to special lanes or roads dedicated to automated and/or manual driving, road markings, traffic signs, roadside solutions and I2V/V2I infrastructure which are useful already for Level 3 automation increase for higher levels of automation as the coverage of the road network needs to be more comprehensive. In addition, some new needs for investments arise in the form of changes in road paving and re-paving practices and costs due to narrower lanes and stricter lane-keeping and other changes in road infrastructure.

Road paving and re-paving practices may face major changes due to automated driving. Stricter lane-keeping allows narrower lane width and thereby fitting more lanes on the same carriageway improving road capacity. This will also mean that vehicles’ wheels run over the same parts of the road cross-section focussing pavement wear on narrow strips along the road, resulting in the formation of wear and deformation ruts on the road. Depending on the percentage of trucks with wider axle width than for cars, the ruts may also be wider. These ruts necessitate shortening of the repaving cycle by perhaps 20%. Otherwise or in addition, changes are needed in road paving so that the narrow strips, where the vehicle wheels run, will be equipped with material tolerating wear better. This material with higher quality aggregate for better wear resistance could be 10–15% more expensive to use. Furthermore, paving equipment could face major changes to facilitate paving of 'virtual rails' on the road. In any case, the costs for paving and re-paving will be affected [32]. In addition, Levels 4 and 5 automation requires 'safe harbours' along the road, where vehicles can retire in case of system malfunction or other necessity.

Facilitating automated driving may also require higher asset management standards for operation and maintenance, for instance concerning road pavement conditions.

Also other changes in road infrastructure may be required due to automated vehicles. For instance, modelling studies have found that, particularly at high vehicle volumes, roundabouts are more efficient for automated vehicles with V2V communications than are traffic signals [33]. Hence, signalized intersections could be gradually replaced with roundabouts in the long term. In case of the establishment of urban zones restricted to automated public transport as well as pedestrians and bicyclists, substantial investments could be needed.

Service providers

For Levels 4 and 5 automation, the quality of digital maps and traffic information must be at a very high level, requiring high maintenance and operation costs from the relevant service providers.

As with non-automated vehicles, there is a need for breakdown services to deal with broken down or otherwise stopped vehicles. For automated vehicles, a higher service level will likely be required, resulting in increased costs. On the other hand, the I2V communications and accurate vehicle positioning may make the service more efficient [14].

Automotive industry

The industry may change drastically in that fewer vehicles will be in use (perhaps reducing income from servicing), but vehicles will be used more intensively. Relationships with service providers may be more important than relationships with individuals. There is a possibility that the balance of power may switch to the service providers, as has happened to some extent in such markets as mobile phone use and television services (IPTV) [14].

Authorities

The liability, security, harmonization and standardization issues already addressed in the short- and medium-term need even more efforts in the long term when dealing with full automation. Security issues include, for instance, the use of driverless vehicles to commit crimes and as weapons.

Desouza *et al.* argue [34] that many city and state authorities will see their revenue sources acquired from driving-related violations greatly reduce as automated vehicles will always comply with existing traffic rules and regulations.

11.4 Methods and approaches for assessment of automated driving functions

Automated driving at Levels 3–5 is mostly at a prototype or pilot phase, restricting somewhat the methods for its assessment as seen in Figure 11.2.

Comprehensive guidance on how to assess Field Operational Tests (FOTs) exist in the form of FESTA Handbook [36], and basically these can be applied in all kinds of field trials. Currently, an EU-US-JP Automation in Road Transportation Working Group [37] is working towards harmonization of impact assessment framework for automation in road transport, expected to produce a state-of-the-art description of the assessment methods used. Thereby, a compilation of the methodologies is not provided here as a more complete one will be available in 2016 or 2017.

Some examples of specific assessment targets and data sources are listed below for illustrative purposes only.

11.4.1 Assessment of technical performance

Typical targets for technical assessment are sensors, communication systems, data quality as well as functions and sub-functions as a whole (success rate, failure rate, etc.).

11.4.2 Assessment of HMI

Driving simulators and test tracks are the normal environments for assessing the quality of in-vehicle HMI, in terms of usability, workload, acceptance and comprehension. One vital quality of HMI in automated driving is that it maintains the required understanding of vehicle operation and restores a full appreciation of the current driving situation in all its complexity in advance of operator takeover. That understanding is often termed ‘situation awareness’ [38], but the term begs the

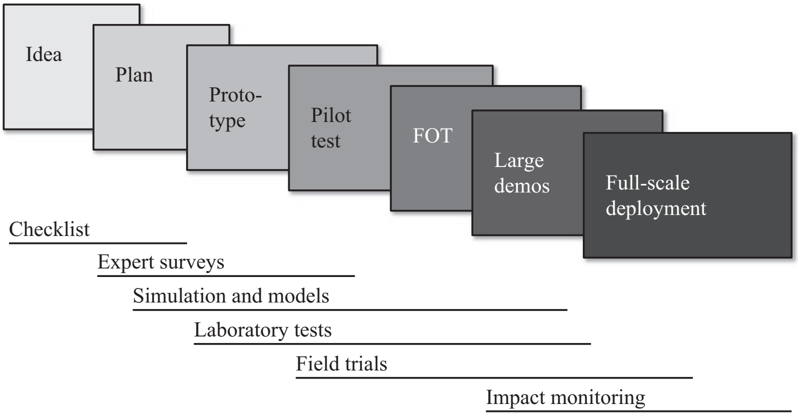

Figure 11.2. Assessment setups for different phases in system lifecycle. Adapted from Reference 35

question of what aspects of the situation are mission-critical. Those aspects will vary with the driving situation – roadway type, traffic conditions, weather, road surface conditions and even the trip type (e.g. commuting versus long-distance travel).

11.4.3 Assessment of user acceptance and use of automated driving functions

User acceptance studies will utilize the traditional surveys, interviews and focus group discussions are their main method. The use of automated driving functions can also be queried with the methods above, but with automated functions the use metrics can also be collected automatically from system logs, keeping in mind the limitations set by privacy requirements. Such logs will be needed to identify instances of misuse and abuse.

11.4.4 Impact assessment

Impact assessment is the most interesting assessment area for automated driving as the changes foreseen in personal mobility and driver behaviour are so profound that it is unlikely the current theories do not apply anymore.

Smith lists a number of indicators [39] to be used for the impact assessment of automated driving functions:

Safety

- Fatalities, injuries
- Exposure, prevention and fatality ratios

Vehicle mobility

- Car following headway
- Gap acceptance
- Lane-keeping performance

Regional mobility

- Road segment and intersection performance (speed/volume, capacity)
- Corridor average and 95% travel times

Energy/Environment

- Tailpipe emissions: greenhouse gas, other pollutants
- Energy consumption per vehicle-distance, person-distance and person
- Total fossil (gasoline, diesel, compressed natural gas, liquefied natural gas) energy consumption from highway transportation
- Expenditure for fuel

Accessibility

- Percentage of people within *x*-minutes of major activity (employment, medical, etc.)
- Average wait for shared vehicle
- Effective system capacity

Transportation system usage

- Total trips, travel distance and time
- Average trip duration, speed
- Various congestion indices
- Trips per household
- Vehicle occupancy

Land use

- Housing and transportation affordability index
- Land use mix

Sources of data include [39]

- Naturalistic driving data
- Test track studies
- Simulation studies
- Tests of automated vehicle system
- In-road or road side sensors
- Vehicle probes
- Crash data
- Energy and emission modelling

11.4.5 Socio-economic assessment

Socio-economic assessment is also interesting especially with regard to the value of time, which is usually a quite dominating factor with regard to transport investment benefits, but automated driving can cause major changes in this respect by allowing vehicle drivers and occupants to use their time more productively while in transport. Also changes in vehicle ownership and use of Mobility as a Service (MaaS), ride- and car-sharing services will cause major changes in socio-economic assessment models and aspects. It will also be necessary to pay more attention than currently to the allocation of benefits and costs to different stakeholders involved as new stakeholders will enter the transport domain along with automated driving.

11.5 Review of assessment of automated driving functions

11.5.1 Knowledge base

The potential benefits of Advanced Driver Assistance Systems have been studied in the past decade by several studies which have assessed the potential benefits for improving road safety, traffic efficiency and reducing the environmental impact of traffic. Relevant studies comprise amongst others SEiSS, INVENT, eIMPACT and euroFOT [40–45]. A synthesis of the available knowledge is provided by a recent TRL study [46]. The special topic of the impact of driver assistance systems on insurance claims is analysed in Reference 47.

Table 11.1 Characteristics of the reviewed studies

Study characteristics		**SEiSS [40]**	**INVENT [41]**	**eIMPACT [42]**	**eIMPACT [43]**	**euroFOT [45]**
Study goal	Methodology study with application examples	X		X		
	Ex-ante impact assessment		X		X	
	FOT-based impact assessment					X
Studied functions	ACC	X		X		
	Congestion assistant		X			
	FSR-ACC				X	
	ACC plus FCW					X
Geographical scope	Germany	X	X	X		
	EU	X			X	X
Reference year	2010	X	X	X	X	X
	2020	X	X	X	X	
Studied impacts	Road safety	X	X	X	X	X
	Traffic efficiency		X		X	X
	Fuel consumption and environmental impact		X	X	X	X

The common viewpoint of these studies is directed to analysing the impacts of increasingly more comprehensive functions of driver assistance while automation remains mostly a goal in the distant future which is not further specified. An example for this viewpoint, illustrating the functional dependencies between different driver assistance systems, is provided in Reference 44.

Table 11.1 characterizes the studies concerning different elements:

- Study goal (methodology study with application examples, benefit assessment based on ex-ante impact assessment, benefit assessment based on impacts measured in FOTs)
- Studied functions (ACC, congestion assistant, FSR-ACC, ACC plus forward collision warning (FCW) as bundle of functions)
- Geographical scope (Germany, EU)
- Reference year (2010, 2020)
- Studied impacts (road safety, traffic efficiency, fuel consumption, environmental impacts)

Basically it can be stated that the varying study designs are justified by the specific research questions and functional definitions. For example, studying the impact of a congestion assistant focuses only on a specific part of all traffic situations and the related impacts. This implies that despite of similar and best practice oriented impact assessment procedures the study results are not fully comparable. The study context remains always relevant for the interpretation of the results.

11.5.2 Synopsis of results

In the following, the results are summarized across studies according to the impact categories. Results apply, unless specified otherwise, for Germany:

- Concerning road safety impacts, an important assumption of the methodology studies is a combined impact of ACC on the number and severity of accidents. The assumption is justified by a faster system reaction in the presence of critical situations. The impact modelling is based on a cascade model of accident severity where a part of the fatalities ends up in severe injuries and a part of the severe injuries will result in slight injuries.
- Considering the accident database (generally between 2002 and 2005 for the above mentioned studies), technology progress with regard to road safety and the reference years (2010, 2020) and estimated fleet penetration rates (generally below 5% in 2010, approximately 10% in 2020) the studies assess the reduction potential in the order of magnitude of about 100 fatalities, about 1,000 severe injuries and about 2,500 slight injuries.
- The impact assessment for the congestion assistant shows for similar penetration rates a significantly lower reduction potential. This is due to the lower speeds addressed by the congestion assistant and hence also lower accident consequences involved. The reduction potential is assessed to about 20 severe injuries and about 1,000 slight injuries.
- The impact assessment for ACC + FCW based on in-depth accident databases (e.g. GIDAS, STATS 19, STRADA) and on the FOT-based classification of incidents likely resulting in accidents leads to a range of potentially reduced fatalities between 42 and 88 persons while the reduction of severe and slight injuries is assessed in a range between 5,000 and 10,000 persons. These potential numbers apply to the EU-27.
- An important parameter defining the direction of traffic impacts (positive/negative) is the time gap of the vehicle using ACC to the preceding vehicle. Large time gaps (1.5 s, 2.0 s) result in negative impacts on throughput and increasing total journey times. Small time gaps (approx 1.0 s) help to mobilize capacity reserves of the road infrastructure and to lower total journey times. Huge penetration rates generally help to smooth the traffic flow. Against this background it does not surprise that traffic impacts are more or less negligible when penetration rates are estimated below 10% of the vehicle fleet.
- The congestion assistant studied in INVENT targets explicitly on situations where the traffic flow is broken down or in instable conditions. It is hence plausible that traffic flow simulations result in significant journey time reductions. The magnitude of these reductions can be assessed in a range of 5–10%. The total journey time reduction is estimated in a range between 50 and 140 million vehicle hours.
- The impact assessment of euroFOT has resulted in a small 0.2% increase of total journey times. In absolute numbers, this is equivalent to an increase of 5 million vehicle hours across the EU-27. The effect can be characterized as being rather marginal.

- Because of the impact relation between vehicle speed, fuel consumption and CO_2 emissions, studies with a large impact on journey times also estimate large impacts on fuel consumption and CO_2 emissions. The savings potential of the INVENT congestion assistant denotes to a range between 150 and 500 million litre fuel, and between 0.4 and 1.2 million ton CO_2.
- The benefits resulting from the assessed impacts are summarized in Table 11.2. They show an excerpt of the socio-economic impact assessment results of the different studies for the year 2020. The potential benefits are estimated in a range of several hundred million EUR. When the system is specified in a way that impacts on traffic flow can be expected, the benefits can grow to more than a billion EUR.

11.5.3 Interpretation of results

The available results of earlier impact assessment studies paint a fairly consistent picture about the direction of impacts while the range of results is rather wide, at least with regard to some impacts. The results of the studies on benefits of Advanced Driver Assistance Systems shed some light on the potential benefits of automated driving functions. Of course, assessing the impacts of automated driving will form an important forthcoming task for the ITS evaluation community where IBEC members play a crucial role.

A first estimation of the potential magnitude of socio-economic benefits of highly automated driving for Germany [48] reports benefits of 1.5–3 million EUR per year in the introduction period (0.1% highly automated vehicles) and 4–14 billion EUR per year when fully deployed (100% highly automated vehicles). With regard to functionalities and data framework (penetration rates etc.), it reconfirms once again the order of magnitude of the analyses featured above.

The study goals influence significantly the design and the performance of the study. This is relevant with regard to the addressed impacts, to width and depth of the modelling, to the assessment of bandwidths for impacts and to cost unit rates for socio-economic impact assessment. Even when using standardized methodology and procedures (FESTA V [36], national and European evaluation guidelines such as BVWP or WebTAG [49, 50]), the benefits do vary in considerable ranges. Hence, the results featured above can be interpreted as being fairly consistent.

Table 11.2 Synopsis of Advanced Driver Assistance Systems benefits in road traffic

Benefits (in million EUR)	**ACC [40]**	**Congestion assistant [41]**	**ACC [42]**	**FSR-ACC [43]**	**ACC + FCW [45]**
Road safety	334	78	227	828	810
Traffic efficiency	–	1,419	–	–	−65
Fuel consumption and environmental impact	–	473	37	70	450
Total	**334**	**1,970**	**264**	**898**	**1,195**

The impact assessment in the studies builds on different approaches. Ex-ante impact assessment is typically based on theoretical models to which empirical data are applied to estimate which impacts are addressable and to what extent. The estimates show quite often an inherent optimism bias: experts overestimate the potential impacts. On the other hand, the result of FOTs suggests an inherent pessimism bias because only the best (measured) impacts are taken forward to the impact assessment. The different biases also explain to some extent the ranges of impacts.

11.6 Challenges for impact and socio-economic assessment in the context of automated driving

The advent of automated driving puts also some distinct challenges on impact assessment and socio-economic assessment. The intention of this section is to name some of the challenges to be faced whereas it is not intended to provide a full coverage of the problem landscape.

High levels of automation make it possible that drivers are no longer fully engaged in driving tasks. This bears important consequences. First, the concept of a driver will dramatically change with the evolution or even revolution of the driver's tasks. This means that the theories of driver behaviour and its impacts on road safety, traffic flow, and overall mobility and the whole transport system will need to be updated or even redrafted. This will require substantial efforts in fundamental research utilizing and analysing driver behaviour in automated driving via simulators, naturalistic driving tests, other field tests and pilots.

Second, the time can be made available for other purposes such as checking, planning and monitoring of various business-related and private issues or simply relaxing. Freeing up time has been in the history of mankind an important driver for innovations. Freeing up time represents an enormous potential for improving productivity. Time savings are typically one of the dominating factors in cost–benefit analyses of transport-related investments. Therefore, the potential time savings are huge. As cost–benefit analyses find their roots in neoclassical economics, assuming that saved productive resources are re-used with at least the same productivity, it is more than ever crucial how the freed up time is used. But even an 'unproductive' break (in the logic of textbook economics) might form the basis for higher productivity after the trip. In a longer term assessment perspective, with already some penetration of automated vehicles and the related time savings already reaped, one of the most important benefit drivers will likely diminish as the unit cost of an hour spent in traffic shall dramatically decrease.

Automated driving puts, just as with the cooperative intelligent transport systems (ITS) arena, challenges of intensified cross-sector cooperation on the table. An industry or a public body can no longer organize its supply chain in own responsibility. There is a mutual dependency in inputs and outputs, according to fulfilling specific roles and responsibilities in a value network. For example, who will pay for improved lane markings on roads and who earns the benefits? The partners will contribute to this collaboration when there is 'something in' for them. Apart from defining and agreeing roles and responsibilities in a value network, the development bears the challenge of allocating the costs and benefits to the contributing and benefiting actors. Whereas a classical cost–benefit analysis from society perspective follows a well-established concept, analyses focusing on the incidence of costs and benefits are not very common. They need to have insight, compared to a social planner perspective, into the value of data and information to the stakeholders involved in the collaboration. Limits of this approach have to be explored and could be overcome at least partially on the basis of revealed preferences of the actors.

Alongside with more complex cost–benefit assessment there is potential but also increased complexity of data input to the assessment itself. Instead of using fixed or central values, sensitive parameters should be provided in a range accompanied with likelihoods. For sure, it will widen the bandwidth of results but ideally provide estimates what ranges of results are more or most likely. In the end, this should contribute to making assessment results more robust.

The factors mentioned above all point towards more complex and time consuming analyses. Although assessment processes are highly automated, arranging the input data still involves human work, skills and time. When admitting that evaluation and assessment is typically a part of a project or test with limited resources (in terms of available money and time) it can be a way out to be economic in the economic assessment itself. This would point towards more rule-of-thumb elements involved in the assessment.

References

[1] Gasser, T.M., Schmidt, E.A., Bengler, K., *et al.*, Report on the need for research, Round Table on Automated Driving – Research Working Group, Bergisch Gladbach, 2015, http://www.bast.de [Accessed 31 March 2016]

[2] ERTRAC, Automated driving roadmap, version 5.0, 2015, http://www.ertrac.org [Accessed 31 March 2016]

[3] Brizzolara, D. and Flament, M., Report on VRA network, VRA Deliverable D2.2, 2015, http://vra-net.eu/ [Accessed 31 March 2016]

[4] Die Bundesregierung, Strategy for automated and connected driving, 2015, http://www.bmvi.de [Accessed 31 March 2016]

[5] Ministry of Transport and Communications, Robots on land, in water and in the air. Promoting intelligent automation in transport services. Publications of the Ministry of Transport and Communications 14, 2015, http://www.lvm.fi [Accessed 31 March 2016]

[6] Department for Transport, The pathway to driverless cars, summary report and action plan, 2015, http://www.gov.uk [Accessed 31 March 2016]

[7] Federal Ministry of Transport and Digital Infrastructure, Dobrindt launches digital motorway test bed, Press release 084/2015, 2015, http://www.bmvi.de [Accessed 31 March 2016]

[8] Finnish Transport Safety Agency (Trafi), Aurora to become the first Arctic testing ecosystem for intelligent transport, Press release, 2015, http://www.trafi.fi [Accessed 31 March 2016]

[9] European Commission, Launch of a high level group for competitiveness and sustainable growth of the automotive industry in the European Union (GEAR 2030), C(2015) 6943 final, Brussels, 2015.

[10] EU NL – Dutch EU Presidency, Declaration of Amsterdam, Cooperation in the field of connected and automated driving, 2016, http://english.eu2016.nl/documents/publications/2016/04/14/declaration-of-amsterdam [Accessed 31 March 2016]

[11] SAE, Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. Standard J3016, 2014. Society of Automotive Engineers.

[12] Gasser, T.M., Arzt, C., Ayoubi, M., *et al.*, Legal consequences of an increase in vehicle automation, BASt reports F83, Bergisch Gladbach, 2012, http://www.bast.de [Accessed 31 March 2016]

[13] Shladover, S.E. and Bishop, R., Road transport automation as a public–private enterprise. Commissioned White Paper 1. In: Towards Road Transport Automation: Opportunities in Public–Private Collaboration – Summary of the Third EU-U.S. Transportation Research Symposium. Conference Proceedings 52, Transportation Research Board, Washington, D.C., 2015, pp. 40–64.

[14] Carsten, O. and Kulmala, R., Road transport automation as a societal change agent. Commissioned White Paper 2. In: Towards Road Transport Automation: Opportunities in Public–Private Collaboration – Summary of the Third EU-U.S. Transportation Research Symposium Conference Proceedings 52, Transportation Research Board, Washington, D.C., 2015, pp. 65–76.

[15] Department for Transport, The Pathway to Driverless Cars: A detailed review of regulations for automated vehicle technologies. Department for Transport, London, 2015. 191 p. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401565/pathway-driverless-cars-main.pdf [Accessed 31 March 2016]

[16] Mokhtarian, P. Will rising trip productivity change travel choices? CTS Catalyst. Centre for Transportation Studies, University of Minnesota, Minneapolis, 2015.

[17] Carsten, O.M.J., Lai, F.C.H., Barnard, Y., Jamson, A.H. and Merat, N. (2012). Control task substitution in semi-automated driving: does it matter what aspects are automated? Human Factors, 54(5): 747–761.

[18] Wilmink, I., Janssen, W., Jonkers, E., *et al.* (2008). Impact assessment of Intelligent Vehicle Safety Systems. Deliverable D4 of eIMPACT (Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe). http://www.eimpact.info/download/eIMPACT_D4_v2.0.pdf. [Accessed 31 March 2016]

[19] Carslaw, D.C., Goodman, P.S., Lai, F.C.H. and Carsten, O.M.J. (2010). Comprehensive analysis of the carbon impacts of vehicle intelligent speed control. Atmospheric Environment, 44: 2674–2680.

[20] J.D. Power (2014). U.S. Automotive Emerging Technologies Study. McGraw Hill Financial. http://www.jdpower.com/sites/default/files/2014057_US%20_Auto_ET.pdf [Accessed 31 March 2016]

[21] Öörni, E. and Penttinen, M. (2014). Study on users' awareness and demand for iMobility technologies. iMobility Challenge Deliverable 2.3, Version 1.0, 2014. 57 p. http://www.imobilitychallenge.eu/files/studies/iMobility_Challenge_D2.3__User_Awareness_and_Demand_for_iMobility_systems_version_1.0.pdf [Accessed 31 March 2016]

[22] KPMG (2013). Self-driving cars: are we ready? https://www.kpmg.com/US/en/IssuesAndInsights/ArticlesPublications/Documents/self-driving-cars-are-we-ready.pdf [Accessed 31 March 2016]

[23] Innamaa, S., Kanner, H., Rämä, P. and Virtanen, A. Automation lisääntymisen vaikutukset tieliikenteessä (The impacts of increasing automation in road transport). Finnish with English abstract. Trafi Research reports, Helsinki, 2015. 84 p.

[24] Dreher, S. and Flament, M., iMobility Forum WG automation in road transport, digital infrastructure subgroup. Presentation in Antwerp, 8 May 2014. 14 p.

[25] Försterling, F., Automated driving – key application of ITS and networked car. Presentation at the ITS World Congress Board of Directors' Meeting, Bordeaux, 13 May 2014. 12 p.

[26] Sivak, M. and Schoettle, B., Should We Require Licensing Tests and Graduated Licensing for Self-Driving Vehicles? Report No. UMTRI-2015-33, University of Michigan Transportation Research Institute, Ann Arbor, Michigan.

[27] Chester, M., Horvath, A. and Madanat, S., Parking infrastructure: energy, emissions, and automobile life-cycle environmental accounting. Environmental Research Letters, 5(3), 2010. doi:10.1088/1748-9326/5/3/034001

[28] CityMobil2, Vantaa ex-post evaluation report. CityMobil2 Deliverable D25.3, 2015. 75 p.

[29] US DOT, Beyond Traffic: US DOT's 30 Year Framework for the Future. Draft. US Department of Transportation, Washington, D.C., 2015.

[30] International Transport Forum, Urban Mobility System Upgrade. How shared self-driving cars could change city traffic. OECD Corporate Partnership Board Report, 2015.

[31] Yagci, O. and Clewlow, R., Estimated energy impacts of automated vehicles: implications for policy makers. Presentation given at the Transportation Research Board 95th Annual Meeting, Washington, D.C., 10–14 January, 2016.

[32] Törnqvist, J., Telephone interview of senior research scientist Jouko Törnqvist, a specialist in road engineering at VTT Technical Research Centre of Finland, 2015.

[33] Azimi, R., Bhatia, G., Rajkumar, R. and Mudalige, P., V2V-intersection management at roundabouts. SAE Technical Paper No. 2013-01-0722, 2013.

[34] Desouza, K.C., Swindell, D., Smith, K.L., Sutherland, A., Fedorschak, K. and Coronel, C., Local government 2035: strategic trends and implications of new technologies. Issues in Technology Innovation, 27, 2015.

[35] Kulmala, R., Assessment Methods in ITS Lifecycle. Powerpoint picture. Finnish Transport Agency, 2013.

[36] FOT-NET, FESTA Handbook version 5. Revised by FOT-Net (Field Operational Tests Networking and Methodology Promotion). 2014. 242 p. http://fot-net.eu/?kcccount=http://2doubmisw11am9rk1h2g49gq.wpengine.netdna-cdn.com/wp-content/uploads/sites/7/2014/06/FESTA_HBK_rev5_ref3-2.pdf [Accessed 31 March 2016]

[37] US DOT, EU-US-JP Automation in Road Transportation Working Group (ART WG). Harmonisation of impact assessment framework for automation in road transport. AGENDA & slides modified during the meeting. Telco, GoToMeeting. European Commission, MLIT Ministry of Land, Infrastructure, Transport and Tourism, U.S. Department of Transportation, 2015.

[38] Carsten, O. and Vanderhaegen, F., Situation awareness: valid or fallacious? Cognition Technology and Work, 17(2):157–158, 2015.

[39] Smith, S., Estimation of Benefits for Automated Vehicle Systems. Powerpoint presentation. U.S. Department of Transportation, 2015. 33 p.

[40] Abele, J., Baum, H., Geißler, T., *et al.,* Exploratory Study on the Socio-Economic Impact of the Introduction of Intelligent Safety Systems in Road Vehicles (SEiSS Study). Teltow Cologne, 2005.

[41] Grawenhoff, S., Socio-economic impact assessment of advanced driver assistance systems – methodology fundaments and empirical analyses for congestion assistance and lateral assistance (German), PhD study, University of Cologne, 2006.

[42] Assing, K., Baum, H., Bühne, J.-A., *et al.*, Methodological framework and database for socioeconomic evaluation of Intelligent Vehicle Safety Systems, eIMPACT Deliverable D3, 2006, http://www.eimpact.info. [Accessed 31 March 2016]

[43] Baum, H., Geißler, T., Vitale, C., and Westerkamp, U., Cost-benefit analyses for stand-alone and co-operative Intelligent Vehicle Safety Systems, eIMPACT Deliverable D6, 2008, http://www.eimpact.info. [Accessed 31 March 2016]

[44] Malone, K., Wilmink, I., Noecker, G., Galbas, R., Roßrucker, K., and Alkim, T., Final report and integration of results and perspectives for market introduction of IVSS, eIMPACT Deliverable D10, 2008, http://www.eimpact.info [Accessed 31 March 2016]

[45] Geißler, T., Bühne, J.-A., Dobberstein, J., Gwehenberger, J., and Knieling, M., Overall cost–benefit study, euroFOT Deliverable 6.7, 2012, http://www.eurofot-ip.com [Accessed 31 March 2016]

[46] Hynd, D., McCarthy, M., Carroll, J., *et al.*, Benefit and Feasibility of a Range of New Technologies and Unregulated Measures in the Fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users. Final report, Luxembourg, 2015.

[47] Gwehenberger, J. and Borrack, M., Influence of driver assistance systems on insurance claims (German). Automobiltechnische Zeitschrift, 10, 60–65, 2015.

[48] Cacilo, A., Schmidt, S., Wittlinger, P., *et al.*, Highly automated driving on motorways – industrial policy conclusions (German). Study for the Federal Ministry of Economics and Energy, 15/14, 2015.

[49] PTV *et al.*, Methodenhandbuch zum Bundesverkehrswegeplan 2030, Draft version, March 2016, http://www.bmvi.de [Accessed 31 March 2016]

[50] Department for Transport, Transport analysis guidance: WebTAG, last updated: 10 November 2014, https://www.gov.uk/guidance/transport-analysis-guidance-webtag [Accessed 31 March 2016]

Chapter 12

User-related evaluation of ADAS and automated driving

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12.1 Introduction

Newly developed Advanced Driver Assistance Systems (ADAS) and automated driving offer support to the driver in his/her driving task. Besides driver comfort, these systems are expected to give significant safety improvements. However, the expected positive safety effects only will be achieved if the driver uses the system in the way it was intended to be used, he/she follows its recommendations and does not compensate for perceived safety improvements by driving faster or less attentively. The financiers of technology development programmes (e.g. the European Commission) are becoming increasingly conscious of this possible phenomenon of behavioural adaptation, when the driver perceives safety improvements, and hence give growing importance to user-related assessment of new technology, since it is through the user the expected advantages of a new system may (or may not) materialize.

User-related evaluation of ADAS and automated driving applications involves a great variety of issues (such as locus of control, trust, mental representation of the system, situational awareness (SA), mental and physical workload, feedback, stress and acceptance), hence it is of importance to identify and define these issues as focus of user-related evaluation. As a first step of the user-related evaluation process, research questions concerning these issues are to be outlined, and based on them working hypotheses to be formulated and evaluation indicators to be identified. For testing the hypotheses, there is a great variety of evaluation methods and tools that can be employed.

The aim of this chapter is to list and describe relevant issues of user-related evaluation of ADAS and automated driving applications, to give examples of hypotheses and evaluation indicators, as well as describe available evaluation methods and tools and discuss relevant study design issues.

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12.2 Relevant issues in user-related evaluation

Stanton and Young [1] presented a number of psychological issues pertinent to vehicle automation that they noted should be considered in empirical evaluation studies. These issues include locus of control, the trust the driver has in the automated system, the SA of the driver, the mental representation that the driver develops of the automated system, the mental and physical workload associated with automation, feedback, driver stress and its implications. The relevance of these and additional issues are described in more detail below.

12.2.1 Behaviour-related issues

People adapt their behaviour as a response to changes in the road–vehicle–user system [2]. Reallocation of attention is an intelligent response to the change [3]. The adaptive process develops dynamically over time, based on operator experiences of interaction with the automated system [4].

12.2.2 Understanding of automation issues

An insufficient and/or erroneous mental model the driver develops of the automated system may lead to increased risk of user errors [5]. Jenness *et al.* [6] in a survey among early adopters of in-vehicle technology found that system owners often do not understand the limitations of the systems and manufacturers' warnings.

12.2.3 Trust- and reliance-related issues

Over- or under-reliance on automation can have crucial effects on automation outcome. Users rely more on automation they trust more [7]. Over-trust may lead to misuse of automation, leading to failure of the driver to override the system when necessary and under-trust may yield disuse of automation when users fail to rely on automation when doing so would improve performance [8]. There is a variation among users, younger and older users rely on automation differently [9]. Merritt *et al.* [10] found that user trust in automation was influenced by both implicit and explicit attitudes. They asked participants to complete both a self-report measure of propensity to trust and an Implicit Association Test measuring implicit attitude towards automation and found that explicit propensity to trust and implicit attitude towards automation did not correlate. They concluded that implicit attitudes have important implications for automation trust and users may not be able to accurately report why they experience a given level of trust. User's implicit attitudes, as well as user mood and emotion may affect their trust in automated systems. Since implicit and explicit processes often dissociate, 'implicit preferences may provide predictive power that cannot be obtained via traditional explicit measures' [10] (p. 3). To understand why users trust or fail to trust automation, measurements of both implicit and explicit predictors are necessary.

12.2.4 Locus of control

Locus of control means the extent to which removal of control from the driver affects the performance of the vehicle/driver entity. Locus of control refers to the extent to which individuals believe they can control events affecting them. Drivers with an internal locus of control believe their vehicle performance derives primarily from their own actions, while drivers with an external locus of control believe the behaviour of the vehicle is due to the automated system [11]. Stanton and Young [1] mean that some drivers may perceive that they are in overall control of the vehicle when it is in automated mode whereas others may not. According to them, research findings had shown that people with an internal locus of control generally perform better than individuals with an external locus of control which might be attributed to the degree of task engagement for the individual. An internal locus of control may lead drivers to take on an active role, while an external locus of control might lead a driver to assume a passive role with the automated system. Stanton and Young [1] found that the passive drivers failed to intervene when the automated system failed whereas the active drivers took control of the situation.

12.2.5 Resuming control

Resuming control of driving is an important issue in automation. Merat *et al.* [12] examined how different methods of transferring control of a highly automated (Level 3) vehicle affected the driver's ability to resume control of driving and found 'an overall better performance by drivers when control was transferred after a fixed duration of 6 min, compared to when the automated system disengaged if drivers removed their visual attention away from the road centre' (p. 281).

12.2.6 Skill degradation

There is a non-negligible risk that skill degradation accompanies automation of the driving tasks due to overreliance, as the reinforcement coming from constant engagement in the driving task becomes absent [13]. Endsley and Kiris [14] refer to Shiff [15] who found that 'despite initial manual training, those subjects who had been operating as supervisory controllers of automation in a simulated process control task were slower and more inefficient in bringing the system under control than were subjects who had operated only in a manual mode' (p. 381). If drivers learn to drive with automated systems initially, without extensive manual experience, appropriate skills may not be developed. Such skills may be important not only for performing a task manually, but also for detecting the need for manual performance [14].

12.2.7 Mental workload

Automation monitoring may lead to increased mental workload of the driver. Humans are inefficient in monitoring automation [16–19]. Overreliance on automation contributes to this inefficiency [8]. Banks *et al.* [20] in a case study concluded that the number of processes conducted by the driver appears to increase as the level of automation increases. In intermediate levels of automation, driver decision-making remains apparent (only at full automation can this decision be removed). The addition of sub-system monitoring increases task loading and hence driver workload as the driver must remain aware of system state and operation. Automation has different effects on users' (younger or older) workload [9].

12.2.8 Stress

Stress is a factor that may affect driver workload and safety [21]. Stress and vehicle automation has been studied by Funke *et al.* [22], who explored (among others) the effects of stress and vehicle automation on driver performance manipulating stress by exposing drivers to a loss of control experience and found that both stress and automation influenced subjective distress, with higher levels of distress under the stressful driving conditions and lower levels of distress under the automated speed control conditions; however, the two factors did not interact. Reimer *et al.* [23] evaluated the extent to which vehicle-parking-assist systems affected driver stress by using heart rate measurements along with self-reported ratings and found that participants exhibited lower average heart rates and they reported lower stress levels when using the assistive parking system.

12.2.9 Boredom

Boredom in low-task-load environment might lead to distraction [24]. According to Farmer and Sundberg [25], 'Boredom is a common emotion, with boredom proneness a predisposition with important individual differences' (p. 4). Stark and Scerbo [26] found significant correlations between boredom proneness, workload and complacency potential, which might indicate that the psychological state of boredom may be a factor that induces complacency [27]. Also, Sawin and Scerbo [28] in their vigilance tasks study found association between boredom proneness and vigilance performance.

12.2.10 Fatigue

Fatigue may affect driving performance negatively [29] and it reportedly contributes to a significant share of car accidents [30]. Prolonged driving may induce a variety of fatigue symptoms such as drowsiness, boredom, irritation, physical discomfort and daydreaming [31]. Matthews and Desmond [32] found that fatigue induction elicited various subjective fatigue and stress symptoms, raised reported workload, increased heading error, reduced steering activity and reduced perceptual sensitivity on a secondary detection task. Their results suggest that task-induced fatigue is associated with impaired performance evaluation in 'underload' and 'interventions should be geared towards enhancing driving motivation, rather than reducing attentional demands on the driver' (p. 681). They conclude that 'passive fatigue' (associated with tasks requiring monitoring the environment but infrequent response) 'may become increasingly common in intelligent vehicle highway systems as control passes from driver to vehicle, and it merits further investigation' (p. 681).

12.2.11 SA

The SA of the driver concerning the driving context and the operational status of the system is of vital relevance. Increased automation may increase the tendency of shifting attention away from the driving task [33]. Endsley and Kiris [14] studied the automation of a navigation task and found that SA was lower under automated conditions than under manual conditions and low SA corresponded with out-of-the-loop performance decrements in decision time following a failure of the system. Based on a review of earlier studies, Stanton *et al.* [34] conclude that 'loss of situational awareness is correlated with poor system performance' and 'people who have lost situational awareness may be slower to detect problems with the system they are controlling as well as requiring additional time to diagnose problems and conduct remedial activities when they are finally detected' (p. 199). Stanton *et al.* [34] suggest that 'understanding the nature of situational awareness errors can be helpful in deciding upon strategies for developing effective counter-measures' (p. 201). They discuss various theories of SA and conclude that the 'Three-level model' put forward by Endsley [35] seems to be the most developed approach, in terms of measures and interventions and it offers a functional model for assessing different degrees of insight in a pragmatic manner. According to Endsley's [35] definition: 'Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future' (p. 36). Endsley's [35] model of SA is arranged into three hierarchical levels: (1) perception of the elements in the environment, (2) comprehension of the current situation and (3) prediction of future status. Endsley proposes that SA is discussed in terms of mode awareness, spatial awareness and time awareness.

12.2.12 'Out-of-the-loop' performance

The 'out-of-the-loop' performance problem making the driver handicapped in his/her ability to take over in the event of automation failure is attributed to loss of situational awareness and skill degradation, which leads to declining operator performance [14]. There is no failure free system [36]. If reliability is below 70 per cent, it is better having no automation at all [37]. Automation failure detection better with varying automation reliability [16]. When exposed to automation failure drivers perform better with a lower level of automation [38, 39]. Complacency and over-reliance may cause loss of SA leading to errors when automation fails [4].

12.2.13 Complacency

Automation-related complacency may occur when the operator has to perform both manual tasks and supervise automation. It can be described in terms of an attention allocation strategy where the operator may attend to manual tasks at the expense of the automated task, especially when task load is high [4]. Wiener [40] defined complacency as 'a psychological state characterized by a low index of suspicion' (p. 117). Parasuraman and Manzey [4] concluded that 'attention allocation away from the automated task associated with complacency may include not only fixation failures but attention failures as well' (p. 389). Complacency may lead to the consequence that a system malfunction, anomalous condition or failure is missed or reaction is delayed [4]. Parasuraman *et al.* [16] reported considerable individual differences in the performance effects associated with automation complacency. Also, Prinzel *et al.* [27], investigating the relationship between individual differences of complacency potential, boredom proneness and automation-induced complacency, found that personality individual differences are related to whether an individual will succumb to automation-induced complacency.

12.2.14 Automation bias

Automation bias is reflected in omission errors (the user fails to respond to a critical situation because the automation aid failed to notify him/her) and commission errors (following a wrong recommendation) made by operators when decision aids are imperfect [4]. According to Mosier and Skitka [41], automation bias is characterized by that operators use the decision aid as a heuristic replacement for vigilant information seeking and processing and commission errors can be the result of not seeking out confirmatory or disconfirmatory information or discounting other sources of information in the presence of computer-generated cues. Automation bias can lead to decisions that are not based on a thorough analysis of all available information but that are biased by the advice of decision aid and it can compromise performance considerably in case of automation failures [4]. One reason for automation bias is that users have a tendency to ascribe greater power and authority to automated aids than to other sources of advice [4]. User trust in automated aids as powerful agents with superior capability might make users to overestimate the performance of the aids as they may ascribe to the aid greater authority than to other humans or themselves [4]. Another contributory factor to automation bias is the phenomenon of diffusion of responsibility. When sharing monitoring and decision-making tasks with an automated aid (or other humans in a group) humans may reduce their own effort compared to when they work individually on a given task. The operator may perceive him/herself as less responsible for the outcome and, as a consequence, reduce his/her own effort in monitoring and analysing other available information [42].

12.2.15 Complacency and bias

In a review of empirical studies of complacency and bias in human interaction with automated and decision support systems, Parasuraman and Manzey [4] found that complacency and automation bias represent different manifestations of overlapping automation-induced phenomena, where attention plays a central role. Further, they found that automation complacency and automation bias occurred in both naive and expert operators and it cannot be prevented by training or instructions. An integrated model of complacency and automation bias put forward by Parasuraman and Manzey [4] implies that these issues result from the dynamic interaction of personal, situational and automation-related characteristics.

12.2.16 Usability

Usability of a product is of importance for its success among potential users. There are various definitions of usability, but as Harvey *et al.* [43] expressed, 'consideration of the context of use is essential in defining usability criteria and this will be different for each system under investigation' (p. 563).

12.2.17 Acceptance

Acceptance is a key factor for intended use of new technology in the vehicle [44]. However, as Adell *et al.* [45] put it, ‘Despite the recognised importance of acceptance there is no established definition of acceptance, and there are almost as many ways to measure acceptance as there are researchers trying to do so’ (p. 73). Adell *et al.* [44] put forward a proposal for a common definition of acceptance focusing on a system’s potential to realize its intended benefits; that is, the incorporation by the driver of the technology into his/her driving: ‘Acceptance is the degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it’ (p. 17).

12.3 Research questions, hypotheses and evaluation indicators

Based on the issues pertinent to vehicle automation presented above, research questions and hypotheses can be formulated. Examples of such hypotheses and evaluation indicators related to the individual issues are presented below.

Examples of hypotheses concerning driver behaviour and performance issues are as follows:

1. The system gives the expected user-related outcome. The relevant indicators to test this hypothesis should be specific for the system to be tested and they should reflect the expected outcome in the scenario the system is designed for. Examples of evaluation indicators are: safe and lawful enter / exit / lane change / merging / overtaking; safe and lawful passage of intersection/roundabout; lane position; driving speed; adaptation of speed to potentially critical situations; distance forward and back; accepted gap; side distance to obstacle or to vulnerable road users (distribution, mean and standard deviation of these).
2. Driver behaviour does not differ when driving with a well-functioning system from behaviour without the system. Examples of evaluation indicators are: driving speed, adaptation of speed to potentially critical situations, the frequency and duration of being in an ‘unsafe state’, the distance to the vehicle ahead, lane choice, lane change, lane keeping, over-taking, stopping, yielding, behaviour at traffic lights, interaction with other road users.
3. The driver uses the system in all situations for which it is available. Examples of evaluation indicators are: usage of system in percentage of total driving time during relevant situations.
4. The driver stays in the function setting suggested by the system. Examples of evaluation indicators are: driving in suggested system setting in percentage of total time of a certain suggested system setting.
5. There are no long-term changes in driver behaviour when driving with the system. Examples of evaluation indicators are: driving speed, adaptation of speed to potentially critical situations, the frequency and duration of being in an ‘unsafe state’, the distance to the vehicle ahead, lane choice, lane change, lane keeping, overtaking, stopping, yielding, behaviour at traffic lights, interaction with other road users.

Examples of hypotheses concerning the effects of automation on the driving task are as follows:

6. The drivers' SA is not affected by the system. An example of evaluation indicator is: Situation Awareness Global Assessment Technique (SAGAT) scores [46].
7. Driver stress is not affected by the system. Examples of evaluation indicators are: heart rate measures and Short Stress State Questionnaire (SSSQ) scores [47].
8. The mental workload of the driver is not affected by the system. An example of evaluation indicators is: subjective rate of the Raw Task Load indeX (RTLX) [48].
9. The mental workload does not change after prolonged driving with the system. An example of evaluation indicator is: change in the subjective rate of the RTLX [48].
10. Transfer of control is not affected by mental workload. An example of evaluation indicators is: time for the driver to make decision of transfer of control.
11. The drivers do not engage more in secondary activities when driving with the system compared to driving without the system. An example of evaluation indicators is: percentage of driving time the driver being engaged in secondary activity.
12. The time for the drivers to make decision after a safety critical event does not differ between manual driving mode and automated driving. Examples of evaluation indicators are: RTLX [48], Task-related Boredom Scale (TBS) [49], the probability of detection of automation failure, reaction time (RT) for detection of automation failure, and the number of detection errors and Root-Mean-Squared Error (RMSE) of secondary task.
13. The drivers do not become complacent when driving with automation. An example of evaluation indicators is: the time from a safety critical event arises until the driver takes action.
14. Driving skills don't degrade with time using automation. Examples of evaluation indicators are: standard deviation of speed, adaptation of speed to potentially critical situations, the frequency and duration of being in an 'unsafe state', the distance to the vehicle ahead, lane choice, lane change, lane keeping, standard deviation of the lateral position, overtaking.

Examples of hypotheses concerning take-over situations and regaining control are as follows:

15. There is no change in the drivers' take-over behaviour in long term. Examples of evaluation indicators are: driver reaction type and RT in a take-over situation.
16. The drivers do detect automation failures. An example of evaluation indicators is: the share of registered automation failures.
17. The drivers do not fail to respond to a critical situation because the system failed to notify them. An example of evaluation indicators is: the number of driver responses to critical situations related to all situations the system did not notified them.

18. The drivers take the appropriate measure after a system brake down. An example of evaluation indicators is: driver reaction type to a system brake down.
19. The drivers do not follow a wrong recommendation instead of vigilant information seeking and processing. An example of evaluation indicators is: driver reaction type after a wrong recommendation in a critical situation.
20. The drivers are confident about the correctness of their decision after a system brake down. Evaluation indicators are: questionnaire answers.
21. There is no difference in intervention time between drivers with an internal locus of control and those with an external locus of control. An example of evaluation indicators is: the time from a safety critical event arises until the driver takes an action.

Examples of hypotheses concerning the driver's understanding, trust, opinions and acceptance of the system are as follows:

22. The drivers have the correct mental representation of the system. Evaluation indicators are: questionnaire answers.
23. The drivers have no over- or under-trust on the system. An example of evaluation indicators is: scores on the self-report scale of trust [7].
24. The drivers experience automated driving as an improvement in their driving. Evaluation indicators are: questionnaire answers.
25. The drivers have their distinct opinion about the system. Evaluation indicators are: questionnaire answers.
26. The drivers find the system useful and satisfactory. An example of evaluation indicators is: usefulness and satisfaction scale [50].
27. Automation failures do not influence the drivers' attitude to the system. Evaluation indicators are: questionnaire answers.
28. The drivers are interested to have and to pay for the system. Evaluation indicators are: questionnaire answers.

12.4 Methods and tools for user-related evaluation

To investigate behaviour-related issues when driving with a well-functioning ADAS or driving automation, logging of driving data, observation of driver behaviour and reactions, as well as interviews with test drivers are to be carried out either in a driving simulator or on a test track with staged scenarios and/or in real traffic. The type of the test environment chosen depends on:

- the criticality of the relevant scenario of interest,
- the expected reaction of the system (warning/intervening),
- the time point at which the system becomes active (the more critical time to collision at warning/intervention, the more the use of a simulator environment is preferable for safety reasons).

The suitable test environments for investigating the user-related issues pertinent to vehicle automation are presented in Table 12.1.

Table 12.1 Suitable study environment for the various user-related evaluation issues

Measurement issue	**Driving simulator**	**Test track**	**Real traffic**
Driver behaviour	√	√	√
Driver performance	√	√	√
Understanding the system	√	√	√
Trust and reliance	√	√	√
Transfer of control	√	√	-
Mental workload	√	√	√
Stress	√	√	√
Perceived boredom	√	√	√
Fatigue	√	√	√
SA	√	-	-
Out-of-the-loop performance	√	-	-
Complacency	√	-	-
Usability	√	√	√
Acceptance	√	√	√
Perceived benefits	√	√	√

The controlled environment of a driving simulator and a test track has the advantage that damages to persons or objects can be prevented. Tests in real traffic require extraordinary safety considerations since such tests also involve other road users. Furthermore, the environment cannot be controlled in the same manner as on test tracks. Therefore, the safety measures need to focus on the test vehicle, the function and the driver of the test vehicle. The applied test tools should enable a safe, efficient and accurate evaluation of the ADAS/driving automation function in question.

A legislative aspect to take into account is that the test drivers should have an appropriate driving license. Furthermore, insurance for third party and personal damage must exist. The coverage of the insurance should be at least as high as requested by the law. A road test approval for the test vehicle and the testing region must be available.

Of ethical concern is the fact that the test drivers can be identified, and that this information can be misused. The anonymity and privacy of the test drivers, as well as non-disclosure of their driving-related data is to be ensured. The test drivers should be made aware of the fact that only the researchers analysing the data collected during the tests should know the test drivers' identities during the research process before they enrol in the tests and they should sign an informed consent before participating in the study.

The test vehicle/driving simulator needs to be equipped with logging equipment. The logging equipment should register besides to the CAN-Signals also video data of the relevant perspectives (e.g. front view, rear view, side view when necessary) during the tests.

12.4.1 Measuring driver performance

Driver performance can be measured through assessments of drivers' attention to potential hazards (i.e. detection accuracy), accuracy of vehicle control (i.e. variability in lateral position) and variations in mean speed (reflecting the effort to compensate for increased workload). The findings of Matthews and Desmond [32] suggest that loss of on-road driving performance should be assessed through indices of heading error or fine-steering reversals in undemanding conditions.

Logging of driving data either in a driving simulator, in the test car on a test track or in real traffic can yield indicators, such as driving speed, distance to the vehicle ahead, lateral position, distance to side obstacles, accepted gap, the frequency and duration of being in an 'unsafe state', the time from a safety critical event arises until the driver takes an action, usage of system in percentage of total driving time during relevant situations, driving in suggested function/system settings in percentage of total time of a certain suggested function/system setting.

12.4.2 Behavioural observations – the Wiener Fahrprobe

To observe driver behaviour and possible changes in it, the in-car observation method (Wiener Fahrprobe), originally developed by Risser and Brandstatter [51] and designed to observe learning drivers can be employed. The method also proved to be useful for studying driver behaviour in real traffic. The observations are carried out by two observers, riding along in the car with the driver, where one of the observers (called the coding observer) studies standardized variables such as speed behaviour, yielding behaviour, lane change and interaction with other road users. The other observer carries out 'free observations' such as conflicts, communication and special events that are hard to predict, let alone to standardize. The method was validated by Risser and Brandstatter [51] when they showed that there was a correlation between observed risky behaviour and accidents. Other validation work was done by Hjälmdahl and Várhelyi [52] who showed that drivers' speed levels with observers in the car did not differ from their speed levels when driving their own cars. They also demonstrated that it was possible to train observers to perform the observations objectively and reliably.

Behavioural observations either in a driving simulator, on a test track or in real traffic can yield indicators, such as adaptation of speed to potentially critical situations, lane choice, lane change, lane keeping behaviour, overtaking behaviour, stopping behaviour, yielding behaviour, behaviour at traffic lights, interaction and communication with other road users.

12.4.3 Understanding the system

Users' understanding of the limitations of the system can be investigated with help of open interview questions after have driven with the system. Issues of interest here are if the test person can describe how the system helps him/her in car driving or if she/he is aware of any limitations of the system and in that case he/she can describe them.

12.4.4 Trust and reliance

Merritt *et al.* [10] conclude that users do not fully understand why they experience a given level of trust in an automated system. 'When asked why they trust or do not trust a system, the users will be capable of describing the effects of only their explicit attitudes – not their implicit ones' (p. 11). Thus, interviews, surveys and focus groups may provide an incomplete understanding of factors influencing user trust. To better understand why users trust automation, implicit attitudes must be measured using carefully constructed implicit techniques.

Merritt [7] demonstrated that automation is influenced by affective processes, ‘suggesting that this decision-making process may be less rational and more emotional than previously acknowledged’ (p. 356). She found that trust and liking predicted reliance, as well as, besides ‘propensity to trust’, affective variables, such as moods and emotions are important for trust.

Actual ‘trust’ in the system in question can be assessed using a 6-item self-report scale and ‘Liking for a system’ can be assessed using a 5-item self-report scale created by Merritt [7] (p. 367). Both scales are on a 5-point Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

Merritt *et al.* [10] measured automation reliance by the number of times a test person changed his/her response away from his/her initial opinion to correspond with the system’s advice, divided by the number of times he/she had the opportunity to do so. Opportunities to rely included only trials where the test person’s initial opinion differed from the system’s advice. The test persons could not switch their response to agree with the system when their initial opinion matched the system’s advice.

12.4.5 Transfer of control

To measure driver’s ability to resume control of driving, the following variables can be used: mean and minimum values of speed and their standard deviation, standard deviation of lane position (SDLP), number of 1° steering reversals per minute, high frequency control of steering (0.3–0.6 Hz band) and visual attention measured by eye tracking value of ‘Percent Road Centre’ [12]. To study if mental workload affects transfer of control to and from the driver, during a driving simulator study, the driver should be engaged in a secondary task.

12.4.6 Mental workload

Mental workload of the driver can be assessed with the help of the RTLX method proposed by Byers *et al.* [48]. According to this method, the subjects rate six different workload aspects, namely mental demand, physical demand, time pressure, performance, effort and frustration level. Continuous scales ranging from 0 (*very low*) to 100 (*very high*) are used. The difference in workload between driving with the system on compared to off can be calculated for each test driver. To investigate if mental workload changes after prolonged exposure to the system, observations should be carried out both before implementing the system of automation, directly after and after a longer period of driving with the system.

12.4.7 Stress

To measure impact on driver stress, heart rate as an objective physiological arousal measure can be used [23]. There are various heart beat detectors available on the market.

To assess driver stress based on subjective measures, stress state questionnaires can be used. Helton [47] presented validation evidence of a short multidimensional self-report measure of stress state, the SSSQ derived from the Dundee Stress State Questionnaire (DSSQ) [32]. Factor analyses differentiated three aspects of subjective stress (similar to the DSSQ): task engagement, distress and worry. The SSSQ appeared to be a useful measure of stress state [47]. It consists of 24 items with five categories of response, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The test drivers should complete the SSSQ before and after test driving.

12.4.8 Boredom

To assess perceived boredom experienced by the drivers, the TBS [49] can be used. The TBS addresses eight factors thought to contribute to feelings of boredom: stress, irritation, relaxation, sleepiness, alertness, concentration, passage of time and satiation. In addition, respondents are asked to provide an estimation of their overall feeling of boredom. A total boredom score is calculated by summing all the subscales.

12.4.9 Fatigue

To quantify driver fatigue, objective and/or subjective measurements can be employed. Objective measures are standard deviation of speed, standard deviation of lateral position, frequency of extremely large steering wheel movement (>N10°), frequency of line crossings and RT [53]. Data to be acquired in simulated driving using a common method to induce fatigue by having subjects perform a demanding secondary task. Ting *et al.* [53] used a simple RT-test to assess the sustained attention of drivers throughout the driving task: Two red circular images (radius of 25 cm; horizontal angle of 11–23° left) were randomly displayed on a screen every 2 km. When the visual stimulus appeared (duration of 3.6 s), the subject was required to respond to the stimulus by turning off an identical indicator. The system automatically recorded individual RTs. If no response was made within 3.6 s, a new RT-test was started. The variation in mean RT was employed to assess driver vigilance.

Matthews and Desmond [31] developed a multidimensional measure of subjective fatigue state (SFS). The fatigue scale comprises 24-items, relating to four aspects of fatigue: (1) visual fatigue, (2) muscular fatigue, (3) boredom and (4) malaise. Subjects are required to rate on 0–5 numerical scales the extent to which they experience the 24 items of fatigue symptoms.

12.4.10 SA

Endsley [46] developed the SAGAT for air-fight scenarios. Adopted to the car driving context, SAGAT measures a driver's SA in the following manner: (a) The driver drives the car with given automation in a driving simulator and in a given scenario. (b) At some random point in time, the simulation is halted and the instrument panel and the displays are blanked. (c) The driver is asked a series of questions to determine his/her knowledge of the situation at that exact moment. The

SAGAT queries are programmed on a computer to allow for quick input and storage of information. As it is impossible to ask the driver about all of these SA requirements in a given stop, a portion of the SA questions are randomly selected and asked each time. (d) The query answers are evaluated on the basis of what was actually happening in the simulation. This is made by comparing the driver's answers to data collected from the simulator computers. The comparison of the real and perceived situation provides an objective measure of driver SA. A composite SAGAT score is then determined. (e) This random sampling process is repeated a number of times for each driver driving with the same system, to obtain the number of observations required for statistical significance. SAGAT scores for any system design can then be compared to SAGAT scores for other systems.

12.4.11 Out-of-the-loop performance problem

To investigate if automation can have an impact on the out-of-the-loop performance problem, a driving simulator experiment comparing automated driving with manual driving is appropriate. The primary independent variable should be manual driving versus automation with a simulated system brake down. The dependent variables should be: SA, the decision selected, time for the drivers to make decision, drivers' confidence about the correctness of their decision made and mental workload.

12.4.12 Complacency

Singh *et al.* [54] developed a 20-item scale, the Complacency Potential Rating Scale (CPRS), which measures attitudes towards automation that reflect a potential for developing automation-induced complacency. By factor analysis, they indicated four complacency-potential-related dimensions: trust, confidence, reliance and safety, which suggests that high scores on these factors are associated with complacency. Although the CPRS has been shown to be a good indicator of an operator's complacency potential [27], it does not measure factors that may influence the onset of complacency, such as workload, boredom or cognitive failure. Hence, other measures are also needed to assess automation-induced complacency.

Investigating the relationship between the individual differences of complacency potential, boredom proneness and automation-induced complacency, Prinzel *et al.* [27] found that operators performing the monitoring task under variable automation reliability condition did significantly better than those in the constant automation reliability condition, indicating that a constant high automation reliability (87.5 per cent of malfunctions detected by the automation) impairs an operator's ability to monitor for infrequent automation failures in a multitask environment. Hence, in assessing automation-induced complacency, a high automation reliability level (above 87.5 per cent) should be used with occasional automation failure.

12.4.13 Usability

Usability evaluation can be made to assess the degree to which a system's human–machine interface (HMI) complies with usability criteria applicable in the specific context of use [43]. Harvey *et al.* [55] reviewed over 70 usability evaluation methods for in-vehicle information systems (IVIS) and matched each of the selected methods with thirteen usability criteria, clustered in six main factors, that is, dual task environment, range of users, environmental conditions, training provision, frequency of use and uptake.

To evaluate the users' perceptions of the system under investigation, the subjective method of System Usability Scale (SUS) can be employed. The SUS consist of ten statements, against which participants rate their level of agreement on a 5-point Likert scale with five categories of response, from 1 (*strongly disagree*) to 5 (*strongly agree*) [56]. A single usability score is computed from the ratings, which allows for comparing user opinions across different systems. A total score is calculated by adding the scores of the items. The total SUS score ranges between 0 (*very low usability*) and 100 (*very high usability*).

12.4.14 Acceptance

One of the methods, widely used to assess acceptance of driver assistance systems is the usefulness and satisfaction method proposed by van der Laan *et al.* [50]. According to the method, the subjects assess nine components related to usefulness and satisfaction: 'good – bad', 'pleasant – unpleasant', 'effective – superfluous', 'nice – annoying', 'likable – irritating', 'useful – useless', 'assisting – worthless', 'desirable – undesirable', 'raising alertness – sleep inducing' on a bipolar scale.

More recently, Adell [57, 58] put forward another model, based on the Unified Theory of Acceptance and Use of Technology (UTAUT) used in the area of information technology [59], for analysing acceptance issues of driver assistance systems. Adell [60] undertook a pilot test of her model with promising results. The 17 items for assessing 'behavioural intention', 'performance expectancy', 'effort expectancy' and 'social influence' were adopted from Venkatesh *et al.* [59], some of them adapted to fit the context of driver assistance systems. Each item is rated on a 7-point scale, ranging from 1 (*strongly disagree*) to 7 (*strongly agree*).

12.4.15 Perceived benefits

The drivers can be asked to state in what extent they think the system would give them benefits or disadvantages if they were to use the system in their everyday driving on some given items: 'Do you think the system can give you benefits or disadvantages in your everyday driving?' The answers can be given on a continuous scale from 'very large disadvantage' to 'very large benefit', with 'neither' represented by the middle point.

12.5 Study design

The participants (by practice 20–30 persons – although the adequacy of this relatively low number is discussed by scientists), stratified by gender and age, representing the driver population are to be observed individually. They should complete two driving sessions on a test route consisting of road types that contain the relevant traffic scenarios of interest for the tested system. Experience from various in-car observational studies show that a 40–50 min driving session in real traffic environment should give satisfactorily enough events to assess the user-related issues (see, e.g. [52, 61, 62]). A somewhat shorter duration of test drives should be enough in a driving simulator as relevant scenarios with desired frequency can be staged there. The test drivers serve as their own controls (within subject design). The order of driving should be balanced in such a way that every other subject drives first with the system switched off and then with the system switched on. For the following subject, the order of driving is reversed. By doing this, the effects of biasing variables, such as getting used to the test route or to the observers and the test situation cannot be eliminated, but such effects can be spread evenly across the situations.

Before starting the test rides, the drivers should be informed about the system and its limitations (in the manner a car dealer would inform the purchaser of a new car equipped with the function in question) and that the trial is about the system and not about them as drivers. The drivers should be instructed to drive as they usually drive and that they are welcome to ask for whatever doubts or questions they might have during the study. They should be given a 10-min practice session to make acquaintance with the system and the test situation.

It is one thing how the test driver reacts to and drive with a new system at a first acquaintance and another thing is how he/she does it when he/she got used to the system. A few studies could show that a change in the driving environment (in the infrastructure or the vehicle) gives a significant initial change in driver behaviour, but this initial change attenuates after getting used to the new situation. Hydén and Várhelyi [63] evaluating the effects of large-scale implementation of roundabouts in the city of Växjö, Sweden as well as Várhelyi *et al.* [64] assessing the long-term effects of the active accelerator pedal in the city of Lund found that the initial significant decrease in driving speed, diminished somewhat after long-term (4–6 months) exposure to the system. Hence, the long-term effects of driving with a new ADAS or automated driving system also should be evaluated.

An interesting issue is how non-users react when driving in a mixed traffic environment since there will be a quite significant period of time until all vehicles are equipped with similar systems. Drivers of non-equipped vehicles might imitate the behaviour of equipped vehicles which in some cases may deteriorate the traffic safety situation in total. Such effects can, of course only be assessed after a number of equipped vehicles have been moving around in the traffic system so other drivers got some period of interaction with these vehicles. Important variables to look at when assessing the effects on non-users are: driving speed, adaptation of speed to potentially critical situations, the frequency and duration of being in an ‘unsafe state’, the distance to the vehicle ahead, lane choice, lane change, lane keeping, overtaking, stopping, yielding, behaviour at traffic lights, interaction and communication with other road users.

12.6 Conclusions

It is important to have a good overview of the issues user-related evaluation of ADAS and automated driving applications involve. However, since resources for user-related evaluation often are limited, not all of these issues can be included in the evaluation.

It is important, however, to make an informed decision when deciding what issues are included and what methods and tools to be used. Also, it is important to follow a systematic evaluation process starting with formulating research questions and hypotheses, defining indicators and appropriate data collection methods and tools.

The output from user-related evaluation in form of driver behavioural effects will then constitute an important basis for traffic simulation activities for assessing the network effects at various penetration rates assuming that the equipped vehicles will behave as the findings from the behavioural observations show. The output from the traffic simulation in its turn will give input for socio-economic assessment of the system in question.

References

[1] Stanton, N.A., Young, M.S. Vehicle automation and driving performance. *Ergonomics*, 1998 41, 1014–1028.

[2] Smiley, A. Behavioural adaptation, safety, and intelligent transportation systems. *Transportation Research Record*, 2000 1724, 47–51.

[3] OECD. *Behavioural Adaptations to Changes in the Road Transport System*. Chicago, MI: University of Chicago Press. 1990.

[4] Parasuraman, R., Manzey, D.H. Complacency and bias in human use of automation: an attentional integration. *Human Factors*, 2010 52(3), 381–410.

[5] Preece, J., Rogers, Y., Sharp, H. *Interaction Design: Beyond Human Computer Interaction*. New York, NY: John Wiley & Sons. 2002.

[6] Jenness, J.W., Lerner, N.D., Mazor, S., Osberg, J.S. Tefft, B.C. Use of Advanced In-Vehicle Technology by Young and Older Early Adopters: Selected Results from Five Technology Surveys. Report No. HS 811 004. Washington, DC: US Department of Transportations, National Highway Traffic Safety Administration, USA. 2008.

[7] Merritt S.M. Affective processes in human-automation interactions. *Human Factors*, 2011 53, 356–370.

[8] Parasuraman, R., Riley, V. Humans and automation: use, misuse, disuse, abuse. *Human Factors*, 1997 39(2), 230–253.

[9] McBride, S.E., Rogers, W.A., Fisk, A.D. Do younger and older adults differentially depend on an automated system? Paper presented at the Human Factors and Ergonomics Society 54th Annual Meeting, San Francisco, CA. 2010.

[10] Merritt, S. M., Heimbaugh, H., LaChapell, J., Lee, D. I trust it, but I don't know why: effects of implicit attitudes toward automation on trust in an automated system. *Human Factors*, 2012. doi: 10.1177/0018720812465081.

[11] Halpert, R., Hill, R. 28 measures of locus of control. 2011. http://teachinternalcontrol.com/uploads/LOC_Measures__1_.pdf [Accessed December 10, 2015].

[12] Merat, N., Hamish Jamson, A., Lai, F.C.H., Daly, M. Carsten, O.M.J. Transition to manual: driver behaviour when resuming control from a highly automated vehicle. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2014 27(B).

[13] Trimble, T. E., Bishop, R., Morgan, J. F., Blanco, M. Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts: Past Research, State of Automation Technology, and Emerging System Concepts. Report No. DOT HS 812 043. Washington, D.C.: National Highway Traffic Safety Administration. 2014.

[14] Endsley, M.R., Kiris, E.O. The out-of-the-loop performance problem and level of control in automation. *Human Factors*, 1995 37, 381–394.

[15] Shiff, B. An experimental study of the human–computer interface in process control. Unpublished thesis, University of Toronto, Department of Industrial Engineering, Canada. 1983.

[16] Parasuraman, R., Molloy, R., Singh, I.L. Performance consequences of automation induced 'complacency'. *International Journal of Aviation Psychology*, 1993 3(1), 1–23.

[17] Singh, I.L., Molloy, R., Parasuraman, R. Automation-induced monitoring inefficiency: role of display location. *International Journal of Man–Machine Studies*, 1997 46, 17–30.

[18] Sheridan, T.B. *Humans and Automation: System Design and Research Issues*. Santa Monica, CA: Wiley. 2002.

[19] Strand, N. When driving automation fails. Drivers experiences and interactions. PhD thesis, Chalmers University of Technology, Gothenburg, Sweden. 2014.

[20] Banks, V.A., Stanton, N.A., Harvey, C. Sub-systems on the road to vehicle automation: hands and feet free but not mind free driving. *Safety Science*, 2014 62, 505–514.

[21] McDonald, A.S., Davey, G.C.L. Psychiatric disorders and accidental injury. *Clinical Psychology Review*, 1996 16(2), 105–127.

[22] Funke, G., Matthews, G., Warm, J.S., Emo, A.K. Vehicle automation: a remedy for driver stress? *Ergonomics*, 2007 50(8), 1302–1323.

[23] Reimer, B., Mehler, B., Coughlin, J.F. *An Evaluation of Driver Reactions to New Vehicle Parking Assist Technologies Developed to Reduce Driver Stress*. Cambridge, MA: New England University Transportation Centre, Massachusetts Institute of Technology. 2010.

[24] Cummings, M.L., Mastracchio, C., Thornburg, K.M., Mkrtchyan, A. Boredom and distraction in multiple unmanned vehicle supervisory control. *Interacting with Computers*, 2013 25(1), 34–47.

[25] Farmer, R., Sundberg, N.D. Boredom proneness – the development and correlates of a new scale. *Journal of Personality Assessment*, 1986 50, 4–17.

[26] Stark, J.M., Scerbo, M.W. The effects of complacency potential and boredom proneness on perceived workload and task performance in an automated environment. Presented at the Human Factors and Ergonomics Society 42nd Annual Meeting. Chicago, October 1998, Vol. 42(23), pp. 1618.

[27] Prinzel, L.J., De Vries, H., Freeman, F.G., Mikulka, P. Examination of Automation-Induced Complacency and Individual Difference Variates. NASA/TM-2001-211413. 2001.

[28] Sawin, D.A., Scerbo, M.W. Effects of instruction type and boredom proneness in vigilance: implications for boredom and workload. *Human Factors*. 1995 37(4), 752–765.

[29] Brown, I.D. Prospects for technological countermeasures against driver fatigue. *Accident Analysis & Prevention*, 1997 29(4), 525–531.

[30] Maycock, G. Driver Sleepiness as a Factor in Car and HGV Accidents. TRL Report No. 169, Crowthorne, Berkshire, UK. 1995.

[31] Matthews, G., Desmond, P.A. Personality and multiple dimensions of task-induced fatigue: a study of simulated driving. *Personality and Individual Differences*, 1998 25, 443–458.

[32] Matthews, G., Desmond, P.A. Task-induced fatigue states and simulated driving performance. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 2002 55(2), 659–686.

[33] Carsten, O., Lai, F.C.H., Barnard, Y., Jamson, A.H., Merat, N. Control task substitution in semi-automated driving: does it matter what aspects are automated? *Human Factors*, 2012 54(5), 747–761.

[34] Stanton, N.A., Chambers P.R.G., Piggott J. Situational awareness and safety. *Safety Science*, 2001 39, 189–204.

[35] Endsley, M.R. Toward a theory of situation awareness in dynamic-systems. *Human Factors*, 1995 37(1), 32–64.

[36] Perrow, C. *Normal Accidents: Living With High-Risk Technologies*. New York, NY: Basic Books. 1984.

[37] Wickens, C.D., Dixon, S.R. The benefits of imperfect diagnostic automation: a synthesis of the literature. *Theoretical Issues in Ergonomics Science*, 2007 8(3), 201–212.

[38] Nilsson, L. Safety effects of adaptive cruise controls in critical traffic situations. In: *Proceedings of the Second World Congress on Intelligent Transport Systems*, Yokohama, Japan, 9–11 November, 1995, pp. 1254–1259.

[39] Vollrath, M., Schleicher, S., Gelau, C. The influence of cruise control and adaptive cruise control on driving behaviour – a driving simulator study. *Accident Analysis and Prevention*, 2011 43(3), 1134–1139.

[40] Wiener, E.L. Complacency: is the term useful for air safety? In: *Proceedings of the 26th Corporate Aviation Safety Seminar*. Denver, CO: Flight Safety Foundation, Inc. 1981, pp. 116–125.

[41] Mosier, K.L., Skitka, L.J. Human decision-makers and automated decision aids: made for each other? In: Parasuraman, R., Mouloua, M. (Eds.), *Automation and Human Performance: Theory and Application*. Mahwah, NJ: Lawrence Erlbaum Associates. 1996, pp. 201–220.

[42] Domeinski, J., Wagner, R., Schoebel, M., Manzey, D. Human redundancy in automation monitoring: effects of social loafing and social compensation. In: *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society. 2007, pp. 587–591.

[43] Harvey, C., Stanton, N.A., Pickering, C.A., McDonald, M., Zheng, P. A usability evaluation toolkit for In-Vehicle Information Systems (IVISs). *Applied Ergonomics*, 2011 42(4), 563–574.

[44] Adell, E., Várhelyi, A., Nilsson, L. The definition of acceptance and acceptability. In: Regan, M.A., Horberry, T., Stevens, A. (Eds.), *Driver Acceptance of new technology. Theory, Measurement and optimisation*. Ashgate. 2014, pp. 11–22.

[45] Adell, E., Nilsson, L., Várhelyi, A. How is acceptance measured? Overview of measurement issues, methods and tools. In Regan, M.A., Horberry, T., Stevens, A. (Eds.), *Driver Acceptance of New Technology. Theory, Measurement and Optimisation*. Surrey, UK: Ashgate. 2014, pp. 73–89.

[46] Endsley , M.R. Situation awareness global assessment technique (SAGAT). In: *Proceedings of the National Aerospace and Electronics Conference*. New York, NY: IEEE. 1988, pp. 789–795.

[47] Helton , W.S. Validation of a short stress state questionnaire. In: *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana, USA. 2004.

[48] Byers. J.C., Alvah, J., Bittner, C., Hill, S.G. Traditional and raw task load index (TLX) correlations: are paired comparisons necessary? In: Annual International Industrial Ergonomics and Safety. Cincinnati, OH: Taylor & Francis. 1989.

[49] Scerbo, M.W., Rettig, K.M., Bubb-Lewis, C.L. A validation study of a task-related boredom scale. In: *Proceedings of the 2nd Mid-Atlantic Human Factors Conference*. Washington, D.C. 1994. pp. 135–136.

[50] Van der Laan, J.D., Heino. A., de Waard, D. A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C*, 1997 5, 1–10.

[51] Risser, R., Brandstatter, Ch. *Die Wiener Fahrprobe. Freie Beobachtung*. Wien: Literas Universitatsverlag. 1985.

[52] Hjälmdahl, M., Várhelyi, A. Speed regulation by in-car active accelerator pedal – effects on driver behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2004 7(2), 77–94.

[53] Ting, P.H., Hwang, J.R., Doong, J.L., Jeng, M.C. Driver fatigue and highway driving: a simulator study. *Physiology & Behaviour*, 2008 94, 448–453.

[54] Singh, I.L., Molloy, R., Parasuraman, R. Automation-induced ‘complacency’: development of the complacency-potential rating scale. *International Journal of Aviation Psychology*, 1993 3, 111–121.

[55] Harvey, C., Stanton, N.A., Pickering, C.A., McDonald, M., Zheng, P., Context of use as a factor in determining the usability of in-vehicle devices. *Theoretical Issues in Ergonomics Science*, 2011 12(4), 318–338.

[56] Brook, J. SUS: a ‘quick and dirty’ usability scale. In: Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, I.L. (Eds.), *Usability Evaluation in Industry*. London, England: Taylor and Francis. 1996. pp. 189–194.

[57] Adell, E. The concept of acceptance. In *Proceedings of the 20th ICTCT-Workshop*, Valencia, Spain. 2007.

[58] Adell, E., Várhelyi, A., Nilsson, L. Modelling acceptance of driver assistance systems: application of the unified theory of acceptance and use of technology. In: Regan, M.A., Horberry, T., Stevens, A. (Eds.), *Driver Acceptance of New Technology. Theory, Measurement and Optimisation*. Surrey, UK: Ashgate. 2014. pp. 23–35.

[59] Venkatesh, V., Morris, M.G., Davis, G.B., Davis, F.D. User acceptance of information technology: toward a unified view. *MIS Quarterly*, 2003 27(3), 425–478.

[60] Adell, E. Driver experience and acceptance of driver support systems – a case of speed adaptation. PhD thesis, Lund University, Sweden. 2009.

[61] Várhelyi, A. Kaufmann, C. Persson, A. User-related assessment of a driver assistance system for Continuous Support – a real-life field study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2015 30, 128–144.

[62] Adell, E., Várhelyi, A., Dalla Fontana, M. The effects of a driver assistance system for safe speed and safe distance – a real life field study. *Transportation Research Part C*, 2010 19 145–155.

[63] Hydén, C., Várhelyi, A. The effects on safety, time consumption and environment of large scale use of roundabouts in an urban area: a case study. *Accident Analysis and Prevention*, 2000 32(1), 11–23.

[64] Várhelyi, A., Hjälmdahl, M., Hydén, C., Draskóczy, M. Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas. *Accident Analysis and Prevention*, 2004 36, 729–737.

Chapter 13

Towards a coherent cost–benefit analysis of ITS – A review of effects and assessments of ITS applications for traffic management in Sweden

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13.1 Introduction

There is a need to compare the costs and benefits of investments in Intelligent Transport Systems (ITS) and Services [1] with those of investments in traditional infrastructure [2]. Such comparisons need quantified data. However, some impacts of introducing ITS measures are difficult to quantify [3].

For the Swedish Transport Administration (STA), which is nationally responsible for long-term planning of the transport system, as well as for building, operating and maintaining public infrastructure in accordance with the national transport policy in Sweden, the impact on society of building ITS installations is in need of clarification.

The STA has made substantial efforts over the years to develop methods to evaluate road infrastructure investments. This work has resulted in a series of publications with quantified impact assessments, which aim to define the relationships between investments and their consequences on society. The purpose has been to enable cost–benefit analysis (CBA) for all types of road investments, including investments in ITS. Despite several attempts to create a foundation for the estimation of effects of ITS, few of these efforts has resulted in full CBA models.

A long-term goal for the STA is to promote better ITS evaluations and follow-ups so that such input can be aggregated to create good knowledge and understanding of ITS effects. The goal is to enable the impacts of ITS measures to be described at a level of detail equal to that of traditional infrastructure measures. The aim has been to enable effect comparisons of ITS against other infrastructure measures.

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Several projects have been carried out in Sweden, sometimes in cooperation with Nordic partners, to investigate and quantify the impacts of ITS measures. Among these are the TEMPO/Viking 'Evaluation strategy with common practice and principles for evaluation of EU-projects within ITS' (2003), STEGLITS-CONTRAM-IDAS-VIKING 'A guideline for evaluation of ITS with the purpose of establishing common practice for evaluation, reporting and the spreading of knowledge in Sweden' (2008) and SEVITS, an Excel-based calculation tool developed by TØI (Norwegian Institute of Transport Economics) for the STA and the Norwegian Public Roads Administration (2013). Some of the conclusions generated by these efforts are: The economic effects of introducing an ITS system are often difficult to estimate, due to the fact that the resulting effects can many times be bound to a specific situation. ITS systems are moreover dynamic by nature, which means that the system is constantly responding to variations in the traffic, which also makes it more difficult to estimate the effects.

As previous attempts of introducing ITS in existing CBA tools in Sweden has largely been fragmented, the purpose of this chapter is to contribute to a coherent CBA of ITS by describing methodology and results from a review of ITS applications for traffic management in Sweden. This chapter is based on the evaluations and aggregations of effects on four types of ITS systems: systems for traffic controlled variable speed limits; systems for ramp metering; systems for travel time and incident information; and Motorway Control Systems (MCS). An effort has been made to estimate the effects of these measures in economic terms.

CBA is not enough to describe all effects of specific infrastructure measures on society. Some effects can be quantified, but are not possible to value in economic terms – whereas other effects also are hard to quantify. To make fair judgements, CBAs are supplemented with judgements of non-monetary effects. In Sweden, impacts (monetary and non-monetary effects) and distribution effects on society are combined to judge the fulfilment of the transport policy objectives of ensuring economically efficient and long-term sustainable transport provision for citizens and establishments of the society.

13.1.1 Aim

This study aims to support a basis for comparability of CBA of ITS systems with traditional investments. More specifically, this study investigates into studies of effects of ITS, using a systematic approach, by combining results from several studies. The aim is also to see to what extent applicable studies can serve as a basis for comparability with traditional infrastructure measures in the STA planning and decision process which include the valuation of monetary effects, non-monetary effects and other effects, as previously mentioned. Swedish studies have been in focus due to the need of applicability on Swedish conditions and the need of enabling a basis for comparability on metrics related to the best documented Swedish results. The STA has responsibility for both railway and roadway traffic in Sweden. However, ITS systems for railway are often large and complex and were not part of this study, only ITS for road infrastructure are treated in this work.

13.2 Method

The study was conducted in the following three steps:

1. Literature study (data collection)
2. Selection of ITS measures
3. Expert workshops (validation of findings)

13.2.1 Literature study/Data collection

A literature study, which encompassed the study of relevant publications, was undertaken. No new data collection has been performed; instead, the study is an overview of applicable available studies. Materials were studied in the following order:

- Swedish evaluations
- Swedish aggregations
- Nordic studies
- European aggregations
- Other international studies (to a lesser extent)

All in all, this study was conducted with strict boundaries to produce relevant results for Swedish conditions regarding road building, traffic density, and population factors, planning principles, legislation and other influencing aspects of ITS implementation. The prioritized studies were often conducted or commissioned by the STA and had a focus on applicable road conditions. Second, studies from the Nordic countries were looked at. They have some similarity regarding road conditions and planning principles. There is also a tradition of cooperation between the road authorities in the Nordic countries in sharing experience in evaluation processes. This means that there are general knowledge about evaluation methodologies used in each other or joint studies. European studies, which are often aggregations, were next in order. Sweden also has a long tradition of cooperation, participation and observation in EU-related evaluation studies such as EasyWay and TEMPO. Although these projects can be deemed valuable for sharing experiences and spreading knowledge, their evaluation results are aggregated on a more general level from many different sources. This leads to limited applicability in this particular study. Finally, other international studies were briefly looked at for reference; however, it was regarded that such materials had limited use for this work, as methodology and conditions of study often differ considerably from Swedish circumstances. Also, descriptions of the types of effects which are needed for relevant CBA are often lacking. It should be noted that for non-Scandinavian studies, only works produced in English, were studied. All source materials which actually have been used for producing results in this work were of Swedish origin (although international studies have been used for verification). Selected studies have data with usable precision, this is important because effects that are too broad will lead to incomparable analyses.

13.2.2 Selection of ITS measures

Only ITS measures that had previously been evaluated in a way that was deemed adequate were considered. The measures had moreover to be under the responsibility of STA to be considered. Moreover, the selected systems also needed to be operational in Sweden as well to be considered for further implementation. This led to a focus on motorway-related systems. It also meant that ITS systems such as parking guidance systems managed by municipalities were omitted.

Prioritized measures were studied with the purpose of estimating effects of the respective ITS measure and to what extent available evaluation and aggregation materials can serve as a basis for the development of a coherent CBA. All selected measures were lacking a fully established base for the judgement of economic effects within the present STA guidelines.

13.2.3 Expert evaluation workshops

Two workshops were conducted as part of this study. An initial workshop was held in June 2015 with a total of 15 participants from the academia, the STA, and from consultancy companies that work with ITS and/or CBA analysis. The participants were hand-picked for their expertise and for their professional roles. A compilation of findings from the literature study was distributed to the participants as a basis for discussions. The agenda of the workshop was to discuss needs, evaluations and effects of these specific measures.

The purpose was to: (1) collect input and exchange experience regarding effects and economic assessments of ITS measures, (2) discuss to which extent known effects and evaluations can be used for economic judgements to make relevant comparisons with non-ITS measures, (3) discuss base-requirements/prerequisites regarding applicable traffic situations to make the respective ITS measure relevant and (4) facilitate the spreading of knowledge about the effects of ITS.

Collecting input from these activities led to the creation of an advisory document, featuring recommendations for effect assessments regarding the four previously mentioned ITS applications. To verify the conclusions, a final review workshop was held to confirm the findings. This assembly was comprised of roughly the same categories of participants, as with the previous workshop, although with somewhat broader selection through an open invitation. The final conclusions were moreover independently reviewed by an external senior STA-expert.

13.3 Results

The results were decided by the STA to be incorporated into the existing guiding documents, which were to be revised in April 2016. The established values and practices are intended for use in future analyses undertaken by the STA.

The findings and the adopted values, measure by measure:

13.3.1 Travel time/incident information

13.3.1.1 Description

Travel time and incident information services for the road-user leads to reduced stress in traffic and contribute to improved journey efficiency by letting motorists choose alternate routes in case of traffic congestion and incidents [32].

Information about incidents and travel times can be communicated in different ways and the effect of the information on the road-user varies according to how the message was communicated [33]. Considered travel time and incident information services in this study are used by road-users who have already started their journey. Moreover, the information is communicated via Variable Message Signs (VMS) along the road, VMS-signs.

13.3.1.2 Effects based on the studied evaluations and input from workshops

Reviewed source materials [4–10] include evaluations of several different measures with somewhat differing characteristics. A common feature is that all the measures intend to inform about traffic-related incidents and facilitate modal shift or changes in route choice. The means to accomplish this varies; many communication strategies are used. This means that it is difficult to create a unified view of travel time/incident information. One challenge is to estimate to what extent the road-user actually modifies her/his behaviour according to the information, and in which way this adaptation takes place. There appears to be several studies which have attempted to estimate the value of information from the road-user's perspective [33].

Travel time/incident information may lead to shorter travel times and increased traffic safety, as fewer drivers choose the route where an incident has occurred. The magnitude of effects on travel times and traffic safety are dependent on a great number of factors. Examples of plausible factors include the type of incident, time of the incident and availability of alternative routes. But due to the large span of effects and the number of factors found here, no recommendation of travel effects are given. However, synthesizing these aspects has in this study led to the conclusion that the value of information in case of an incident from a road-user standpoint is SEK20/journey [11, 12] and person and SEK4/journey and person for information that decreases journey time uncertainty with ±10 min [7, 11]. It is possible to add travel time effects and traffic safety effects as non-monetary effects in a conclusion regarding effects for incident information and non-monetary positive travel time effects regarding travel time information.

13.3.1.3 Adopted values

The values found in Tables 13.1–13.4 have been adopted for implementation by the STA after systematic analysis, following discussions in workshops, on studies regarding travel time and incident information.

Table 13.1 Value of travel time information

Travel time information		
Parameter	**Recommended value**	**Unit/prerequisite**
Information value	SEK 4 equivalent of: c. €0.4 (March 2016)	Per person and journey for information leading to decreased travel time uncertainty with ±10 min

Table 13.2 Value of travel time information

Travel time information	
Parameter	**Non-monetary effect**
Journey efficiency	Shorter travel times

Table 13.3 Value of incident information (the duration of the incident should be at least 30 min)

Incident information		
Parameter	**Recommended value**	**Unit**
Information value	SEK 20 equivalent of: c. €2.1 (March 2016)	Per person, journey and incident

Table 13.4 Value of incident information

Incident information	
Parameter	**Non-monetary effect**
Journey efficiency	Shorter travel times
Road safety	Reduction of accidents

13.3.1.4 Application example

Apart from the willingness to pay for information regarding incidents, there is a value in information about travel time on stretches of road with recurring travel time uncertainty. Travellers have in general a travel time margin of 5–10 min, but in the case of larger disruptions there is a benefit of travel time information which is comparable to SEK 4 [7, 11]. This value is applied per person and journey as a basis for establishing the value of travel time information for journeys on stretches of roads where there is a recurring random time variation of ±10 min.

SEK 20 per person and journey should be used as a basis for calculations aiming to establish the value of incident information in case of a traffic disruption. The duration of the disruption should be at least 30 min for this value to be used. Moreover, it is assumed that the traveller is informed about the cause, extent and consequences of the incident.

13.3.2 Ramp metering

13.3.2.1 Description

On motorways with traffic congestion, additional incoming traffic from joining entrance ramps can cause capacity breakdowns on the main road. With ramp metering, it is possible to moderate the incoming traffic flow to facilitate smoother traffic interactions and avoid capacity breakdown on the motorway, thus leading to better capacity usage of the traffic system. Ramp-traffic signals break the connecting traffic flow with short red–yellow–green intervals. This type of system is common in the United States and in many European countries but is relatively scarce in Sweden, with only a handful of installations.

13.3.2.2 Effects based on the studied evaluations and input from workshops

Ramp metering affects travel times both on the motorway and on the motorway entrance ramps. If designed improperly, it will cause blocking of traffic on the local road-network connected to the motorway. Red-light driving also compromises system efficiency. The size of the effects varies to some extent between different studies [13–23]. Evaluations regarding Swedish implementations concern E4 Essingeleden in Stockholm [18, 19]. The shortage of local evaluations is due to the limited number of systems in operation in Sweden (four at the time of this study). Studies on international evaluations showed similar effects as the Swedish studies on average speed on the main road. Numerous studies show an increase with approximately 10% under similar circumstances [13–18, 20]. Ramp metering gives positive effects on traffic safety, but the order of magnitude of this effect is uncertain. However, it is possible to add traffic safety effects as a positive, non-monetary effect in a combined conclusion regarding effects. Environmental effects are moreover regarded as a positive, non-monetary effect.

13.3.2.3 Adopted values

The values found in Tables 13.5 and 13.6 have been adopted for implementation by the STA after systematic analysis, following discussions in workshops, on studies regarding ramp metering.

13.3.2.4 Application example

The effects of ramp metering are to a very large degree dependent on site specific traffic conditions. Detailed effect calculations must therefore be based on a

Table 13.5 Value of ramp metering

Ramp metering		
Parameter	**Recommended value**	**Unit**
Average speed on main road	+10%	Increased average speed past connecting ramp

Table 13.6 Value of ramp metering

Ramp metering	
Parameter	**Non-monetary effect**
Environmental impact	Emission reduction
Road safety	Accident reduction

dynamic traffic simulation model. However, for indicative calculation of the effect on travel times, an approximate method has been established.

The method uses a simplified approach stating that ramp metering increases the average speed with 10% when the traffic flow exceeds 80% of maximum main road capacity. Traffic from the incoming ramp is assumed to disrupt the main road flow, resulting in speed reduction compared to normal situations. With ramp metering, the average speed increases 10% up to normal speed according to the current flow. The relevant speed/flow relationship for the current road section is used for interpreting the average speed with and without ramp metering.

The example in Figure 13.1 applies to a 6 lane road in a suburban area with speed restriction of 80 km/h and with maximum capacity ($Q_{\max}$) 4 700 vehicles/h. The reduction of travel time (T) is calculated as:

$$T = Q_{\max} \times t \times s \times \left(\frac{1.1}{v} - \frac{1}{v} \right) \tag{13.1}$$

where,

t = time period (number of hours) when flow exceeds 80% of the maximum capacity;
s = length (km) of road section;
v = speed at saturation flow (maximum capacity point).

Using the 6 lane road example on a 1.5 km section, with a 2 h long period of flow exceeding 80% of saturation flow which results in 28 h travel time reduction per day ($4\,700 \times 2 \times 1.5 \times (1.1/51 - 1/51) = 28$ h).

It is important to consider the distance to nearby motorway junctions, as well as the distance of the motorway section affected by the measure in the calculation.

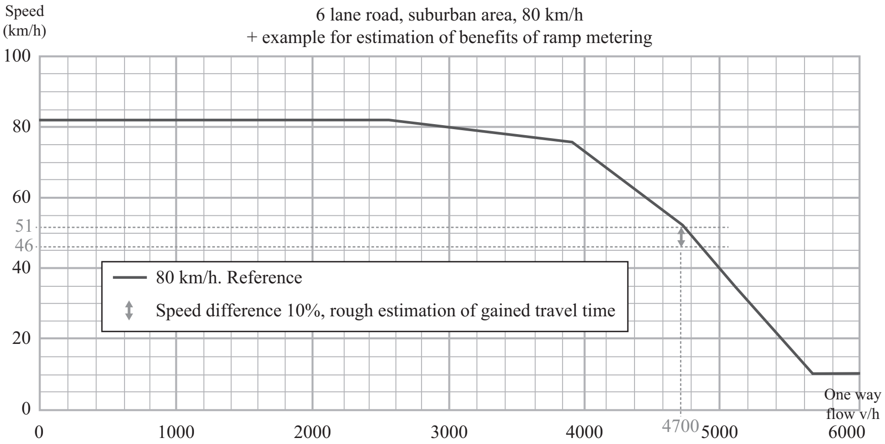

Figure 13.1 Illustration of the relationship between speed and capacity with and without activated ramp metering system used in Sweden

Also, the time period and length of the road section used in the calculation should be clearly stated and motivated. The calculation is valid under the assumption that the capacity restriction is isolated to the specific traffic interchange. This means that nearby traffic interchanges and their influence on the total traffic situation should be considered in this context.

13.3.3 Traffic controlled variable speed limits

13.3.3.1 Description

There are many different situations where variable speed limits can be useful. For instance, speed can be varied with respect to weather conditions, traffic safety, traffic intensity or other parameters. One of the most relevant forms of variable speed limits from a Swedish perspective is that of traffic control. This is applied on stretches of roads (often motorways) for improving traffic flow conditions, achieving homogenization effects and improving traffic safety. The control parameter for speed limit variation is thus traffic intensity, not time of day/year or any other factors.

13.3.3.2 Effects based on the studied evaluations and input from workshops

Traffic controlled variable speed limits lead to increased road capacity [18, 19, 24–31], due lower vehicle speed distribution. The largest improvement of capacity will be obtained at an average vehicle speed of at least 80 km/h, and with regular speed reductions of at least 10 km/h [18]. Several studies show that variable speed limits lead to 5% increased capacity, under these circumstances [19]. The effect of speed homogenization is most evident on roads with speed limits of at least 110 km/h or 120 km/h [18, 19]. These speed limits are relatively uncommon in Sweden. Urban road environments in Sweden, where capacity-related issues often occur, commonly have lower speed restrictions.

There are not enough evidence to give firm recommendations on values suitable for calculation regarding environmental effects. There are indications that this measure may lead to positive environmental effects. Thus, it is possible to add environmental effects as a positive, non-monetary effect in a conclusion regarding effects. It has also been shown that traffic controlled variable speed limits decreases accidents by 10% [18].

13.3.3.3 Adopted values

The values found in Tables 13.7 and 13.8 have been adopted for implementation by the STA after systematic analysis, following discussions in workshops, on studies regarding traffic controlled variable speed limits.

13.3.3.4 Application example

The effects of traffic controlled variable speed limits are highly related to the local traffic situation and road design. Hence, accurate and detailed calculations of the effects of the measure require detailed data on traffic flow and speed to be used in a dynamic traffic simulation model. However, a method for approximate calculation of potential effects on travel times has been established.

This method uses a simplified approach stating that traffic controlled variable speed limits increases traffic flow with 5% when traffic flow exceeds 80% of maximum main road capacity. The system is assumed to be activated when traffic flow exceeds 80% of maximum road capacity. Initially, the activation of the system means a reduction of average speed due to the reduced speed limit. When the flow moves towards saturation, the average speed is upheld compared to the situation

Table 13.7 Value of traffic controlled variable speed limits

Traffic controlled variable speed limits		
Parameter	**Recommended value**	**Unit**
Capacity	+5%	Increased capacity on road section with variable speed limits
Accidents	–10%	Decreased accident rate on road section with variable speed limits

Table 13.8 Value of traffic controlled variable speed limits

Traffic controlled variable speed limits	
Parameter	**Non-monetary effect**
Environmental impact	Emission reduction

without the measure activated. The decrease and increase of speed is, however, ignored in the calculation and the difference of speed at saturation flow is used for the whole period when the system is activated.

An example of speed before and after implementation is illustrated in Figure 13.2.

The example in Figure 13.2 applies to a 6 lane road in a suburban area with speed restriction of 80 km/h and with maximum capacity ($Q_{\max}$) 4 700 vehicles/h. The reduction of travel time (T) is calculated as:

$$T = Q_{\max} \times t \times s \times \left(\frac{1}{v_0} - \frac{1}{v_1} \right) \tag{13.2}$$

where,

t = time period (number of hours) when flow exceeds 80% of the maximum capacity;
s = length (km) of road section;
v_0 = speed at 5% over saturation flow (according to speed/flow relationship);
v_1 = speed at saturation flow (maximum capacity point).

Using the 6 lane road example on a 1.5 km section, with a 2 h long period of flow exceeding 80% of saturation flow which results in 51 h travel time reduction per day (4 700 × 2 × 1.5 × (1/43 – 1/51) = 51 h).

Time period and road stretch distance used in calculations need to be carefully motivated and described.

This method should be used only for initial and indicative calculation of effects to identify road sections for further analysis. For further analysis, the calculation should ideally be dynamic and based on detailed data on traffic flow and speed

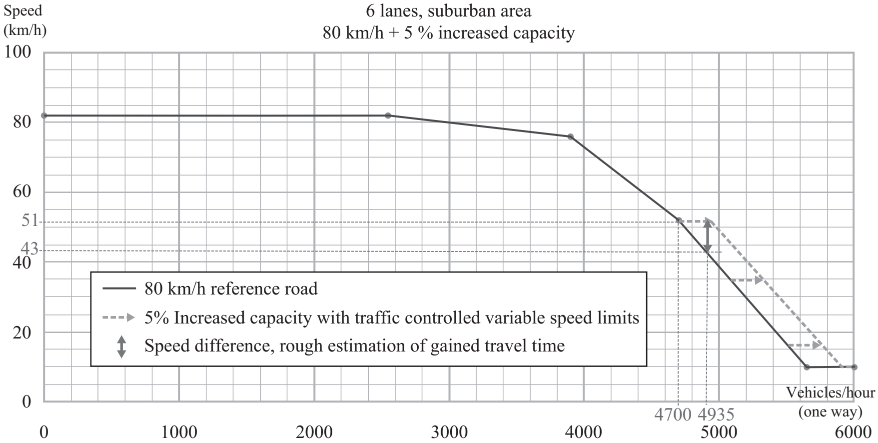

Figure 13.2 Illustration of relationship between speed and capacity with and without activated variable speed limit system used in Sweden

from 5-min intervals (as opposed to the average based method in the example). The effects will in this case be based on two factors mainly: extension of the time until capacity breakdown and the speed difference before and after capacity breakdown.

13.3.4 MCS

13.3.4.1 Description

MCS are systems comprising several subsystems. The overall purpose is to improve capacity, increase road safety and facilitate rescue and maintenance operations on roads. Central to the system is a control and surveillance function, most often located in a traffic control centre. Systems which affect the road user can be lane control symbols, variable speed limits and queue warnings. MCS are common on motorways around the world with heavy traffic intensity. Investments in improving existing systems as well as introduction of new systems are made in and around the largest cities in Sweden.

13.3.4.2 Effects based on studied evaluations and input from workshops

The literature offers little consistent evidence of the effects of MCS [18, 19, 30, 31]. This may be explained by MCS being a measure comprising several subsystems, intended to achieve effects on a system-level. Comparisons are difficult, as the setup of these subsystems differs. The most comprehensive work on MCS is, from a Swedish perspective, the research study ‘Evaluation of Impacts of the Motorway Control System (MCS) in Stockholm’ by Nissan [31]. This study [31] stated for example indications of MCS increase capacity. However, there does not seem to be enough evidence to draw definitive conclusions. Road-users were not deemed to have made any significant speed shift due to the presence of MCS. Other studies stressed homogenization of traffic flow as an important effect of MCS [18]. Also, queue warning has been found to contribute to a 20% reduction of rear-end collisions [18]. However, there is not enough evidence to give firm recommendations on values suitable for calculation regarding environmental effects.

Based on results from seminars/workshops, it was concluded that MCS has a role in improving effectiveness and safety when maintenance work on motorways is performed. Moreover, lane management functions were moreover found to result in accessibility and increased road safety for road-side maintenance operations, something that was regarded as a non-monetary effect.

13.3.4.3 Adopted values

The values found in Tables 13.9 and 13.10 have been adopted for implementation by the STA after systematic analysis, following discussions in workshops, of studies regarding MCS.

13.3.4.4 Application example

Travel time effects of MCS can be related to the effects achieved by the subsystem traffic controlled variable speed limits. In such case, the previous example as described for traffic controlled variable speed limits may be applied. Consequently,

Table 13.9 Value of queue warning

Queue warning as a function of MCS		
Parameter	**Recommended value**	**Unit**
Accidents	–20%	Decreased rear-end collision rate when the system is active

Table 13.10 Value of lane management

Lane management as a function of MCS	
Parameter	**Non-monetary effect**
Maintenance procedures for road-side equipment and general roadway work	Improved effectiveness

the effects of traffic controlled variable speed limits as part of an MCS are greatly influenced by road design and traffic situation factors. Detailed assessment of effects from MCS would thus require detailed data on traffic flows and speeds. However, for travel time, the effects of traffic controlled variable speed limits, an approximate calculation of potential effects, can be accomplished. This is based on the assumption of a general increase of capacity with 5% under times when traffic flow exceeds 80% of maximum capacity on the analysed road section. An example of speed before and after implementation is illustrated in the previous example in Figure 13.2. Time period and length of road section used in the calculation should be clearly stated.

13.4 Discussion

The aim of this study was to support a basis for comparability of CBA of ITS systems with traditional investments. More specifically, the study investigated into the effects of ITS for traffic management, using a systematic approach through the combination of results from several studies.

The analysis of the four studied ITS measures has given an insight into whether the source materials are of enough quality to be used for comparability purposes. The study of different sources has also led to some general conclusions. One such deduction is that there is a lack of empirical data, despite the existence of numerous evaluations.

Several studies describe effects on a general level, with a relatively large variation regarding the magnitude of the effects. For example, it may be stated that traffic controlled variable speed limits decreases traffic related injuries with

20–40%. Such variations in judgement decreases any possibility of use in calculations and assessments, such as CBA tools used by the STA. This is due to the need for comparability between CBAs.

Even though there are several applicable studies regarding a specific measure, evaluations often describe different types of effects. For example, one evaluation of queue-warning systems may describe the effect on queuing, while another study is describing how the effects on rear end collisions are affected. This makes comparisons of studies difficult. Furthermore, often only positive effects are described, whereas negative or small effects might be ignored. This adds to the difficulty in correctly assessing the effects of a specific ITS measure.

In many cases, it was difficult to draw conclusions about the effects of a measure as the circumstances, in which the evaluations had taken place, were not clear. The exact nature of the traffic situation, before and after implementation of a measure, was in several cases not clear. There is therefore a need for further clarification on how the evaluations were conducted as well as of exact traffic situation before evaluation.

Moreover, there is a tendency among the studied ITS evaluations to only investigate a single, or just only a few parameters, thus not providing full overview of the effects. In relation to the ITS contribution to improvement of capacity, it should be noted that maximum traffic capacity is not a static concept, and can vary according to numerous traffic factors. This means that an improvement of traffic flow due to ITS must be related to a dynamic maximum capacity, in a theoretically correct context. In practical terms, it means that the application examples discussed are based on simplifications to make estimations feasible.

A brief discussion on the systems and the findings concerning them are as follows:

Travel time information and incident information may serve different purposes and can be applied in different ways. Effects of these kind of measures are evaluated differently from the other three ITS measures as these are information systems (control systems). There is a basis for estimations in monetary terms of the user assessment of these measures, as some studies have been undertaken in Sweden. These evaluations serve as a basis for effect estimations. It is also possible to refine the results through additional studies and data.

Ramp metering is a system of limited use in Sweden, albeit steadily increasing in the number of implementations. However, there are numerous systems and a large experience and knowledge base for these types of measures in the United States, for example. Ramp metering must be applied properly to have the desired effects. It is only useful when regulating ramp traffic flow to a main road which is close to maximum capacity. The ramp metering system then supports keeping the traffic on the main road as close to the maximum as possible without causing capacity breakdown, thereby giving optimum system capacity. However, special consideration must be taken to factors such as red-light violation and the risk that ramp queuing extends backwards to the local traffic systems, causing traffic congestion on local roads. The knowledge about certain effects of ramp metering is established internationally, while empirical data are limited in Sweden.

Traffic controlled variable speed limits have been implemented and evaluated for many years in Sweden and abroad, and there are estimations of effects which can serve as a basis for quantified benefit assessments. It is important to note the significance of compliance of the variable speed message in order for the system to be effective. It is also noteworthy that speed homogenization is one of the major benefits of the system. This, alongside improved capacity and shortened travel times, leads to improved traffic safety due to decreased vehicle speed variance.

MCS is an ITS measures which is composed of subsystems, of which lane management, variable speed limits and queue warning are the most common. MCS is the most difficult system to evaluate due to the variety of different types of installations and the difficulty of estimating total system-effects. The only effects directly linked to MCS which has been established are the non-monetary effect of lane management and the accident reduction, due to the effect of queue warning. Traffic controlled variable speed limits can both be part of an MCS system or be used as an independent system. Variable speed limits are primarily treated as an independent system in this study, but also used as an application example for MCS. All in all, it can be concluded that the effects of MCS in general, and the system-effects of MCS in particular, are largely uncertain.

13.5 Conclusion

This study had the intention to support a basis for comparability of CBA of ITS systems against traditional investments. More specifically, the study intended to investigate the effects of ITS, using a systematic approach, combining results from several studies. The aim was to see to what extent applicable studies might serve as a basis for comparing ITS against traditional infrastructure measures in the STA planning and decision process which include the valuation of monetary effects, non-monetary effects and other effects.

This was achieved through a process including systematic literature studies and workshops with experts. Four selected ITS measures, such as traffic controlled variable speed limits, ramp metering, travel time/incident information and MCS, were studied. The results will form the basis for further development work in this field, with the goal of establishing a solid ground for coherent CBA of all applicable ITS measures.

It has been possible to establish some basic conclusions regarding the effects of the chosen ITS measures. The results will serve as an initial basis for comparability of ITS effects in the STA planning process.

The work has been verified by a panel of experts and has moreover been adopted for use in impact assessments in selection and prioritization of appropriate infrastructure measures. However, it has not been possible to describe all the effects. Some effects are described in monetary terms, some are described in other ways and there are also effects which are not described at all. The results should nonetheless be regarded as a step towards coherent CBA of ITS and serve to shed light on the order of magnitude of these effects. It might also serve as an indicator whether specific ITS measures are relevant for further studies in an extended analysis according to the STA planning and decision process.

13.6 Further work

The long-term goal of the STA is that high-quality estimations of effects regarding ITS should be comparable to those of infrastructure measures. The reason for this is that CBA is an important tool in the initial parts and processes of infrastructure projects. It means that additional studies of ITS measures should produce quantified assessments of high quality. In order for this development to take place, evaluations of relevance and quality are needed. Particular questions that need to be answered in this process are: What are the demands for evaluations to be useful for CBA? How do we distinguish the effects of an ITS system in relation to the effects of the surrounding infrastructure in general, and how should more and better ITS evaluations be promoted?

Future development should include verifying the complete impacts of effects for the studied ITS measures. The vision is to be able to describe all relevant effects of all relevant ITS measures. Therefore, there is a need for studies which clearly highlight the actual effects of ITS in relationship with other traffic-related circumstances. It should be pointed out that extensive work remains to be completed before the effects of common ITS measures can be regarded as well documented, in comparison with other infrastructure means and investments. Finally, a systematic framework for evaluation should be established which should be applied to all new ITS investments.

References

[1] EC DG MOVE C-ITS Platform, “Final report”; 2016.

[2] Jianwei, H.E., Zhenxiang, Z., Zhiheng, L.I., 2010. “Benefit evaluation framework of intelligent transportation systems”. Journal of Transportation Systems Engineering and Information Technology 10, 81–87.

[3] Newman-Askins, R., Ferreira, L., Bunker, J.M., 2003. “Intelligent transport systems evaluation: from theory to practice”. In Jaeger, V. (eds.), Proceedings 21st ARRB and 11th REAAA Conference, Cairns.

[4] EasyWay., “Multi-modal Traveller Information Service, Trafikken.dk/Hovedstaden, Denmark”; 2009.

[5] Tempo, “UK-TMC Service Evaluation 1998–2001”; 2003.

[6] Tempo, “Traffic Scotland Web Information Services”; 2008.

[7] TØI, “Trafikanternes värdesättning av information i samband med arbetsresor? TØI rapport 620”; 2006.

[8] VIKING, “Overview of evaluations, MIP2005”; 2006.

[9] TÖI, “Verktöy för virkningsberegning av ITS-tiltak”; 2013.

[10] Vejdirektoratet, “Vaerdisaettning af trafikinformation”; 2013.

[11] Börjesson, M., Dillén, J., Lind, G., Avery, R.P., “Trut – information search cost and benefits of traffic information”, 15th World Congress on Intelligent

Transport Systems and ITS America Annual Meeting. New York, 16–20 November 2008.

[12] Väverket, “Verifiering av nyttan med bätre trafikinformation? Väverket Publikation”; 2009:43.

[13] CEDR, “Ramp Metering, CEDR Fact Sheet Task 12”; 2011.

[14] EasyWay, “Evaluation of Ramp Metering on the A10 Amsterdam Ring Road”; 2011.

[15] EasyWay, “EURAMP Deliverable 6.3”; 2007.

[16] FDOT, “District Six ITS ANNUAL REPORT – Fiscal Year 2008/2009”; 2009.

[17] Highways Agency, “Integrated Traffic Management at Junction 33 of the M1, Evaluation Report”; 2008.

[18] Lind, G., Lindkvist, A., “Aktiv hötrafikledning – Kunskapsdokument och tillämpningsråd”. Stockholm: Movea; 2010.

[19] Lindkvist, A, Lind, G Lindqvist E, Kronborg, P, “ITS i kapacitetsutredningen, behov, system och effekter”. Stockholm: Movea; 2011.

[20] Tempo Evaluation Expert Group, “Design, Setting Up and Installation of Ramp Metering on Motorways Intersections”; 2009.

[21] Tempo Secretariat, “UK-M6 Motorway Ramp Metering 1986–1997”; 2004.

[22] EasyWay, “Guideline for the Deployment of Ramp Metering – DG03”; 2012.

[23] TÖI, “Verktöy för virkningsberegning av ITS-tiltak”; 2013.

[24] Strömgren, P., Lindkvist, A., Kronborg, P., “E4/E20 Södertäljevägen: Effekter av trafikledning, vägrensutnyttjande och nödfickor”. Stockholm: Movea; 2015.

[25] EasyWay, “Guideline for the Deployment of Speed Control/Variable Speed Limits – DG02”; 2010.

[26] TEMPO, “M25 Controlled Motorway Summary Report”; 2006.

[27] VIKING Evaluation Group Sweden, “Traffic Controlled Variable Speed Limits”; 2009.

[28] VIKING, “Overview of Evaluations, MIP2005”; 2006.

[29] Väverket, “Variabel hastighet – en lysande idé”; 2008.

[30] Federal Highway Administration, “Active Traffic Management: The Next Step in Congestion Management”; 2007.

[31] Nissan, A., “Evaluation of Variable Speed Limits: Empirical Evidence and Simulation Analysis of Stockholm’s Motorway Control System”. KTH Royal Institute of Technology, Stockholm, Sweden; 2010.

[32] Skoglund, T., Wallgren, P., Karlsson, M., Franzén, S., “Users’ perception and reported effects of long-term access to in-vehicle traffic information services mediated through Nomadic devices: results from a large-scale inter-European field operational test”. Transport and Telecommunication Journal, 2015, 16, doi:10.1515/ttj-2015-0018

[33] Skoglund, T., “Effects of long-term access to ICT-mediated travel information services – users’ assessments and reported behavioural changes? Doctoral thesis, Chalmers University of Technology, Göeborg; 2014.

Chapter 14

Effectiveness of Intelligent Transport Systems: Wet Weather Pilot

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14.1 Background

The M1 Motorway (formerly F3) is an important part of the National Highway network with a total length of 127 km providing a link between Sydney and Newcastle and the regional areas of Central Coast. This road is one of the most significant transportation routes (for both people and goods) in the country, carrying an average Annual Average Daily Traffic (AADT) of 37,000 vehicles in each direction. The M1 is reported to have one of the highest numbers of crashes for this type and capacity of the road mainly due to its curvilinear alignment, filled batters and deep cuttings. The section of the road between Hawkesbury River to Mount White Heavy Vehicle Checking Station (HVCS) is particularly prone to a higher rate of crashes as the curvilinear road is in addition subject to steep grades (see Figure 14.1). In this Intelligent Transport Systems (ITS) deployment, the stated goal was to reduce speed during Wet weather condition.

14.2 Speed reviews

Road and Maritime Services (RMS) conduct a periodic review of speed on different sections of the road in NSW as part of the 'Audit of Speed Zones – Top 100 Roads' programme, in accordance with NSW speed zoning guidelines. This speed review includes a number of factors such as road environment, traffic characteristics and crash profile of each of these roads. This speed review is based on a route based approach i.e. a holistic view of the impact of speed changes along a route or precinct to ensure speed limits along the route balance road safety and mobility needs.

Before 1999, speed in both directions of traffic on the M1 between the Hawkesbury River and Mount White HVCS was 110 km/h. In June 1999, owing to

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[2] Australian Road Research Board, Australia
[3] Charles Sturt University, Australia

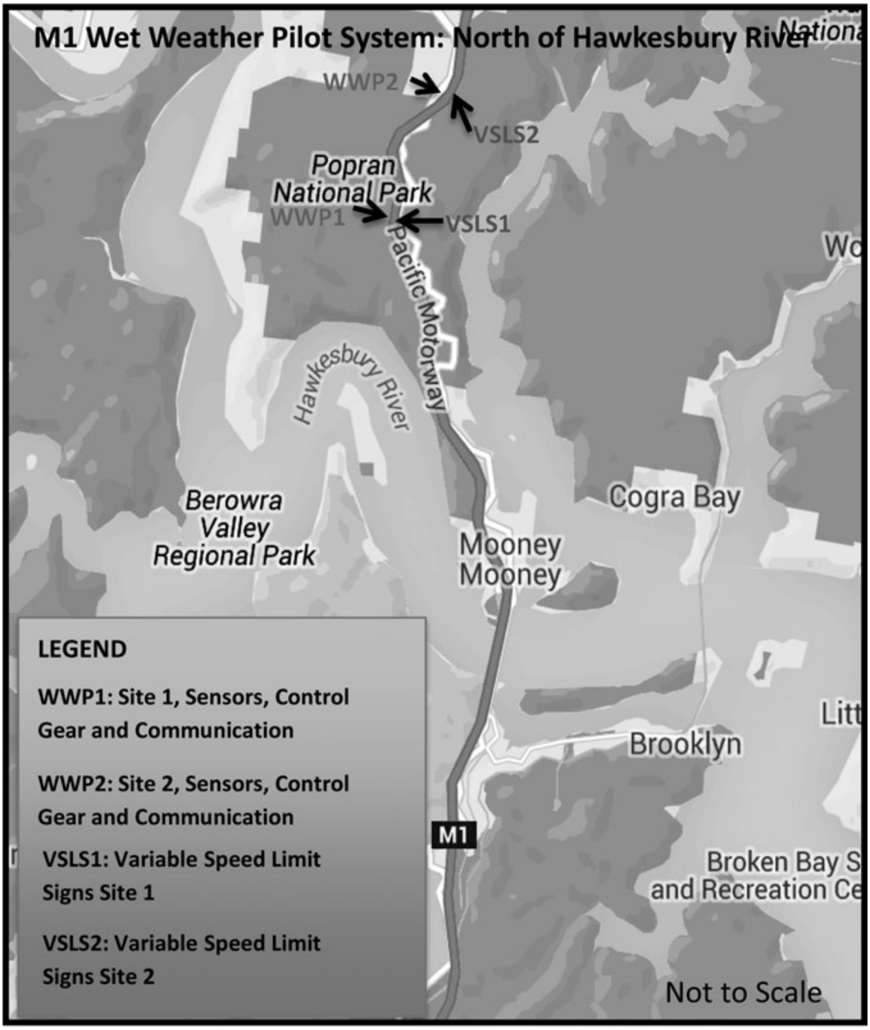

Figure 14.1 Location map for Wet Weather Pilot Scheme. This map was developed using Google Maps of the area as a template and adding project specific information

the higher crash rates on this section of the road, the speed limit was reduced to 100 km/h for both directions of traffic. Between the years 2000 and 2005 there were four more fatalities, three northbound (NB) and one southbound (SB). Subsequently, Tierney Page Kirkland Pty Ltd was commissioned by RMS to carry out a risk assessment and present an action plan for installation of a variable speed limit scheme (Wet Weather Pilot [WWP]) utilizing ITS.

14.3 The ITS solution

The WWP scheme is an ITS designed to monitor the weather on a 24/7 basis and changes the speed displayed on the Variable Speed Limit Signs (VSLS) mounted on the road crossing gantries to a lower limit when it starts raining and as soon as the pavement becomes wet. This means that the speed limit remains at 100 km/h in a fine weather condition but drops down to 90 km/h when the wet pavement condition is detected by electronic sensors. The map of the area showing the ITS system components installed at two different sites; Site 1 and Site 2, NB, installed and commissioned in April 2006 is produced in Figure 14.1.

This has been achieved with a wetness sensor installed flush with the road surface and a rain sensor on the side of the road on a pedestal to detect the onset of rain. The VSLS were installed as part of this ITS solution on road crossing gantries to advise the motorist of the legal speed in both Dry (fine weather) and Wet (rain) conditions. As soon as the first droplets of the rain falls on the sensors the Dry speed limit of 100 km/h displayed on the VSLS changes to 90 km/h i.e. the speed limit set for Wet conditions. This 90 km/h speed limit is enforceable by a co-located speed camera system that is linked to the WWP scheme.

The WWP scheme uses sensors and VSLS that are installed at two locations along the NB carriageway. The first set of rain sensors and VSLS are installed at WWP1 (Site 1) shown in Figure 14.1. The second set of sensors and VSLS are installed at the WWP2 (Site 2) about 2 km away. The speed camera co-located with WWP2, is informed by the WWP system when the legal speed on the VSLS has changed from 100 to 90 km/h. As you travel Northwards from the Hawkesbury River on the M1 you first see the legal speed displayed at WWP1 providing you sufficient reaction time to slow down to the lower speed limit of 90 km/h (if Wet condition is encountered). The speed camera at WWP2 enforces the legal speed limit.

14.4 Road and speed environment

The section of the road that is being analysed covers the high crash area extending north from the Hawkesbury River to the Mount White HVCS i.e. about 5.4 km NB and 5.8 km SB. Lane widths are generally around 3.7 m, with 2–3m wide shoulders for the NB and SB carriageways. Historically, this section of the dual carriageway has always been prone to higher number of crashes. Data analysed indicates that the crashes along the NB carriageway have been significantly higher in number from the SB before 2006. The road profile is different for the two carriageways. In the NB, the M1 steeps up with between the Hawkesbury River and WWP2 encountering turns; levels off somewhat between WWP1 and WWP2 and then steeps down from WWP2 towards the Mount White HVCS involving a few turns from the start of the decline to where it levels off close to the HVCS. For the SB, there is a constant slope from the Mount White HVCS to the Hawkesbury River with mainly slight turns. For the purpose of this research, it is important to understand other mitigating factors, initiatives and physical changes in the subject road environment that could possibly affect the traffic characteristics and impact on the number of crashes. These are explained in the following section.

14.4.1 Speed changes

In early 1992, the speed limit in this section was brought down to 100 km/h (from 110 km/h) first time after the opening of the freeway following some crashes during Easter. However, this lower speed limit was maintained only for few months and the speed limit was brought back up to 110 km/h the same year before Christmas. In 1999, the speed in this section of the road was reduced from 110 to 100 km/h in both directions on the motorway owing to some serious crashes. Following two more serious crashes during 2001, the speed limit was further lowered to 90 km/h for both carriageways. In 2006, the Minister of Roads intervened to increase the speed limit for the NB traffic to 100 km/h for Dry condition only and revert to 90 km/h for Wet conditions. This variable speed limit is maintained by means of the WWP scheme. For the SB carriageway, no ITS system has yet been installed and the speed limit is fixed to 90 km/h for both Dry and Wet conditions. The affect of speed limit reduction on crashes before 2006 and further impact of speed changes after 2006 has been analysed for both NB and SB carriageways.

14.4.2 Road geometry changes

Looking at the construction work on the M1 in recent years we come across a number of activities in the period before the WWP scheme was installed as recorded by Ozroads (see Reference 1). Also, some detail on the latest construction works is available from a number of news articles and information websites; express advocate on stages of development [2] and Paul Rand's news on the construction dates (see Reference 3). Also, the construction dates for latest developments have been obtained from Australian government Department of Infrastructure and Regional Development news bulletins (see Reference 4). These works can be summarized as follows:

(a) The two lane each for NB and SB carriageways between Hawkesbury River and Mount White was converted to three lane in each direction. This work was completed in May 2004.
(b) Jolls Bridge North of Hawkesbury River was widened to accommodate the six lanes capacity. This work was completed in May 2004.
(c) Widening of the road between Mount White and Calga (four to six lanes) and increasing the traffic handling capacity of Calga Interchange just North of Mount White was carried out in parts between 2002 and 2004. Completed in December 2004.
(d) No record of construction work or geometry changes after 2006 that could have any effect on the crash rates was found.

As a result of the construction work, there were road closures in the area and the posted speed was lowered from time to time at a number of locations depending on the intensity of work resulting in high variation in crashes during this period.

The data depict exponential rise in crash rates for NB after the construction period ended in December 2004.

14.4.3 Signs and delineation changes

As explained in section 14.4.1, the speed limit on this section on the M1 has changed a number of times in the past two decades. The static signage has been replaced accordingly. From 1999 the speed designations have changed from 110 to 90 km/h in two steps. The 90 km/h speed limit for both carriageways continued till 2006 when the WWP scheme was implemented. Hereon, the speed limit has been made variable in the NB only, i.e. 100 km/h for Dry and 90 km/h for Wet conditions.

New static signage has been installed since 2006 to make the motorists aware of the variable speed zone i.e. a lower speed of 90 km/h during Wet conditions in the NB. Also, the VSLS on the road crossing gantry are designed to display the legal or authorized speed limit. A speed camera in the NB assists in enforcing the displayed speed limit.

14.5 Analysis

Data on crashes 7 years before and after the year WWP scheme was implemented was obtained from road safety crash link [5] for both Dry and Wet road conditions. The volume of the traffic in Million Vehicle Kilometres Travelled (MVKT) was also obtained for the desired section of the road for the same period. Based on the available data from RMS, a list of possible cases was developed for analysis.

14.6 Findings

The detailed comparison of different possible scenarios was carried out such that the changes in the number of crashes in Dry and Wet conditions after the WWP scheme were implemented can be better understood. These scenarios are explained in the following sections.

14.6.1 Overall crashes for Dry and Wet condition

Before the implementation of the WWP scheme, the number of crashes for NB and SB has been fluctuating a lot between highs and lows. One reason for this is the construction work in the area between 2000 and 2004 that leads to lowering of speeds due to traffic control and posting of static signs with the mandated 40 km/h speed limit in such conditions. After the implementation of the WWP scheme, the number of crashes for NB and SB has significantly reduced and the fluctuation witnessed in the earlier period has dampened a lot. We also know that there was no construction work or geometry changes to the road post installation of the system. It may be noted that during 1996–2005, NB had significantly more crashes than SB

(29 per cent more or 61 crashes more than SB). Comparing the 2007–2013 period; post WWP installation, to the 7 years before the ITS system installation we get:

14.6.1.1 NB

The number of crashes for NB decreased by 25 per cent i.e. 52 less crashes; 23 less crashes for Dry condition and 29 less for Wet condition. We also observe that the total number of crashes in Wet condition during 1999–2005 is 127, which is much more than for Dry condition with 80 crashes. With only 100 Wet days on the average in a year for this area, the number of crashes for Wet condition is considered very high (see Reference 6). The crash data show crash variations stabilizing after 2006, after the ITS system was installed. This is confirmed by the average standard deviation for NB decreasing by 73 per cent (refer Table 14.1 for standard deviation values).

14.6.1.2 SB

The number of crashes for SB decreased by 27 per cent i.e. 40 less crashes; five less crashes in Dry condition and 35 less crash for Wet condition. We also observe that the total number of crashes in Wet condition during 1999–2005 was 103, which is double that for Dry condition with 43 crashes. With only 100 Wet days on the average in a year, the number of crashes for Wet condition is considered very high (see Reference 6). The crash data indicate average standard deviation for SB decreased by 55 per cent post installation of the system (refer Table 14.1 for standard deviation values).

Figures 14.2 and 14.3 graphically display the reduction in the average number of all types of crashes (Dry and Wet conditions) for NB and SB. However, for Dry condition improvement in NB is much more significant i.e. 29 per cent decrease in crashes instead of 12 per cent decrease for SB. It may be noted that for the NB Dry condition the legal speed is at 100 km/h; 10 km/h higher than the SB. To achieve a higher reduction for NB Dry is therefore statistically more significant. For NB Wet the reduction in crashes is 23 per cent while for SB Wet it is 34 per cent at the same speed (90 km/h) for both directions of traffic. Historically, it has been established that the curvilinear and steep profile of the NB carriageway makes it more prone to crashes as compared with SB. This proclivity is confirmed by the available data; 34 per cent more crashes were recorded for NB traffic as compared to SB from 1999 to 2005. This section of the F3 is characterized by a steep incline followed by a steep decline that makes the NB journey particularly challenging to heavy

Table 14.1 Traffic volumes for NB and SB

Period	**MVKT**
Av. MVKT NB 1999 to 2005	74
Av. MVKT NB 2007 to 2013	78
Av. MVKT SB 1999 to 2005	70
Av. MVKT SB 2007 to 2013	74

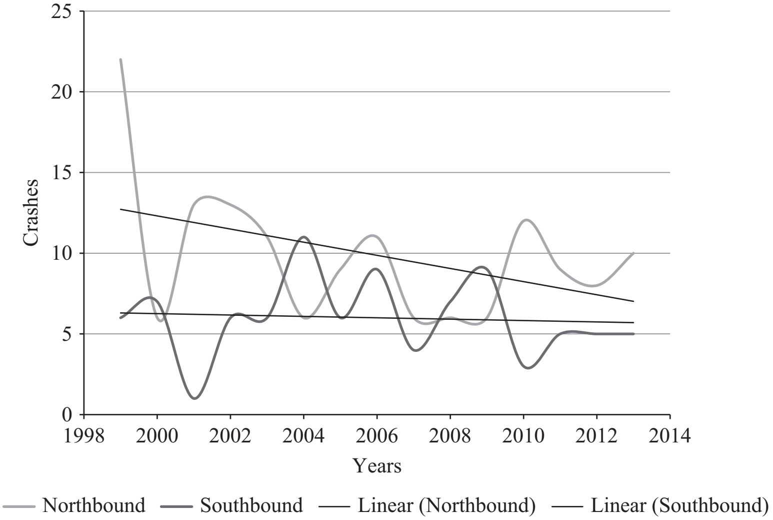

Figure 14.2 Northbound and southbound (dry)

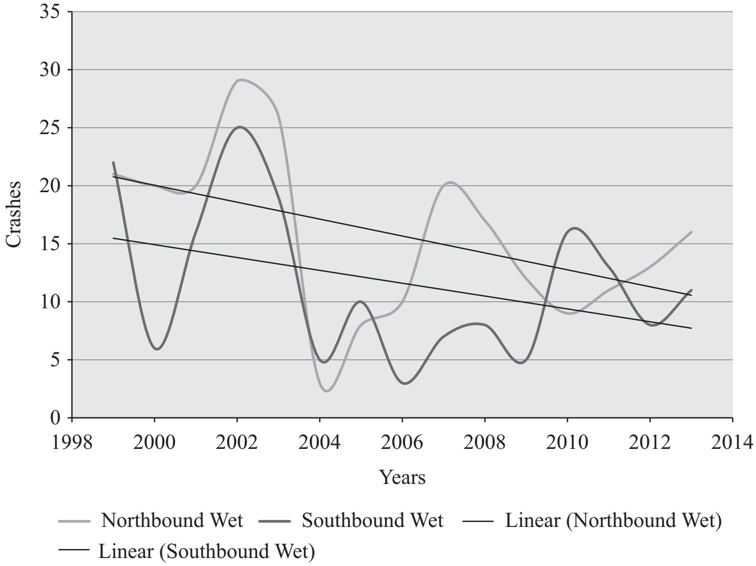

Figure 14.3 Northbound and southbound (wet)

vehicles and more prone to crashes as compared to SB. Another factor that drives a higher number of crashes for NB as compared to SB is a higher average MVKT for NB as compared to SB.

The average traffic volumes have been four MVKT higher for NB for the considered periods as compared to SB (see Table 14.1).

The system is designed for displaying a reduced legal speed for NB traffic in Wet weather. But it is important to note that a speed camera has been co-located with the Wet weather system as well. Reduction of crashes in Dry condition for NB by 25 per cent, reflects the awareness induced by the enforcement system to drive within speed limits and the overall impact the physical presence of the WWP has on driving safely as a whole. It is noted that the ITS solution has only been implemented in NB while we see reduction in the number of crashes in SB as well. There is some explanation for this. The Global Positioning System (GPS) can pick up the speed camera in the NB carriageway while travelling SB. This can create a pseudo presence for the speed camera in SB. Unless one is travelling on a daily basis and is very sure that the speed camera is on NB only, there will be a tendency to slow down to within speed limits for cars with GPS. The improvement in SB can also be due to the fact that the SB is patrolled by the Police on a daily basis, especially on long weekends and holidays (as there is a natural tendency for the motorist to speed while descending rather than ascending).

14.6.2 Injury crashes in Dry and Wet condition

The Injury crashes form 25 per cent of the total overall NB crashes and 34 per cent of the total SB crashes before the installation of the WWP system. The performance for NB and SB post installation of the WWP system is detailed below.

14.6.2.1 NB

> As per available data the average number of Injury crashes increased by 27 per cent for NB i.e. 14 more crashes; ten more crashes in Dry and four more in Wet condition. However, the fluctuations in the Injury crashes improved by 36 per cent for Dry and 43 per cent for Wet condition (refer Table 14.1 for standard deviation values).

14.6.2.2 SB

For SB there was a 29 per cent reduction in Injury crashes i.e. 14 less crashes; one less crash in Dry and 13 less in Wet condition. However, the fluctuations in the Injury crashes improved by 55 per cent for Dry and 37 per cent for Wet (refer Table 14.1 for standard deviation values).

Figure 14.4 depicts that there have been more Injury crashes for NB between 2007 and 2013 while the SB performed better with reduction in number of crashes for this same period. It is important to note that the increase in Injury crashes is more significant when the pavement is dry, i.e. when the NB speed goes up to 100 km/h (10 km/h higher than the SB). Therefore, when comparing NB and SB this difference in speed needs to be given consideration. In addition; during the 2007–2013 period the traffic volumes have increased by 5 per cent (Table 14.1). As per Nilsson's doctoral studies (p. 68), traffic safety dimensions and the power model, a 4–6 per cent increase in mean speed increases the crashes by 10 per cent and the fatality by 20 per cent and vice versa [7], considering all other crash-related criteria remain unchanged. Another reason for the apparent increase of Injury

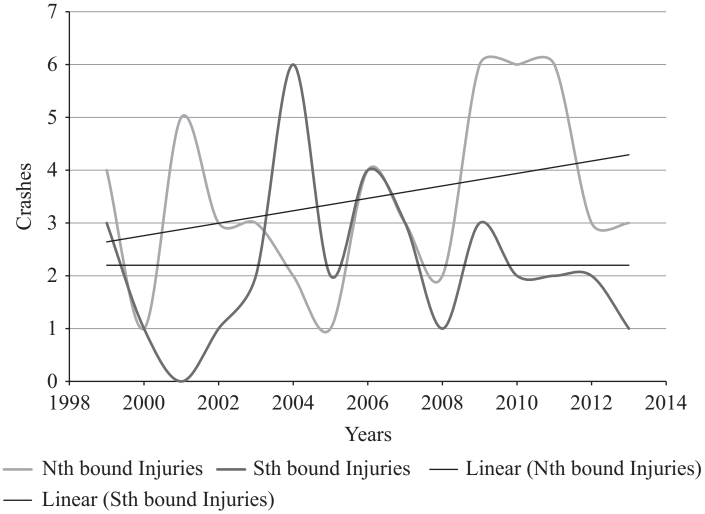

Figure 14.4 Northbound and southbound injuries (dry)

crashes in NB in Dry condition after 2006 is because the speed limit increased to 100 km/h in Dry condition in 2006 (see section 14.4.1). Moreover, till the end of 2004 the average speeds would have been much lower due to traffic control and road works. That can explain the dip in the Injury crashes in NB around 2004. The data show the Injury crashes reducing to only 6 from 11 in 2003 in Dry condition and only 3 from 26 in 2003 for Wet condition.

In the NB, the profile of the road in NB further adds to the complexity. The overall variable speed section of the road is only about 5 km. In Wet condition, the speed limit is the same in this stretch of the road for both directions of traffic. For NB in Dry condition, there will be a speed change from 110 to 100 km/h as the vehicles approach the variable speed zone. After crossing WWP1 and WWP2, there will be an increase from 100 to 110 km/h at the end of the variable speed zone in case there is no rain. However, in a rainy condition the speed changes will be more drastic, i.e. 110 to 90 km/h on the way up and 90 to 110 km/h on the decline while travelling NB.

Incidentally, the start of the variable speed zone is signified by the start of a steep curvilinear incline that stretches out to WWP1. Between WWP1 and WWP2, there is a slight dip in the road and then the road climbs back to WWP2. As soon as the vehicles cross WWP2, the road transforms into a steep curvilinear decline. This is when the vehicles are speeding back to 110 km/h on a steep decline it can result in different vehicles accelerating at different speeds and making major turning movement as well. Heavy vehicles e.g. may not be able to join back to the designated speeds in the same time as compared to lighter vehicles thus causing a speed deferential between different types of vehicles at high speeds.

Comparing the increase in crash severity (i.e. more injuries) for NB for Dry and Wet conditions in the 2007–2013 period, it is noted that there was a 43 per cent

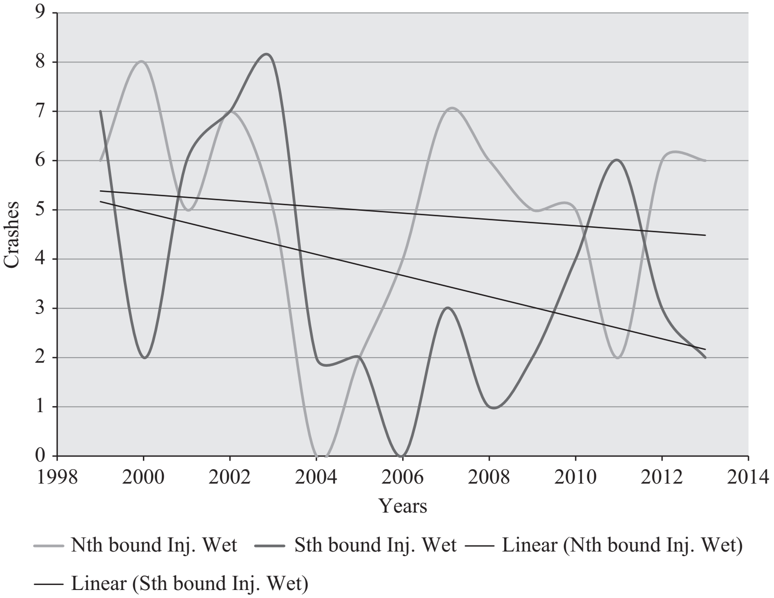

Figure 14.5 Northbound and southbound injuries (wet)

increase in injuries for Dry condition vs. 12 per cent increase for Wet condition. That said, the graph in Figure 14.5 shows that the average number of Injury crashes in Wet condition for NB is showing a slope downwards i.e. the average number of crashes has decreased for Wet condition in the NB after the installation of the WWP scheme. SB displays more improvement than the NB in the same period. The reason for this is the proximity of the ITS system, a much less severe slope and curves in the SB as explained above.

14.7 Non-Injury crashes in Dry and Wet conditions

The Non-Injury crashes are the bulk of the total crashes as they form 73 per cent of the total NB and 66 per cent of the total SB crashes. The performance for NB and SB post installation of the WWP system is detailed below.

14.7.1 NB

As per available data, the average number of Non-Injury crashes decreased by 41 per cent for NB i.e. 63 less crashes; 31 less in Dry and 32 less in Wet condition between the years 2006 and 2013. Moreover, the fluctuations in the Non-Injury crashes decreased by 32 per cent for Dry and 37 per cent for Wet for NB (refer Table 14.1 for standard deviation values).

14.7.2 SB

For SB, there was a 28 per cent reduction in Non-Injury crashes i.e. 30 less crashes; four less in Dry and 23 less in Wet condition. However, the fluctuations in the Non-Injury crashes decreased by 7 per cent for Dry and decreased by 38 per cent for Wet for SB post installation of the system (refer Table 14.1 for standard deviation values).

The Non-Injury crashes for NB has significantly improved between 2007 and 2013 both for Dry and Wet conditions (see Figures 14.6 and 14.7). Since Non-Injury crashes form 73 per cent of the total NB crashes, a 41 per cent overall reduction after the WWP installation means significant improvement in safety. The decrease in Non-Injury crashes for SB is also appreciable. The reduction of these crashes in SB signifies that the motorists are more aware and conscious of their speed when they are travelling around this section of the road. For NB it is attributable to the ITS solution as no other traffic safety initiative was implemented in the area that can claim this change. For SB the benefit seems to be due to the juxtapositioning of the two carriageways and the false impression that the motorist get of the ITS WWP working in SB as well.

The study of the Non-Injury data prior to the WWP installation reveals that there were 152 Non-Injury crashes in the NB as compared to 96 in the SB. This differential can be attributable to more severe road environment in the NB as compared to the SB. Also, this disparity in Non-Injury crashes between NB and SB is more pronounced in Dry condition than Wet condition. This is because in Dry

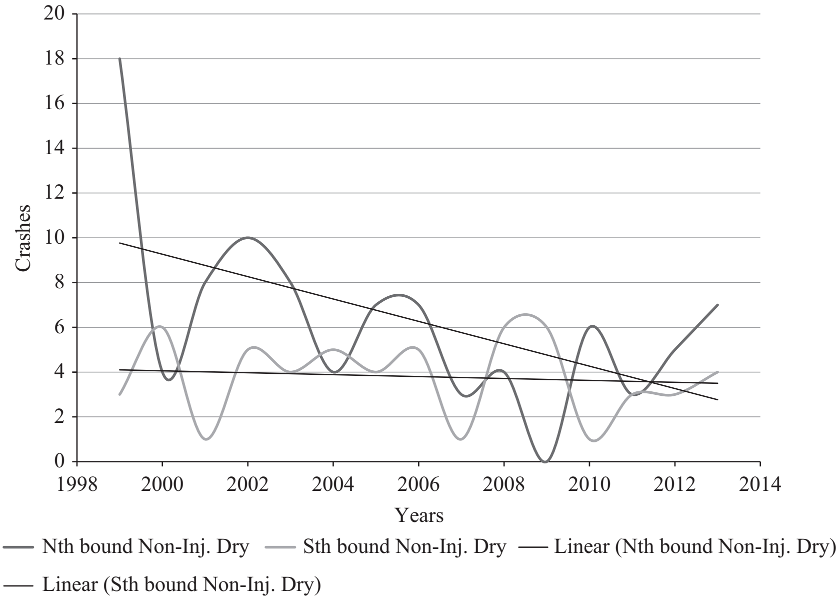

Figure 14.6 Northbound and southbound non-injuries (dry)

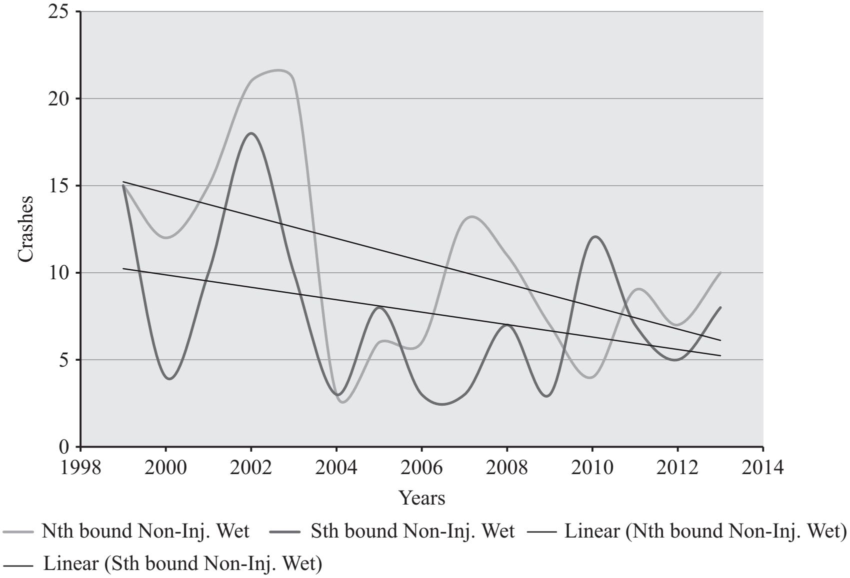

Figure 14.7 Northbound and southbound non-injuries (wet)

condition the speed limit for NB is 10 km/h higher than in SB (100 km/h instead of 90 km/h). A 4–6 per cent increase in mean speed increases the crashes by 10 per cent and the fatality by 20 per cent and vice versa (see Reference 7).

In Wet conditions, the speed in both NB and SB is the lower speed limit of 90 km/h. Despite the geometry challenges for the NB section, there has been a significant decrease in Non-Injury crashes attributable to lowering of the speed limit enabled by a variable speed limit that decreases the legal speed for NB in Wet conditions and allows higher speeds during Dry conditions.

The road profile discussed above can cause a variable speed effect at exactly the same locations; start of variable speed limit (that coincides with the start of steep incline) and end of variable speed limit (that coincides with the start of the steep decline) even if no actual ITS based variable speed limit is implemented. This road profile was responsible for the high number of crashes in the NB before the WWP was implemented, albeit nearly three fourth of these are Non-Injury crashes. However, after installation of the WWP there is a significant reduction in the Non-Injury crashes in the NB that contributes to a large impact on the overall crash numbers.

14.8 Fatal crashes in Dry and Wet conditions

Before the implementation of the ITS solution there were two Fatal crashes in NB in Dry condition and one crash in Wet condition. After installation of the ITS solution there were zero Fatal crashes in the NB for both Dry and Wet condition.

Before the implementation of the ITS solution there was one Fatal crash in SB for Wet condition. After installation of the ITS solution there were two Fatal crashes in the SB in Wet condition. Elimination of the Fatal crashes for NB after the installation of the WWP is a remarkable achievement. No other road safety initiative was implemented in this direction of the traffic in the subject time period. On the other hand, for SB the number of Fatal crashes has doubled i.e. increased from 1 to 2 in Wet condition after implementation of the ITS solution. Although, overall results for the SB show that motorist are generally more careful in the SB post installation of WWP but the fact is that SB is a continuous decline and encourages some motorists to over-speed resulting in more severe crashes.

14.9 Average crash rates and standard deviation

The data show that the volume of the traffic on the M1 has been steadily ascendant over the considered period. As the NB and SB are experiencing different volumes of traffic, it is useful to look at crash rates as well rather than mere number of crashes. To obtain a more realistic measure of the number of crashes per year per traffic volume for the desired section of the road, the yearly crash values needs to be divided by the value of the traffic volume, that is:

$$\text{Average crash rate} = \frac{\text{Total crashes for the year}}{\text{Volume of traffic (in MVKT)}} \tag{14.1}$$

The standard deviations of the crash rates over the mentioned periods were also calculated and comparison was made between the period before and the period after the system was installed. The crash rates and the standard deviation calculations were carried out on the data for the period before and after the installation of the ITS solution. Another useful comparison is the average standard deviations (ASTDEV) for the two periods. Table 14.2 displays the per cent decrease in average crash rates (ACRs) and the ASTDEV after the ITS solution was implemented. The values in the negative are the cases where the ACR or the ASTDEV has increased rather than decreased.

As evidenced in Table 14.2, the overall decrease in the ACR is 29 per cent for NB and 32 per cent for SB while the decrease in ASTDEV is 73 per cent and 55 per cent, respectively. The decrease in ACRs is quite significant for all types of crashes except the Injury crashes.

This means that after the installation of the system although the overall crash rate has improved significantly the severity of some of the crashes has gone up. There were ten more Injury crashes in Dry condition and four more crashes in Wet condition in NB after installation of the system. Moreover, if we discount this increase in crashes by the increase in average MVKT (increase in number of vehicles travelling this section of the road) then the increase in Injury crashes becomes negligible.

Table 14.2 Average crash rates (ACR) and average standard deviations (ASTDEV)

NB/SB	Decrease in ACR (%)	Decrease in ASTDEV (%)
NB total	29	73
SB total	32	55
NB total Dry	33	61
SB total Dry	27	55
NB total Wet	15	42
SB total Wet	38	56
NB Injury Dry	−44	36
SB Injury Dry	10	55
NB Injury Wet	−5.4	43
SB Injury Wet	43	37
NB Non-Injury Dry	56	32
SB Non-Injury Dry	18	7
NB Non-Injury Wet	38	37
SB Non-Injury Wet	38	38

14.10 Cost of crashes

The cost analysis is based on the principle of willingness to pay (WTP) as per Transport for NSW Guidelines for Economic Appraisal (see Reference 8, p. 269, table 47). For this analysis the cost of Injury, Non-Injury and Fatal crashes have been considered. The costs for a 7-year period before the installation of the WWP scheme and the 7-year period immediately after the installation of system has been included. The WTP values used are $6,369,128 for Fatal crashes, $467,815 for injuries and $77,589 for Non-Injuries crashes. The summary of crashes for NB and SB, Dry and Wet condition and for these two periods, 1999–2005 and 2007–2013, is shown in Tables 14.3 and 14.4.

Tables 14.5–14.8 tabulate the costs of each type of crash using the WTP figures from the economic analysis. It is important to compare the costs of the overall crashes before and after the installation of the WWP scheme.

The WWP scheme cost $2.3 million to install. The recurring cost for maintaining the system is $10,000/year. The amount spent over its 15-year life will only be $150,000. The replacement cost for the system will be much lower than the original cost as the civil work, power and communication and the road crossing gantry will already be there. This cost is estimated to be $250,000. All these costs for installing and maintaining a WWP scheme in NB are negligible as compared with the savings of $17.4 million (in the 7-year period after installation of the WWP scheme). Considering the road profile for NB the cost of crashes could have increased rather than decreased from 2006 onwards.

For the SB no WWP scheme has been installed. However, some improvement is seen in the Injury and Non-Injury crashes. This benefit as discussed earlier is due to more speed awareness in the variable speed zone due to the installation of the

Table 14.3 Summary of crashes 1999–2005

Direction of travel	**Injury**		**Non-Injury**		**Fatal**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
NB	19	33	59	93	2	1
SB	15	34	28	68	0	1
Total	101		248		4	

Table 14.4 Summary of crashes 2007–2013

Direction of travel	**Injury**		**Non-Injury**		**Fatal**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
NB	29	37	28	61	0	0
SB	14	21	24	45	0	2
Total	101		158		2	

Table 14.5 WTP costs 1999–2005 for NB

NB	**Number**	**Cost ($)**
Injury Dry	19	8888485.00
Injury Wet	33	15437895.00
Non-Injury Dry	59	4577751.00
Non-Injury Wet	93	7215777.00
Fatal Dry	2	12738256.00
Fatal Wet	1	6369128.00
Total		**55227292.00**

Table 14.6 WTP costs 2007–2013 for NB

NB	**Number**	**Cost ($)**
Injury Dry	29	13566635.00
Injury Wet	37	17309155.00
Non-Injury Dry	28	2172492.00
Non-Injury Wet	61	4732929.00
Fatal Dry	0	–
Fatal Wet	0	–
Total		**37781211.00**

Table 14.7 WTP costs 1999–2005 for SB

SB	Number	Cost ($)
Injury Dry	15	7017225.00
Injury Wet	34	15905710.00
Non-Injury Dry	28	2172492.00
Non-Injury Wet	68	5276052.00
Fatal Dry	0	–
Fatal Wet	1	6369128.00
Total		**36740607.00**

Table 14.8 WTP costs 2007–2013 for SB

SB	Number	Cost ($)
Injury Dry	14	6549410.00
Injury Wet	21	9824115.00
Non-Injury Dry	24	1862136.00
Non-Injury Wet	45	3491505.00
Fatal Dry	0	–
Fatal Wet	2	12738256.00
Total		**34465422.00**

system in NB and frequent police checks. However, the number of Fatal crashes in the SB rose from one Fatal crash before the installation of the WWP scheme to two Fatal crashes after the installation of the WWP. On the other hand, Fatal crashes in the NB have reduced from three to zero during the same period.

14.11 Conclusion

The M1 has been experiencing high number of crashes between Hawkesbury River and Mount White since the 110 km/h speed limit was set at the Motorway opening in the 1980s. As a result of these crashes, the speed limit in this area was reduced a number of times but somehow put back up to 100 km/h in 1999 and further lowered to 90 km/h in 2001. In 2006 on intervention by the Roads Minister the speed for NB carriageway was increased to 100 km/h. It is then that the RMS decided to put a variable speed solution for NB using ITS. Consequently, the WWP variable speed regime was implemented in the NB carriageway between Hawkesbury River and Mount White in April 2006 to reduce the speed for NB to 90 km/h during Wet conditions only.

Raw data were obtained from RMS on crashes in Dry and Wet condition 7 years prior to the implementation of the ITS solution and 7 years afterwards. Analysis of the data was carried out by comparing number of crashes, crash rates, average crashes, ACR, standard deviations between crashes for Dry, Wet conditions and Injury, Non-Injury and Fatal type of crashes before the installation and after the installation of the WWP scheme in 2006.

The analysis revealed that the number of overall crashes for NB has significantly reduced i.e. 52 less crashes for NB. The number of overall crashes for SB has also reduced i.e. 37 less crashes. The improvement in SB can be attributed to the close proximity of the SB carriageway to the NB that leads to the pseudo detection of the speed camera from the SB by a GPS device as if the camera is positioned on the SB. Also, the SB is subjected to a regular Police Patrol on a daily basis and also on weekends and holidays. It may be noted that the standard deviation for the crash rates for the NB has reduced significantly for the post 2006 periods; much more than for the SB.

The number of Injury crashes for NB has increased from the pre 2006 values i.e. 14 more crashes in NB in the 2007–2013 period. The bulk of this increase i.e. ten crashes were in Dry conditions and only four were in Wet condition. One major contributory factor for this is that the speed limit for NB is 100 km/h and the speed limit for SB is 90 km/h for Dry condition. Moreover, if we discount this increase in crashes by the increase in average MVKT (increase in number of vehicles travelling this section of the road) then the increase in Injury crashes becomes negligible. The injuries for the SB for Dry condition have decreased by 14 crashes during this period. Another mitigating factor for the apparent increase in the NB Injuries after 2006 is the much lower values for Injuries in NB in 2004 due to construction works in that area.

The number of Non-Injury crashes and standard deviations have reduced significantly for Dry and Wet condition in the NB. Since the Non-Injury crashes for NB form 72 per cent of the total NB crashes, a major improvement on the Non-Injury crashes has a major impact on the overall reduction in crashes. This decrease is equally significant in Dry and Wet condition. For NB Dry condition this improvement is even more important as the speed limit in Dry condition is 10 km/h higher than for Dry condition in the SB. The improvement in Fatal crashes is exceptional as there have been no Fatal crashes in the NB after the implementation of the ITS solution while for the SB there have been two Fatal crashes post 2006.

The NB environment is much tougher to negotiate for the heavy vehicles and the trucks. The reason is the steep incline followed by a steep decline. The trucks have to slow down from motorway speeds to 90 km/h, lose their momentum while going up and then have to speed up to the motorway speeds to join the lighter traffic that is moving at a higher speed on the decline along with managing the higher curvatures in the road geometry. This leads to speed differential in the curvilinear path that is not desirable from a road safety perspective. In spite of this, there have been appreciable improvements overall in the number of crashes, rate of crashes and the standard deviation of crash rates after the installation of the WWP system.

The cost of overall crashes significantly reduces for the period of 2007–2013. Considering the road profile for NB and the increase of 5 per cent in MVKT (number of vehicle km travelled) the cost of crashes could have increased rather than decreased from 2006 onwards. Since no other road safety initiative is known to exist in this section of the road in the same period, the above benefits can be attributed to the implementation of the ITS solution in 2006.

References

[1] Ozroads, Sydney (Australia). 'Newcastle F3 Freeway NH', 2014. http://www.ozroads.com.au/NSW/Freeways/F3/f3.htm (Accessed 13 September 2015)

[2] Local News, Advocate, Central Coast (Australia). 'M1 Sydney to Newcastle Motorway Historic Achievement in NSW Roads Infrastructure'. *Central Coast Advocate*, 1 September, 2015. http://www.dailytelegraph.com.au/newslocal/central-coast/m1-sydney-to-newcastle-motorway-historic-achievement-in-nsw-roads-infrastructure/story-fngr8h0p-1227507736929?sv=fd5a5483630d4f65c7cda95e71bcf367 (Accessed 13 September 2015)

[3] Rand P. 'Road Photos & Information: Sydney to Newcastle Freeway, NH1', 16 November, 2013. http://expressway.paulrands.com/gallery/roads/nsw/numbered/decommissioned/nationalhighways/nh1/index.html (Assessed 13 September 2015)

[4] Australian Government, Department of Infrastructure and Regional Development (DIRD). 'Over $600 million for New South Wales Roads', 2003. https://infrastructure.gov.au/department/statements/2003_2004/media/a3.aspx (Accessed 13 September 2015)

[5] Roads and Maritime Services, New South Wales (Australia). M1 – 'Hawkesbury River to Mount White Crashes (1996 to 2013)', 2015. http://roadsafety.transport.nsw.gov.au/statistics/interactivecrashstats/nsw.html?tabnsw=1 (Assessed 10 July 2015)

[6] Australian Government, Bureau of Meteorology. 'Average Annual and Monthly days of Rain', 1961–1990. http://www.bom.gov.au/jsp/ncc/climate_averages/raindays/index.jsp (Accessed 13 September 2015)

[7] Nilsson G. 'Traffic Safety Dimensions and the Power Model'. Unpublished thesis, Traffic Engineering, Lund Institute of Technology, Lund, 2004.

[8] Transport for New South Wales (Australia). 'Willingness to Pay'. *Principles and Guidelines for Economic Appraisal Transport Investment & Initiatives*, 2014, p. 269.

Chapter 15

Benefits and evaluation of ITS projects – Examples from China

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and Hongtong Qiu[3]

15.1 Introduction

Compared with the traditional transport infrastructure projects, although Intelligent Transport Systems (ITS) projects are of higher amount of investment, their impacts on society, economy, and environment are not easy to predict. On the other side, policymakers, investors, and the public are all very concerned about the benefits brought about by construction of ITS projects on the society, the economy, and the environment, as well as potential risks and possible negative impacts. In consequence, how to evaluate the benefits of ITS projects and how to select right indexes for evaluation have been hot topics in recent years.

Since the evaluation of ITS projects contains many aspects including social, economic, and environmental, very often we need to use different methods for evaluation including qualitative and quantitative methods, according to what factors to be evaluated. In general, many ITS projects use both quantitative and qualitative evaluation including methodologies of the traditional cost–benefit analysis and the multi-objective analysis. These evaluation methods serve for the purpose of ITS project feasibility study and the provision of a scientific basis for optimization of the operation of existing systems.

This chapter includes two typical examples of ITS project evaluations in P.R. China.

15.2 BRT project evaluation (Guangzhou, P.R. China)

15.2.1 Guangzhou BRT system

Bus rapid transit (BRT) is a new type of urban public transport, an intermediate between the rail transit and conventional bus services. It has high quality and low cost, and it is fast, comfortable, flexible and convenient.

[1] Tsinghua University, China
[2] South China University of Technology, China
[3] Traffic Management Research Institute of the Ministry of Public Security, China

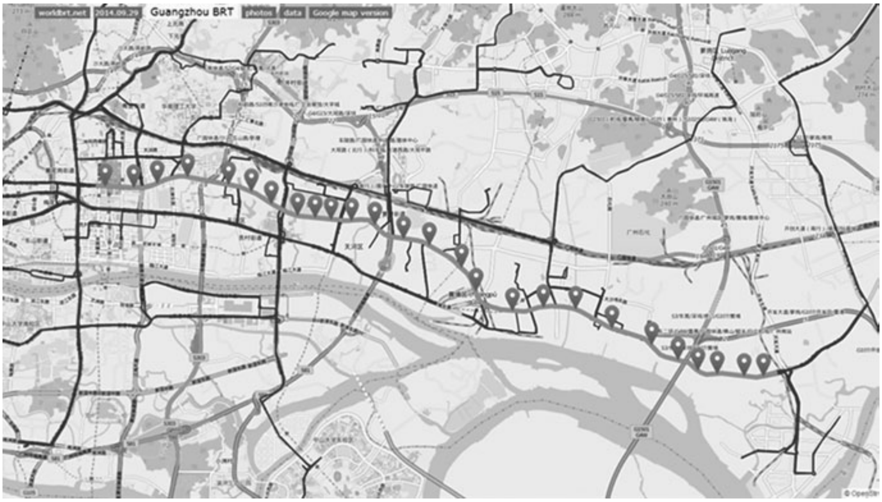


Figure 15.1 Guangzhou BRT corridor. © The Institute for Transportation and Development Policy (ITDP) www.itdp-china.org (Accessed on 30 March 2016)

Guangzhou city BRT system was officially opened in 2010 [1]. Its total length is 22.9 km, 22.5 km of which is the special bus lane running east-west, starting from the Guangzhoudadao Road in the west and ending in Huangpuxiayuan Road, comprising of Tianhe Road (2.8 km), Zhongshang Avenue (13 km), and Huangpudong Road (7.1 km) (see Figure 15.1). There is a two-way BRT lane in the middle of the road which expands to four at the bus station, along with six to ten social lanes. There are 26 bus stations in Guangzhou city BRT system. During the rush hour, average bus occupancy is 78 arrivals.

It handles approximately 1,000,000 passenger-trips daily with a peak passenger flow of 26,900 passenger peak hour per day (second only to the TransMilenio BRT system in Bogota), which is higher than most metro and all light rail lines worldwide [2]. In fact, this rapid transit system contains the world's longest BRT stations – around 260 m including bridges (see Figure 15.2) – with bus volumes of 1 bus every 10 s or 350 buses/h in a single direction.

15.2.2 Guanzhou BRT simulation evaluation

In 2009, before the construction of the Guangzhou city BRT system, Guangzhou Transportation Committee began the Guanzhou BRT simulation evaluation project.

Since the Guangzhou BRT along Zhongshan Road is the first stage of GZ BRT system, its operations will directly affect the subsequent Guangzhou BRT project.

Along Zhongshan Road, the volume of bus passengers is large and there are more than 20 bus lines. The road traffic situation is very complex. Guangzhou BRT

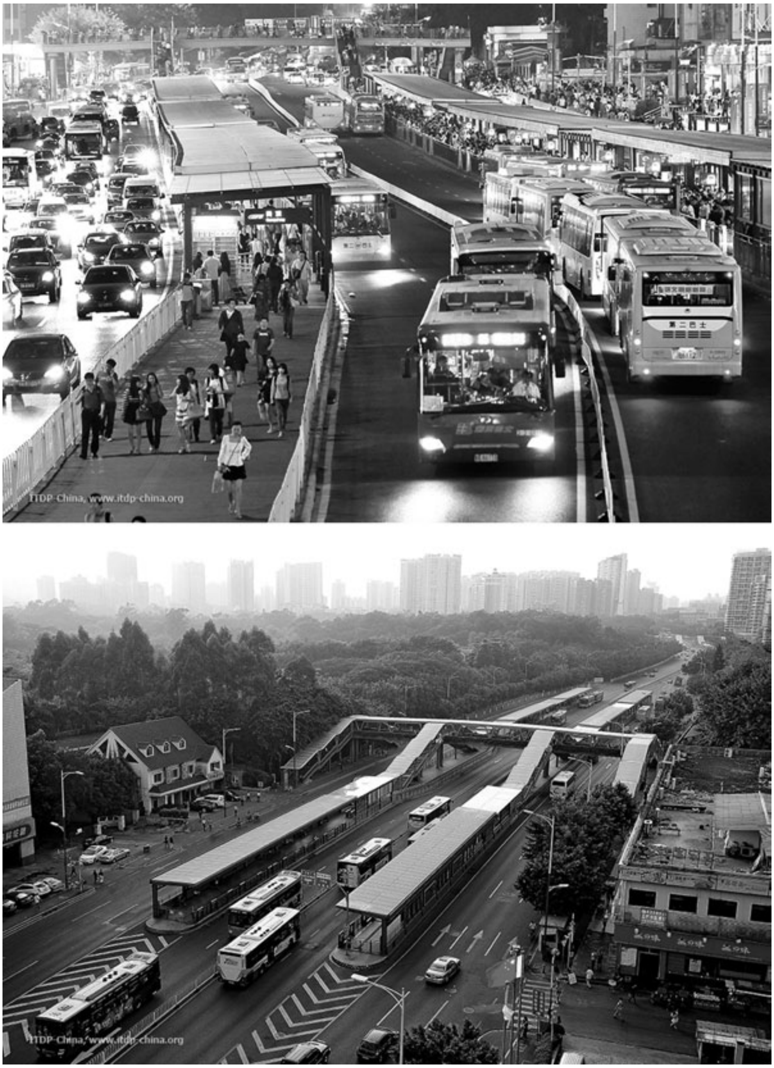


Figure 15.2 *Guangzhou BRT. © The Institute for Transportation and Development Policy (ITDP) www.itdp-china.org (Accessed on 30 March 2016)*

uses intelligent traffic management system for all lines and vehicle scheduling, with more than 20 BRT lines and a large number of vehicles, the BRT scheduling is of high complexity.

To verify the BRT ITS can fully function and ensure an orderly scheduling and operation, it is suggested to apply a microscopic traffic simulation evaluation before the implementation of Guangzhou BRT ITS project.

By use of microscopic traffic simulation model to analyse, forecast and evaluate the effects of various BRT operations scheduling schemes that may arise, to achieve the BRT transportation operations detailed, quantitative analysis of Guangzhou BRT operations scheduling. Thereby provide decision support for the BRT ITS scheduling and optimization.

The main contents of the Guangzhou BRT simulation project include: "Preliminary investigation, Basic data collection, Simulation Modelling, Simulation program implementation, Evaluate and correct simulation parameters, Result analysis."

The following describes the BRT simulation model, and analysis of BRT simulation results.

15.2.3 BRT simulation model

15.2.3.1 Microscopic simulation software: Vissim

Vissim is a kind of microscopic, time-driven, driving behaviour-based simulation modelling tool. It can be used to model and analyse conditions of urban traffic and public transport of various traffic conditions (such as: lane setting, traffic composition, traffic signal, bus stops) [3]. It is an effective tool for evaluation of transportation engineering design and urban planning.

When constructing the BRT system in 2009, a micro-simulation model Vissim was applied to evaluate the effects of various BRT operation scheduling schemes, and give quantitative analysis to determine the feasibility of BRT operation scheduling schemes, thus to provide decision support for BRT operation optimization.

The BRT simulation model would represent the operation situations of BRT lanes, BRT vehicles, platform of BRT stations, other lanes under the influence of BRT lanes, the intersections along the BRT route, and the like.

15.2.3.2 Data requirements for Guangzhou BRT simulation

Reliable data of the facilities are prerequisites for the successful implementation of the Guangzhou BRT simulation project. The main data required for the simulation include: road network data, traffic flow data and BRT operations data.

The road network data include: detailed road network map; detailed traffic design scheme of the intersections and links, including channelling schemes, designed BRT lanes and width, and position and design of the BRT stations.

The traffic flow data include: traffic flow compositions (including passenger cars, BRT vehicles, ordinary bus and trunks), static origin–destination matrix for all traffic modes along the BRT route, BRT lines and operation schedules, distributions of expected speeds for each type of vehicles, and Traffic signal scheme of each intersection.

BRT simulation modelling also needs data from BRT operation, including BRT only lanes, expected running speed of BRT vehicles, BRT operation schedules, distributions of passenger boarding time at each BRT stations, and BRT vehicle sizes and physical properties.

15.2.3.3 The main technical points

To make the simulation system as consistent as in reality, special attention has been paid to model function setting for the complexity and diversity of urban traffic system in this process. Four points below are the simulation technical keys of BRT line modelling.

Building distribution of speeds, accelerations and decelerations for various vehicles

The distribution of speeds at links and intersections are built based on the field data collected from seven intersections along Tianhe Street and Huangpudong Road.

BRT bus-only lane

To set BRT bus-only lane, other types of vehicles except buses have to be shielded. In Vissim simulation projection, to realize the goal of single-type vehicle release, "lane closed" function needs to be inserted in the toolbar.

Bus routes based on the harbour bus stop

With the harbour bus stop not activated by default in any bus route, in the Vissim simulation system, BRT buses had activated them one by one to get access to the platform.

Vehicle flow selection

When vehicles enter the approaches through lanes that have switch function, they need to have the choice. If there is only one road between two intersections, this choice becomes impossible. Therefore, it is necessary to build the lane that has lane switch function to connect with the approaches of each corresponding intersection, allowing vehicles to enter the approaches (Figures 15.3 and 15.4).

Figure 15.3 Intersection model on Tiyu East Road, Guangzhou, P.R. China

Figure 15.4 Overpass and platform at Gangding Station, Guangzhou, P.R. China

15.2.4 Analysis of BRT simulation results

15.2.4.1 BRT operation evaluation

BRT operation evaluation index include: average bus dwell time at stations, average occupancy rate, and average passenger waiting time. Simulation results show that the average bus dwell time at stations was 27.2 s, and the average occupancy rate was 79.94%, the maximum load factor was 100%, and the average passenger waiting time was 3.6 min overall.

Average bus dwell time at stations

The maximum stop time at stations determines the maximum capacity of the BRT line, and then determines the maximum capacity of the line, thus shortening the dwell time can improve the capacity of BRT. Overall, the current BRT ordinary bus with the average dwell time of 27.2 s (see Figure 15.5), in long term, if the high-capacity vehicles such as the biarticulated buses (see Figure 15.6) are taken, which

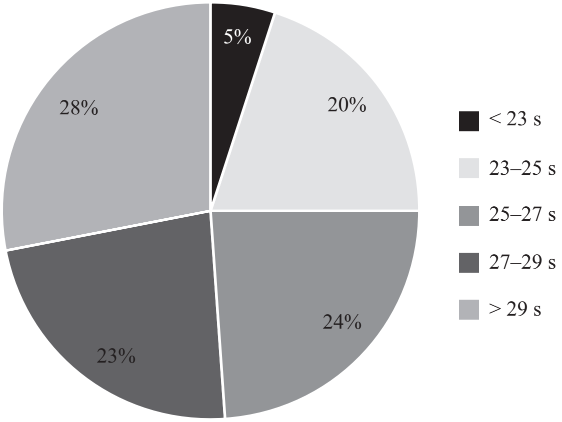


Figure 15.5 *Average bus dwell time at stations*

Figure 15.6 *Biarticulated buses. © The Institute for Transportation and Development Policy (ITDP) www.itdp-china.org/en/city/yichang (Accessed on 30 March 2016)*

with more doors for passengers to get on and off, dwell time at stations will be shorter.

Bus average occupancy rate

The average occupancy rate of bus lines would best describes the utilization efficiency of the lines. Meanwhile, it is also an important index for bus passenger

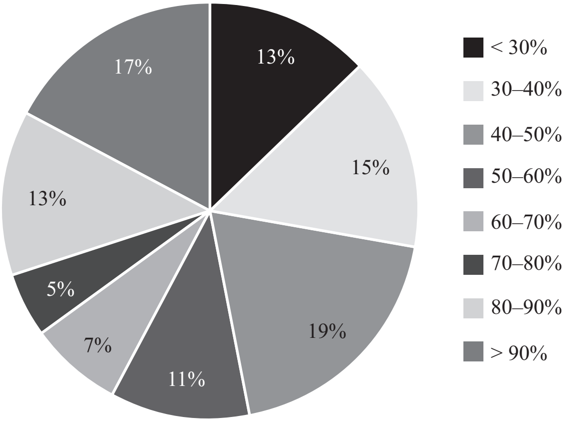


Figure 15.7 BRT average occupancy rate

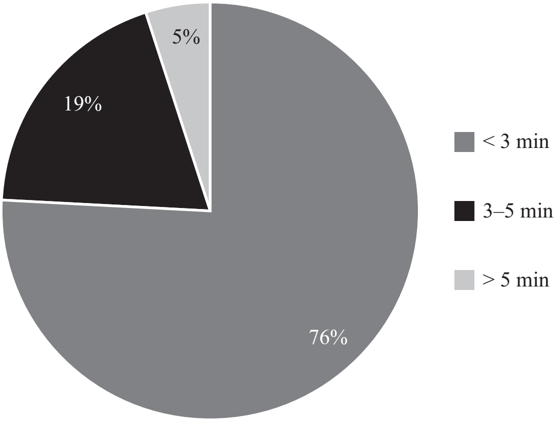


Figure 15.8 Passenger average waiting time

comforts. The maximum load factor can indicate the level of bus dispatching at peak hours, while bus average capacity rates reflect the capacity that a BRT line would provide to meet the travel needs of passengers.

The simulation results were shown in Figure 15.7, 17% of the bus lines have a bus average occupancy over 90%. The high occupancy rate not only reduces passenger comfort, but also hinders the passengers on and off the bus. Therefore, it will certainly extend the vehicle dwell time at the stations and reduce the capacity. So, Guangzhou BRT system has higher requirements for bus capacity.

Average passenger waiting time

The passenger average waiting time of each BRT line is shown in Figure 15.8, 77% of the total 76 BRT lines' average passenger waiting time was within 3 min, there were 18% of the BRT lines' average passenger waiting time was 3–5 min, and only 5% was longer than 5 min.

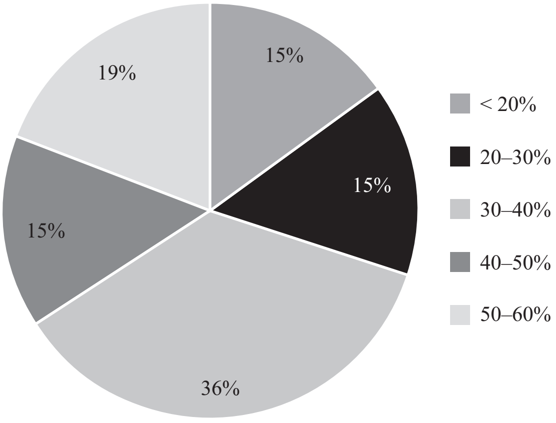
15.2.5 BRT station operation evaluation

15.2.5.1 BRT station saturation index

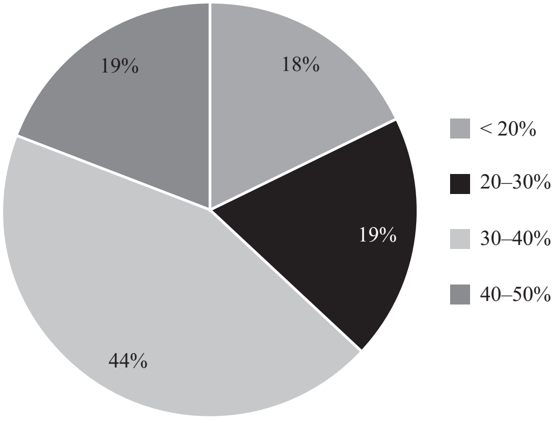
BRT station saturation index is referred to the ratio of the number of bus arrived each hour to the BRT station capacity. The simulation results were shown in Figure 15.9.

15.2.5.2 BRT queue length at stations

When buses are queueing at the station means that the following buses has to wait.



(a) Upstream direction



(b) Downstream direction

Figure 15.9 BRT station saturation

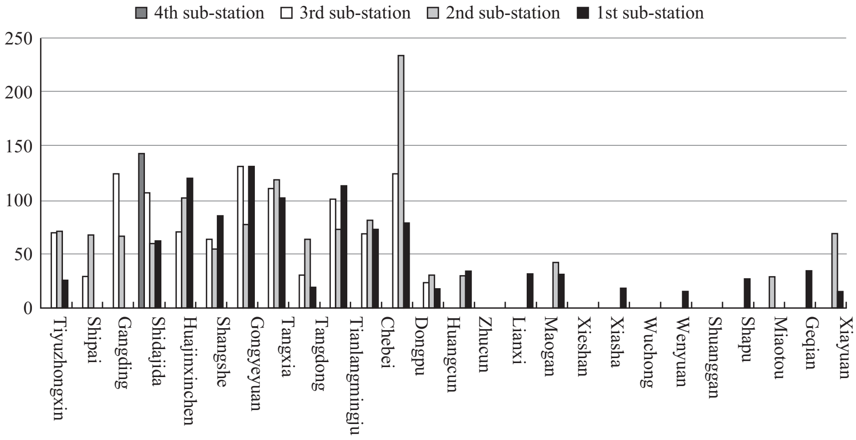


Figure 15.10 Queue length at stations in upstream direction

In upstream direction, 17% of the stations are of the maximum queue length over 100 m. While the maximum queue length at Dongpu stations is up to 234 m (about 16 buses in queue). In downstream direction, 7.9% of the stations are of maximum queue length more than 80 m, wherein the maximum queue length of Huajinxinchen station is up to 94 m (about 7 buses in queue) (Figure 15.10).

To improve these, higher capacity vehicles such as biarticulated bus is recommended to apply in Guangzhou BRT system.

15.2.5.3 Volumes of the BRT only lanes

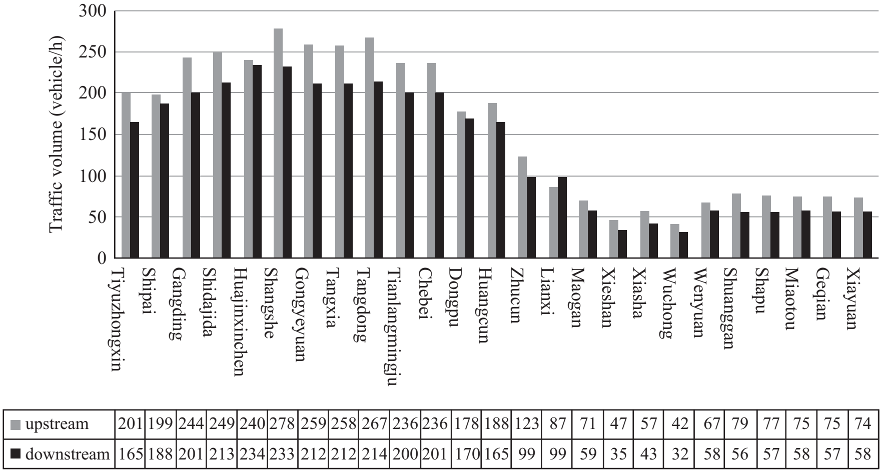
There are 26 stations in the BRT route. In the BRT simulation model, the traffic volumes of the BRT only lanes between each of the two stations were collected. The volumes of the BRT only lanes are shown in Figure 15.11.

15.2.5.4 Intersection and link evaluation

The previous index data of road network before BRT system were from Guangzhou Zhongshan Road. BRT test facilities engineering design plan written by Guangzhou Urban and Rural Construction Committee. Those data and the simulation data obtained from the microscopic simulation model were compared, which are shown in Tables 15.1 and 15.2.

The level of service defined in “High Capacity Manual 2000” was referred to, as shown in Table 15.3.

In summary, the simulation evaluation of Guangzhou BRT project was a successful example of ITS evaluation project. The evaluation results have been the important guidance to the design of BRT stations, BRT vehicle size/type selection, and BRT schedule program.



▨ upstream	201	199	244	249	240	278	259	258	267	236	236	178	188	123	87	71	47	57	42	67	79	77	75	75	74
■ downstream	165	188	201	213	234	233	212	212	214	200	201	170	165	99	99	59	35	43	32	58	56	57	58	57	58

Figure 15.11 Volumes of BRT only lanes (bus/h)

Table 15.1 Node evaluation results before and after BRT construction

Name of the intersection	**Delay time**		**Queue length**		**Level of Service**	
	Before	After	Before	After	Before	After
Tianhe Road–Tiyu East Road	123.1	36.8	187	121	F	D
Tianhe Road–Tianhe East Road	116.8	28.9	179	113	F	C
Tianhe Road–Wushan Road	32	26.2	98	88	C	C
Zhongshandadao Road–Tianfu Road	49	31.2	102	80	D	C
Zhongshandadao Road–Keyun Road	46	25.8	112	92	D	C
Zhongshandadao Road–Chebei Road	34	27.5	108	98	C	C
Zhongshandadao Road–Huicai Road	20.1	14.2	99	78	B	B
Zhongshandadao Road–Tangkoucun Road	19.9	10.2	59	45	B	B
Huangpu East Road–Gangwan Road	17.2	14.3	88	68	B	B
Huangpu East Road–Dianchang East	23	26.7	134	95	C	C
Huangpu East Road–Xiayuan Road	20.3	23.8	93	75	B	C

Table 15.2 Vehicle travel speed before and after BRT construction

Section	**Unfinished (km/h)**	**Finished (km/h)**
Tianhe Road	13	28.2
Zhongshandadao Road	17	34.2
Huangpudadao Road	22	35.5

Table 15.3 Delay–service level standard

Level of service	Delay of each car (s)
A	<10
B	11–20
C	21–35
D	36–55
E	56–80
F	>80

15.3 Evaluation of the Tsingdao Advanced Traffic Management System (ATMS)

15.3.1 Background of Tsingdao ATMS

Figure 15.12 shows the system structure of the ATMS in Tsingdao. The Tsingdao ATMS consists of one centre, three platforms, and eight systems.

One centre

One centre, the city's traffic system data integrated centre is mainly applied to collect, store, and manage all traffic system data, and to provide each platform and system with data support and calculation service.

Three platforms

1. The advanced traffic management platform provides many application services, including traffic condition monitoring, command and dispatch, traffic enforcement, route guide information management, safety facilities management, analysis and judgment, and traffic parallel control.
2. The traffic management integrated application platform, developed and deployed by the Institute of Traffic Management in Ministry of Public Security of China, is integrated with the integrated application platform to obtain vehicle and driver data from this platform and submit traffic offense data to this platform.
3. The traffic information service platform performs traffic information collection, dissemination, service operation, and maintenance.

Eight systems

1. The traffic signal control system collects traffic flow data and deploys adaptive, congestion-oriented, emergency, and multi-system simultaneous control. This system is applied to simulate and analyse the control scheme.
2. The traffic enforcement system is mainly employed to capture photographic evidence of red light violation, one-way system violation, occupation of the bus transit lanes, over speeding, and illegal parking.
3. The traffic guidance system provides road traffic condition, traffic regulation, and traffic event information through variable message signs.

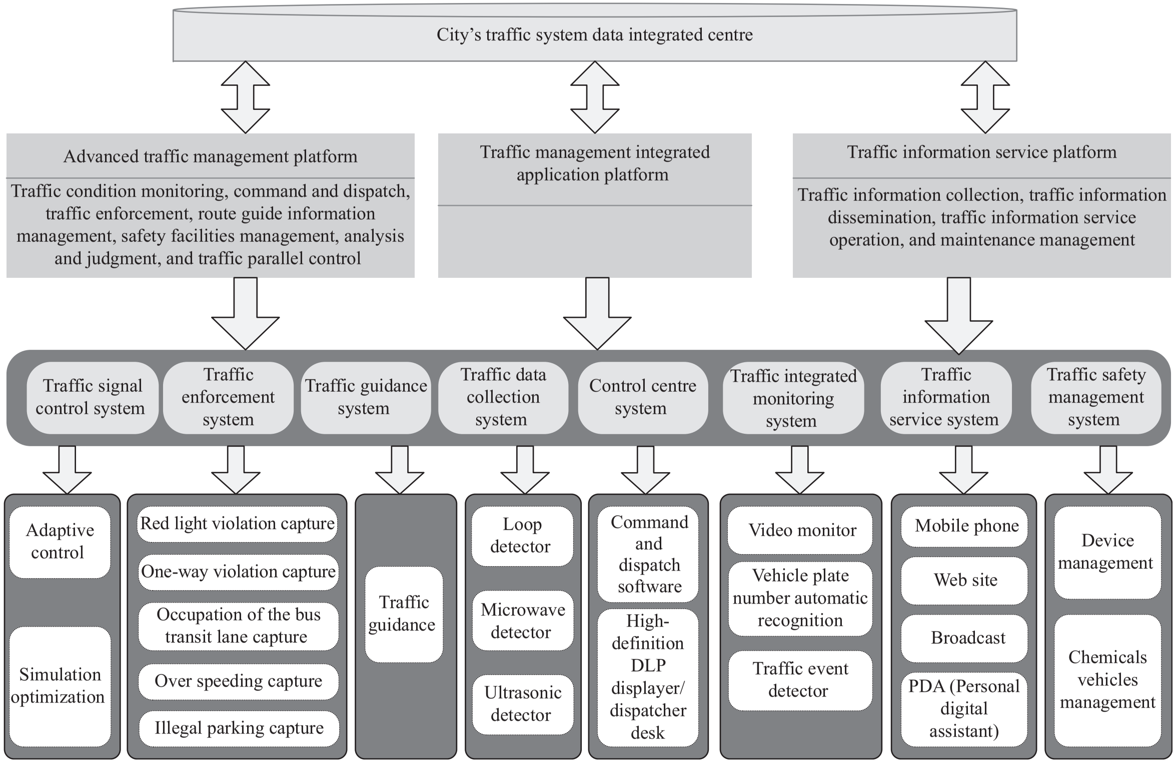


Figure 15.12 *System structures of ATMS in Tsingdao. © 2016 China Architecture & Building Press. Reprinted with permission from China Architecture & Building Press (R Li, H Qiu. Intelligent transportation system planning, design and case study. Chinese)*

4. The traffic data collection system detects road traffic flow volume, average speed, occupancy, and several other parameters of traffic flow, which are applied to support other systems, such as traffic signal control, traffic information service, and command and dispatch.
5. The control centre system includes the following equipment: 122 telephone system, high-definition (HD) digital light processing displayer, dispatcher desk, and a computer room. This system deploys traffic command and dispatch based on all types of in-field devices and real-time police force and police alarm conditions.
6. The traffic integrated monitoring system includes a HD monitoring system, vehicle number plate automatic recognition, and a traffic event detector based on the HD video.
7. The traffic information service system provides dynamic traffic information service through various means and establishes a personalized information dissemination and data sharing system. This system also provides drivers with dynamic navigation service based on real-time road conditions and public transport users with real-time transit and transfer information at public transport hubs. It provides all travellers with personalized traffic information service.
8. The traffic safety management system performs unified management of various types of urban road traffic intelligent manage devices, including various equipment on the road and various devices in the control centre. These devices can be displayed on the user-friendly interface of the system to allow the traffic administrator to manage all the devices in his or her administrative region.

Figure 15.13 shows the system architecture of Tsingdao ATMS. The overall system includes six layers and two support systems. The six layers are perceptual, access, fusion, storing and sharing, application, and information service layers. The two support systems are operation and maintenance, and data security systems. The main function of each layer and support system are as below.

Six layers

1. The perceptual layer includes all types of in-field detectors. It is the basic layer of ATMS and provides real-time data to other systems.
2. The access layer interacts with the perceptual layer through an intelligent transport access network, which includes a 2G/3G/4G networks and/or an optical fibre. This layer contains a traffic data detection system adaptor, a violation enforcement system adaptor, a traffic signal control system adaptor, a GPS adaptor, a video monitoring system adaptor, and other adaptors linked to other systems. With various access adaptors, ATMS can realize data collection and sharing.
3. The fusion layer fuses various types of data, including basic source information, police force and alarm condition information, accident information, violation information, traffic flow parameters, and other basic operational business data. This layer provides data for traffic control, traffic guidance, traffic congestion control, and travel time calculation.
4. The storing and sharing layer includes the production, history, analysis, and backup databases. Based on the characteristics of different types of data, such as

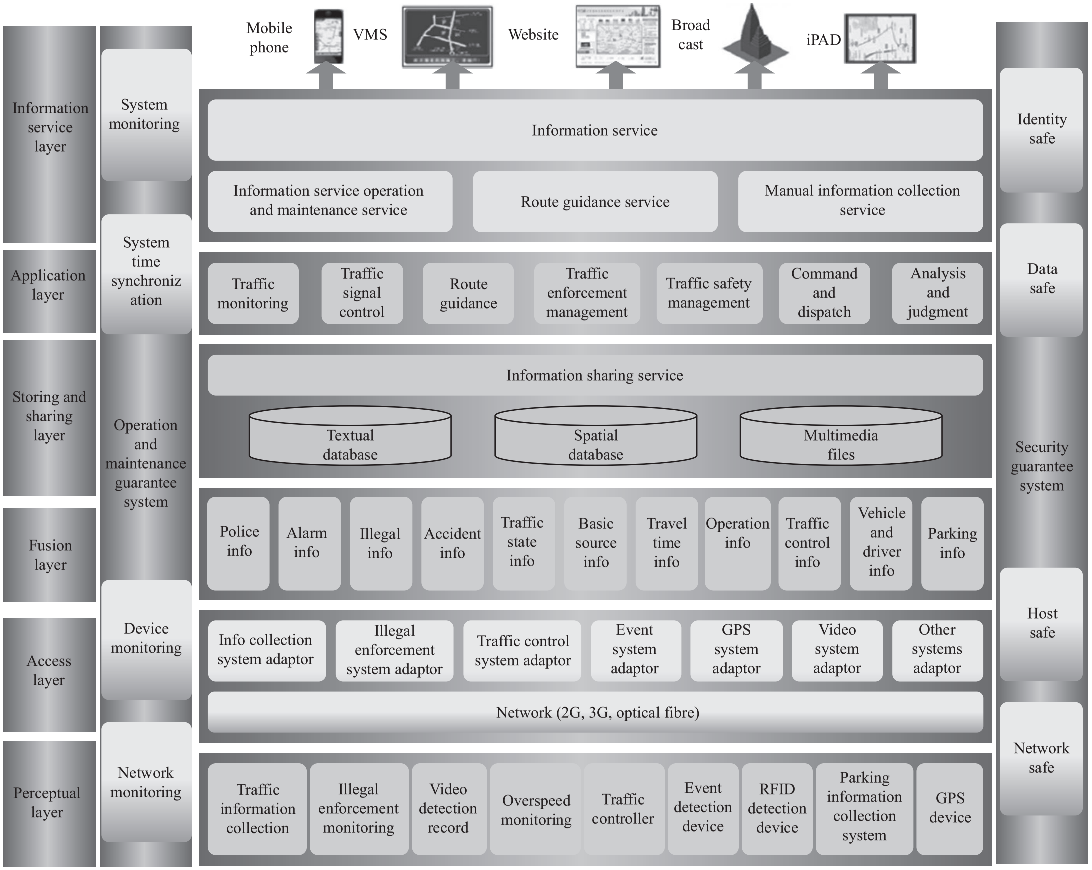


Figure 15.13 System architecture of Tsingdao ATMS. © 2016 China Architecture & Building Press. Reprinted with permission from China Architecture & Building Press (R Li, H Qiu. Intelligent transportation system planning, design and case study. Chinese)

text and multimedia, this layer sorts and stores various traffic management information through different technical means and provides various application systems with traffic information and data through the information sharing service.

5. The application layer has various traffic management functions, including traffic condition monitoring, command and dispatch, traffic signal control, traffic guidance, traffic enforcement management, traffic safety management, and analysis and judgment.
6. The information service layer has two parts according to the functions: the information publication within the traffic management intranet and the information service to the public. The first part refers to publishing road condition, traffic regulation, traffic event, and guidance information through a variable message sign at the roadside. The second part refers to the provision of various information to the public through an Internet website, cell phone, intelligent personalized terminal, and radio traffic broadcast.

Two support systems

1. The operation and maintenance support system includes system monitoring, Internet monitoring, device monitoring, time synchronization among various systems, and Internet operation and maintenance functions.
2. The data security system includes Internet security, host security, data security, and identity authentication functions.

15.3.2 Evaluation of Tsingdao ATMS

The evaluation scope of the ATMS in Tsingdao covers the entire road network of the city's built-up area. The evaluation process investigating the comprehensive advantages of ATMS includes four stages: establishment of an evaluation index system, selection of the evaluation index for ATMS, identification of the benchmark time and specific evaluation time to be used for performance comparisons, and data processing and analysis based on the data collected by the in-field detection device.

The evaluation of ATMS in Tsingdao is based on the traffic operation situation in the city. The evaluation mainly focuses on traffic operation efficiency, social and economic efficiency, road safety performance, and management efficiency [4–6]. Several evaluation indices, such as link travel time, link average speed, and link length, are derived from the data collected by the number plate automated recognition system.

The benchmark time is set as the first few days in which ATMS had just been deployed, and the specific evaluation time is the days after ATMS had finished testing period and began its formal operation.

15.3.3 Evaluation index system

The evaluation index system of ATMS includes four aspects: traffic operation efficiency evaluation, social and economic efficiency evaluation, road safety performance evaluation, and management efficiency evaluation [7,8]. The evaluation index system of ATMS is shown in Figure 15.14.

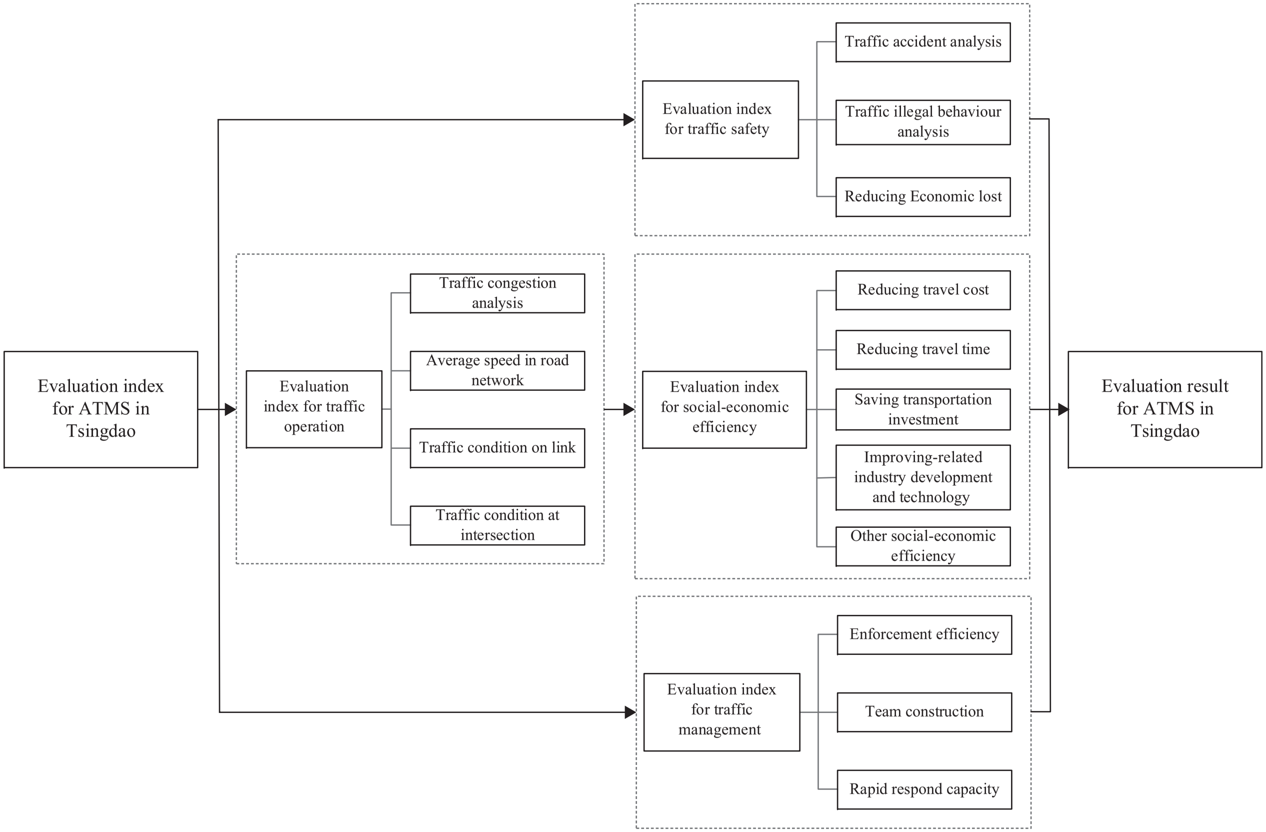


Figure 15.14 *Evaluation index systems of ATMS. © 2016 China Architecture & Building Press. Reprinted with permission from China Architecture & Building Press (R Li, H Qiu. Intelligent transportation system planning, design and case study. Chinese)*

15.3.4 Traffic operation efficiency evaluation

The establishment and application of ATMS have an important impact on the traffic operation condition of a city's road network. This part evaluates the positive effect of using ATMS on traffic operation efficiency through a comparative analysis of the road traffic condition before and after the application of ATMS.

15.3.4.1 Traffic congestion index evaluation

Traffic congestion index analysis reveals the difference between actual travel time and theoretical travel time under ideal road traffic conditions. According to the calculation method of the traffic congestion index in Tsingdao and based on the data extracted from the number plate automatic recognition system, the traffic congestion index can be calculated as shown in Table 15.4.

Table 15.4 indicates that after ATMS application, the durations of smooth and nearly smooth increase obviously from 14.99 to 16.70 h/d (increase of 11.4%). The durations of congestion (from slight to heavy) exhibit a significant decrease from 9.01 to 7.3 h/d (decrease of 18.9%).

The traffic congestion index variation tendency in a day and on a workday before and after the application of ATMS is shown in Figure 15.15.

Figure 15.15 shows that after the application of ATMS, the traffic congestion index exhibits an obvious decrease both on average and workdays, especially in the morning and evening peak hours. It means the application of ATMS significantly relieves traffic congestion.

15.3.4.2 Road network operation speed

The average road network operation speeds were calculated based on data extracted from the number plate automatic recognition system. The calculation covered most of the main road within Tsingdao, including 71 unidirectional road links. The final road network average speed was calculated as the weighted sum of four speed values for four different time intervals in a day (morning and afternoon peak hours, common traffic hours, and nonpeak hours). The results are shown in Table 15.5.

After the application of ATMS, the weighted travel time for unit distance decreased by 29.93 s, and the decrease percentage is 12.8%. The average road network speed increased by 1.75 km/h, and the increase percentage is 11.35%.

Table 15.4 Traffic congestion index before and after ATMS application in a day

Traffic congestion index region	(0,2]	(2,4]	(4,6]	(6,8]	(8,10]
Traffic condition	Good	Common	Congested		
Average duration before ATMS application (h)	7.36	7.63	6.98	1.97	0.06
Average duration after ATMS application (h)	8.58	8.12	5.73	1.55	0.02

Note: (0,2] means smooth, (2,4] means nearly smooth, (4,6] means slight congestion, (6,8] means medium congestion, and (8,10] means heavy congestion.

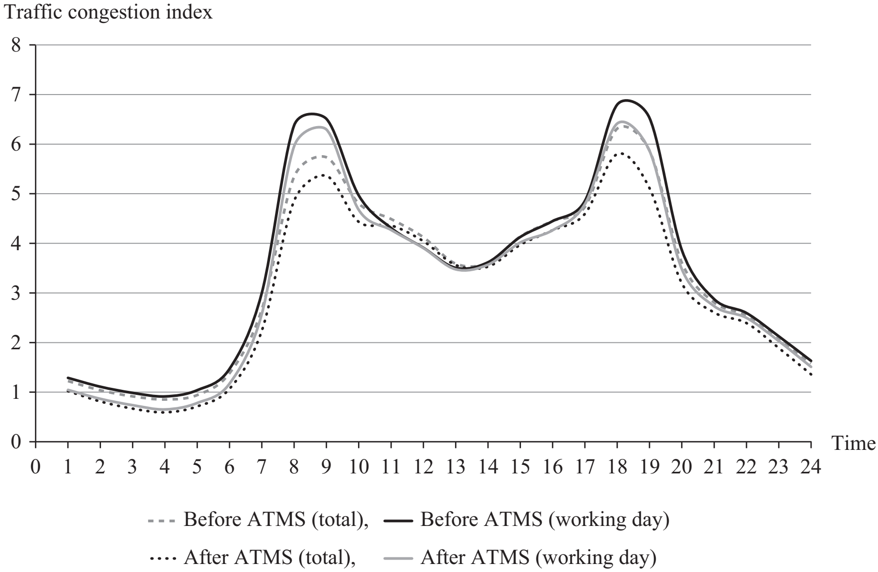


Figure 15.15 Traffic congestion index in 24 h before and after the application of ATMS. 15 © 2016 China Architecture & Building Press. Reprinted with permission from China Architecture & Building Press (R Li, H Qiu. Intelligent transportation system planning, design and case study. Chinese)

Table 15.5 Travel time for unit distance and average road network speed

	Before	**After**	**Relative change (%)**
Travel time for unit distance during peak hours (s/km)	348.32	325.57	−6.99
Travel time for unit distance during common traffic hours (s/km)	249.28	233.69	−6.67
Travel time for unit distance during nonpeak hours (s/km)	174.89	155.62	−12.38
Weighted travel time for unit distance (s/km)	263.65	233.72	−12.80
Average road network speed (km/h)	13.65	15.40	11.35

15.3.4.3 Road link operation condition evaluation

Based on the data extracted from the number plate automatic recognition system located on 71 unidirectional road links, for four different time intervals in a day (morning and afternoon peak hours, common traffic hours, and nonpeak hours), three indices for each link were calculated. These three indices for comparison were: travel time, delay, and average speed. Based on these three indices, Table 15.6 shows the traffic condition of each link before and after the application of ATMS. It is shown in Table 15.6 that after the application of ATMS, most of the 71 links improved on average speed.

Table 15.6 Improvement of the 71 unidirectional links after ATMS application

	Travel time	Delay	Average speed	Total[a]	Improvement percentage
Number of links improved during morning peak hours	67[b]	67	67	67	94.37
Number of links improved during afternoon peak hours	66	66	68	68	95.77
Number of links improved during common traffic hours	68	67	67	69	97.18
Number of links improved during nonpeak hours	59	58	57	63	88.73

[a] Total means if one index of one link has been improved, it will be added to the total column.

[b] The numerical value in the table means the number of unidirectional links which has been improved in travel time, delay, or average.

15.3.4.4 Intersection operation condition evaluation

Thirty signalized intersections were selected for using as the evaluation intersection. Most of the 30 signalized intersections are the cross of two arterials. The data applied to evaluate were extracted from the traffic detection system, which includes the microwave detector and number plate automatic recognition system. The intersection operation condition was evaluated on 3 typical workdays: Monday, Tuesday, and Friday.

Degree of saturation evaluation

The degree of saturation of these 30 signalized intersections can be calculated based on the detected data, intersection channelization information, and signal timing plans. Interestingly, the change in the degree of saturation on each intersection exhibited a different tendency. Several of them improved, whereas the others did not. Forty-seven intersections (78.33%) performed well 1 day out of 3, and 23 intersections (38.33%) performed well 2 days out of 3.

Level of service evaluation

Similar to the result of saturation degree evaluation, the level of service on each intersection after ATMS application exhibited different change tendencies. Several of them improved, whereas the others did not. Seven out of 30 intersections performed well with improvement of 11.67%. Five intersections became worse (8.33%). In total, only two intersections were in the level of F after the application of ATMS comparing with six in level of F before the ATMS. This condition reveals that the application of ATMS has a positive effect on the level of service on intersections.

15.3.5 Social and economic benefit evaluation

The establishment and application of ATMS have a significant effect on the city's social and economic efficiency. Based on the effect on travellers, which can be transformed to economic indicators, this section evaluates how the system promotes the city's social and economic efficiency. It mainly considers the following evaluation indices: travel cost, trip time, traffic investment, and related industries.

15.3.5.1 Travel cost reduction

The main vehicle type in ATMS coverage area is the passenger car. Trucks are limited by specific time and space, so the passenger car and coach were selected for evaluation. The category of passenger car mainly includes private cars, taxis, and coach, which mainly denotes bus transit.

The total trip distance in a day for the studied area estimated based on the sample NPAR data of 71 unidirectional links is shown in Table 15.7. The saving on fuel per 100 km of passenger car and bus transit reached 0.12 and 0.16 L, respectively. According to the evaluation, the reduced travel cost in a year reached 78 million CNY.

15.3.5.2 Trip time reduction

Three different travel modes exist in Tsingdao: bus transit, private car, and taxi. Through a survey, the total trip for each travel mode in the studied area in a day is shown in Table 15.8.

According to the per capita GDP in 2014 (CNY 97734.73) and the total work hours in 2014 (1,872 h), the value of travel time in 2014 was estimated to be 52.21 CNY/h. Through a traffic survey, the total reduced trip time is 107.94 million hours in 2014, which equivalent to a saving travel time of CNY 5635.55 million in 2014.

15.3.5.3 Other social and economic benefits

Other social and economic benefits are difficult to evaluate. These benefits include traffic infrastructure investment saving, development of related industries and promotion of related technology, promotion of employment, appreciation of land value, and improvement of life quality of local people.

15.3.6 Traffic safety benefit evaluation

The establishment and application of ATMS also have an important effect on traffic safety benefits to some extent. This section mainly investigates the benefit in traffic accident reduction, traffic violation reduction, and traffic safety.

Table 15.7 Total trip distance in a day after the application of ATMS

	Bus transit	**Private car**	**Taxi**
Total trip distance in 1 day (km)	618161.71	37806934.26	3379500

Table 15.8 Total trip for the three travel modes

	Private car	**Bus transit**	**Taxi**
Total trip (1,000/d)	2475	1926	16.9

15.3.6.1 Traffic accident evaluation

The four basic indices of traffic accidents in the studied area in the past 6 years are shown in Table 15.9.

The traffic accident condition in the entire year of 2014 can be predicted based on the history data in the past 5 years and the first 10 months in 2014. The result of the prediction is shown in Table 15.10 together with the actual traffic accident condition in 2014.

Table 15.10 indicates that after the application of ATMS in November 2014, the traffic accident condition improved, revealing that ATMS has a positive effect on traffic accident conditions.

15.3.6.2 Traffic violation evaluation

Traffic violation data were extracted from the automatic violation capture system. Seven weeks data were applied to analyse the effect of ATMS on illegal acts in the road traffic network. The data after the application of ATMS are shown in Table 15.11.

Table 15.11 shows that after the first 4 weeks, the number of violations captured per device decreased, which means the violation-capture devices have a positive effect on illegal traffic acts.

In summary, a before and after assessment for the Tsingdao ATMS evaluation has been successful. The evaluation results indicate that the Tsingdao ATMS achieved good results with significant savings on time, monetary, and accidents.

Table 15.9 Four basic indices of traffic accidents in the studied area in the past 6 years

Year	Accident	Death	Injuries	Equivalent monetarily lost (million CNY)
2009	37,293	82	1,677	26.49
2010	44,694	77	1,885	29.82
2011	43,783	74	1,746	27.96
2012	46,853	86	2,331	34.48
2013	49,027	85	2,542	32.15
2014 (1–10)	42,984	75	2,352	28.19

Table 15.10 Predicted and actual traffic accident conditions in 2014

Type	Accident	Death	Injuries	Equivalent monetarily lost (million CNY)
2014 predicted	52018	86	2689	34.97
2014 actual	46892	82	2566	30.75
Change	−9.85%	−4.65%	−4.57%	−12.07%

Table 15.11 Number of violations in the studied area

	First week	**Second week**	**Third week**	**Fourth week**	**Fifth week**	**Sixth week**	**Seventh week**
Total number of violations in a week	5593	6134	13093	39550	44289	51085	53101
Number of capture devices	20	20	43	43	71	71	150
Number of violations captured per device	280	307	304	920	624	720	354

15.4 Conclusions

The introduced evaluations examples of the projects on intelligent road transport systems indicate that either simulation evaluation or before-and-after assessment can work properly for ITS evaluation in different stages and conditions. Clearly, simulation evaluation is more often used for a pre-construction evaluation; and a before-and-after assessment plays well for an after construction evaluation.

The simulation evaluation results showed that the construction of the BRT system can improve the traffic condition effectively on improving average vehicle travel speed and the road network traffic capacity. Meanwhile, with the improvement of efficiency and quality of services, BRT may attract more passengers using the public transport system.

The Tsingdao ATMS evaluation project indicated that it has significantly improved the urban traffic condition by reduced trip time, increased network capacity, and reduced traffic violations and accidents.

References

[1] Chen, Y., Xu, J. (2011) Study on evaluation system of bus rapid transit program based on Vissim simulation. Journal of Transport Information and Safety. 29(2), 52–58.

[2] Lin, P.-Q., Xu, J.-M. (2012) Modelling solving and simulation for combinatorial optimization problem of bus stopping in BRT station-group. System Engineering Theory and Practice. 32(11), 2570–2576. (in Chinese)

[3] Xiaodan, W., Junhao, H. (2015) Traffic simulation modelling and analysis of BRT based on Vissim. Proceedings – 7th International Conference on Intelligent Computation Technology and Automation, ICICTA 2014, pp. 879–882. Changsha, China.

[4] Ekedebe, N., Lu, C. Yu, W. (2015) Towards experimental evaluation of intelligent transportation system safety and traffic efficiency. in: IEEE ICC 2015 – Mobile and Wireless Networking Symposium, London, UK.

[5] Abu-Lebdeh, G., Benekohal, R.F. (2003) Design and evaluation of dynamic traffic management strategies for congested conditions. Transportation Research Part A. 37, 109–127.

[6] Zhu, F., Li, G., Li, Z., Chen, C., Wen, D. (2011) A case study of evaluating traffic signal control systems using computational experiments. IEEE Transactions on Intelligent Transportation Systems. 12(4), 1220–1226.

[7] Oh, Y.-T., Yun, I.-S., Lee, H.-P., Lee, C.-K. (2011) Evaluation on effectiveness of intelligent transport systems in Suwon. Journal of the Korea Institute of Intelligent Transport Systems. 10(2), 55–65.

[8] Kim, J., Mahmassani, H.S., Alfelor, R., *et al.* (2013) Implementation and evaluation of weather-responsive traffic management strategies insight from different networks. Transportation Research Record: Journal of the Transportation Research Board. 2396, 93–106.

Chapter 16

Overload control benefit and cost considerations

Johann Andersen[1]*, Berino Lorio*[2] *and Paul Vorster*[3]

16.1 Introduction

Overloading of heavy goods vehicles is a significant problem. Overweight vehicles lead to a number of negative issues, related to, for example, road safety, driver's safety, road degradation, environmental impact and competition.

It is reported in Europe that, on average, one in three vehicles checked is overloaded. These excess loads often exceed the maximum authorized weight by 10–20% [1]. Overload control statistics in the Province of Gauteng, South Africa indicates that up to 38% of the heavy vehicles weighed were overloaded [2].

Heavy vehicle overloading can seriously hamper economic growth within a region. This is particularly true in developing countries, where precious road infrastructure, worth millions of dollars, has been lost through accelerated deterioration of roads and inadequate attention to road maintenance.

Overloading is further exacerbated by the lack of enforcement, inadequate levels of fines, inefficient prosecution systems and the frequent occurrence of corruption at weighbridges.

Collectively, this has led to the increased use of technology to assist in measurement and management of heavy vehicle movement and associated overload control systems. This chapter explores the various technology components and technology's contribution towards the overall effectiveness of overload control systems. It is done within the context of a developing country environment, while also reflecting on the extended infrastructure requirements associated with effective overload control.

16.1.1 Effect of overloading

The major effect of overloaded vehicles is on pavement wear. The increased pavement wear contributes to premature pavement failure. This is best understood when it is recognized that the rate at which a vehicle wears down a road is

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proportional to the fourth power of its weight; the effect of 5% overload would result in a 22% increase in fatigue damage [3].

Overloading of heavy vehicles also has a negative impact on vehicle performance. Overloaded vehicles become under-powered when travelling uphill, causing lower speeds along inclines, resulting in a detrimental effect on congestion levels. The additional weight also has a negative impact on engine braking; often resulting in downhill speeding as well-reduced stability due to decreased braking efficiency.

Overloading, furthermore, leads to serious distortions in freight transport competition between road transport companies and operators. For example, in France, it was estimated that a 5-axle articulated truck operated at 20% overload all year round, could generate an additional €26,500 benefit per year [1].

16.1.2 Overload compliance measurement

Weight compliance checks can be cumbersome. In its simplest form, vehicles need to be flagged down and stopped, and then guided to the closest available certified weighing scale in case of suspected overloading. Since this can be very time-consuming and resource intensive, it should only be done when there is a clear indication of substantial overloading.

The screening of vehicles in freely flowing traffic can be assisted by the provision of permanent weigh-in-motion (WIM) installations or by directing all heavy vehicles into a side-lane or parking lot temporarily equipped with a mobile weighbridge. It should be noted that the accuracy of WIM installations is deemed to be insufficient to enable the direct issuing of a fine. It merely serves as a pre-selection aid to identify possible transgressors for closer inspection on a mobile or fixed scale.

The density of weight compliance checking is typically low, largely due to the cumbersomeness of such operations. It is further noted that traffic police are also more inclined to focus on traffic safety and ensuring smooth traffic flow, rather than dealing with consequences of overloading, that is, damages to infrastructure, associated anti-competitive and environmentally negative effects.

Inadequate density of overload compliance checking can result in increased overload indiscretions. The risk to be caught with an overloaded vehicle is comparatively low, at least when driving outside areas known for WIM installations or increased presence of enforcement personnel. Organized campaigns lose part of their effectiveness, since their location will be known and can easily be avoided. Such a campaign typically consists of a screening section, a section where suspect vehicles are flagged down and a control site with parking lot and a certified scale.

16.1.3 Need for an overarching strategy for the provision of weighbridges

Given the severity of overloading on the one hand and the challenges in curtailing it on the other, it is clear that an overarching strategy is needed to overcome this gap and increase the density of overload compliance checking [4]. One method for this is the strategic provision of numerous comprehensively equipped overload control facilities or weighbridges.

A comprehensive national or regional strategy is needed that deals with policy and regulation, guides the operational approach and indicates available budget. If these issues are not addressed and funds are utilized in an incoherent way, it can result in weighbridge facilities being sub-optimally located, improperly operated and inappropriately equipped. This all leads to ineffectiveness and waste and detracts from the credibility of overloading countermeasures.

An operational strategy should support the overarching strategy, ensuring that the weighbridge facility is a direct result of the intended utilization thereof. Furthermore, it is imperative that priority routes are identified and that the weighbridges are located on the roads with the highest heavy vehicle traffic volumes thus maximizing its impact.

The overarching strategy should also take cognisance of future directions in overload control approaches. These could include advances in heavy vehicle on-board weighing [1], or the non-intrusive environment of virtual weigh stations [2].

16.1.4 Provision of a traffic control centre

The implementation of an overarching strategy could culminate in the provision of a number of traffic control centres (TCC) along priority corridors. A TCC is instrumental in providing a full range of facilities, incorporating a weighbridge or overload control facility, to efficiently and effectively undertake an overload control process at minimum disruption to relatively large volumes of heavy vehicle traffic.

A good example of a TCC provided on both sides of a national road is shown in Figure 16.1.

Figure 16.1 Layout of the Heidelberg TCC, South Africa (Source: SANRAL)

16.2 Overload control systems

Overload control systems refer to the Intelligent Transport Systems (ITS) incorporated into an overload control facility to improve the operation and management of such a facility. This section considers the components of overload control systems and the operation of overload control or weighbridge facilities as part of a TCC.

16.2.1 Components of overload control

Overload control facilities or weighbridges would typically be comprised of the following elements:

- the TCC building, housing the operations
- roads and paving, allowing access and circulation on the premises
- the static (typically multi-deck) scale
- various services, such as water and electricity
- *control systems*
- equipment and furniture
- vehicle testing equipment

The *control systems* component refer to technology or ITS applications for overload control facilities. The extent to which technology is utilized, is largely dependent on user needs and should be mapped and described in the operational concept of the overload control facility.

Typical control systems components with a brief description are provided in Table 16.1.

Vehicle testing facilities are often provided in conjunction with weighbridge or overload control facilities.

The vehicle testing station (VTS) consists of a ventilated and illuminated inspection pit equipped with the following equipment built into the structure:

- brake tester,
- vehicle height gauge,
- linkage play detector,
- hydraulic jack (pair), and
- wheel alignment tester.

In addition to the installed equipment, other measurement instruments are typically provided, including:

- headlight tester,
- noise level meter,
- alcohol breath tester, and
- vision tester.

The VTS facility is furthermore supplied with a range of tools to assist with the inspection process.

Vehicles should ideally be tested while under full load (i.e. before any transfer of load has taken place) so that the characteristics of the laden vehicle can be determined.

Table 16.1 Typical ITS control systems components

Control systems component	Description
1. Safety and security surveillance	The provision of CCTV cameras with recording equipment. The cameras would often be positioned to have full coverage of the site.
2. Access control	The provision of personnel identification objects, readers, and an access control database of personnel with access history.
3. Vehicle identification	The provision of vehicle identification equipment, such as automatic number plate recognition (ANPR) cameras, general identification cameras, vehicle presence sensors and vehicle classification sensors.
4. Driver identification	The provision of a driver license scanner with an interface to the national traffic information system.
5. Communication hardware	The provision of hardware to establish communications between all equipment that is part of the system.
6. Traffic control equipment	The provision of all electronic signs, such as traffic lights, lane instruction variable message signs, as well as booms where necessitated.
7. Vehicle weighing equipment	The provision of the static scale as well as the various WIM sensors.
8. Human interface equipment	The provision of all equipment necessary for the human operators to interact with the system. It includes computer equipment, audible and visual alarm systems.
9. Data processing equipment	The provision of servers and other hardware or infrastructure to enable data processing.
10. Prosecution system	The provision of a system that allows the compilation of traffic offences and its enforcement.
11. System integration	The provision of hardware and software that establishes the integrated use of all of the components listed.

This is especially important for the brake test as the required braking force is a function of the measured axle load.

16.2.2 Concept of operations

It is critical that the operational concept is well defined and mapped to the weighbridge or overload control facility layout. The layout of weighbridges is affected by a number of factors, which includes (i) a clear definition of the overall purpose of the facility, (ii) whether screening or prosecution or both takes place, and (iii) the anticipated hourly or daily volume of heavy vehicles to be weighed.

In the case of a full TCC, the facility would normally operate on both sides of the road and would typically include within its operational system the following [4]:

- A high-speed WIM (HSWIM) screening device in the main traffic lane (screener lanes);
- A low-speed WIM (LSWIM) screening device to confirm vehicles suspected to be overloaded as indicated by the HSWIM; and
- A static platform scale for accurately weighing axle and axle unit loads and total vehicle or combination mass for prosecution purposes.

Figure 16.2 Typical screener lane installation, Zebediela, South Africa (Source: SANRAL)

WIM installations under free flowing traffic conditions require permanent installation into a selected and prepared road section. The section needs to be flat so that no vertical movement takes place and also disallows acceleration or deceleration. Accuracy of WIM stations under free flowing traffic conditions is not sufficient for directly fining a vehicle. It only serves as a screening device and an indicator that the vehicle requires closer inspection on a static scale.

A typical screener lane installation is depicted in Figure 16.2, while Figure 16.3 shows the covered area with the various boom-control systems that houses the fixed scale.

16.3 Benefit–cost methodology

This section explores a methodology to perform a benefit–cost analysis, starting with a review of the key assumptions related to the benefits and costs to be included in the analysis of a TCC.

It is important to keep in mind that the analysis considers economic costs and therefore includes more than simply financial values generated by, or absorbed by the overload control schemes.

The purpose of the TCC is to bring about a change in the status quo of freight transport along a specific corridor. As such, its benefit is measured in the extent to which it can bring about a reduction in existing overloading trends. The benefit–cost analysis must therefore clearly set out the key assumptions

Figure 16.3 Covered static scale and TCC building, Zebediela, South Africa (Source: SANRAL)

present in the scenario with a TCC, versus the do-nothing scenario over a specified time period.

Costs and benefits are converted to a financial value, incurred or received, at various points over the course of the analysis timeframe. The following sections describe each cost and benefit, and how they are distributed over the course of the analysis timeframe.

16.3.1 Costs

As discussed earlier in this chapter, the construction of an overload control centre consists of more than simply the ITS components. It includes construction of road pavements, buildings, scales, vehicle testing pits, water and electrical reticulation, and other infrastructure. The component more specifically associated with ITS, consists mainly of the automatic vehicle identification, WIM, decision systems, traffic control and prosecution systems. These systems typically form a relatively small part of the overall construction costs but deemed to contribute disproportionately to the success of the facility.

In this chapter, the combined benefits and costs of the overall overload control system are considered, as opposed to considering the cost and benefit of only the electronic systems contained therein.

The costs associated with the provision of overload control systems are primarily financial values associated with construction (capital expenditure), and the operation and maintenance of the facility (operating expenditure).

16.3.1.1 Capital costs

The capital costs include all expenditure associated with the design and construction of the TCC. It typically includes the following:

- consultation: design, tendering and construction supervision fees
- land expropriation (if necessary to obtain land for this purpose)
- earthworks
- roadworks and structures such as bridges
- building works (TCC building)
- water supply works
- cost of establishing electrical supply connection
- control and monitoring systems
- static scale for weighing vehicles
- vehicle testing pit and equipment (if VTS is included)

The above costs must include all works associated with the TCC, screener lane and additional access roads to enter/exit from the facility.

The capital costs are included in the cash flow series as an expense at commencement (typically year 0).

16.3.1.2 Operating costs

The operating costs include salaries and wages of personnel, service costs such as water, electricity and sanitation. Operations costs also include transport costs, electronic communications costs and consumables.

These costs are incurred throughout the operations period of the facility and are shown as a series of recurring outgoing cash flows.

16.3.1.3 Maintenance costs

Maintenance of the facility includes both preventative and corrective maintenance. Naturally, the occurrence of corrective maintenance needs cannot be predicted and typical average values are usually applied. For electronic systems, these values are often in the order of 20% of the original capital expense per year, while civil works and buildings are assumed to have a lower maintenance cost rate at approximately 10% of the capital value per year.

16.3.2 Benefits

Benefits refer to the economic improvement brought about by a particular facility, in terms of financial income or reduced cost. The benefits associated with the provision of overload control facilities are primarily financial savings associated with reduced pavement deterioration, income from fines and savings from reduced crashes on the affected routes.

16.3.2.1 Reduction in pavement deterioration

The primary reason for enforcing load limits is to protect the road from being damaged. It is known that the amount of damage caused to a road by the rolling of wheels over it, is dependent on the force being exerted by the wheel (caused by the weight of the vehicle on top of it). The amount of damage is furthermore not only proportional to downward force, but rather exponentially related [3] thereby increasing disproportionately as the wheel loads become greater.

The benefit in the case of a reduction in pavement deterioration is therefore not an income, but rather a reduction in future expenses to maintain road infrastructure. For this reason, a benefit–cost study for overload control must be conducted as a comparison with the do-nothing alternative, in which it must be assumed that overloading will continue unabated at the current levels.

16.3.2.2 Fines income

The income from fines is derived as amounts payable by vehicles found guilty of transgressing load limits. This is a financial value received by the law enforcement agency.

Ironically, the more effective the overload control system becomes, the smaller this benefit becomes. It is generally found that the financial values received from fines generally have little impact on the benefit to cost (B/C) ratios and other investment appraisal indexes.

16.3.2.3 Reduction in crash costs

The load limits as set out in road traffic laws are established not only for the protection of road infrastructure, but also for ensuring safe operation of the vehicles carrying the loads. The specifications set by manufacturers that design and manufacture the vehicles provide an indication of safe working loads. By exceeding these values, the possibility of causing damage to the vehicle, and/or adversely affecting the driving characteristics of the vehicle becomes likely. For example, overloading would place extra strain on braking components which could ultimately lead to overheating and failure thereof.

The incidence of overloading along a corridor reduces significantly following the commissioning of a new TCC. A TCC is furthermore useful to provide a secondary purpose that in turn improves the longer term livelihood for its operations. For this reason, the addition of vehicle testing facilities at the TCCs should be considered favourably.

The combination of overloading and vehicle fitness enforcement is expected to reduce crash rates, even though the quantitative value is not easily estimated.

Although there has been some research into the economic costs of crashes, it remains a challenge to estimate the reduction in the crash rates as a result from reduced overloading and improved vehicle fitness. Consequently, these benefits are often used qualitatively rather than quantitatively.

16.4 Application

16.4.1 Data/inputs needed

Each of the different benefits and costs require assumptions or information to estimate the value thereof. The following sections briefly deals with how these values are determined.

16.4.1.1 Construction costs

Construction costs are typically either estimated by engineers tasked with the design of the facility, or derived from comparison of other similar facilities that have been constructed previously.

A detailed cost estimate will require:

- Knowledge of the site (i.e. in cases where the site has already been selected) to estimate the sizing and access arrangements;
- Design standards (particular with regard to the screener lane); and
- Concept of operations/envisaged facility layout including proposed routeing of vehicles through the site.

16.4.1.2 Operating costs

Operating costs can be estimated by considering the number of persons who will be working at the site and their level of remuneration. Some of the information needed would include:

- Concept of operation in terms of staffing structure and their roles and responsibilities,
- Information on staff remuneration, and
- Typical utility bill values for similarly sized buildings.

If available the operating cost of existing facilities can be used as a valuable benchmark.

16.4.1.3 Maintenance costs

Only the preventative maintenance costs can be estimated in detail, while corrective maintenance costs are based on the occurrence of failures and are thus more unpredictable.

Typical values are available from literature, alternatively existing facilities could be consulted to obtain benchmark values.

16.4.1.4 Pavement damage reduction

Determining the reduction in pavement damage is often the most analytically challenging task of an overload control benefit–cost assessment. It is also usually the most significant of the benefits.

Pavement damage is a combination of the volume of heavy vehicles (expressed as axle loads) and the loading of vehicles, combined with the distance that the vehicles travel. In determining the status quo, it is necessary to collect information on:

- The mix of vehicle types passing the TCC, including the vehicle and trailer configurations and number of axles;
- The axle-loading trends of those vehicles; and
- The trip distribution patterns (trip origins and destinations [OD]) of the vehicles passing the facility.

The above data can be collected by means of a combination of classified traffic counts, axle-loading surveys and OD surveys.

The presentation of trip distribution is based on the definition of a zonal structure (subdivision of the total study area into a number of smaller contiguous parcels of land covering the entire study area). The study area must be sufficiently large to incorporate the OD of the majority of trips passing the TCC (if trips are truncated the benefit will be understated). In the case of TCCs located along routes of national significance, the study area may be vast.

It is, however, not important to extend the study area beyond the area for which the benefit is to be determined (e.g. benefit incurred by neighbouring countries may not be of interest to the infrastructure provider in which the TCC is located).

Distance travelled by heavy vehicles

The trip distribution pattern is expressed as a matrix with the origins listed along the vertical axis of the matrix and the destinations along the horizontal axis in a manner similar to typical transport demand modelling practice. Each cell of the matrix (e.g. to be denoted as row *i*, column *j*) therefore represents the number of trips made by heavy vehicles travelling past the TCC as part of a trip from zone *i* to *j*. The matrix should ideally contain annualized trip volumes (annual average daily heavy vehicle or truck traffic).

The reduction in pavement deterioration is then calculated by multiplying the annual truck traffic matrix (containing the traffic volumes of heavy vehicles) with another matrix containing representative distances between each OD pair (i.e. from zone *i* to *j*) to determine the estimated annual distance that trucks passing the proposed facility travel. (Note that this operation refers to cell-by-cell multiplication, not linear algebra matrix multiplication.)

The above calculation yields the total distance that all heavy vehicles travel during the course of making trips which pass the TCC, over the period of a year, in both directions.

Loading of heavy vehicles

From the load surveys the average E80 (equivalent 80 kN axle loads) per vehicle can be determined. The dataset from a load survey should contain detailed information such as the axle configurations of the vehicles and the load on each axle. The actual load survey information provides the status quo scenario of vehicle loading.

The next step is to estimate the vehicle loading for the scenario where it is assumed that all vehicles are legally compliant to the stipulated load limits, that is, after the successful implementation of the TCC. It is necessary to assess the loading survey dataset, and to review each vehicle's loading against the various vehicle loading regulations as may be contained in the specific country's road traffic laws. Regulations may relate to individual axle loads, axle-group loads, or total vehicle mass, for example. Where transgressions are identified, the measured load should be reduced by an amount no greater than necessary for no transgressions to be present anymore, that is, to the maximum allowed load limit. This dataset of reduced loads represents a legally compliant loading scenario and can be used to calculate the average E80 per vehicle in a similar manner as was done with the originally measured dataset.

The total pavement deterioration of the two scenarios (status quo scenario and legally compliant scenario) can then be calculated by multiplying the total truck travel distance by the rate of deterioration expressed as a monetary value for every kilometre that the E80 axle load travels.

$$\text{Pavement deterioration} = (\text{Annual truck traffic OD matrix}) \times (\text{Distance matrix}) \times \frac{\text{monetary value}}{\text{E80 km}}. \qquad (16.1)$$

16.4.1.5 Fines income

The income from the collection of fines is challenging to estimate deterministically. First, the rates of transgression during steady-state operations can vary widely; second, the extent of overloading (thus affecting the value of the fines) can vary widely; and third, the value of fines ultimately paid is highly uncertain (especially in developing countries where non-payment of road traffic fines is widespread). In some cases, transgressors will apply for (and be granted) a reduction in the fines value by the local judiciary. Obtaining fine collection rates from existing facilities is typically the method most likely to yield a reasonable estimate for assessing a proposed TCC.

16.4.1.6 Reduction in crashes

While estimates related to the cost of different types of crashes are typically available in the research literature for a specific country, accurately predicting the reduction in crash rates, or obtaining relevant local literature in crash rate reduction is unlikely.

16.4.2 Method of calculating net present value

Calculating the net present value (NPV) of the various values, and subsequently indices like the B/C ratio, internal rate of return (IRR), or other investment evaluation indices are well documented and are not discussed in detail here.

16.5 Case study

The following case study relates to the eTeza TCC in South Africa [5].

The eTeza TCC is located on the National Route 2, a route of national significance that carries mainly traffic between the North Coast of South Africa (the coastal region North of Durban), notably the Richardsbay harbour and the North-Eastern portions of the Country (Province of Mpumulanga) that is known for extensive mining and mining-related activity.

The TCC is located in a rural area, with little to no practical alternative routes without adding significant distance to most trips. The layout of the eTeza facility is shown in Figure 16.4. The operational environment for this facility is discussed in detail in the following section, focusing on the operations of:

(i) The external road network and approaching the screener lanes, and
(ii) Within the premises of the TCC.

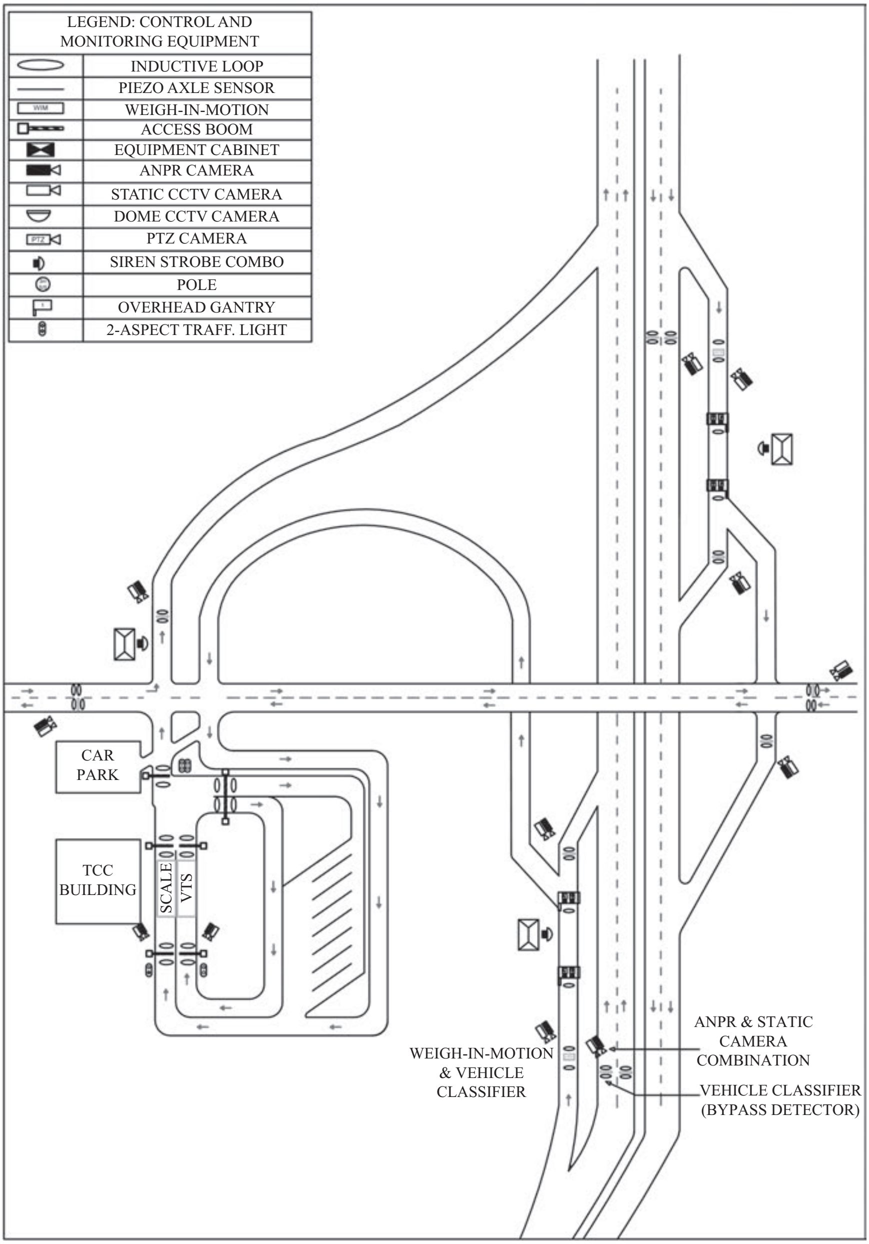

Figure 16.4 Layout of the eTeza overload control facility

16.5.1 eTeza overload control scheme operations

16.5.1.1 Operations on the external road network and approaching screener lanes

The screener lanes are accessed from the N2 mainline in each direction. The eTeza TCC is slightly different from the conventional full TCC configuration referenced in section 16.2 due to its integration with an access interchange for general traffic.

All heavy vehicles, but also any other traffic desiring to turn onto the crossroad are required to keep left and take the slip lane into the WIM screener lane.

Each vehicle passing over the WIM sensor, and associated identification and classification equipment, is assessed. The system determines the load on each axle, determines the axle configuration, and applies the regulatory calculations to determine whether the vehicle appears to be overloaded.

If a vehicle appears not to be overloaded, it may proceed in either direction at the following split, where the left leg of the fork leads to the crossroad, and the right leg of the fork leads back to the mainline lanes of the N2.

If however, a vehicle appears to be overloaded, electronic signage (on a series of two road signs mounted on overhead gantries) will indicate that the vehicle must take the left leg of the split and continue to the TCC.

A closed cordon of vehicle identification points around the TCC and interchange supports an alarm system that is activated when a vehicle that has been identified as potentially overloaded attempts to exit the area without having passed the static scale within the TCC. It is the responsibility of traffic authorities to respond to alarms of errant vehicles. For this purpose, several staging points have been supplied in the area.

16.5.1.2 Operations within the premises of the TCC

Having entered the TCC a vehicle's routeing is prescribed by the automated decision system using a combination of traffic lights and booms, supported by identification equipment consisting of inductive loops and ANPR cameras.

There is a control node that controls (a) the exit from the scale, (b) the exit from the VTS, (c) the exit from the TCC, (d) the entrances to holding yard (and back to the static scale), and (e) the entrance to the lane leading back to the VTS. The control philosophy is that only one vehicle may be present in the control node at any time and all booms are normally closed.

A heavy goods vehicle entering the TCC follows the internal road and arrives at the static scale. Once the vehicle has been weighed, the system will determine whether the vehicle is to be released (in which case the booms from the scale exit and the TCC exit will be opened), or detained inside the TCC until its load has been corrected. If the vehicle is overloaded, it would first be routed to the VTS for testing (in which case the booms from the scale exit and entry to the VTS lane would be opened). Once testing is completed, the vehicle will be routed to the holding yard (by opening of the booms from the VTS to the holding yard).

Depending on the transgression (load or vehicle fitness) vehicles are allowed to circulate over the static scale and VTS until such time as the load has been corrected or an officer deems it safe to exit the TCC. Typically, a freight carrier would send a relief vehicle to the TCC onto which some of the load could be moved to reduce the load on the overloaded vehicle. The relief vehicle would be required to follow the same entry procedures into the TCC, but would announce its intention to access the holding yard so that it is admitted to the TCC and not released automatically due to its legal load.

16.5.2 Cost–benefit analysis

The cost–benefit analysis for the eTeza TCC was performed over a 20-year period using typical local inflation and interest rates.

Table 16.2 summarizes the costs and estimated benefits.

Despite the cautionary tone in this chapter when estimating traffic fines and accident reduction, an estimate was nonetheless calculated using typical crash rates (typically expressed in crashed per million vehicle kilometres) that are available from road traffic safety studies, the costs associated with crashes and a coarse percentage-based reduction value.

Traffic fines income was estimated using data obtained from existing TCCs elsewhere in the country. The typical income is related to the total traffic at a TCC and factored in accordance with the traffic volumes observed at the eTeza TCC.

From Table 16.2, it can be seen that in the case of eTeza TCC the reduction in pavement damage exceeds the other benefits by far, and the overall B/C ratio of the facility is 3.73, thus benefits significantly exceeding costs.

In the case of the eTeza, TCC the favourable B/C ratio is mainly ascribed to:

(a) A high level of current overloading; and
(b) The presence of a large proportion of long-distance trips passing the TCC.

Table 16.2 Summary of costs and benefits for the eTeza TCC

	Annual (2014 ZAR)
Benefits	
Pavement damage cost saving	R 115 027 489
Total fines income	R 13 741 365
Crash reduction savings	R 9 862 588
Costs	
Capital expenditure	R 336 830 001
Total operating and maintenance excl. officers	R5 809 410 (p.a. @ 2014)
Officer salaries	R 8 937 394 (p.a. @ 2014)
NPV of benefits	**R 2 082 391 735**
NPV of costs	**R -558 342 683**
Overall NPV	**R 1 524 049 053**
B/C ratio	3.73
IRR	43%

16.6 Practical considerations for designing and operating TCCs (and lessons learnt)

16.6.1 Alternative routes

When one considers the observed behaviour of some freight carriers and drivers (at the hand of accounts from people involved in operating TCCs) then overloading is clearly considered a lucrative activity. Anecdotes about the extents to which operators that knowingly overload will go to avoid being prosecuted abounds when discussing the topic with enforcement officers and operators. Enforcement clearly does not simply have to deal with raising awareness to unsuspecting carriers who overload by chance, but rather with sophisticated freight carriers that will purposefully overload and go to great lengths to evade prosecution.

For the above reason, the placement of TCCs must be such that there are no convenient alternative routes. Using an alternative route must ideally incur sufficient additional cost (in travel time and travel distance) that the freight carriers will deem it less costly to simply load their vehicles within the legal loading limits. This principle however makes the placement of TCCs more practical in rural/intercity locations where the road networks are sparse. Where a small number of alternatives do exist, technology can be used to operate more than one screening facility, and to route potentially overloaded vehicles to a common static scale. Such solutions could use Global Positioning System (GPS) or Radio-frequency identification (RFID) tags for keeping track of vehicles between the screener and static scale.

16.6.2 Screening rate and hours of operation

The overloading discouragement effect of a TCC is clearly related to the likelihood of a transgressor being identified and prosecuted. In this regard, the use of screener lanes that measure all vehicles is highly recommended. For similar reasons, the hours of operation should ideally be 24 h/day.

16.6.3 Overlapping areas of influence

From the method described in section 16.4, it is clear that the trip distribution (OD) of trips that pass by the TCC is pivotal to the amount of benefit derived. If, however, other TCCs have an overlapping area of influence (consider e.g. that two TCC are placed not far from each other on the same route), then it is clear that the benefit of the TCCs cannot be considered individually. In such cases, it would be important to identify those vehicles (traffic volumes of the specific OD pairs) that passes both facilities. The benefit in reduced pavement damage for these trips must be shared between the two (or more) TCCs.

16.6.4 Statistical screening errors and variable decision thresholds

Due to the inherent inaccuracies present when attempting to measure a vehicle in motion, WIM systems are generally not considered sufficiently accurate for the purposes of prosecution. In these cases, it can only be used to assist law enforcement as an indicator that a vehicle may be overloaded. Its use is therefore also subject to the statistical hypothesis testing errors:

- Type 1 error: identifying a vehicle as overloaded when it is in fact not overloaded
- Type 2 error: not identifying a vehicle as overloaded when it is in fact overloaded

Naturally, the occurrence of type 1 and type 2 errors are dependent on the accuracy of the WIM screener (which is a combination of several factors such as the evenness of the roadway leading up to and beyond the axle scale, the accuracy of the scale itself, the speed of the passing vehicle among others).

To increase the accuracy of the screening process, the construction of the WIM screener is performed according to specific standards (e.g. the ASTM 1318 standard) [6].

It is possible to introduce an adjustable grace value or threshold value that is applied to the WIM measured values as part of the decision process for sending a vehicle from the WIM screener to the static scale. While this grace/threshold value does not make the process more accurate (i.e. cannot eliminate the errors described above), it can be used to reduce one type of error at the detriment of the other type.

It is important to note that a type 1 error adds to the workload of the TCC, while it does not contribute to the prosecution rate, whereas a type 2 error means that an offender has evaded prosecution.

The use of sophisticated systems with configurable parameters means that the thresholds/grace values can be adjusted over time so that initially (when overloading is high) only the worst offenders are directed into the TCC so as not to add or cause congestion in the TCC. It is thus unnecessary to design the TCC to deal with the number of offenders present before the TCC is constructed, but rather to design for the expected volume of offenders that is estimated to be present under a steady state (i.e. once overloading levels have stabilized after commissioning of the TCC).

16.6.5 Cost versus complexity trade-offs (qualitative discussion)

When designing the control and monitoring systems for a TCC, it is often tempting to aim for a design that would eliminate fraud and corruption entirely by automating all processes, and monitoring every aspect of the TCC including the vehicles and persons in it.

In the context of a developing country, it is important to consider the maintainability of systems at locations that are often far removed from technical support and maintenance teams.

Resistance from personnel (in some cases, high ranking and influential persons) that are not used to working under constant surveillance should not be ignored.

Systems should only be as complicated as necessary to perform its objective, and should not prevent operation of the site in case of minor failures of equipment.

16.7 Conclusion

This chapter has given a broad overview of the various aspects of overload control. It has shown the context for technology applications as a supporting element of overload control systems. The typical ITS control system components were identified and clearly defined. The role of various technology components must be clearly mapped to an operational concept. It is noted that benefit and costs analysis for overload control system should incorporate all aspects, and not consider the ITS elements in isolation.

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The contents of this chapter reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents to do not necessarily reflect the official views of, or policy of SANRAL. This chapter does not constitute a standard, regulation or specification.

References

[1] Rapp Trans AG. *Study on Heavy Vehicle On-Board Weighing*. Brussels: Rapp Trans AG Transport & Environment; 2013.
[2] Bosman J, Essa I, Andersen SJ. Overload control for the Gauteng Freeway Improvement Project. *Proceedings of the 4th SARF/IRF Regional Conference for Africa*; October 2010; Cape Town: South Africa.
[3] Znidaric A. Heavy-duty vehicle weight restrictions in the EU: enforcement and Compliance Technologies. ACEA Scientific Advisory Group Report; 2015.
[4] Pinard MJ. Guidelines on vehicle overload control in Eastern and Southern Africa. Sub-Saharan Africa Transport Policy Program. Working Paper No. 90; 2010.
[5] Techso. eTeza traffic control centre benefit cost study. SANRAL Project Report; 2014.
[6] ASTM International. Standard specification for highway Weigh-In-Motion (WIM) systems with user requirements and test methods. ASTM E1318-02; 2014.

Part IV

Discussion and conclusions

Chapter 17

Evaluation of intelligent road transport systems: key findings, challenges and future work

*Meng Lu**

17.1 ITS deployment and evaluation – summary and key findings

Intelligent Transport Systems (ITS), based on Information and Communication Technologies (ICT), have been developed and deployed for more than three decades. The core technologies in the ITS domain are positioning (both relative and absolute, and using various sensors) and telecommunication, and different options can be combined in different ways to create stand-alone in-vehicle systems and cooperative systems (using communication between vehicles and with the infrastructure) (Lu *et al.*, 2005). ITS applications cover all transport modes (road, rail, waterborne and air), and both for people (mobility) and goods (logistics). This chapter targets road transport – part of surface transport. ITS applications for road transport are reaching the stage of large-scale deployment, for instance in the following domains:

1. private vehicles and travellers (examples: advanced driver assistance systems (ADAS)[1], telematics[2] and better information for travellers);
2. public transport (examples: e-ticketing, multi-model services, vulnerable user services via data exchange and telecommunications);
3. commercial vehicles and intelligent logistics (examples: tracing and tracking goods, telematics, document automation in supply chain management, also called e-freight);
4. infrastructure-based traffic management and control (examples: extended Floating Car Data [xFCD], Traffic Control Centre [TCC], Traffic Information Centre [TIC], Variable Message Signs [VMS], incident and tunnel management, road pricing).

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[1] ADAS is a collective name for a whole range of ICT-based in-vehicle systems, intended to support the driver in the driving task. ADAS applications are typically stand-alone systems, meant to improve traffic safety, efficiency, network capacity and comfort of driving, and hold the promise to also improve driver performance, e.g. by avoiding or correcting human error.

[2] Telematics (telecommunication and informatics) can be defined as provision of information and services, via wireless communication, to and from vehicles and their occupants.

ITS development enables safer, more efficient, cleaner, more accessible and more homogenous transport systems. Enabled by the rapid development of technology, the past years saw a proliferation of consumer electronic devices, ubiquitous commercially-available wireless coverage, emergence of new communication and sensing technologies, while connected vehicles and automated driving are going mainstream. Note that different approaches for implementation of automated driving exist, based either on just autonomous systems, or on a combination of autonomous and cooperative systems.

While ITS applications were booming, aiming to improve driving comfort, traffic safety, transport efficiency, environment and energy efficiency, their impacts were not comprehensively and systematically evaluated and documented. The contribution of this chapter is to fill this gap by providing an overview of ICT-based intelligent road transport systems, by presenting and discussing adequate evaluation methods for different stages of ITS development and deployment in various regions (e.g. Europe, North America, Asia, Pacific and South Africa), and by providing and reviewing related evaluation results. There is a common understanding about the rationale for the evaluation of ITS impacts, which can be summarized as follows (Studer, 2015):

1. demonstration of the benefits of ITS implementations;
2. enabling comparison among various ITS project results, even in different contexts;
3. facilitating the choice of the most appropriate ITS solution, based on previous experiences, for specific problems or contexts;
4. supporting forecast of benefits of future implementations;
5. avoiding repetition of bad practices (lessons learned);
6. checking achievement of the objective(s);
7. justifying investments.

Two levels of evaluation can be distinguished: microscopic evaluation and macroscopic evaluation. The former provides inputs to the latter. Microscopic evaluation targets technical assessments and performance evaluations. Main methods at the microscopic level are tests, (on-line or off-line) simulation, (theoretical) modelling and qualitative analysis. Macroscopic evaluation targets impact evaluations (benefits and costs) for decision-making. Two categories of commonly used (macroscopic) evaluation methods can be distinguished (Lu, 2007): (1) economics-based evaluation methods, e.g. cost–benefit analysis (CBA) (Boardman, 1996; Hauer, 2011), cost-effectiveness analysis (CEA) (Trilling, 1978), planning balance sheet (PBS) (Lichfield, 1956, 1964) and goal achievements matrix (GAM) (Hill, 1968); and (2) normalization based evaluation methods, e.g. analytic hierarchy process (Saaty, 1980, 1995), simple additive weighting (Yoon and Hwang, 1995), technique for order preference by similarity to ideal solutions (Hwang and Yoon, 1981), ÉLimination Et Choix Traduisant la RÉalité (Roy, 1968), Preference

Ranking Organisation METHod for Enrichment Evaluations (Brans, 1982, 1996; Brans *et al.*, 1986), fuzzy multiple criteria decision aid (Zadeh, 1965) and grey relational analysis (Deng, 1982; Guo, 1985). Each method from both categories in essence provides a procedure to process the evaluation matrix in order to provide a preference ranking of the alternatives.

Key Performance Indicators (KPIs), qualitative evaluation and educated guess can also be used for macroscopic evaluation. KPIs can only target the benefits. Proper determination of common KPIs may improve the possibility to use and apply the results of ITS evaluation in different countries and regions. The European Commission (EC) determined some KPIs addressing ITS for road transport, and intended to encourage member states to use these common KPIs at a European level (see EC, 2015a, 2015b, 2015c). However, it seems that substantial commitment of member states to use the proposed KPIs is lacking.

ITS deployment KPIs

Road network covered by information gathering infrastructures

Road network covered by

- incident detection and management
- traffic management and control measures
- cooperative-ITS (C-ITS) services and applications

Road/transport network covered by

- real-time traffic information services
- dynamic travel information services
- freight information services
- 112 eCalls

Benefit KPIs

- Change in journey time
- Change in load factor
- Change in accident numbers and severity
- Change in CO_2 emissions

Financial KPIs

- Annual investment in road ITS
- Annual operating and maintenance costs of road ITS

The results of the evaluation of intelligent road transport systems presented in this chapter are summarized in Table 17.1. Note that the results of the evaluation of impacts can show substantial differences in different countries and regions, due to differences in assumptions, (character of the) input data, methods used, and/or ways of using a same or very similar method. Therefore, evaluation results should be interpreted with great care and interpretation should be based on proper understanding of the assumptions, the available data and the approach used. Appropriate comparison and analysis cannot be done by merely sticking to the numbers of benefit and costs.

17.2 Lessons learned, research needs and challenges

A substantial number of evaluation studies concerning intelligent road transport systems have been carried out in different countries and regions. However, the related evaluation results are often:

1. not systematically published;
2. not accessible elsewhere;
3. not comparable with each other; and/or
4. not easily applicable to other regions or countries for estimation of impacts.

Different evaluation methods were used in the past years, and substantial differences may occur in the way a method is used in different situations. Furthermore, data for doing the evaluation are often not well structured, and certainly not always available, or not available with sufficient detail. In addition, the assumptions made for evaluation are often not clearly and explicitly provided, and an adequate discussion of the shortcomings of an evaluation method and how to best address these is regularly lacking in evaluation reports. The various evaluation methods that are used in practice do all have shortcomings and generally lack a strong theoretical basis. Therefore, it remains a challenge to define adequate and acceptable approaches to do evaluation, based on current or new (integrated) methods.

Both economics- and normalization-based methods have their advantages and limitations, and the results often give a room for arguments. Economics-based methods express attribute values as much as possible in a monetary unit. In practice, this often appears to be costly, and sometimes inoperable. But the less stringent this condition is applied (e.g. in CEA, PBS and GAM), the less feasible it becomes to obtain a clear analytical answer. Normalization-based methods try to remove the issue of dissimilar units, but none of them has rigorous theoretical foundations. Each of the normalization-based methods is, in fact, no more than an advanced calculation recipe, and some of these methods are not always able to provide an unambiguous ranking order. The presence of multiple attribute value types that cannot be expressed in monetary units precludes by nature the use of an economics-based method (Lu, 2007).

CBA has been widely used, especially in the United States, in the domain of ITS in the past decades to justify the investment of public money and to establish priority between projects. CBA aims to provide representative results for decision-making, but there is no ground to believe that the CBA tool fits the aim, due to its deficiencies,

Table 17.1 Summary results and key findings of the evaluation of intelligent road transport systems (based on chapters 2–16)

Chapter no.	Description of intelligent road transport systems implementation	Approach	Key findings and/or results
2	ITS evaluation needs, especially from the policy perspective	Questionnaire, desk research, interviews	Independent evaluation; non-stand-alone decisions; harmonized evaluation method; availability and quality of input data
3	Overview of evaluation methods and frameworks	Extensive literature review, expert knowledge and experience	Evaluation of ITS projects (based on valid and solid methods) is very important; a socio-economic evaluation is essential to quantify the impacts on society and assess these from both a technical and a market perspective; there are advantages and shortcomings in the methods
4	Variable speed limits (VSL), ramp metering, dynamic lanes, road pricing in urban areas, information services via Internet, indication of the journey time	Extensive literature review, expert knowledge and experience	Review of ITS evaluation in Europe and the United States; introduction of an ITS Toolkit; comparative analysis of various ITS applications in different countries by using various indicators
5	Autonomous vehicles from a network perspective	Expert knowledge and experience, case study	Network investments create economic value; a case study of firm-level productivity is presented; evaluation of autonomous vehicles from an ITS network perspective, and related challenges are addressed
6	ADAS functions, autonomous and cooperative systems	Literature review, expert knowledge and experience	Comprehensive discussions on method and implementation of field operational tests
7	Assessment Method for Demand and Traffic Management (AMDTM)	Determination of interactions, costs, benefits, other impacts, priority order, weights; performing MCA and sensitivity analysis; discussion and decision-making	Benefits-oriented instead of costs-oriented evaluation

(Continues)

Table 17.1 (*Continued*)

Chapter no.	Description of intelligent road transport systems implementation	Approach	Key findings and/or results
8	Technical assessment tools for testing and validation, and application in ISA++ for determining proper driving speed limit	Simulator and real driving conditions	Methods and procedures for validation of complex in-vehicle systems
9	Investigation of how new data forms can contribute to the evaluation; and how the impacts of ITS schemes can be evaluated	Literature review, expert knowledge and experience, comparative analysis	Compilation of the new mobility scheme and social innovation scheme; an extension of the traditional evaluation approach is needed; the ethical issues are addressed
10	C-ITS services: local dynamic event warnings, in-vehicle speed and signage, travel information and dynamic route guidance	Ex-ante impact assessment (previous studies, expert judgement)	No. of fatalities: −4% to −7% No. of non-fatal injuries: −5% to −8% No. of injury accidents: −5% to −7% Time spent travelling: −11% to +4% Petrol and diesel: −10% to −1% CO_2: −9% to +2% NOx: −5% to −10% $PM_{2.5}$: −1% to −10%
11	Automated driving	Impact and socio-economic assessment	Potential impacts of automated driving are classified (by stakeholders and timelines); methods and approaches for assessment of functions are reviewed; also challenges for impact and socio-economic assessment in the context of automated driving are addressed
12	ADAS and automated driving	User-related evaluation	Main measurement issues: driver behaviour, driver performance, understanding the system, trust and reliance, transfer of control, mental workload, stress, perceived boredom, fatigue, situational awareness, out-of-the-loop performance, complacency, usability, acceptance, perceived benefits

(Continues)

Table 17.1 (*Continued*)

Chapter no.	Description of intelligent road transport systems implementation	Approach	Key findings and/or results
13	Examples of traffic management in Sweden: travel time information and incident information, ramp metering, traffic controlled VSL, motorway control systems (MCS)	Literature study, expert workshops	Travel time information recommended value (March 2016): c. €0.4; incident information recommended value: c. €2.1; ramp metering recommended value: average speed on main road +10%; traffic controlled VSL recommended value: capacity +5%; accidents −10%; MCS queue warning recommended value: accidents –20%
14	Automatic speed assistance on motorway when raining	Analysing road crashes before and after deployment of the ITS application for which data were reliably and continuously collected	The performance of the M1 Wet Weather Pilot (WWP) system on the M1 Motorway is assessed; very positive safety effects were shown by setting VSL to a lower mandatory speed limit when it is raining or in case the road pavement is wet
15	Bus Rapid Transit (BRT) and Advanced Traffic Management System (ATMS)	Traffic simulation; comprehensive road network evaluation on traffic operation, social and economic, aspects, safety performance, and management efficiency through before-and-after study	BRT can improve traffic condition effectively by improving average vehicle speed and the road network traffic capacity, and attract more passengers using public transport system; ATMS has significantly improved the urban traffic condition by reducing trip time, increasing network capacity and reducing traffic accidents
16	TCC, electronic monitoring and control systems to avoid overloading of vehicles, including weigh-in-motion (WIM)	CBA, case study, expert knowledge and experience	The annual costs and benefits for the eTeza TCC in South Africa (2014 ZAR): benefits NPV 2.08 million, costs NPV −0.56 million, benefit/cost ratio 3.73, IRR 43%; CBA for overload control system should incorporate all aspects, and not consider the ITS elements in isolation

such as: (1) the inconsistent estimation of the value of statistical life (VSL) and injury (Mrozek and Taylor, 2002; Viscusi and Aldy, 2003; De Blaeij *et al.*, 2003), and arbitrary guidance from the government to determine the VSL; (2) the foundation of CBA is welfare economics, the premises of which apply only in rare circumstances; and (3) biased determination of the discounting rate (Hauer, 2011).

KPIs seem very easy to use to provide an overview of the whole ITS domain, and do not require extensive knowledge of economics and mathematics. However, serious drawbacks are connected to the use of KPIs. The domain of ITS for road applications is very broad and can be categorized from different perspectives and aspects by different stakeholders. Generic KPIs cannot sophisticatedly take such circumstances and characteristics into account. Furthermore, sustainable impacts of intelligent road transport systems have three main dimensions, each with several sub-dimensions:

1. economic, e.g. efficiency, cost-effectiveness, quality and responsiveness;
2. environmental, e.g. emissions, noise and natural resources utilization; and
3. social, e.g. safety, health and employees.

Generic KPIs do not always adequately cover the dimensions and subdimensions of the impacts. Moreover, very often in evaluation studies too few KPIs were selected to enable usability, while these were expected to be used for a wide variety of situations. This substantially limits the coverage and the scope of KPI-based evaluation. In addition, the success of using KPIs is strongly influenced by data availability, collection, analysis and reporting, and may be strongly dependent on the type of ITS technologies that need to be assessed, and in which context.

Both at national and international level, we do need harmonized approaches for both macroscopic evaluation and KPI-based evaluation. Criticism of evaluation methods shall not hamper achievement of evaluation results. On the contrary, constructive criticism may:

1. encourage and stimulate researchers to find (theoretical and practical) solutions to overcome drawbacks of (current) methods, and to develop new methods as well as guidelines for best ways of using the methods;
2. support decision-makers in: avoiding bias (by selecting independent bodies to carry out evaluation studies); choosing appropriate methods and using them properly; unambiguously clarifying assumptions; interpreting the results in a reasonable and sensible way; and
3. help all stakeholders, including industry partners, with better understanding the challenges that are at stake, and with providing relevant high-quality input data for evaluation.

17.3 Discussions

For the evaluation of intelligent road transport systems, the availability of complete, accurate and well-structured data is a prerequisite. To improve the availability and quality of data, efforts from authorities, industry and academia are needed. Good practices of the US Department of Transportation (DOT) can be helpful for other countries. The US DOT publishes all evaluation results of projects funded by the government, and this information is freely accessible (also for foreigners). As the international forum for benefits and costs evaluation in the ITS domain, with strong support from worldwide ITS associations, academia, industry and authorities, the ITS Benefits Evaluation Community (IBEC) intends to play a significant role in enabling data exchange between stakeholders in different countries and regions (see IBEC, 2014).

IBEC vision

To support the widespread deployment of ITS through the use of evaluation and assessment that highlights and execute sound choices in to improve safety, reduce congestion, support sustainable transportation, and contribute to economic prosperity through evaluation of impacts on sustainable transport widely integrated into planning, decision-making and monitoring of the deployment of smart technology for transport (mobility and logistics).

IBEC mission

1. To advocate/promote the use of evaluation in planning, decision-making and monitoring of the deployment of smart technology for mobility with the ITS industry and government agencies.
2. To develop and share a body of knowledge, by international practitioners for international practitioners, on how to conduct evaluation (and CBA) of ITS programmes and individual services/applications.
3. To attract an international cadre of professionals and students from across academic institutions, the public sector and private companies that bring a range of expertise to transportation.
4. To compile and add to the growing body of evaluation and assessment resources that give meaning and direction to smart transportation choices.
5. To work closely with organizations to highlight evaluation and assessment through their channels.
6. To facilitate efforts of transportation organizations around the world to make choices, including, but not limited to the:
   - compilation of knowledge resources that highlight effective evaluation and assessment
   - development of new knowledge resources that highlight effective evaluation and assessment
   - promotion and distribution of these resources
   - engagement of its subject matter experts
   - undertaking of training and education services to promote evaluation and assessment

Concerning macroscopic evaluation methods, a harmonised approach needs to be explored. Integration of methods and/or the establishment of an index could be investigated. The evaluation framework should be transparent, easy to be operated and widely acceptable. In addition, the assumptions used must be clearly stated.

Maybe a mind shift is needed with respect to the idea that it is possible to obtain accurate results in 'true' numbers. Due to the fact that all current evaluation methods have drawbacks (see above), it may in principle not be feasible to determine 'true values' for benefits and costs by using any of these methods. Therefore, instead of struggling to identify 'true values', an alternative approach may be necessary. Imagine that one common (harmonised and acceptable) method would be used in many instances (even though not perfect), then, at least, comparable results would be obtained.

The idea of such fundamental approach for determining relatively accurate results in many instances in the same way by using a common method may drive our thinking to remodel ITS evaluation. It would concern a common evaluation method, which shall be transparent, and can be quickly and widely accepted by all stakeholders, and easily adopted. This deserves further discussion, and research in the domain of evaluation of intelligent road transport systems.

In addition, intelligent road transport systems have seen substantial development and rapid deployment in the past decades. Re-thinking, in a holistic way, of planning, modelling, design, control and comprehensive management is required for the future. The challenges for industry, academia and administrations in the domain of evaluation of intelligent road transport systems are to enhance (technical) assessment and evaluation, to overcome evaluation obstacles and to substantially reduce investment risks.

17.4. Conclusion

Intelligent road transport systems aim: to improve the sustainability of transport of people and goods; to reduce the frequency and consequences of traffic accidents; to reduce local nuisances and greenhouse gas emissions; to reduce the need for (more) public space for transport; and to offer transport that is accessible to all, and affordable.

Although most microscopic evaluation methods are mature for basic applications, researchers and industry partners are continuously improving these methods and developing new algorithms. Macroscopic evaluation is still challenging. Methods for macroscopic evaluation provide a recipe for analysis and ranking of different available alternatives for achieving a certain goal or objective. In general, it may be said that no algorithm can act as a complete substitute for human judgement. Due to (fundamental) drawbacks, neither macroscopic evaluation methods nor KPIs are widely used and accepted by all stakeholders. There is a need for a harmonized evaluation approach, which is a challenge for researchers, industry and authorities. Evaluation studies should be done by independent bodies. IBEC, together with all stakeholders, will play a key role for sharing and exchanging evaluation data.

References

Boardman AE, Greenberg DH, Vining AR, Weimer DL. *Cost–Benefit Analysis: Concepts and Practice*. Upper Saddle River, NJ: Prentice Hall; 1996.

Brans JP. *L'ingénierie de la décision. L'élaboration d'instruments d'aide à la décision*. Quebec: Université Laval; 1982. (in French).

Brans JP. The space of freedom of the decision maker modelling the human brain. *European Journal of Operational Research*. 1996; 92:593–602.

Brans JP, Vincke P, Mareschal B. How to select and how to rank projects: the PROMETHEE method. *European Journal of Operational Research*. 1986; 24:228–238.

De Blaeij A, Florax RJGM, Rietveld P, Verhoef E. The value of statistical life in road safety: a meta-analysis. *Accident Analysis & Prevention*. 2003; 35 (6):973–986.

Deng J. Control problems of grey systems. *Systems and Control Letters*. North-Holland Co. Publisher. 1982; 5:288–294.

European Commission. *ITS (Intelligent Transport Systems) Action Plan and Directive*; 2015a. Available from: http://ec.europa.eu/transport/its/road/action_plan_en.htm (Accessed 01 January 2016)

European Commission. *Studies – Intelligent Transport Systems*; 2015b. Available from: http://ec.europa.eu/transport/themes/its/studies/its_en.htm (Accessed 01 January 2016)

European Commission. *Study on Key Performance Indicators for Intelligent Transport Systems*. Final Report. Brussels: European Commission; 2015c. Available from: http://ec.europa.eu/transport/themes/its/studies/doc/its-kpi-final_report_v7_4.pdf (Accessed 01 January 2016)

Guo H. Identification coefficient of relational grade. *Fuzzy Mathematics*. 1985; 5:55–58. (in Chinese).

Hauer E. Computing what the public wants: some issues in road safety cost-benefit analysis. *Accident Analysis and Prevention*. 2011; 43(1):151–164.

Hill M. A goal-achievements matrix for evaluating alternative plans. *Journal of the American Institute of Planners*. 1968; 34:19–29.

Hwang CL, Yoon K. *Multiple Attribute Decision Making: Methods and Applications*. Berlin: Springer-Verlag; 1981.

IBEC (ITS Benefits Evaluation Community). IBEC vision and missions. IBEC Management Committee, finalised based on email exchanges between Tom Kern (Chair, IBEC, 2011–2014) and Meng Lu (Chair, IBEC, September 2014–January 2016), IBEC; 2014.

Mrozek JR, Taylor LO. What determines the value of life? A meta-analysis. *Journal of Policy Analysis and Management*. 2002; 21(2):253–270.

Lichfield N. *The Economics of Planned Development*. London, England: Estates Gazette, Ltd.; 1956.

Lichfield N. Cost–benefit analysis in plan evaluation. *Town Planning Review*. 1964; 35:159–169.

Lu M. *Modelling and Evaluation of the Effects of Traffic Safety Measures: Comparative Analysis of Driving Assistance Systems and Road Infrastructure*. Doctoral thesis, Lund University, Lund; 2007.

Lu M, Wevers K, Van der Heijden R. Technical feasibility of advanced driver assistance systems (ADAS) for road traffic safety. *Transportation Planning and Technology*. 2005; 28(3):167–187.

Roy B. Classement et choix en présence de critères multiples (la méthode ELECTRE). *RIRO*. 1968; 8:57–75 (in French).

Saaty TL. *The Analytic Hierarchy Process*. New York, NY: McGraw-Hill; 1980.

Saaty TL. *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. Pittsburgh, PA: RWS Publications; 1995.

Studer L. Evaluation methods and experiences. IBEC Session 1 'How to identify the proper ITS evaluation methodology?' *World Congress on ITS (Intelligent Transport Systems)*, Bordeaux. 2015 October.

Trilling DR. A cost-effectiveness evaluation of highway safety counter-measures. *Traffic Quarterly*. 1978; 32:41–67.

Yoon KP, Hwang CL. *Multiple Attribute Decision Making: An Introduction*. London, England: Sage Publications; 1995.

Viscusi WK, Aldy JE. The value of a statistical life: a critical review of market estimates throughout the world. *Journal of Risk and Uncertainty*. 2003; 27 (1):5–76.

Zadeh L. Fuzzy sets. *Information and Control*. 1965; 8(3):338–353.

Appendix I
Biographies

Meng Lu is Strategic Innovation Manager at Dynniq, The Netherlands; VP, IBEC (international forum for ITS evaluation); Member of the Editorial Board of IET Intelligent Transport Systems (ITS); VP, IEEE ITS Society (ITSS); and Member of the Board of Governors, ITSS. During 2009 and 2010, she worked as a visiting professor at the National Laboratory for Automotive Safety and Energy, Tsinghua University, PR China. Since 2002, she is active in two areas: ICT-based ITS and logistics. She has participated in European initiatives and projects since 2005. She received her PhD at LTH (Faculty of Engineering), Lund University, Sweden. She received a master's degree in engineering in PR China, and a master's degree in engineering in The Netherlands based on the Chinese diploma.

Adrian Zlocki studied mechanical engineering at the RWTH Aachen University. From 2004 to 2012, Dr.-Ing. Zlocki was employed at the Institut für Kraftfahrzeuge, RWTH Aachen University (ika) as scientific assistant. Since 2010 he is leading the Driver Assistance department. Currently he is employed with the Forschungsgesellschaft Kraftfahrwesen mbH, Aachen (fka). He is active in the field of ADAS, active safety systems and automated driving.

Felix Fahrenkrog studied mechanical engineering at the RWTH Aachen University with focus on Automotive Engineering. Since 2009, Dipl.-Ing. Fahrenkrog is employed at the Institut für Kraftfahrzeuge, RWTH Aachen University (ika) as scientific assistant in the Driver Assistance department. Here, he is responsible for the development and assessment of Driver Assistance Systems and automated driving functions. From 2014 he is leading the active safety team.

Martin Böhm is Head of Unit 'Mobility Systems and ITS Deployment' at AustriaTech, a federal agency for technological measures; providing Austrian Transport Ministry (ITS) policy support; national representative at the EC for specification issues regarding the ITS Directive. He is the coordinator of European projects, including R&D and deployment activities. Evolution of the mobility system (based on e.g. Internet of Things and Automation) is one of his key interests. His main expertise is bringing research in the field of ITS and services to real deployments. He holds a master's in the field of Geography and a master's in the field of Traffic Telematics Management.

Barbara Flechl works at AustriaTech, a federal agency for technological measures in the business unit ‘Mobility Systems & ITS Deployment’ since 2011. She works in several European projects where among other things she participates in evaluation groups and coordinates the evaluation of an ITS corridor project. Further, she is involved in the definition of Key Performance Indicators for Intelligent Transport Systems on a European level and has worked on strategic papers on ITS evaluation. She holds a master’s in the field of Geography with focus on Cartography and Geoinformation.

Walter Aigner is Managing Director of HiTec, a Vienna-based research institute and innovation hub since 1997. Specialising in new instruments within ITS policies, he helped preparing and designing one Europe-wide and several national ITS co-funding programmes. He evaluated ITS-related outcome of one of Europe’s larger countries’ ITS flagship initiative, and managed HiTec’s involvement in 16 ITS projects. He worked for 14 years at Vienna University of Economics and Business Administration. He holds a PhD in Innovation Management, Vienna University of Economics and Business Administration, and has focussed on the role of key individuals in ITS projects and ITS-programme success.

Caroline Visser runs Global Road Links, an independent transport consultancy focusing on knowledge and innovation to build modern road infrastructure networks. Her client portfolio includes Cardno Emerging Markets (UK) Ltd., ViaGroup Ltd Switzerland, and the EC’s Innovation and Networks Executive Agency, among others. Previously she worked with the International Road Federation (IRF) as Deputy Director General and Programme Manager, and was responsible for the ITS activities. She has also worked for the Dutch and French national road administrations. She received master’s degree in public policy and public administration from Twente University (NL), with a specialisation in infrastructure networks.

Evangelos Mitsakis holds a PhD in Civil and Transportation Engineering from the Aristotle University of Thessaloniki, Greece. He is elected Associate Researcher at the Hellenic Institute of Transport of the Centre for Research and Technology Hellas (CERTH-HIT). Evangelos Mitsakis is the author of more than 100 scientific papers on the topics of Intelligent Transport Systems, Urban Mobility and Transportation Modelling.

Josep Maria Salanova Grau holds a PhD in Civil and Transportation Engineering from the Universitat Politècnica de Catalunya, Spain. He is Research Associate at the Hellenic Institute of Transport of the Centre for Research and Technology Hellas (CERTH-HIT). Josep Maria Salnova Grau is the author of more than 150 scientific papers on the topics of Intelligent Transport Systems, Data Analytics and Transportation Modelling.

Panagiotis Iordanopoulos is a Civil Engineer holding an MSc in Transportation Engineering from the Aristotle University of Thessaloniki in Greece. Since 2010 he works as a research associate at the Hellenic Institute of Transport-Centre for Research and Technology Hellas in Thessaloniki. He is a PhD Candidate in the Economics Department of the University of Piraeus. His research focuses on the assessment of Intelligent Transport Systems and the identification of Business models for the deployment of ITS. His scientific interests include also issues relevant to Intelligent Transport Systems, Transport modelling, Transport policy and Transport economics.

Evangelos Mintsis works as a Research Associate at the Hellenic Institute of Transport (HIT) since September 2013. He holds a Bachelor's Degree from the Civil Engineering Department of the Aristotle University of Thessaloniki and an MSc in the field of Transportation Engineering from the Department of Civil and Coastal Engineering at the University of Florida – USA. He has previously worked as a Research Assistant at the Transportation Research Centre of University of Florida. His research interests focus on traffic flow theory, traffic management, simulation of urban and freeway traffic, as well as on Intelligent Transport Systems (ITS).

Luca Studer is graduated in Civil/Transport Engineering at Politecnico di Milano; is Researcher at Politecnico di Milano, Italy; and is Manager of the Mobility and Transport Laboratory. His expertise is in the field of Transport Systems Management, Transport Planning, Traffic Techniques, Road Safety and Intelligent Transportation Systems. He is specialised in the study of models for assessing the vulnerability of transport networks, in developing methods for networks management in crisis situation, in researching sustainable mobility services and in the evaluation of ITS. He is the member of the Research Group on transport management on behalf of the Italian Civil Protection National Department.

Giovanna Marchionni is graduated in Environmental Engineering, land planning and management, at Politecnico di Milano in 2001. She is a Research Fellow at the Politecnico di Milano. She is predominantly focused to the study and research of models for assessing the vulnerability of transport networks, the development of methods and policies for managing networks in case of significant event, to elaborating policies and services for sustainable mobility and evaluation of Intelligent Transportation System. She is a member of the Skill Point of the Civil Protection National Department Research Group for transport management and safety.

Richard Mudge is a recognised expert in the economics, finance and planning of all modes of transportation. Dr. Mudge has held a series of management positions as a transportation consultant including work for Apogee Research, the RAND Corporation and Delcan. Earlier he directed the transportation policy group for the Congressional Budget Office. He currently serves as President of Compass Transportation and Technology Inc. His work involves market assessments of new transportation systems for private or public entities. He holds a PhD and master's in Regional Economics, University of Pennsylvania; he did his undergraduate degree in Columbia College. He was the founding chair of IBEC.

Stig E.R. Franzén holds a PhD in Transportation and Logistics, with a scientific background from Electrical and Systems Engineering, Learning Psychology and Human Factors Engineering. He is professor of Human Machine Interaction (HMI) at Division Design & Human Factors, Chalmers. His main areas of interest include 'Human beings and their roles in complex socio-technical systems'. He has worked in European R&D programmes for transportation of both goods and people for more than 30 years. Prof. Franzén is involved in the Chalmers Area of Advance in Transport, runs his own consultancy and is also associated with the foundation Chalmers Industriteknik.

I.C. MariAnne Karlsson is Professor (Chair) of Human Factors Engineering and Head of Division Design & Human Factors at Chalmers University of Technology. Her research concerns the relation between people and technology in a broad sense. She has been responsible for and/or engaged in ITS-related research since the beginning of the 1990s, including projects such as SeMiFOT and TeleFOT. A particular interest in these projects has been prerequisites for users' adoption of technical innovations and the effect of ITS on travel behaviour.

Henk Taale is a senior consultant at Rijkswaterstaat since 1991. He has 25 years of experience in the fields of traffic management, traffic models and evaluation and was project manager for numerous projects in those fields. Henk holds an MSc in Applied Mathematics from Delft University of Technology and finished his PhD in December 2008 on the subject of anticipatory control of road networks. Since 2011 he also works as an assistant professor at Delft University of Technology, where he supervises PhD and MSc students and continues his research on traffic management and control.

Jan Kiel is senior consultant and project manager at Panteia since 2011. He holds a degree in Economic Geography (University of Groningen, 1988). Jan started his career as consultant in public transport at Fram Heerenveen. In 1990 he joined Hague Consulting Group where he worked on the development and application of passenger transport models such as the Dutch National Model System. In 2000 Jan joined NEA (since 2011 Panteia), where he got involved into freight transport modelling. Other activities comprised cost-benefit analysis, training, feasibility studies and policy analysis for different clients such as the European Commission and Rijkswaterstaat.

Arnoud Muizer is a business developer and holds a PhD in business administration. He has been working for Panteia since 1997 as a consultant and is an expert in the field of innovation, new business development and sustainability. During the last few years, he has been applying his skills and knowledge in the Mobility and Transport Sector. Since 2012 he is active within the Dutch Programme 'Better use of road infrastructure' with various projects and roles. He has been involved in several SUMP-studies, CBAs and MCAs. For the development of the method he has combined his thematic expertise with his innovation skills.

Jacques Ehrlich is a Research Director Emeritus, Doctor of Telecom Paris (France) in Electronics and Telecommunication. He joined the Physics department of IFSTTAR in 1973. From 1999 to 2014, he was successively deputy director and then director of the LIVIC-IFSTTAR, a research laboratory on Autonomous Vehicles and Cooperative Systems. He had responsibilities in many projects on cooperative systems or Field Operational Test: LAVIA (FR), ARCOS 2004 (FR), SAFESPOT (EU), PLATA (DEUFRAKO) and SCOREF (FR). His research interests include autonomous vehicles, systems assessment and in-vehicle embedded architecture. He is now the Chairman of the PIARC Technical Committee B1 'Road Networks Operations'.

Nicolas Hautière received an MS degree in civil engineering from the National School of State Public Works (ENTPE), Vaulx-en-Velin, France, in 2002; an MS and PhD degrees in computer vision from Université Jean Monnet, Saint-Étienne, France, in 2002 and 2005, respectively; the Habilitation to manage research from Université Paris-Est, Champs sur Marne, France, in 2011; and the specialised master's degree in political science and sustainable development from École des Ponts ParisTech, Champs-sur-Marne, France, in 2013. He is currently Project Director within the COSYS Department at the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), Champs-sur-Marne, France.

Susan Grant-Muller is Professor of Technologies and Informatics at the Institute for Transport studies and Consortium Leader for the EU EMPOWER project, concerned with positive incentives for behavioural change in transport choices delivered through smart technologies. She is co-investigator to the ESRC Consumer Data Research Centre ('Big data' centre), University of Leeds. Leeds Principle Investigator for the CEDR UNIETD project (researching the contribution of social media data for highways management) and led the evaluation methodology for new technology schemes in the EU SUNSET project. Susan has published widely in the fields of ITS, new technologies and policy studies.

Frances Hodgson, Co-investigator for the EU EMPOWER project, has over 25 years' experience in transport research. Recent work includes the evaluation of social innovation schemes in transport. Other projects include the EU SUNSET project (developing and implementing a smartphone app for sustainable transport) and CEDR UNITED project (assessing new data sources for transport management systems). Frances is a UK leader of the EU GenderSTE action, concerned with gender and pervasive technologies in transport and is an expert advisor on transport and older people to the UKRC Co-Motion project. She has worked in Asia and Africa and has published widely in international journals.

Alan Stevens is the Chief Scientist and Research Director, Transportation at TRL. He is a Chartered Engineer and Fellow of the Institute of Engineering and Technology. Prof. Stevens is Chair of ITS (UK) and an active member of IBEC

(International Benefit Evaluation and Costs). He has led or participated in many projects involving evaluation of benefits in Intelligent Transport and has acted as external evaluator for several European Commission projects. His consultancy activities focus on providing advice on policy and interoperability issues to Government, developing research programmes and carrying out specific technical studies in information systems in transport.

Simon Ball is a Senior Researcher at TRL specialising in ITS, with a background in mathematics and has been the technical lead on several research projects. His Cooperative ITS experience includes developing a spreadsheet tool under the COBRA project to enable European national road operators to better assess the impacts, costs and benefits of options for delivering ITS services. He has also worked on data integrity, data markets and business models for ITS services, and is now working on a follow-up project to COBRA. Simon has recently completed an MPhil on mining of large datasets collected by transport operators.

Jean Hopkin is an experienced Team Leader and Project Manager at TRL specialising in policy research, social research and evaluation with much of her recent experience in Intelligent Transport Systems. She is a Fellow of the Chartered Institution of Highways and Transportation. She has developed guidelines for evaluation of the impacts, costs and benefits of European ITS projects and programmes, written the monitoring and evaluation section of a new international ITS Handbook, and worked in many projects involving evaluation of benefits and development of deployment models including European projects CODIA, COBRA and automatic crash notification (eCall).

Torsten Geißler is Economist, works as scientific officer for BASt, the Federal Highway Research Institute of Germany. In the section of Cooperative Traffic and Driver Assistance Systems he is responsible for deployment of innovative technologies in public–private collaboration. Earlier he has worked for the Institute for Transport Economics at the University of Cologne. Geißler has 20 years' research and policy implementation background in ITS, being involved in numerous Cooperative ITS related research projects and Field Operational Tests and acting in various European ITS related institutions. Dr. Geißler is (co-)author of more than 50 scientific reports and congress papers.

Risto Kulmala works as Principal Advisor on ITS at the Finnish Transport Agency, and has previously worked as Research Professor on ITS at VTT in Finland and as Adjunct Professor at Lund University, Sweden. He has a long experience in road safety, ITS impacts, benefits, and costs, and development of ITS deployment roadmaps including cooperative ITS and automated driving. Prof. Kulmala has coordinated several major national and international R&D and deployment programmes and projects, and acts as a chair of various international ITS bodies. He has written more than 300 publications in terms of scientific papers, reports and congress papers.

Oliver Carsten is Professor of Transport Safety at the Institute for Transport Studies, University of Leeds. His major research focus is on driver interaction and safety with new driver support systems. He led the UK national project on Intelligent Speed Adaptation and chairs the Road User Behaviour Working Party of PACTS, the Parliamentary Advisory Council for Transport Safety. He has provided advice on safety policy to the UK Department for Transport and the European Commission. He is editor-in-chief of the academic journal Cognition, Technology and Work.

András Várhelyi is Professor of Transport in the Department of Technology and Society, Lund University, Sweden. His main research field is about the effects of various systems and interventions on road user behaviour and road safety. He has coordinated field trials in evaluation studies of ADAS in both national and EU-projects, such as MASTER, PROSPER, PReVENT, InteractIVe and AdaptIVe.

Carsten Sachse was born in Sweden 1958. He received an MSc in Civil Engineering in 1984 from the Faculty of Engineering, Lund University. Since then he has most of the time been with the Swedish Transport Administration (previously the Swedish Road Administration). He has also been working for the International Labour Organization in the Philippines, for SweRoad with shorter consultant missions abroad and as a consultant in Sweden. His main areas of work are within transport modelling and cost-benefit analysis. He is responsible for cost-benefit analysis made as input to the Swedish long-term infrastructure investment plans every fourth year.

Andreas Larsson is an internationally award winning technical writer (Best technical paper, 22nd ITS World Congress 2015). He is specialised in road-side ITS-solutions, with focus on traffic signals. His portfolio includes the publication series 'The Road to ITS – A guide to the process of introducing road-based ITS solutions, with examples of implemented applications', commissioned by the Swedish Transport Administration. Larsson is an ITS consultant at Sweco since 2008.

Carl-Henrik Sandbreck (MSc Civil Engineering) is a senior consultant at Sweco with extensive experience of applied transport modelling and Cost Benefit Analysis (CBA). He has been in charge of numerous comprehensive and complex analyses such as the modelling on congestion charging schemes for Stockholm and Gothenburg. Over the years, he have regularly been contracted for development and revision of the Swedish national system for CBA and demand modelling: SAMPERS/SAMKALK, as well as development of specific models and methods such as tools for impact analysis of Intelligent Speed Adaptation (ISA), travel time information and distribution of incident warning messages.

Tor Skoglund is an expert on the effects of ITS and has more than 10 years' professional experience of transport consulting and research. He holds a PhD in ITS and Human – Technology – Design, and an MSc in Electrical Engineering.

His research portfolio includes impacts of access to ICT-mediated services for both public and private modes of transport. Dr. Skoglund has a background as CTO and as Process Developer.

Qudus Wazirzada received Bachelor of Engineering in Electronics; MBA from Deakin University; graduate diploma in project management. He is completing a Doctorate in ITS business at Charles Sturt University. Initially he was an engineering officer in the Air Force abroad. Later he joined Philips International, managing multi-technology projects. He is working with Road and Maritime Services NSW, since 14 years and involved in the design installation and commissioning of numerous complex ITS projects. For the last 5 years he is working on Traffic Facilities Asset in Network Optimisation. Here, he is responsible for providing leadership in ITS Asset Management, Life Cycle Management and managing innovation in ITS Assets across NSW.

Glenn Geers is Principal Engineer, ITS at ARRB; Australia's largest, independent transport research organisation. He is a Conjoint Associate Professor in the School of Computer Science and Engineering at the University of New South Wales; and is a member of SIAM and ACM. Glenn received his PhD in theoretical physics from the University of Sydney. Prior to joining ARRB in 2015 Glenn worked on biometrics, image processing and distributed systems at CSIRO and in private industry. Glenn is on academic, government and industry transport advisory boards both in Australia and overseas. He is on the editorial board of *GeoInformatica*.

Parikshit Kumar Basu is Associate Professor of Economics, Charles Sturt University. He has worked as an economist in the private corporate sector in e.g. India, PNG and Australia, prior to becoming an academic (at Griffith University and CSU). His teaching interests have a strong emphasis on macroeconomics and financial markets. He was principal supervisor of doctoral students. His primary research interests were in the areas of business relations between Australia and China, applied finance and, more recently, regional labour market analysis in Australia. In the latter area he authored and co-authored a number of publications including in the highly prestigious journal Regional Studies.

Jianping Wu is Professor, School of Civil Engineering at Tsinghua University, Beijing, PR China; Director, Tsinghua – Cambridge and MIT Centre for Future Transport Research. Research interests include smart city and smart transport, traffic modelling and simulation, and sustainable and ecological transport. He has been the main investigator for over 50 research projects and (co-)authored over 250 papers in journals and conferences. Selected memberships: Chairman, China Association of Traffic Modelling and Simulation; Vice Chair, China Digital City Association; Standing committee member of IBEC; IET Fellow and Editorial Board Member, IET ITS; Transportation Adviser, Beijing, Hangzhou, Nanning and Haikou municipalities.

Ling Huang was born in Guangdong province, China, in 1979. She received her PhD in system engineering from Beijing Jiaotong University in 2007. From 2001 to 2007, she was a Research Assistant with the UK-China ITS Centre. Since 2007, she has been a Lecturer with the School of Civil Engineering and Transportation, South China University of Technology. She is the author of one text book, over 30 articles and over 20 inventions. Her research interests include road user's behaviour, traffic simulation, computer vision and traffic simulation applications. She is a peer reviewer of journals such as *IEEE Transactions on Intelligent Transportation Systems*.

Ruimin Li PhD, is Associate Professor in the Department of civil engineering, Tsinghua University. His research is focused on intelligent transportation system, traffic operation and traffic simulation. He is the principle investigator of more than 30 research projects funded by, e.g. National Science Foundation of China, Ministry of Science and Technology. He has published more than 100 peer-reviewed papers and is the author or co-author of seven books. He has directed or participated in the formulation and revision of five industrial standards.

Hongtong Qiu Research Professor, Traffic Management Research Institute of the Ministry of Public Security. He is engaged in the research of urban traffic and intelligent traffic management system. In the past two decades, he has directed or participated in the formulation and revision of more than 20 national or industrial standards, and participated in or presided more than 10 national research projects and directed more than 10 research subjects of Ministry of Public Security. He has directed more than 30 public security traffic control system design projects. He has been awarded four science and technology awards of Ministry of public security.

Johann Andersen is Industry Associate Professor in ITS, Stellenbosch University, RSA. He teaches ITS principles in Civil Engineering programmes and guides research activities in ITS. He heads up the Stellenbosch Smart Mobility Laboratory (SSML), an industry-focused initiative, creating a multidisciplinary research environment in the use of technology in transport applications. The SSML aims to be a renowned Knowledge Centre for development of innovative and cost-effective solutions in ITS, with a developing country perspective. In his capacity as CEO of Techso, a specialist consultant company, he has gained extensive experience in ITS planning, design and implementation in FMS, APTMS and Overload Control.

Berino Lorio is a professionally registered transportation planner and traffic engineer, specialising in ITS and transport demand modelling. His experience in ITS ranges from planning through to implementation, and stretches over a range of user services including Heavy Vehicle Load and Fitness Enforcement, Traffic Management, Freeway Management, Electronic Fare Collection, Advanced Public Transport Management and Electronic Tolling. He has been involved (in various capacities) on nine overload control facilities and his experience in overload control include control systems procurement (including concepts, requirements and specifications, tender documents and evaluation) through to construction supervision.

Paul Vorster CEO of ITS South Africa since its establishment in 2001. Dr. Vorster is a Founder Member of the ITS Africa Working Group, member of the ITS Policy Committee of the International Road Federation and has served as Vice President of IBEC. He also serves on the panel of advisors to the Gauteng Transport Commission. He is a passionate advocate for smart mobility as subsystem for the emerging Smart Cities. He has been invited to speak on multiple international forums, including at the United Nations Economic Commission for Europe Transport Committee and at several ITS World Congresses.

Appendix II

Bibliography of further reading

Access Economics (Australia) (2009). *The Economic Benefits of Intelligent Technologies*. Access Economics Pty Ltd., Report.

Agatz, N., Erera, A, Savelsbergh, M., and Wang, X. (2012). Optimization for dynamic ride-sharing: a review. *European Journal of Operational Research*, 223:295–303.

Austroads (Australia) (2014). *Strategic Priority Initiative Congestion and Reliability*. Issues paper.

Austroads (Australia) (2012). *Best Practice Study on the Use of Intelligent Transport Systems (ITS) Standards in Traffic Management*. Austroads Report.

Ballús-Armet, I., Shaheen, S. A., Clonts, K., and Weinzimmer, D. (2014). *Peer-to-Peer Carsharing: Exploring Public Perception and Market Characteristics in the San Francisco Bay area, California*. Transportation Research Record No. 2416, Transportation Research Board of the National Academies, Washington, D.C., pp. 27–36.

Bardhi, F. and Eckhardt, G. (2012). Access-based consumption: the case of car sharing. *Journal of Consumer Research*, 39:881–898.

Belk, R. (2014). You are what you can access: sharing and collaborative consumption online. *Journal of Business Research*, 67:1595–1600.

Brynjolfsson, E. and McAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York, London.

Buehler, R. and Dill, J. (2016). Bikeway networks: a review of effects on cycling, *Transport Reviews*, 36(1):9–27.

Bureau of Transport and Regional Economics (Australia) (2007). *Estimating Urban Congestion and Cost Trends for Australian Cities*. Available from www.bitre.gov.au/publications/2007/files/wp_071.pdf (Accessed July 2012).

Cairns, S. (2011). *Accessing Cars: Different Ownership and Use Choices.* Royal Automobile Club Foundation, United Kingdom. Available from www.racfoundation.org/research/mobility/accessing-cars-international (Accessed 30 March 2016)

Chandrasekar, P., Long Cheu, R., and Chin, H. (2002). Simulation evaluation of route-based control of bus operations. *Journal of Transportation Engineering*, 128(6):519–527.

Celsor, C. and Millard-Ball, A. (2007). *Where Does Carsharing Work? Using Geographic Information Systems to Assess Market Potential*. Transportation Research Record, No. 1992, Transportation Research Board of the National Academies, Washington, D.C., pp. 61–69.

Cervero, R., Golub, A., and Nee, B. (2007). *City Carshare: Longer-Term Travel Demand and Car Ownership Impacts*. Transportation Research Record, No. 1992, Transportation Research Board of the National Academies, Washington, D.C., pp. 70–80.

Chatterjee, K., Andrews, G., Ricci, M., and Parkhurst, G. (2013). *Qualitative Insights Into the Effect on Travel Behaviour of Joining a Carshare*. Transportation Research Record, No. 2359, Transportation Research Board of the National Academies, Washington, D.C., pp. 76–84.

Cherri, C., Nodari, E., and Tolfetti, A. (2004). *Review of Existing Tools and Methods. Deliverable D2.1.1 of the AIDE – Adaptive Integrated Driver–Vehicle Interface Project.* Information Society Technologies (IST) Programme.

Cohen, B. and Kietzmann, J. (2014). Ride on! Mobility business models for the sharing economy. *Organisation and Environment*, 27(3):279–296.

Collins, D. and Kearns, R. A. (2010). Walking school buses in the Auckland region: a longitudinal assessment. *Transport Policy*, 17(1):1–8.

Engwicht, D. (1992). *Towards an Eco-City: Calming the Traffic*. Envirobook, Sydney, Australia.

European Commission (2011). *White Paper: Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System*. Brussels, Belgium.

FESTA Consortium (2008). *FESTA Handbook*. Deliverable D6.4. of the Field opErational test support Action project within the 7th Framework Programme of the EC.

FHWA (Federal Highway Administration) Office of Operations (2015). *Transportation Systems Management and Operations Benefit–Cost Analysis Compendium*. US DOT (Department of Transportation), Washington, DC.

Fishman, E., Washington, S., Haworth, N., and Watson, A. (2015). Factors influencing bike share membership: an analysis of Melbourne and Brisbane. *Transportation Research Part A*, 71:17–30.

Fishman, E. (2016). Bikeshare: a review of recent literature. *Transport Reviews*, 36 (1): 92–113.

Franzén, S., Karlsson, M., Morris, A., *et al*. (2012). Widening the use of the FOT methodology. Development based on experiences from the TeleFOT project. *Procedia – Social and Behavioural Sciences*, 48 s. 1826–1836.

Furuhata, M., Dessouky, M., Ordóñez, F., Brunet, M.-E., Wang, X., and Koenig, S. (2013). Ridesharing: the state-of-the-art and future directions. *Transportation Research Part B*, 57:28–46.

Gaffney, J. and Lam, P. (August 2015). *VicRoads Managed Motorway Framework (Australia)*. ISBN 978-0-7311-9174-1.

Hampshire, R. and Gaites, C. (2011). *Peer-to-Peer Carsharing Market Analysis and Potential Growth, Transportation Research Record.* Transportation

Research Board, No. 2217, Transportation Research Board of the National Academies, Washington, D.C., pp. 119–126.

Han, C., Espada, I., and Li, J. (May 2014). *ITS Performance & Benchmark Methodology Report.* ARRB 1913 Working Paper 1.

Harvey, C. and Stanton, N. A. (2013). *Usability Evaluation for In-Vehicle Systems.* CRC Press, Taylor & Francis Group.

Hossain, M. and Hasan, M. (2000). Simulation of bus operation under mixed traffic conditions. In: *Proceedings: Traffic and Transportation Studies*, pp. 441–448.

Hyllenius, P., Ljungberg, C., and Smidfelt Rosqvist, L. (2004). *SUMO-System for Evaluation of Mobility Projects*. Swedish Road Administration, Borlänge, Sweden. Available from https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/move_sumo_model.pdf (Accessed 15 March 2016)

IBEC *Framework for a White Paper on ITS Evaluation* [online]. 2014. Available from http://ibec.erticoprojects.wpengine.com/wp-content/uploads/sites/18/2015/09/IBEC-framework-for-White-Paper-Evaluation-2014.pdf (Accessed 06 April 2016)

Jeon, C. M. and Amekudzi A. (2012). *National Intelligent Transport Systems Industry Strategy*. ITS Australia Report.

Jun, M.-J. (2011). Redistributive effects of bus rapid transit (BRT) on development patterns and property values in Seoul, Korea. *Transport Policy*, 19(1):85–92.

Kearns, R. A., Collins, D. C. A., and Neuwelt, P. M. (2003). The walking school bus: extending children's geographies? *Area*, 35(3):285–292.

Kergaye, C., Stevanovic, A., and Martin, P. T. (2010). Comparative evaluation of adaptive traffic control system assessments through field and microsimulation. *Journal of Intelligent Transportation Systems*, 14(2):109–124.

Kingham, S. and Ussher, S. (2005). Ticket to a sustainable future: an evaluation of the long-term durability of the Walking School Bus Programme in Christchurch. *New Zealand Transport Policy*, 12(4):314–323.

Kulmala, R., Luoma, J., Lähesmaa, J., *et al.* (2002). *Guidelines for the evaluation of ITS Projects*. FITS publications 4/2002. VTT Building and Transport, Finland.

Li, J. and Liu, C. (2004). A proposed hybrid evaluation methodology for intelligent transport system deployment. In: *The 5th Asian Control Conference*, pp. 819–827.

Linder, A., Kircher, A., Vadeby, A., and Nygardhs, S. (2007). *Intelligent Transport Systems (ITS) in Passenger Cars and Methods for Assessment of Traffic Safety Impact. A Literature Review*. VTI, Linköping. Sweden. Available from www.vti.se/en/publications/intelligent-transport-systems-its-in-passenger-cars-and-methods-for-assessment-of-traffic-safety-impact/ (Accessed 03 March 2016)

Lu, M. and Wevers, K. (2007). Application of grey relational analysis for evaluating road traffic safety measures: advanced driver assistance systems against infrastructure redesign. *IET Intelligent Transport Systems*, 1(1):3–14.

Lu, M. (2006). Modelling the effects of road traffic safety measures. *Accident Analysis and Prevention*, 38(3):507–517.

Lu, M., Hegyi, A., and Wevers, K. (2006). Perspective of mitigating shock waves by temporary in-vehicle dynamic speed control. In *Proceedings: 85th Transportation Research Board Annual Meeting*, Paper No. 06-1753, Washington, D.C.

Martin, E., Shaheen, S. A., and Lidicker, J. (2010). *Impact of Carsharing on Household Vehicle Holdings: Results From North American Shared-Use Vehicle Survey*. Transportation Research Record, No. 2143, Transportation Research Board of the National Academies, Washington, D.C., pp. 150–158.

Meddin, R. and DeMaio, P. (2016). *The Bike-Sharing World Map*. Available from www.bikesharingworld.com (Accessed 30 March 2016)

Mishan, E.J. (1971). *Cost–Benefit Analysis*. Allen and Unwin. ISBN 0 04 33 80 43 3 1.

New Zealand Government (May 2014). *Transport in the Digital Age*. Intelligent Transport Systems Technology Action Plan 2014-18; ISBN 978-0-478-07262-4.

NRMA (Australia) (2012). *Cost of Road Crashes, Sydney*. National Roads & Motoring Association Report.

Samadi, S., Rad, A. P., Kazemi, F. M., and Jafarian, H. (2012). Performance evaluation of intelligent adaptive traffic control systems: a case study. *Journal of Transportation Technologies*, 2(3):248–259.

Schaefers, T. (2013). Exploring carsharing usage motives: a hierarchical means-end chain analysis. *Transportation Research Part A*, 47:69–77.

SCOTI (Australia). (2012). *Policy Framework for Intelligent Transport Systems in Australia*. Standing Council on Transport and Infrastructure Report, Canberra.

Shaheen, S. A., Cohen A. P., and Chung, M. S. (2009). *North American Carsharing: 10-Year Retrospective*. Transportation Research Record, No. 2110, Transportation Research Board of the National Academies, Washington, D. C., pp. 35–44.

Shaheen, S. A., Mallery, M. A., and. Kingsley, K. J. (2012). Personal vehicle sharing services in North America. *Research in Transportation Business and Management*, 3:71–81.

Shaheen, S. A, Martin, E. W., Chan, N. D., Cohen, A. P., and Pogodzinski, M. (October 2014). *Public Bikesharing in North America During a Period of Rapid Expansion: Understanding Business Models, Industry Trends and User Impacts*. Mineta Transportation Institute Report.

Shladover, S.E., Recent International Activity in Cooperative Vehicle-Highway Automation Systems, Report FHWA-HRT-12-033, December 2012.

Sharma, H. K., Swami, M., and Swami, B. L. (2012). Optimizing performance of at-grade intersection with bus rapid transit corridor and heterogeneous traffic. *International Journal of Transportation Science and Technology*, 1(2):131–145.

Smith, L., Norgate, S. H., Cherrett, T., Davies, N., Winstanley, C., and Harding, M. (2015). Walking school buses as a form of active transportation for children—a review of the evidence. *Journal of School Health*, 85:197–210.

Stefansdotter, A., von Utfall Danielsson, C., Kastberg Nielsen, C., and Sunesen, E. R. (2015). *Economic Benefits of Peer-to-Peer Transport Services*. Copenhagen Economics.

Smith, S., Bellone, J., Bransfield, S., *et al.* (August 2015). *Benefits Estimation Framework for Automated Vehicle Operations*. Report FHWA-JPO-16-229.

Tate, J. E. and Bell, M. C. (2000). Evaluation of a traffic demand management strategy to improve air quality in urban areas. In: *IEE Road Transport Information and Control Conference*, pp. 158–162.

Thamizh Arasan, V. and Vedagiri, P. (2008). Micro-simulation study of bus priority on roads carrying highly heterogeneous traffic. In: *Proceedings: The 22nd European Conference on Modelling and Simulation (ECMS'2008)*. pp. 447–453.

Tupper Lee, L., Chowdhury, M. A., Klotz, L., and Fries, R. N. (2011). Measuring sustainability: how traffic incident management through intelligent transportation systems has greater energy and environmental benefits than common construction-phase strategies for "Green" roadways. *International Journal of Sustainable Transportation*, 6(5):282–297.

Underwood, S. E. and Gehring, S. G. (1993). Approaches to IVHS evaluation: advanced travellers information systems and advanced traffic management systems. In: *IEEE – IEE Vehicle Navigation & Information Systems Conference, Ottawa – VNIS'93*, pp. 247–250.

US DoT (Department of Transportation) website on benefits and costs. Available from www.benefitcost.its.dot.gov (Accessed 30 March 2016)

US DoT (Department of Transportation). *ITS Evaluation Guidelines – ITS Evaluation Resource Guide.* Available from www.its.dot.gov/evaluation/eguide_resource.htm (Accessed 30 March 2016)

Victorian Government (Australia) (June 2014). *Using ICT to Improve Traffic Management.* Victorian Auditor-General's Report. ISBN 978 1 922044 86 0.

Vollmer, D., Baum, H., Fausten, M., Geisler, T., Malone, K., and Schultz, W. (2006). *Socio-Economic Impact Assessment of Stand-Alone and Co-Operative Intelligent Vehicle Safety Systems (IVSS) in Europe)*. Deliverable D2 of the eIMPACT – project within the 6th Framework Programme of the EC.

Widanapathiranage, R., Bunker, J. M., and Bhaskar, A. (2015). Modelling the BRT station capacity and queuing for all stopping busway operation. *Public Transport*, 7(1):21–38.

Yang, M., Wang, W., Wang, B., Han, J., and Niu, H. (2013). Performance of the priority control strategies for bus rapid transit: comparative study from scenario microsimulation using VISSIM. *Discrete Dynamics in Nature and Society*, Article ID 398938.

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