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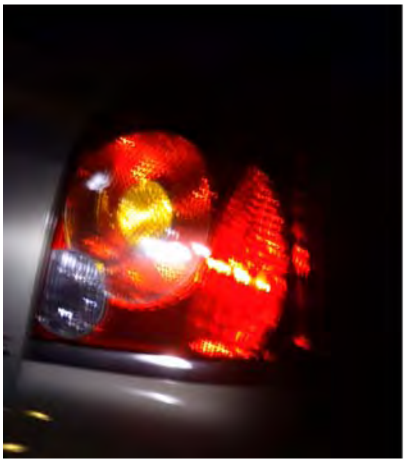

Intelligent Transport Systems (ITS) in passenger cars and methods for assessment of traffic safety impact

A literature review

Astrid Linder
Albert Kircher
Anna Vadeby
Sara Nygårdhs

FINDING A BETTER WAY

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Abstract (background, aim, method, result) max 200 words:

The background for this study is that many Intelligent Transport Systems (ITS) are currently introduced in passenger vehicles aiming at providing increased traffic safety. This provides a need to assess the traffic safety effects from these systems. The question that this report highlights is how these systems are designed and how the effects are evaluated.

The review resulted in identification of 300 references of which the most relevant are found in this report. The report contains a description of the background of why and how 20 systems or groups of systems have been developed, in which vehicles they can be found, a short technical description of how they work, publication of traffic safety effects and future development plans. Regarding statistical methods, an overview of how they work and the results when using these methods on ITS are described. In addition, the report contains a summary of ways of assessing safety effects from areas such as food, nuclear power and pharmaceutical industries.

The conclusion is that there are currently many different ways of supporting the driver in the task of driving the vehicle. Regarding the impact on traffic safety ofthese systems it is still an open question which evaluation methods to use.

Keywords:
Intelligent Transport Systems, ITS, active safety, traffic safety, statistical methods

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Referat (bakgrund, syfte, metod, resultat) max 200 ord:

Bakgrunden till studien är att många olika så kallade ”intelligenta transportsystem” (ITS) utvecklas och finns idag i fordon för att öka trafiksäkerheten. Därmed finns det ett behov av att uppskatta trafiksäkerhetseffekten av dessa system. Frågor som den här rapporten belyser är hur dessa system är utformade och hur trafiksäkerhetseffekterna av systemen utvärderas.

Litteratursökningen resulterade i 300 referenser varav de mest relevanta finns i rapporten. Rapporten innehåller en beskrivning av bakgrund till varför och hur 20 system eller grupper av system utvecklades, vilka bilar det finns i, en kort teknisk beskrivning av hur systemet fungerar, publikationer om trafiksäkerhetseffekter då sådana har identifierats i litteratursökningen samt beskrivning av framtida vidareutvecklingar och utvecklingsprojekt. Med avseende på statistiska metoder finns de som publicerats beskrivna samt resultatet av dessa. Dessutom finns ett avsnitt om hur säkerhet beaktas i andra branscher så som livsmedel, kärnkraft och läkemedel.

Slutsatserna är att många intelligenta transportsystem som syftar till att stödja föraren i att på ett säkert sätt framföra fordonet har utvecklats och många fler är på gång. Med avseende på erhållna trafiksäkerhetseffekter av dessa system är det fortfarande en öppen fråga vilka utvärderingsmetoder som skall användas.

Nyckelord:

Intelligenta transportsystem, ITS, aktiv säkerhet, trafiksäkerhet, statistiska metoder

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Preface

The present study has been initiated and funded by the Swedish Road Traffic Inspectorate (Vägtrafikinspektionen). Project owner at the Road Traffic Inspectorate has been Peter Larson assisted by Örjan Ellström. The study has been conducted in order to create a basis within the area of assessment of traffic safety effect of Intelligent Transport Systems (ITS), such as Electronic Stability Control (ESC) and Adaptive Cruise Control (ACC), in passenger vehicles. In this report we have aimed at highlighting the methods that are in use and identifying specific needs associated with evaluation of traffic safety effects of active safety systems.

The authors are all associated with VTI. Astrid Linder's research area is biomechanics and crash safety, Anna Vadeby's research area is traffic safety and statistical evaluation, Albert Kircher's research area has a focus on human-machine interaction and traffic simulators and Sara Nygårdhs' research area is mainly night-time traffic.

The authors are grateful for the support of Claes Eriksson regarding the literature search, Tania Dukic and Selina Mårdh for their support to the chapter on driver behaviour and Tarja Magnusson for the support on the wording in English of the content of this report. For copyrighted material a written consent by the copyright owner had to be obtained in order to print it in the report. We express our gratitude to the companies and authors for being allowed to use their material.

Göteborg, December 2007

Astrid Linder

Cover: VTI/Hejdlösa bilder

Quality review

External peer review was performed on 27 September 2007 by Chris Patten at the Swedish Road Administration. Astrid Linder has made alterations to the final manuscript of the report. The research director of the project manager Pontus Matstoms examined and approved the report for publication on 30 November 2007.

Kvalitetsgranskning

Extern peer review har genomförts 27 september 2007 av Chris Patten, Vägverket. Astrid Linder har genomfört justeringar av slutligt rapportmanus. Projektledarens närmaste chef, Pontus Matstoms, har därefter granskat och godkänt rapporten för publicering 30 november 2007.

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Intelligent Transport Systems (ITS) in passenger cars and methods for assessment of traffic safety impact. A literature review

by Astrid Linder, Albert Kircher, Anna Vadeby and Sara Nygårdhs
VTI (Swedish National Road and Transport Research Institute)
SE-581 95 Linköping Sweden

Summary

The background of this study is that many so called Intelligent Transport Systems (ITS) are currently developed and introduced in passenger vehicles aiming at providing increased traffic safety. This provides a need to assess and evaluate the traffic safety effect of these systems. This report highlights how the effects of these systems on the traffic safety are evaluated and gives a review of some ITS that currently (2007) can be found in the car fleet. The method that has been used in the literature review consisted of a literature search in bibliographic databases resulting in identification of 300 references of which the most relevant are found in this report. In addition, discussions with researchers in the transport sector were carried out and searches were done using the Internet. The technical systems described in the report were selected on the basis of that they should be “technically complicated” meaning that they have a potential to improve traffic safety by reducing the number of crashes or by reducing the crash severity when a crash occurs and also be available in the production of vehicles.

In the report 20 systems or groups of systems are described. The report contains a description of the background of why and how the systems have been developed, in which vehicles they can be found as well as details about suppliers when applicable, a short technical description about how the system works, publication of traffic safety effects when such have been found in the literature and future development plans. On the topic of statistical methods an overview of how they work and the results that have been published using these methods on ITS are described. In addition, the report contains a chapter consisting of a summary of ways of assessing safety effects of new products or methods from other areas such as food, nuclear power and pharmaceutical industries.

The conclusion of the review is that many intelligent systems that aim at supporting the driver in driving in a safe way have been developed and more will be developed. Many systems that could improve traffic safety are labelled as comfort or driver support systems. There are currently many different ways of supporting the driver in the task of driving the vehicle without becoming involved in a crash. Regarding the estimated and achieved impact on traffic safety from these systems it is still in many respects an open question which evaluation methods to use.

Intelligenta transportsystem (ITS) i passagerarbilar och metoder för utvärdering av dess inverkan på trafiksäkerheten – en literaturgenomgång

av Astrid Linder, Albert Kircher, Anna Vadeby och Sara Nygårdhs
VTI
581 95 Linköping

Sammanfattning

Bakgrunden till studien är att många olika så kallade ”intelligenta transportsystem” (ITS) utvecklas och finns idag i fordon bland annat för att öka trafiksäkerheten. Därmed finns det ett behov av att uppskatta/verifiera trafiksäkerhetseffekten av dessa system. Frågor som den här rapporten belyser är hur trafiksäkerhetseffekterna av sådana system utvärderas samt vilka är de tekniska system som redan nu (2007) finns i personbilar. Metoden som använts för litteratursökning i studien har bestått av litteratursökning i biblioteksdatabaser som resulterade i 300 referenser varav de mest relevanta finns i rapporten. Även diskussioner med forskare främst inom transportbranschen i Sverige och sökningar via Internet har genomförts. Urvalskriterierna för vilka tekniska system som skulle ingå i rapporten var att de förutom att vara tekniskt komplexa med potential att åstadkomma ökad trafiksäkerhet även skulle finnas i personbilar i produktion.

I rapporten beskrivs 20 system eller grupper av system som finns i personbilar idag. Rapporten innehåller en beskrivning av bakgrund till varför och hur systemet utvecklades, vilka bilar det finns i och uppgifter om eventuella underleverantörer, en kort teknisk beskrivning om hur systemet fungerar, publikationer om trafiksäkerhetseffekter då sådana har identifierats i litteratursökningen samt beskrivning av framtida vidareutvecklingar och utvecklingsprojekt. Med avseende på statistiska metoder finns de som publicerats beskrivna samt resultatet av dessa. Dessutom finns ett avsnitt om hur säkerhet beaktas i andra branscher såsom livsmedel, kärnkraft och läkemedel.

Slutsatserna från litteraturgenomgången är att många intelligenta transportsystem som syftar till att stödja föraren att på ett säkert sätt framföra fordonet har utvecklats och många fler är på gång. Ett stort antal av systemen som kan ha en trafiksäkerhetshöjande effekt betecknas som komfortsystem eller förarstödssystem. Om denna skillnad i beteckning innebär att metoder för att utvärdera och följa upp trafiksäkerhetseffekter inte utvecklas kan det innebära en begränsning med avseende på den kunskap som erhålls om systemen. Tack vara satsningen på utvecklandet av tekniska komponenter finns idag stora möjligheter att ge föraren ökat stöd för framförandet av fordonet på ett säkert sätt. Med avseende på erhållna trafiksäkerhetseffekter av dessa system är det fortfarande en i många avseenden öppen fråga vilka utvärderingsmetoder som skall användas.

List of acronyms and abbreviations

ABS	Anti-lock braking system
ACC	Automatic cruise control or adaptive cruise control
ADAS	Advanced driver assistance systems
BAS	Brake assist system
BMW	Bayerische Motoren Werke, German car manufacturer
eCall	Emergency call
ESC	Electronic stability control
ESP	Electronic stability program
VSC	Vehicle stability control
FIR	Far infrared
GPS	Global positioning system
ITRD	International transport research documentation
ITS	Intelligent traffic system or intelligent transportation systems
IVS	Intelligent vehicle systems
IVIS	In-vehicle information systems
IVSS	In-vehicle safety system
LDW	Lane departure warning
LED	Light emitting diode
NHTSA	National highway traffic safety administration
NIR	Near infrared
SAE	Society of automotive engineering
TRIS	Transport research information service
VDOT	Virginia department of transportation
VT	Virginia tech
VTI	Swedish national road and transport research institute
VTRC	Virginia transportation research council
FARS	Fatality analysis reporting system
GES	General estimates system
GIDAS	German in-depth accident study

1 Introduction

New technical solutions that aim at increasing traffic safety are introduced with increasing speed in passenger vehicles. This development intensifies the need for evaluation of achived improvements. Confirmation of traffic safety improvements is usually obtained from accident statistics.

Technical development of Intelligent Transport Systems (ITS) is associated with high expectations of its potential to increase traffic safety. Intelligent in this context represents some kind of interactive process often including the driver of the vehicle. Another terminology that includes these systems is actice safety, in contrary of non-active safety then is passive safety such as deformation zones and airbags with fixed deployment rate. Active traffic safety systems that interact with the driver and that provide protection in accordance to the result of such interaction cannot be evaluated with methods developed for passive safety such as crash tests. Therefore there is a need to map the knowledge available and the needs in the area of the evaluation/assessment of traffic safety effects of new ITS in motor vehicles.

New safety systems are often introduced in a limited number of vehicles before becoming a part of standard equipment. While new systems only are introduced in specific models traffic safety effects can be assessed by comparing vehicles with and without the studied system (Lie et al., 2004; IIHS, 2006). Such comparisons have been able to quantify increased traffic safety by ESC (Electronic Stability Control).

The need of evaluation/assessment of traffic safety effects of new ITS in motor vehicles exists at many levels of the society: at national level, from a consumer perspective and from the vehicle industry and its suppliers. Not only is there a need to indentify the effect of different types of systems but also a need to identify, if present, differences in various systems that have the same aim as for example different technical ways of designing ESC. Such evaluation will make it possible to identify “Best Practice” and by that highlight the current most promising technical solution to a specific scenario.

Intelligent Transport Systems (ITS) have a potential to make traffic safer, and the large number of research projects on ITS solutions in transport supports this. Further technical development can increase traffic safety. Farmer and Lund (2006) have studied trends over time in driver death and what would have happened if vehicle design had not been improved (Farmer & Lund, 2006). The study was based on data from the Fatality Analysis Reporting System (FARS) in the US and shows that without improvements in vehicle design the declining trend in driver fatality risk in the US would have ended in 1993. Farmer and Lund conclude that improved vehicle design has saved thousands of lives. It is reasonable to assume that the same development that has been seen in the past, and maybe even more, can be achieved in the future.

Initial emphasis is put into the development of technology and methods needed to evaluate the developed systems will be a part of the maturity of a product. Confirmed traffic safety benefits of the systems, impact on the driver and the driver environment, real versus expected (or advertised) benefits, and long term effects are all part of this maturity. The variety of different systems, and their constant development, challenge the efforts of the development of evaluation/assessment methods to scrutinize effects of ITS.

The evaluation is envisaged as a method consisting of 7 steps in a loop from identification of the extent of the type of crashes that the systems aims at reduce or avoid towards the last step which contains a comparison between expected, estimated and achieved traffic safety effect, Figure 1.1.

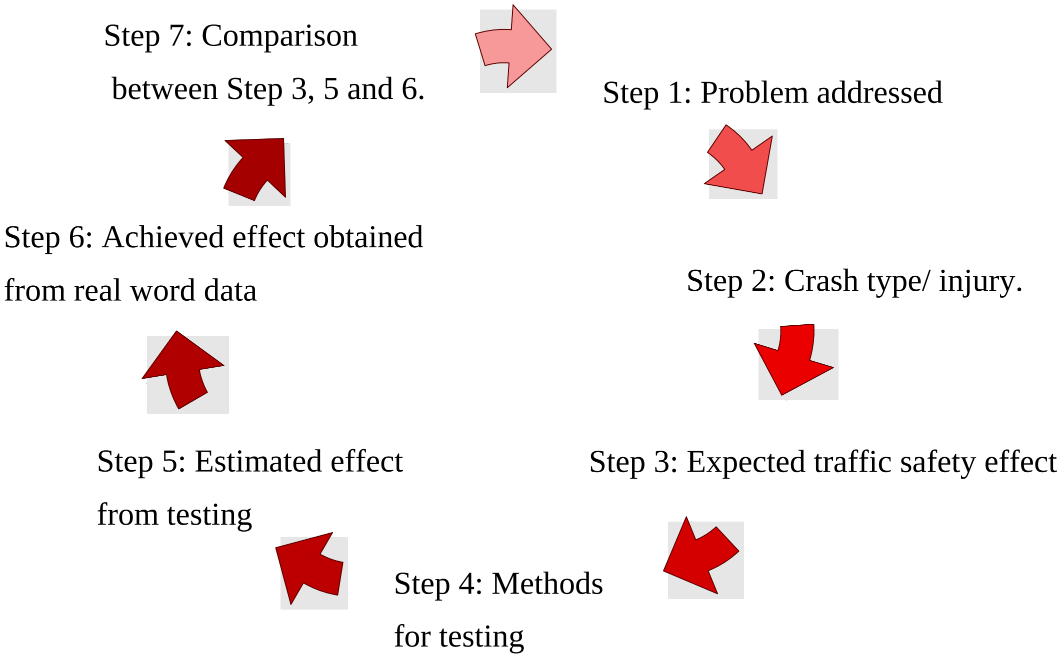


Figure 1.1 The loop with 7 steps from identification of problem to evaluation of achieved effects and comparison of these to expected and estimated traffic safety effects of intelligent transport systems.

The steps can be described with the examples as follows:

Step 1: Problem that the system aims at dealing with is for example the risk of skid or run off the road or loosing control in a steering manoeuvre in order to avoid an obstacle.

Step 2: Crash type/injury that a system aims at reduces for examples ESC (Electronic Stability Control) which aim at reduce the amount of roll over and run of the road crashes.

Step 3: Expected traffic safety effect achieved by the system for example X% reduction of the number of roll over crashes.

Step 4: Methods for testing of the effect of the system for example a steering manoeuvre in order to avoid an obstacle.

Step 5: Estimated effect by the system from testing for example ESC will provide a Y% reduce run off crashes.

Step 6: Achieved effect obtained from real world data by for example usage of the statistical method “paired comparison” (Lie et al., 2004).

Step 7: Comparison between expected, estimated and achieved traffic safety effect.

2 Aim of the study

The aim of this study was to provide an overview of in-vehicle techniques which, in an interactive manner with the driver, have the potential to increase traffic safety and to show how these systems are evaluated when they are present in the car fleet.

The report consists of three parts. First a description of Intelligent Transport Systems (ITS) that are currently available in passenger cars, secondly a review of the statistical methods used to evaluate the traffic safety benefits of ITS and thirdly an overview of how effects of new products and systems are dealt with in other industrial areas.

Due to the focus of the study, this literature review of in-vehicle systems does not cover entertainment systems and nor are inter-vehicle and vehicle-to-environment communication systems included. Furthermore, the study does not include any assessment of the role of different organisations and governmental agencies in the evaluation of the influence on traffic safety concerning technical development of ITS.

3 Material and method

The literature presented in this report was collected from several sources, including bibliographic databases, Internet, specialized magazines, company press releases and reports as well as personal communication with experts from the car manufacturing and safety research sector. Table 3.1 below lists some of these sources of information. Bibliographic database search was performed by the VTI Library and Information Centre (BIC) and by the authors.

Table 3.1 Sources of information for the literature overview.

Literature review	Literature review by VTI's Library and Information Centre (BIC) Databases: • Scopus • Compendex • Inspec • ITRD • TRIS • TRAX • SAE • PsycInfo • MathSciNet Literature review by author (traditional and electronic media)
Consultation of specialized literature	Available at VTI (BIC). Vehicle and traffic publications and specialized journals. Examples: • Inside ITS • Intelligent Highway • International Journal on Injury Control and Safety Promotion • International Journal on Vehicle Information and Communication • ITS international • Journal of Safety Research
Review of relevant projects	For example NCAP+, TRACE, ADASE, 100-Car Study, IVSS projects, etc.
Contact car manufacturers	Research departments of mainly Nordic car manufacturers.
Internet	Company web pages and any other information of interest.

Description of the databases used in the literature search

"Transport databases"

TRAX – library catalogue at VTI. The database started 1979 and contains more than 120,000 references to publications from 1920s and onwards. The annual growth is approximately 6,000 references per year.

ITRD (International Transport Research Documentation) – an international database with references to transport related literature and ongoing research. ITRD started in 1972 and is a part of OECD’s transport research program. It contains more than 350,000 references.

TRIS (Transport Research Information Service) – is run by the American TRB (Transportation Research Board) and aim at distribute information about transport research. It contains more than 600,000 references to transport related literature and ongoing research.

SAE (Society of Automobile Engineering) – contains information on worldwide literature on technologies for self-propelled vehicles for land, sea, air, and space. Topics include engines, materials, fuels and lubricants and design manufacturing. It contains approximately 140,000 references to transport related literature and ongoing research.

“Technical databases”

Compendex – is also named or part of EI Compendex or Engineering Index Compendex or Engineering Village2. Its focus is a broad engineering research perspective. It contains more than 8 million references.

Inspec – "... provides a comprehensive index to the literature in physics, electrical/electronic engineering, computing, control engineering, information technology, production, manufacturing and mechanical engineering. It also has significant coverage in areas such as materials science, oceanography, nuclear engineering, geophysics, biomedical engineering and biophysics". It contains more than 8 million references (May 2006). Produced by the Institution of Engineering and Technology, a non-profit organisation registered as a charity in the UK.

Other databases

Scopus – a biographic reference database containing more than 28 million abstracts and 245 million references added to the abstracts. Scopus covers broadly health and life sciences i.e. technology, social science, psychology, economy, environment etc. Scopus is produced by Elsevier.

PsycInfo – covers broadly behaviour science such as: behaviour psychology and related behavioural and social sciences, including psychiatry, sociology, anthropology, education, pharmacology, and linguistics. It contains approximately 2,200,000 references.

MathSci (also called MathSciNet) – "produced by the American Mathematical Society (AMS), provides comprehensive coverage of the world's literature on mathematics, statistics, computer science and their applications in a wide range of disciplines, including operations research, econometrics, engineering, physics, biology, and many other related fields. Coverage is international, with nearly one third of the documents indexed originally published in languages other than English."

Comment: The large database Medline is not part of the list above since all journals that are found in Medline are indexed in Scopus for the time frame that this search covers.

A list of search words used in the literature search is found in Appendix 3. More than 300 articles and reports were found and scrutinized. Those most relevant are included in the reference list of this report.

4 ITS in passenger vehicles

This chapter introduces intelligent transportation systems from a theoretical point of view, starting with a general definition and then describing different ways of classifying ITS. The scope is to summarize ITS from a traffic safety point of view, without technical descriptions of systems. Much research is ongoing around ITS, a number of focus areas targeted by researchers is presented in subchapter “ITS focus areas” on page 21. Prospects for ITS introduction dates and possible traffic safety potential are summarized in subchapter “ITS road map” on page 21. Technical system descriptions and research findings are presented in the Chapter “ITS available in series-produced passenger cars”) starting on page 25. The groups of the systems described in Chapter 5 follows loosely the ITS classification in Figure 4.2 on page 19.

4.1 What is ITS?

ITS is an acronym for Intelligent Transportation Systems or Intelligent Transport Systems. ITS is generally road based, vehicle based, vehicle to road based or vehicle to vehicle based technologies supporting the driver and/or the management of traffic in a transport system. On the vehicle side of ITS often two major subdivision are found: in-vehicle information and communication systems (IVIS) and advanced driver assistance systems (ADAS). IVIS and ADAS can then be subdivided into active and passive safety systems. The term ”intelligent” is often used for user interfaces (Riecken, 1997), and there are parallels here: An ITS should adapt to the actual situation, anticipate the needs and take initiative and possibly be explanative. This leads to the exclusion of passive safety systems in our context. A distinction between passive and ”intelligent” safety system is for example a standard safety belt, which is considered to be a passive system, whereas an intelligent safety system could be a safety belt that automatically tensions when an impact is considered imminent and adapts the tension to the crash severity and the mass of the driver. This example illustrates the usage of ”intelligent” in relation to safety systems and traffic systems in this report. Figure 4.1 shows the focus of this report which is mainly “intelligent” (advanced) in-vehicle systems for passenger cars related to safety, thus more focus is put on active than on passive safety systems. For the scope of this report Figure 4.1 denotes what systems are reviewed here and where they are placed in the ITS context.

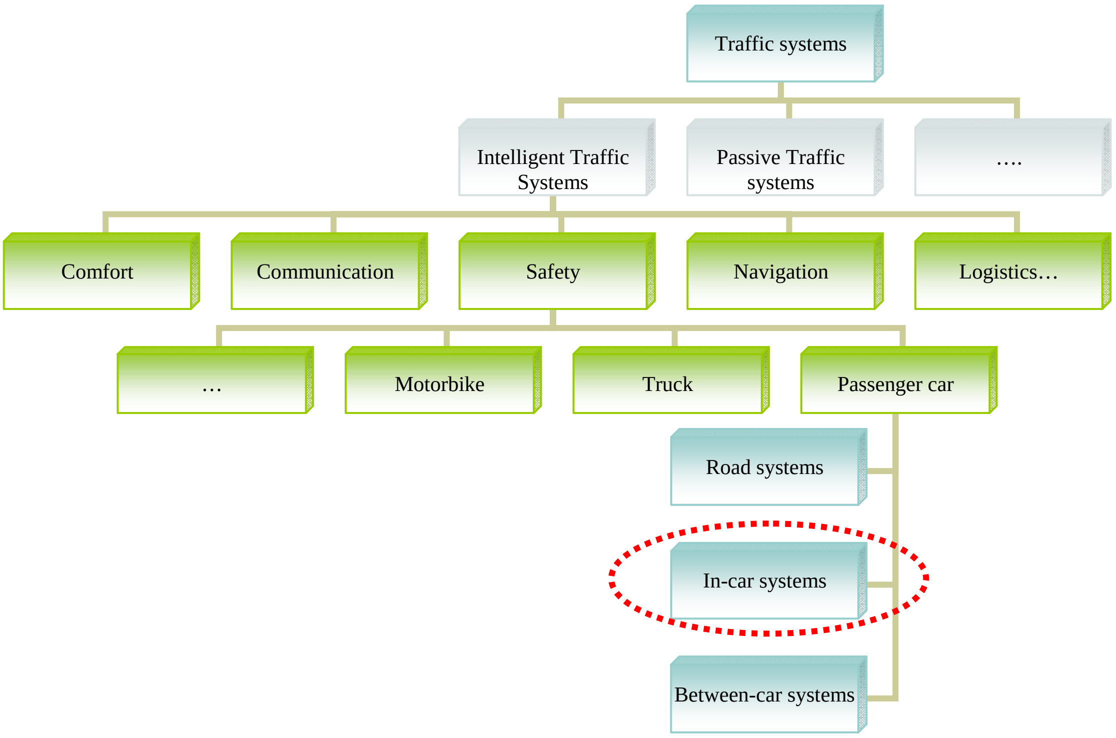


Figure 4.1 ITS in the context of this report which is "intelligent" in-car systems related to safety in passenger cars. Other areas showed in the figure are not included, except if of relevance.

4.2 Classification of ITS

There are different manners of classifying ITS and its two major subdivisions: IVIS and ADAS. No international standards for classification are present to our knowledge, and different authors have different understanding of the acronyms. Generally IVIS is related to information provided to the driver (for example route guidance and various vocal/visual information messages); while ADAS relates to assistance systems for the primary driving task, for example collision avoidance, vision enhancement, etc. Lane departure warning systems (without any corrective steering action) are an interesting example of this sometimes loose delineation of system association: even if lane departure warning systems only provide information to the driver, they are classified as ADAS in a number of reports (see Floudas et al., 2004 for example). One definition of ADAS is found the documentation from the PReVENT project (PReVENT, 2007): "Driver Assistance Systems are supporting the driver in their primary driving task. They inform and warn the driver, provide feedback on driver actions, increase comfort and reduce the workload by actively stabilizing or manoeuvring the car. They are assisting (compared to taking over) due to the fact that the responsibility remains always with the driver. ADAS are a subset of the driver assistance systems. ADAS are characterised by all of the following properties:

- support the driver in the primary driving task
- provide warnings or active support
- detect and evaluate the vehicle environment
- use complex signal processing
- direct interaction between the driver and the system".

A classification of a large number of systems into ADAS or not ADAS is found on page 94 of the report of PReVENT (2007).

Passive safety systems protect vehicle occupants when a collision occurs while active safety systems act before the crash. Figure 4.1shows the general classification of in-vehicle ITS related to safety used in this report.

It loosely follows the timeline from normal driving to critical situation, imminent crash, crash phase and finally post-crash, and has the following main areas: driver monitoring, driver assistance, vehicle control, crash avoidance-mitigation, injury mitigation, pedestrian protection, and finally post-crash systems.

The systems listed in the green boxes in Figure 4.2 are described in this report.

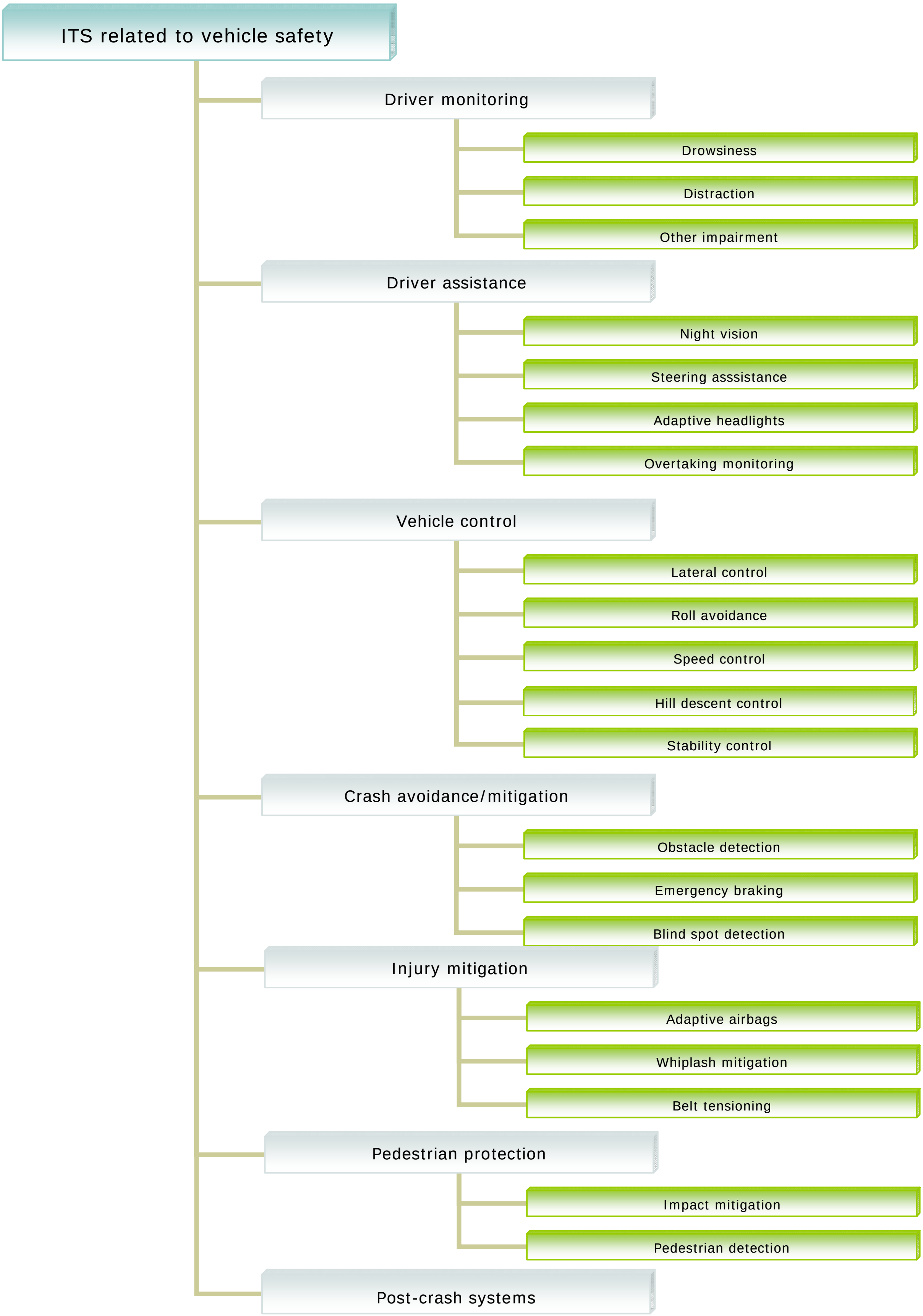


Figure 4.2 Classification of safety systems reviewed in the report. The classification loosely follows the timeline from normal driving to critical situation, imminent crash, crash phase and post-crash.

A strict division into the classes in Figure 4.2 is not possible. For example, a system that is acting on the lateral stability of the vehicle will be classified as “vehicle control” but also as “crash avoidance”. This should not be seen as a dilemma, but rather elucidates the variety and complexity of today’s technology.

Another way of classify systems is based on the occurrence in the chain of events during normal driving, incoming hazardous situation, imminent crash situation, crash impact mitigation, and finally post-crash systems. Yet another classification strategy considers systems only warning the driver or acting autonomously (for example by braking). A classification based on active and passive systems is more difficult given the complexity of a modern system and the interaction between different systems.

There is an important note here: often car manufacturers tend to classify systems as “comfort improving” or “convenience systems” even if they have the potential to improve safety. If the reason for this are legislative issues is not known. In this report focus is on systems with “potential” to increase traffic safety (even if the systems are classified as “systems to improve comfort”). Please consult chapter 5.24 on page 60 for a discussion on this issue.

The ADASE EU project (within the fifth framework programme ADASE Consortium, 2004b) proposed another classification, based on active versus passive safety, and pre- versus post-crash phase: The actions (systems) in each area, for example rescue, collision avoidance and occupant protection are shown in Figur 4.3. Active versus passive safety systems are classified based on pre- and post crash phase, and it is shown which systems are aimed at collision avoidance and which are aimed at occupant protection. In Figure 4.3 systems to protect pedestrians and also systems for driver monitoring and for distraction or drowsiness are excluded.

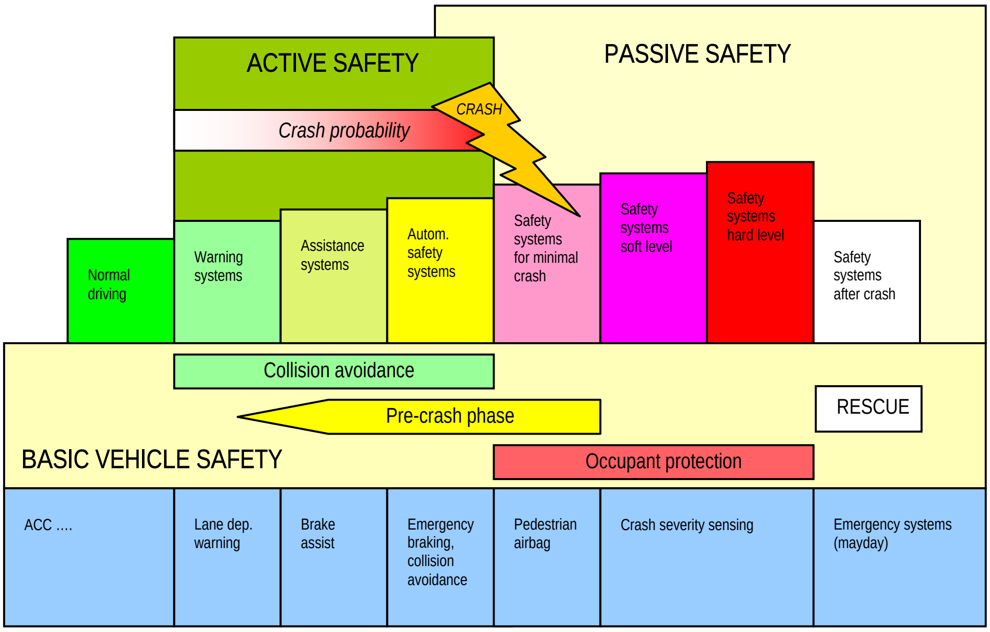


Figure 4.3 Holistic view on safety, adapted from ADASE Consortium (2004b). Active and passive systems, as well as timeline and crash probability are found in the figure.

4.3 ITS focus areas

As described in chapter 4.2, ITS can be used both in the assistance of the driver task and in order to improve traffic safety. Focus areas of ITS can be based on drivers, situations and systems. Figure 4.4, adapted from Bishop (2007), illustrates the main focus areas and the issues addressed in each area. The main areas are systems (embedded, fault tolerant, dependable), communication platforms (encompassing digital maps) and evaluation. Focus is on drivers, speed dictated situations, and biomechanics related to impact. The focus areas require quite different approaches: there are the technical challenges in developing systems, human factors aspects, medical aspects in injury measurement and driver impairment, traffic management and the infrastructure matters, and always legislative requirements when introducing systems on the market.

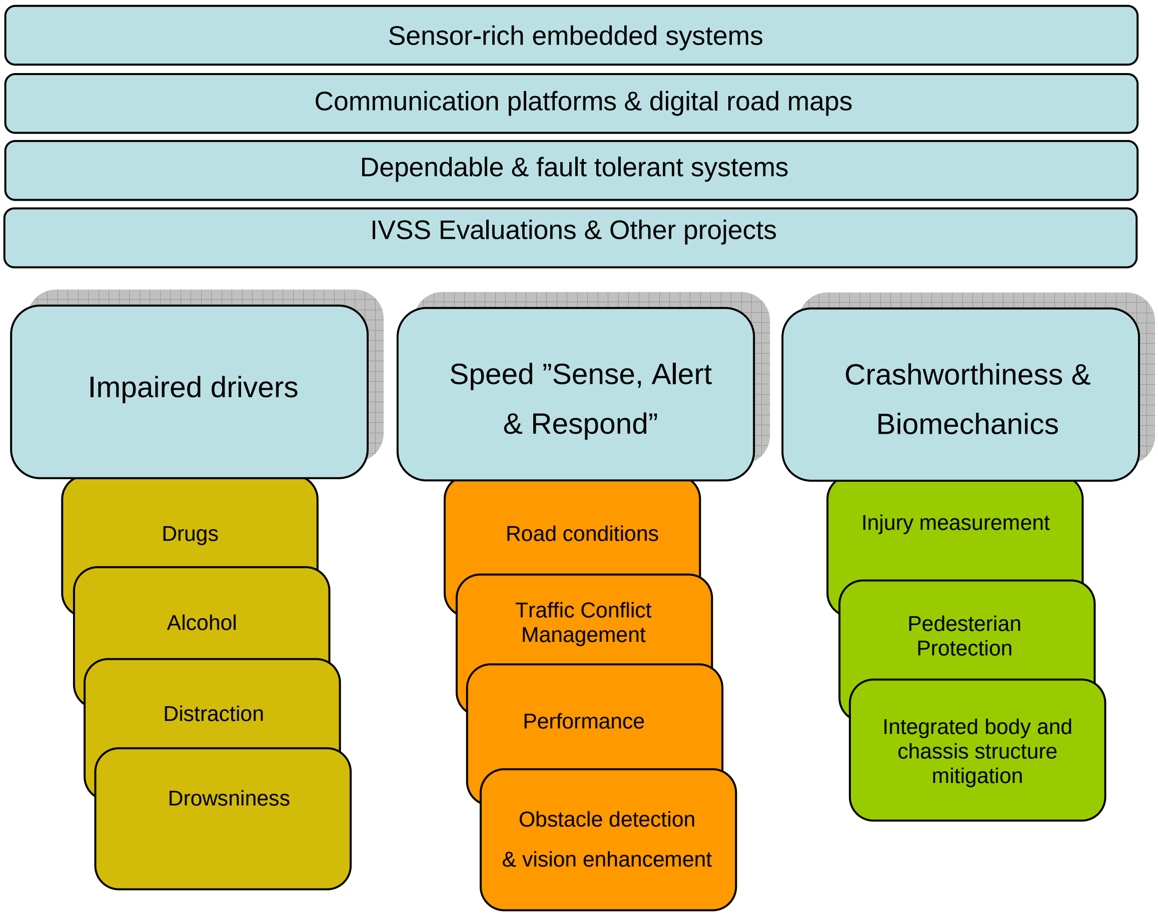


Figure 4.4 ITS focus areas (adapted from Bishop (2007)). Main areas are systems (embedded, fault tolerant, dependable), communication platforms (encompassing digital maps) and evaluation. Focus is on drivers, speed dictated situations, and biomechanics related to impact.

4.4 ITS road map

There are attempts in marketing studies and by researchers to describe and predict the contribution to traffic safety, future development and introduction date of new ITS. Of interest here is the ADASE2 roadmap for complexity and contribution to safety for different ITS (ADASE Consortium, 2004a). The complexity of a system often correlates positively with its development time, and thus with the introduction date. Figure 4.5

shows the safety contribution and complexity of driver assistance systems; some of the systems are already found in cars today, other are in development phase. The size of the circle in Figure 4.5 (white for "contribution to safety" and black for "system complexity") indicates relative impact for the named system (or action by the system). It is interesting to see that stop and go cruise control systems are thought to have high safety enhancement potential (although these are classified as convenience systems by car manufacturers), while obstacle and collision warning is given a lower safety enhancement property.

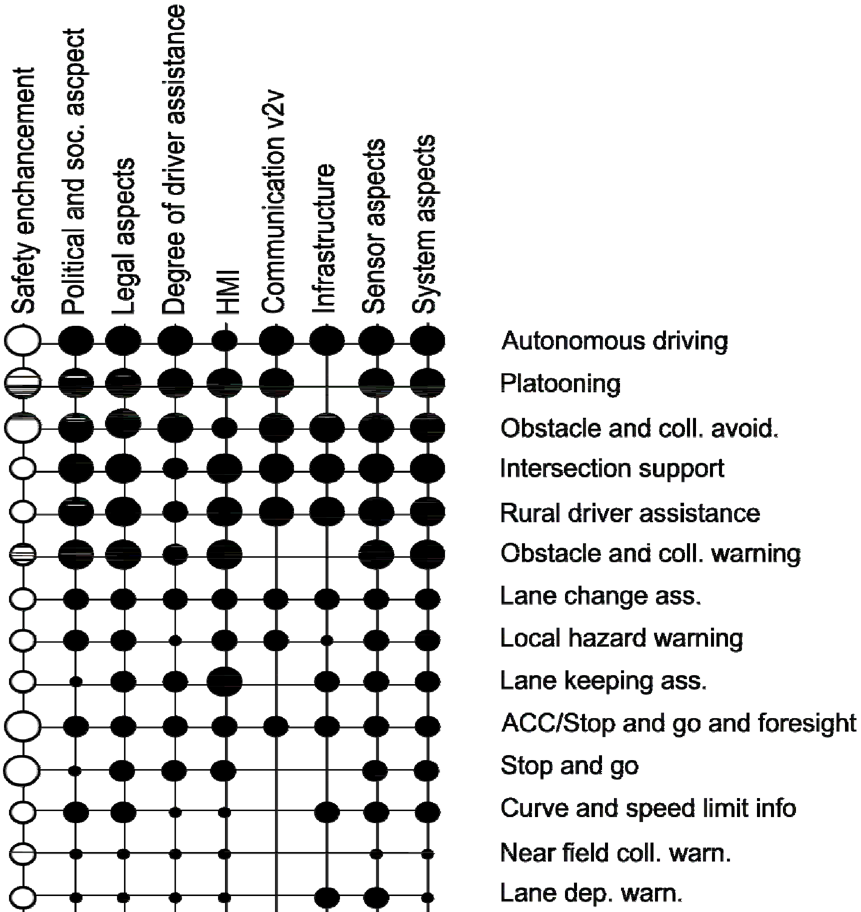


Figure 4.5 ADASE2 roadmap for advanced driver assistance systems in Europe (ADASE Consortium, 2004a). The size of the circle (white for "contribution to safety", and black for "system complexity") indicates effect magnitude.

Leen and Heffernan provided an estimation of the introduction date of different vehicle safety systems, dividing into active and passive safety systems and technology implementation (Leen & Heffernan, 2002). In Figure 4.6 safety potential and level of driver assistance follow the y-axis, while adoption year is represented on the x-axis. It is interesting to note that in the article, (which is from 2002), the authors estimated collision avoidance systems to be introduced by 2020; but in fact the systems start to appear already now. This shows how difficult it is to predict the future development of ITS, and may as well be related to which systems are getting most attention by the car manufacturers. Both in Figure 4.5 and Figure 4.6 autonomous driving is considered the “final” development, which gives the highest contribution to traffic safety. In a way this implies that the driver is the most critical factor for unsafe traffic.

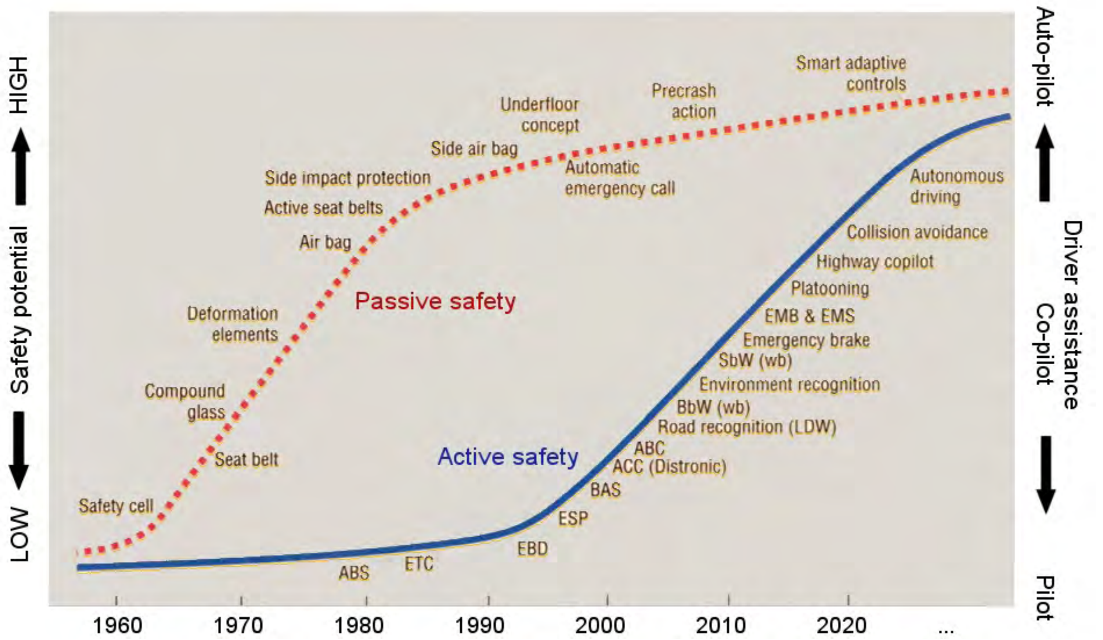


Figure 4.6 Past and future vehicle safety system from (Leen & Heffernan, 2002). Safety potential and level of driver assistance rises on the y-axis, while adoption year rises on the x-axis.

In the final SEiSS report (Abele et al., 2005) another interesting view of ITS is presented. Here systems are classified by timing (pre-post crash), introduction date, and function as shown in Figure 4.7. Timeline raises on the x-axis, while driving situation and systems purpose are colour coded, with red colour signifying crash situations, yellow meaning emergency situations, and green colour normal driving situations. This classification lists eCall as well, which is not often found in other categorizations. Again, here collision avoidance systems were not expected in the next couple of years.

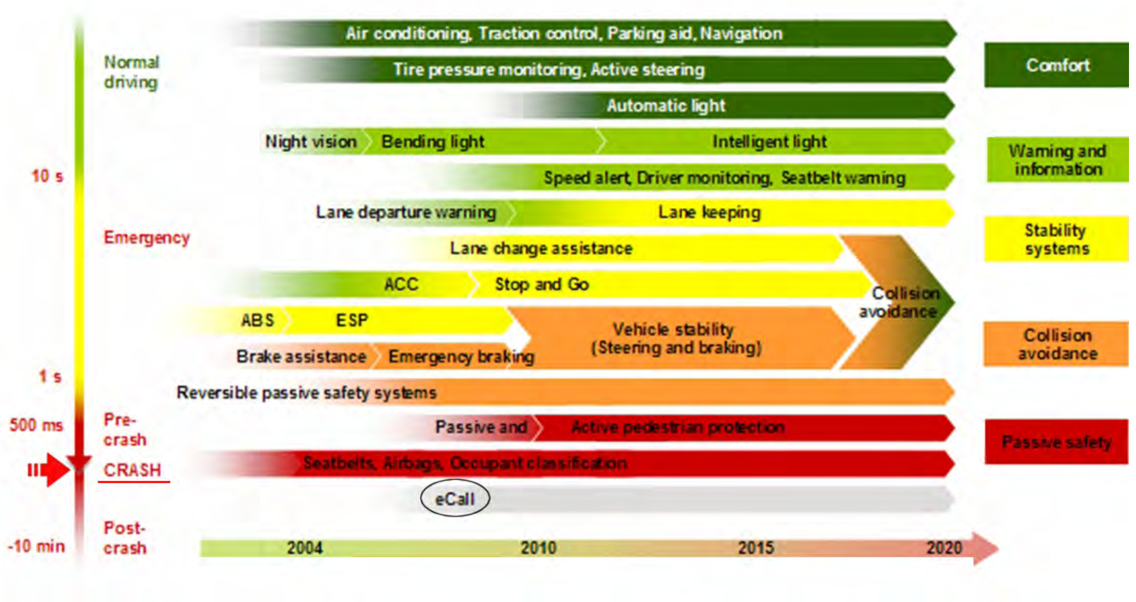


Figure 4.7 ITS roadmap adapted from Abele et al. (2005). Timeline raises on the x-axis, while driving situation is colour coded on the vertical line, with red colour signifying crash situations, yellow meaning emergency situations, and green colour normal driving situations. The colour coding denotation is reflected in the system function.

It should be mentioned that there are an increasing number of major research projects aimed at developing and evaluating innovative ITS. The European Union, National Highway Traffic Safety Administration, and many more are concentrating efforts in this area. Just to name a few: in Europe PReVENT, AKTIV in Germany, in Japan Smartway (intersection collision avoidance, blind curve monitoring, etc), in the US IVBSS and CICAS. Furthermore cooperation between research institutions, government bodies and industry gains weight. An overview of relevant ITS related EC projects is found in the appendix B of (Rekveldt & Labibes, 2003).

4.5 Conclusions

This chapter presented a theoretical framework around the ITS area. Different classification options showed the complexity of ITS, and the focus areas together with the road map gave insight into ongoing traffic safety research. Differences in opinion about introduction date of ITS (see road map in Figure 4.7 and Figure 4.6) from show that forecasting ITS development is challenging. Focus areas and road maps serve to understand where safety focus was in the past, and how this could change in the future. The following main chapter will abandon theoretical frameworks and instead describe real systems found already nowadays in vehicles, citing relevant scientific findings supporting or opposing positive effects on traffic safety.

5 ITS available in series-produced passenger cars

This chapter is a technical review intended to give an outline of the present state of ITS in passenger vehicles. The criteria for choosing the ITS reviewed here are: **a)** only in-car systems, excluding ITS on infrastructure and roads; **b)** systems that have a potential to increase traffic safety; **c)** systems that are technically “advanced” and able for example to adapt to the needs or anticipate situations or take initiative; **d)** systems available in series-produced passenger car.

Each subchapter describes a certain system, and gives references to studies evaluating its safety aspects (if present). A short summary concludes each subchapter. Ordering of the subchapters follows loosely the ITS classification in Figure 4.2. A short description of other safety systems such as tyre pressure monitoring and traffic sign recognition summarizes systems not present as main chapters in the report, but worth mentioning.

The systems presented are all available in series-produced cars; systems in development phase are mentioned in short form if they are likely to be found on series-produced cars soon.

The following systems are described in this chapter (name and page number):

5.1 Driver monitoring

Driver monitoring is a wide field. From passenger detection for seat belts reminder to be activated to airbag activation depending on the present passenger, advanced systems try to monitor driver state in relation to impaired driving performance. Seat belt reminder has showed to substantially increase the seat belt wearing rate (Lie et al., 2007) with a 97.5% seat belt use in cars with seat belt reminder compared to 85.8% in cars without seat belt reminders. These observations were the average of the findings from seven European countries (Lie et al., 2007). Systems aimed at detecting driver impairment are under development. A driver which is tired, distracted, under influence of drugs or alcohol, or any other condition which endangers his or her role as traffic participant, can be classified as impaired driver. Much effort has been aimed on detecting drowsiness or other impairment in drivers, and here only a few publications are named: (Törnros et al., 2000; Englund, 1982; Eriksson & Papanikolopoulos, 1997; Grace et al., 2001; Singh & Papanikolopoulos, 1999; Wierwille et al., 1995; Dinges et al., 1998; and several more). A comprehensive list of references on drowsy driving is found in the National Highway Traffic Safety Administration (US) homepage (NHTSA, 1998). Methods to detect impairment include physiological measurements (such as electrooculogram), scanning of eye lid closure, scanning of facial features, steering characteristics, etc. The vast interest which impaired driving has received from the research community and the governments shows its importance in the traffic safety area. The references above are related to research on impaired driving, and do not review vehicles which already have such systems. The patterns for "impaired driving behaviour" are difficult to subjectively quantify, and this might be the reason why in the last years manufacturers have had limited success in developing systems to recognize impaired driving.

Examples of cars with driver impairment detection systems are presented below. In the Lexus car model (LS 600h model) the driver's head is monitored by a camera mounted on top of the steering column (see Figure 5.1a and b). Infrared LEDs does allow the camera be used both at day and night time.

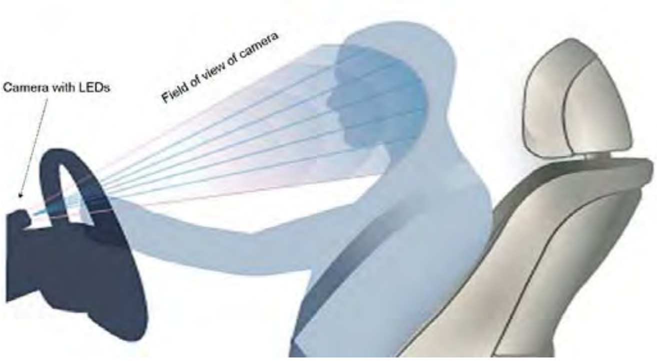


Figure 5.1a Driver distraction monitoring as found in the Lexus LS 600h (figure adapted from www.lexus-europe.com). A camera monitors the driver and detects distraction. Warning and according actions are performed when a driver looks away from the road for too long while an obstacle is detected in front of the car.

Figure 5.1b Device with camera and LEDs in the Lexus LS 600h to monitor the drive (figure adapted from www.autospies.com).

The system monitors facial features, and is able to determine if the driver looks away from the road. If the driver turns his or her head away from the road at an angle of more than 15 degrees whilst the vehicle is in motion and an obstacle is detected in front, the system will warn the driver by an alarm sound and a quick activation of the brakes. If this still fails to elicit action from the driver, the system engages emergency braking preparation and front seatbelt pre-tensioning (AutoMotoPortal, 2006).

Saab and Mercedes are working on driver impairment monitoring systems, and the first cars with such systems are expected in the near future. Volvo is working on a sleep and distraction detection system (which is not on the market yet). The system is said to monitor driver state by measuring vehicle path and distance to cars ahead. A camera monitors the road ahead, not the driver. If the vehicle is moving in an uncontrolled way, the system will alert the driver with an audible warning and a message on the car's information display. Siemens VDO plans to introduce a drowsy driver detection system, integrated with ACC and lane departure warning at the end of the decade (InsideITS, 2006). A prototype vehicle was already demonstrated in 2006. The system will use infrared cameras to monitor the driver's face and eye blink behaviour. Ford has too a drowsy driver detection system patented (Ford Global Technologies, 2003), but not yet introduced.

Generally, driver monitoring systems to come might apply camera technology to scan the driver's face and possibly body, and integrate with information from vehicle dynamics and infrastructure in the future. It is less likely that systems will use biosignal measurement (for example measuring electrocardiogram, electro-encephalogram, or electromyogram), even though there is a lot on ongoing research in this area. It seems that biosignal measurement is less promising, because of high inter-individual differences and measurement issues.

The influence of driver distraction on traffic safety was shown in the 100-car study from the US Department of Transportation (study sponsored by NHTSA, VDOT, VTRC and VT). One main conclusion of the study was that "Nearly 80 percent of crashes and 65 percent of near-crashes involved some form of driver inattention within three seconds before the event. Primary causes of driver inattention are distracting activities, such as cell phone use, and drowsiness". Note that the data is based on 82 crashes, 761 near-crashes, and 8,295 critical incidents (situations requiring an evasive manoeuvre). For more information on the 100-car study please consult (US Department of Transportation, 2006a) and for an overview of the study (US Department of Transportation, 2006b).

ITS developers are well aware that fatigue is recognized as an important factor in traffic accidents, and thus have high expectations in terms of increased safety of driver monitoring systems able to detect fatigue. Vincent et al. (1998) found no positive effects of a fatigue warning system in a field study with 32 drivers. The authors write: "…the FWS (Fatigue Warning System) had no impact on objective and subjective driver fatigue, on driving time, on the number of breaks or on break duration. Results also demonstrate that 30 minute breaks are an ineffective drowsiness countermeasure. These findings suggest that an FWS as currently conceived may not contribute to reduce fatigue induced collisions" and the authors summarize: "… Future research needs to address what mechanism induces subjects to take breaks and ignore warning signals. One hypothesis is that drivers consider the signal redundant" (Vincent et al., 1998).

Summarizing driver monitoring and ITS, the importance of behaviour monitoring (in terms of drowsiness and distraction) is well recognized by research community and industry. The first cars with functioning driver monitoring systems are already on the market, and more car manufacturers are expected to release similar systems on the market in the near future. This can be deducted from the intense research effort to develop these systems, which companies such as Volvo undertake. Further research is needed to evaluate the safety advantage cars with such systems already implemented have.

5.2 Night vision systems

Night vision systems use different technologies to aid drivers in seeing the road during dark hours. Technology usually uses infrared light detection with special cameras; there are passive and active systems. An infrared camera pointing in driving direction can detect obstacles or pedestrians located at a longer distance than what the driver is able to see, allowing early reaction. GM launched a car with this technology in early 2000, but without success in marketing terms. The Cadillac DeVille night vision system was reportedly discontinued after 2005 after disappointing customer experiences (the system suffered from glitches and poor resolution according to unofficial sources) (Peirce & Lappin, 2006). Toyota developed also a system in early 2000, then BMW and Mercedes introduced the system in series-produced cars (ABI-Research, 2007). Honda and Lexus have an ”intelligent night vision system” but the Honda system is only commercialized in Japan. An obstacle towards mass-market production of night vision systems is the high cost which the systems still have. If demand from customers’ raises, car manufacturers could introduce more night vision systems, and systems developers such as Bosch, Autoliv, Hella, Siemens, and Valeo will experience strong demand, the costs might drop. In Europe BMW and Mercedes are the main car manufacturers with night vision systems. A list of other companies and manufacturers developing night vision systems is presented in Appendix 2. BMW’s night vision system is shown in Figure 5.2 and Figure 5.3 below. The figures show the range of the system, and its placement inside the car (monitor) and outside the car (radar). A picture from an actual image produced by the night vision systems is seen in Figure 5.3. The screen of the night vision system found in Mercedes cars is shown in Figure 5.4. Here the screen is located in the centre console. The BMW's system scans up to 984 feet in front of the car at a 12 to 18 degree angle.

The BMW system is based on far-infrared sensors (FIR) using a sensor to process the images the heat emitted by objects outside the car. The warmer the object is, the brighter the image becomes. A far-infrared system thus depends on the heat radiated by an object. A thermal imaging camera directly registers the heat radiated by objects and human beings, making a separate light source from the vehicle superfluous. Cold objects or objects with the same temperature as their surroundings, such as obstacles in the road or dead animals cannot be picked up by a far-infrared system.

While the BMW system is based on far-infrared sensors the Mercedes system is based on near-infrared sensors. With near-infrared systems (NIR), the illumination is not dependent on environmental conditions and objects are therefore significantly more visible. Near Infrared (NIR) light beams an infrared light source into the area in front of the vehicle.

Night vision systems can be integrated with obstacle detection systems, providing the driver with specific warnings on oncoming hazards.

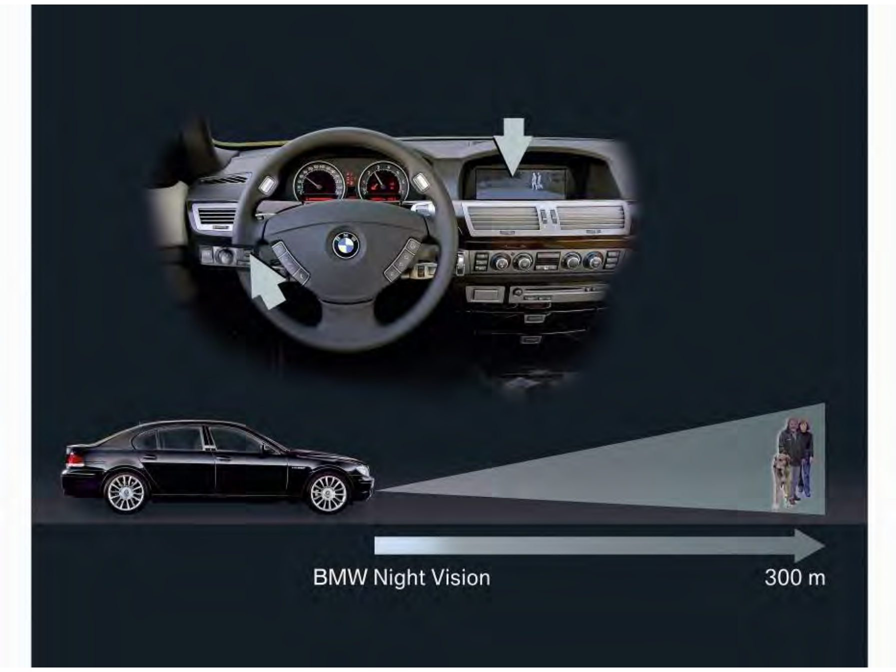


Figure 5.2 Night vision system of BMW (BMW press archive). Range of the system, monitor placement and activation command (arrow to the left of the steering wheel) are shown.

Figure 5.3 Detail of the night vision display (BMW press archive). The monitor (in greyscale) shows the pedestrians with a dog that would otherwise be more difficult to detect by the driver when only looking through the windscreen.

Figure 5.4 Night vision system in Mercedes cars showing the screen with image produced by the night vision system in the centre line of the sight (near tachometer) as seen by the driver through the steering wheel.

The night vision system by Honda (available for Legend models only in Japan) has similar functionality as described above, with the addition that it is able to detect pedestrians and their movements. It uses two far-infrared cameras to detect pedestrians approaching the vehicle's path and provides the driver visual and auditory cautions to help to prevent accidents involving pedestrians. The camera obtains a visual image based on the heat emitted by humans and other objects. Since it uses far-infrared radiation, it is capable of obtaining a viable image without the use of a light source, as is required by visible-light or "near-infrared" cameras. The warning has the form of a visual enhancement frame around the pedestrian image in a head up display, together with audio-warnings. The shape of objects in the camera range is calculated to detect pedestrians, and their path is calculated too. The system provides warnings that inform the driver of the presence of pedestrians that are on the road or about to cross the road.

Research available for night vision systems shows positive effects on traffic safety. In a simulator study by Hollnagel & Kallhammer (2003) night vision systems were found to have positive effects on safety: "…subjects using an NVES (Night Vision Enhancement System) gained time to assess the situation and choose an appropriate response, which was seen in terms of better control of braking and swerving. Altogether the experiments confirmed that an NVES leads to an indisputable improvement in the drivers' anticipatory control, and hence has considerable safety potential…" (Hollnagel & Kallhammer, 2003). Sullivan et al. (2004) conducted a driving study on a test track with young and older drivers in 2004. An infrared night vision systems was used. Their conclusion is that :" … Night vision systems increased target detection distance for both young and old drivers, with noticeably more benefit for younger drivers. Workload measures did not differ between the unassisted visual detection task and the detection tasks assisted by night vision systems, suggesting that the added workload imposed by the night vision system in this study is small" (Sullivan et al., 2004).

Night vision systems are already on the market in a number of car models, mostly upper segment cars. Preliminary research results show promising positive effects on traffic safety. The systems are still expensive, and this factor may compromise large scale introduction. Integration of night vision with obstacle detection and warning systems may be a promising approach.

5.3 Workload management systems

Drivers are supported by an increasing number of complex systems inside cars, and it may become difficult to keep track of all possible warnings and alerts. For instance, there is a rise in the use of mobile phone, navigation systems, in-car entertainment, and other new features in the automobile interior. There is a possible risk of overloading the driver with information with result of possible distraction and difficulty to filter the important information. “Workload managers“ are designed to address this problem by filtering and prioritizing the information made available to the driver. They work by using a "workload estimator", which uses information from vehicle sensors (such as speed, braking, and headlight and windshield wiper usage) to assess the potential difficulty of the driving situation. Additional information on workload estimators can be found in the references (Trent Victor – Volvo Technology, 2003; Engström et al., 2006). When challenging situations are detected, the workload manager postpones or cancels certain messages or situations, such as non-urgent vehicle warnings or mobile telephone calls.

Manufactures have addressed the problem with driver overload in different ways as by optimizing user interfaces and by ergonomics. Since 2003, most Saab 9-3 and 9-5 models have had a rudimentary form of workload manager called a "dialogue manager," which suppresses certain information displays during demanding driving conditions. For example, the system "will postpone a reminder for the 30,000-mile check-up that otherwise might be presented while driving in a torrential downpour, an inopportune time to distract a driver." (Peirce & Lappin, 2006) A similar system, called the Intelligent Driver Information System (IDIS), is available on Volvo S40s and V40s sold in Europe (Volvo Car Corporation, 2007). IDIS blocks telephone calls and text messages during times when the driver is turning, changing lanes or conducting similar manoeuvres. The Volvo S80 model has an updated workload management system, aimed at considering the actual workload of the driver and presenting information accordingly.

FIAT, Daimler Chrysler, BMW, and Toyota are working on implementation of workload management systems, too. No other cars, in which an “intelligent” workload monitoring is used, are known (as a note it should be mentioned that in the military avionics field this area has been explored much more thoroughly). The human factor community can and does greatly contribute to adapting user interfaces and presentations of information for passenger car drivers.

5.4 Emergency steering assist

Emergency steering assistance is a system which detects if the driver performs a rapid evasive manoeuvre. In this case the system reduces the steering gear ratio (which is variable) to provide more direct steering and a faster response to driver inputs. Furthermore the suspension adopts a stiffer damper setting to minimise body roll. According to Lexus (which offer a car model with this system) emergency steering assist substantially improves the car’s response to the driver’s steering input in the likelihood of a collision, increasing the chance of avoiding the obstacle (Lexus, 2007). In the literature search no scientific articles were found to support this.

Emergency steering assist systems are still rare in series-produced cars, which make collection of data to investigate the effects on traffic safety difficult.

5.5 Brake force display

Brake force display is, in comparison with other ITS in this chapter, a rather simple technique that has recently been developed. It displays brake force in a dual-stage brake light system. When applying the brakes in a normal manner, the main brake light element is illuminated, while if the brakes are applied harder the entire brake light glows red. The system uses acceleration sensors in addition to brake pedal pressure, to detect hard applied brakes. It is found in middle and high range BMW vehicles. The company states: ”BMW hopes the adoption of Brake Force Display will lead to a reduction in avoidable rear-end collisions…” (BMW, 2006).

Figure 5.5 shows the two-stage brake light. On the left without applying the brakes (only lights on), in the middle when the brakes are applied normally and on the right when the brakes are applied hard. The intensity of the brake lights is higher in the right car, signalizing stronger deceleration.

Figure 5.5 Brake force display (BMW press archive). Left car: without allying the brakes (only lights on), middle car: applying the brakes normally, right car: allying the brakes hard. The intensity of the brake lights is higher in the right car, signalizing stronger deceleration.

In the Mercedes system there are supplementary light emitting diodes (LED) inside the braking lights, which flash at 5.5 Hz in case of applying the brakes hard. Volvo has a similar system in the new model range: if a hard deceleration is detected, the brake lights automatically flash, warning drivers to the rear. In the Citroen C4 even the hazard warning lights activate in case of applying the brakes hard. The concept is similar to the BMW system, but from the human factors point of view flashing brake lights should be more attention-catching than the BMW two-stage brake light. Volvo warns that "it should be noted that flashing brake lights are still forbidden by law in many countries." (Web Publications Pty Limited, 2007).

Summarizing, brake force display is a relatively simple system with potential to increase awareness of unforeseen situations on the road. A number of manufacturers offer similar systems, but little research on the impact was found in this literature overview.

5.6 Adaptive headlights

Adaptive headlights follow the road curvature actively, illuminating not only in straight forward direction but turning the light beam in road direction when the car is in a curve. This allows for better range of vision, and may improve traffic safety. Figure 5.6 shows the principle of adaptive headlights. The headlamps are motorized and the horizontal angle of the headlights is dependent of speed, gyro and steering wheel angle. In Figure 5.6 the car performs a right turn (seen from above), and the headlights turn accordingly to follow the road curvature (BMW, 2007a). The maximal angle adjustment of the headlights is usually up to 15 degrees, but there are systems which activate an additional headlight in case of 90 degrees turns (see Figure 5.7), which are available for some Opel, Audi, Volkswagen, and other models. The car detects the 90 degrees turn by steering wheel angle and vehicle dynamics. Such headlights are often called cornering headlights.

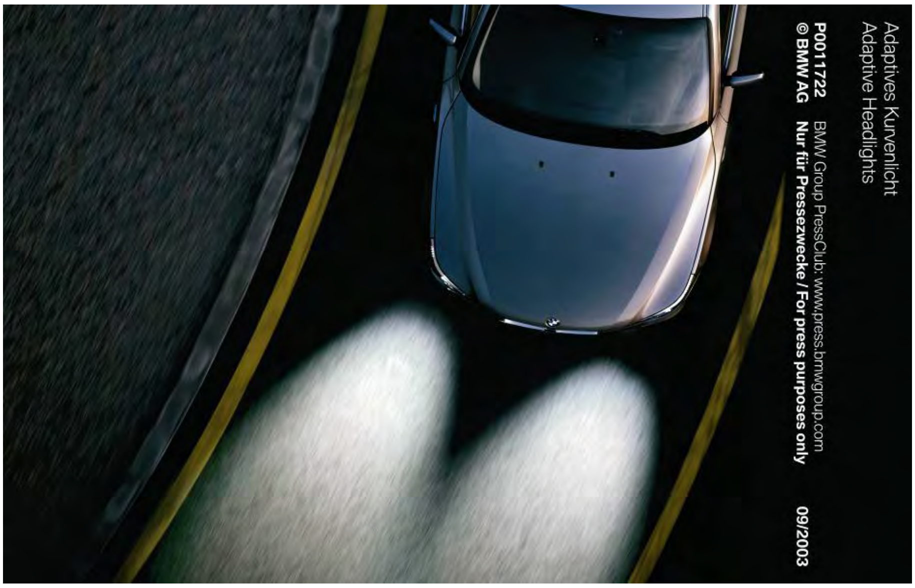


Figure 5.6 Adaptive headlights, car seen from above in a right turn (BMW press archive). The headlights turn to the right, illuminating the road and following its curvature.

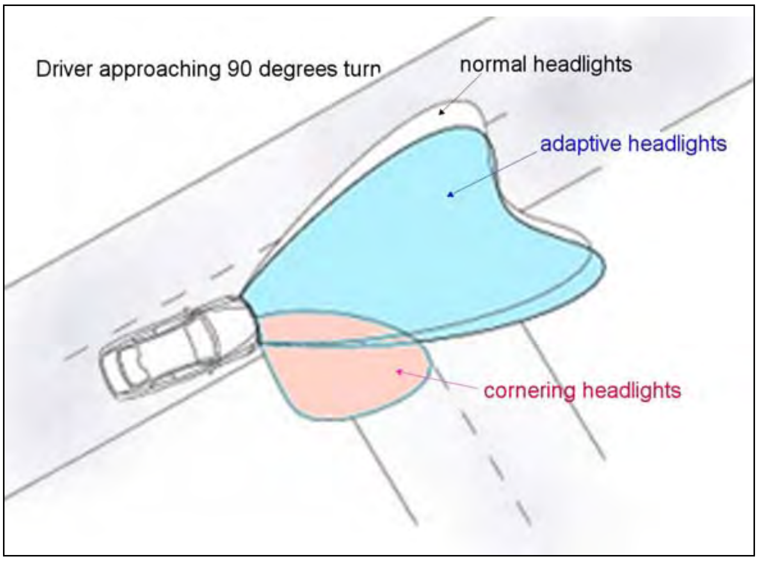


Figure 5.7 Adaptive headlights for 90 degrees turn while car is approaching a turn. The illumination by normal (white), adaptive (light blue) and cornering (light red) headlights is shown.

Adaptive headlights can have an additional feature: the system can switch from high beam to low beam as soon as it detects oncoming traffic or adequate street lighting. A camera integrated in the rear-view mirror monitors ambient brightness and traffic conditions, and can detect approaching traffic up to one kilometre away. When the road ahead is clear again, the system automatically switches up to high beam again (BMW, 2007b). There are several car manufacturers offering adaptive headlight systems, some only in the higher price segment cars. According to marketing research company “ABI Research”, the market in Europe seems to be more interested in this technology than the American market. American automakers are reported to have relatively little interest in adaptive lighting systems at present. While this may change as consumers gain exposure to them and understand their benefits, current projections are that only about 1½ percent of North American vehicles sold in 2010 would be equipped with them (ABI Research (Vehicle Safety Systems Report), 2005). In Europe many car manufacturers offer this system.

Volvo has a similar system in preparation: here the shape and intensity of the light beam is adjusted according to speed and steering. When driving at high speed the light beam can be given a longer reach, while at low speeds (for example in urban traffic) the light beam can be made shorter and broader to light up a larger area close to the car. When the driver steers the car into a curve, the beam can be directed along the track of the curve to light up the entire road as the car changes direction. This system was presented in a concept car and it is not known if series-production is planned. The simpler system with adaptive headlights (following the road curvature) is currently available by Volvo. Other manufactures add features such as turning the headlight on and off automatically in relation to light conditions (for example Mercedes Benz S-class).

On the topic influence on traffic safety by increased visibility in darkness one study was found on the influence of increased visibility due to reflector posts (Kallberg, 1991). The experimental study by Kallberg (1991) indicated that reflector posts on narrow, curvy and hilly roads can significant increase speed and accidents in darkness.

In short, adaptive headlights are offered by an increasing number of car manufacturers, and there is a chance that they might become a standard or largely available option in most cars in Europe. The positive effects of the system are not yet indubitable, as drivers may react differently to the system.

5.7 Lane departure warning

Lane departure warning (LDW) systems monitor the road ahead with vehicle-mounted cameras and image processing software to recognize lanes and detect if a lane departure is imminent. Figure 5.8 shows an example of lane departure warning. In Figure 5.8 the forward facing camera monitors the road marking of the road, and the system alarms the driver if road departure is likely or imminent. The driver is warned by auditory, visual, or other signals. Usually the road is monitored by camera, and clear road markings are necessary. Day or night time does not pose a problem to the system, but unclear road markings, snow, rain, etc, can compromise the functionality. The system might have a potential to reduce the number of accidents related to inattentive driving and drowsiness (single vehicle accidents).

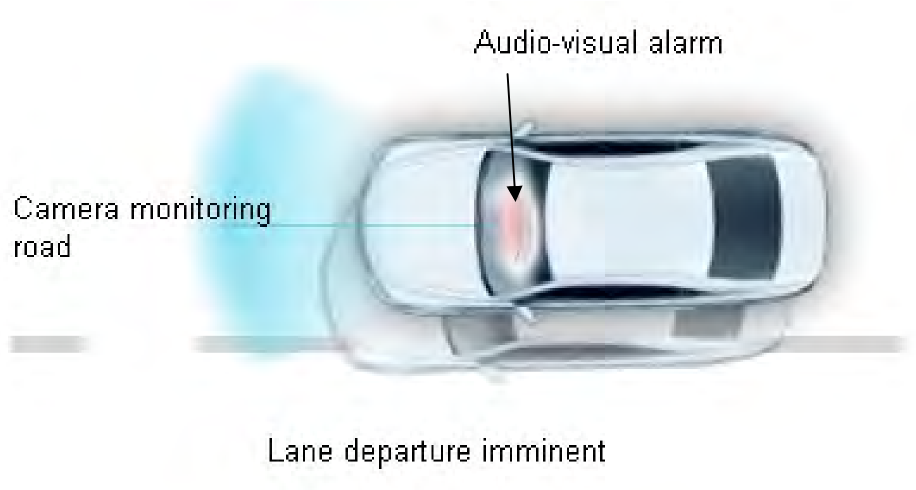


Figure 5.8 Lane departure warning system (figure adapted from www.lexus-europe.com). The road markings are monitored by the forward facing camera, an alarm is given to the driver if the car shows signs of road departure.

Originally LDW systems were developed for heavy trucks and found later their way into passenger vehicles, too. An overview of the heavy truck lane departure warning systems and their effect on crash number reduction can be found in (Inside ITS, 2001).

LDW systems started to appear in series-produced cars in early 2002 in Japan, around 2004 in Europe and in 2005 in America. Nowadays Nissan, Honda, Lexus, Toyota, Infinity, Peugeot, Citroen, Audi, BMW and Mercedes offer such systems, mainly in the high price segment as optional. In Europe Citroën first offered LDW systems on their 2005 C4 and C5 models, and now also on their C6. This system uses infrared sensors under the front bumper to monitor lane markings on the road surface. A vibration mechanism in the seat alerts the driver of deviations. The first production LDW system available in North America was the system jointly developed by Valeo and Iteris for Nissan Motors and fitted to their 2005 Infiniti FX and 2006 M45 vehicles. In this system, cameras mounted on the outside mirrors monitor the striping on highways. A vibrating mechanism mounted in the car seat is triggered on the side corresponding to the direction of vehicle drift to alert the driver who may, for example, be feeling drowsy. Research has shown that haptic warnings (for example steering wheel vibration) have good potential in being interpreted right by the driver, and they were effective for warning of lane departure situations (Suzuki & Jansson, 2003).

As for research on the safety effects of the systems, Rudin-Brown & Noy (2002) found lane keeping performance to be improved by lane departure warnings, but a high degree of trust in both accurate and inaccurate systems was seen in the drivers. The study was performed both in simulator setting and on track. The authors conclude: "…because of the propensity of some people to trust unreliable or faulty devices, caution should be used in attempting to predict the aggregate safety benefits of these systems." (Rudin-Brown & Noy, 2002). In another report by Abele et al. (2005) the effects of lane departure warning systems is seen in a much more positive light, the authors estimate (based on crash statistics) the safety effects as: "25% reduction in accident number and 25% reduction of accident severity in head-on collisions. 25% reduction in accident number and 15% reduction of accident severity in left-roadway accidents. 60% reduction in the number of accidents and a 10% reduction in accident severity for side collisions." (Abele et al., 2005). For heavy trucks Korse et al. (2003) found that lane departure warning systems would decrease the number of accidents by 10% (the study involved 40 professional drivers and 36 heavy duty vehicles).

Lane departure warning may be an efficient system to decrease number of traffic crashes but it should be note that the systems work only if there are road markings, in snowy, foggy or heavy rain conditions the systems are not able to operate. Further research is needed not only to validate the system, but even to analyse long terms effects on the driver, confidence to the system, driver reaction to warnings, etc.

5.7.1 Lane keeping assistance

Lane keeping assistance is a supplementary system related to lane departure warning. In the Lexus models, it provides appropriate steering inputs directly helping to keep the car within the lane. Honda and Nissan offer also lane keeping assist systems, but only for cars on the Japanese market. The system can be activated by the driver, and it applies steering torque autonomously. However, it is no an automatic steering system. The manufacturer specifies that the system will deactivate when it detects hands-free driving for a period longer than 15 seconds or 5 seconds during cornering. From the human factor aspect this makes the system very interesting (in positive and negative terms). Little research was found on lateral control assistance. In a field study on German motorways Schumann et al. (1996) found that active steering support was useful to reduce drivers' workload. The possible implications in terms of responsibility and legislation are worthy of noting. Please consult the presentation by Bishop, (2002) for more information on liability and legislation issues. Regarding performance of the systems it should be noted that the system only works if there are road markings. In snowy, foggy or heavy rain conditions the systems are not able to operate.

5.8 Adaptive cruise control

Standard cruise control keeps the speed constant as set by the driver, while adaptive cruise control adjusts the vehicle speed according to speed of vehicles ahead. This means that when the car approaches a slower vehicle in front, it will decelerate, and when the vehicle ahead accelerates, the speed will increase to the speed selected originally by the driver. The driver can select speed and minimal distance to vehicle in front. The distance to car ahead is measured by radar. Adaptive Cruise Control (ACC) is by Volvo Car classified as a ”convenience system that co-operates with the Collision Warning System” (Volvo Car Corporation, 2007).

There are systems which do not only decelerate passively, but also brake actively when the distance (or time to collision) to the car ahead gets low. The braking force is usually limited. Emergency braking with maximal braking force is in development phase, please consult chapter 5.14.1 on page 50 for more information on this aspect.

ACC became available in the late nineties. Nowadays a number of manufactures offer such systems, for example Audi, Mercedes, Lexus, Infinity, BMW, Jaguar, Maybach, Acura, Aston Martin, Cadillac, Maybach, Range Rover, Toyota and Volvo. In Figure 5.9 the system from Volvo is used as an example to illustrate the function of ACC. Maximal speed and time gap is selectable by the driver. The effect of time gap of one or two seconds is illustrated in Figure 5.9.

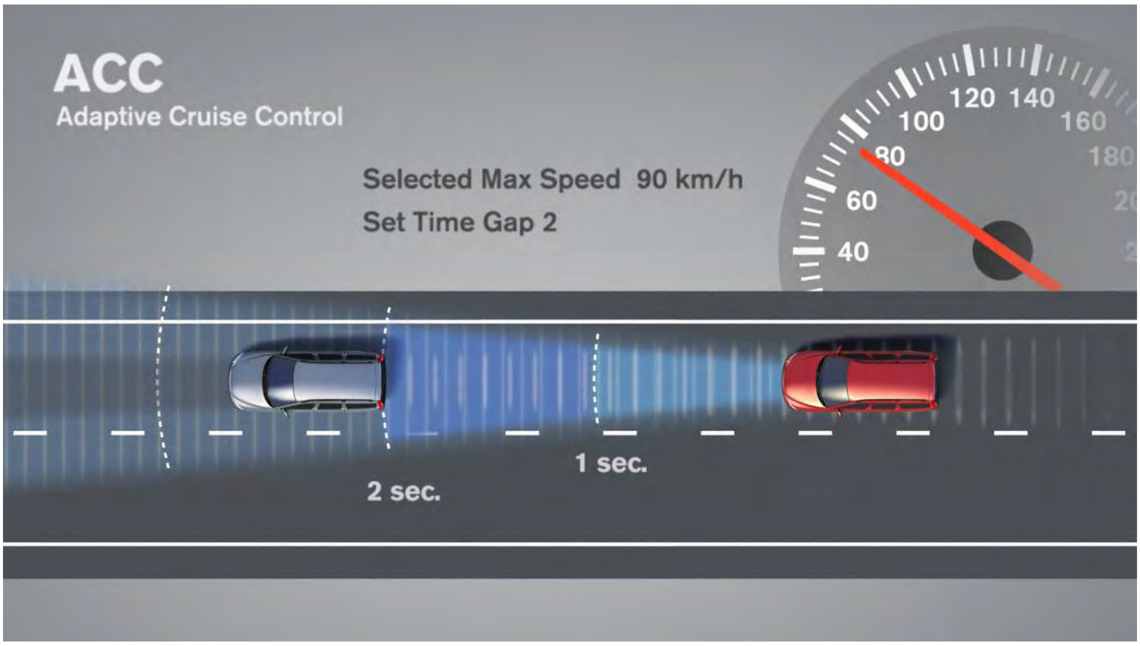


Figure 5.9 Adaptive cruise control with time gap setting 2 seconds. Maximal speed and time gap is selectable by the driver. Effect of time gap being one or two seconds is shown in the figure (Volvo Car Corporation Newsroom).

New systems allow for stop-and-go traffic: this means that the car is able to apply the brakes to a stand-still in case of a queue, and then accelerate again as the traffic flow starts to move. The speed range of the Mercedes cruise control system (DISTRONIC Plus) with stop-and-go possibility is ranging from zero to 200 km/h (Mercedes-Benz, 2007).

Another development in ACC is linkage to the vehicle’s navigation and mapping software, so that the speed control functions can be tied to information on the characteristics of upcoming roadway segments, such as turns and curves. No systems combining ACC and navigation (GPS) software are on the market yet, but research is ongoing. The new Galileo satellite positioning system (European Space Agency) is expected to play a role here, please consult the references: (European Space Agency, 2002; and European Space Agency – GALLANT Pilot Project, 2002) for more information.

ACC became available in Japan around 1997, in Europe around 1999, and in the US around 2001. Currently over 100,000 vehicles are equipped with ACC worldwide, and there were no lawsuits up to now (Bishop, 2007). In a simulator study from 1999, ACC has demonstrated its crash reduction potential in situations when the vehicle in front decelerated harshly. It was found that the longitudinal control of the driver was greatly improved. However, the authors suggest long term monitoring to study driver motivation and skills when using ACC (DIATS Consortium, 1999). Other safety research indicates that there may be some concerns with adaptive cruise control: Stanton and Young (1998) wrote in a paper reviewing other studies on active steering and adaptive cruise control: "These studies suggest that there may be some cause for concern. They show a reduction in mental workload, within a secondary task paradigm, associated with some forms of automation and some problems with reclaiming control of the vehicle in failure scenarios" (Stanton & Young, 1998). On the other hand, situation awareness was found to be improved by ACC systems, and the driver's mental workload was reduced (simulator study) (Ma & Kaber, 2005). In a field study (nine participants drove on a highway in a car equipped with ACC) a positive effect of ACC was found, as the driving speed of overall trips decreases and the distance to the forward vehicle before overtaking increases, indicating a positive effect on traffic safety (Sato et al., 2005). Lee et al. (2006) found that :"… ACC provided a substantial benefit during mild braking events, enabling drivers to maintain a larger and more consistent safety margin. ACC did not produce a safety decrement during the severe braking situations. The combination of visual, auditory, seat vibration, and brake pulse led to slower brake reaction time in severe braking situations…" (Lee et al., 2006). Situation awareness was found to be reduced in a simulator study by Stanton and Young on ACC in 2005. However, workload and stress were additionally reduced (Stanton & Young, 2005). This reduction of driver workload was found in a simulator study from 2002 by Brook-Carter et al. (2003). Transportation safety was found not to be negatively affected by ACC (Rakha et al., 2001).

As cruise control has been available for a number of years, adaptive cruise control is still found only in a relatively low number of cars, most of which are classified as upper segment models. The system is classified as convenience system, but may have a potential to increase traffic safety. Advanced systems are integrated with other safety systems such as obstacle detection, which increases the potential to reduce the number of crashes.

5.9 Counter-steering assistance

There is to our knowledge only one manufacturer who has implemented a counter–steering assistance system in a vehicle on the market. The Volkswagen Touran is equipped with this feature, which actually is a supplement to the standard ESC (Electronic Stability Control) system. The system detects situations where counter steering would be necessary, and together with ESC intervention it sends a steering impulse via the steering wheel to invite the driver to act accordingly (Volkswagen, 2006). No information on expected safety aspects of the systems was found. There is a US Patent for a similar system (United States Patent 6895318, (Barton et al., 2005)), but it is unclear if it is the same system as installed in the Volkswagen car model.

5.10 Hill descent control

A hill descent control system helps drivers to drive on a steep downhill gradient (steep road) by keeping a constant very low speed. Traditionally the driver would have to control the car by putting the lowest gear, and brake. This can lead to loss of vehicle control. A hill descent system aids the driver to descent a gradient by braking individually on each wheel (including ABS system) and in some cars also by controlling engine power (Figure 5.10). Hill descent control can be seen as an addition to ESC and ABS system, as mainly software changes in the car are needed to create a hill descent system. The hill descent control system war originally developed by Land Rover. Nowadays a variety of car manufacturers offer similar systems, especially for terrain vehicles and sport-utility vehicles. The driver can engage the system manually by pressing a button.

Figure 5.10 Hill descent control. The system acts when a certain gradient is reached. It and acts on brakes and engine (the figure is adapted from BMW press archive).

In the case of hill descent control one manufacturer refers to it as “advanced safety feature”. No literature on safety aspects of hill descent control system was found in this literature overview.

5.11 Electronic stability control

The general acronym for electronic stability control is ESC, sometimes also “Electronic Stability Program” (ESP) or “Vehicle Stability Control” (VSC) are used. Electronic stability control was introduced around 1997. In early stability control systems loss of vehicle stability (skid) was counteracted by only braking, in new systems stability is regained by acting on suspensions, traction and braking (for a technical description of ESC see van Zanten (2002)). The basic function of such systems is to individually apply the brakes one or more wheels, in order to recover vehicle control in case of skid. The system helps to correct over steering and under steering.

ESC has proven to be one of the most safety-enhancing systems on the market, and the positive traffic safety effects are proven. The Swedish Road Administration (Vägverket) recommends that all new cars should be equipped with ESC, and urge all car manufacturers, importers and resellers to stop selling cars without ESC (Vägverket, 2004). The recommendation is based on several studies, which have shown the effectiveness of ESC in reducing traffic accidents (Aga & Okada, 2003; Farmer, 2004; Langwieder et al., 2003; Page & Curry, 2004; Papeliset al., 2004; Sferco et al., 2001; Tingvall et al., 2004; Unselt et al., 2004). ESC can reduce the total number of traffic accidents by 17%, and the number of accidents with serious/fatal injuries by 22% (Vägverket, 2005; Lie et al., 2006). In an updated analysis on crash data from the US, Farmer writes: "…Based on all police-reported crashes in 10 states during three years, ESC reduced single-vehicle crash involvement risk by approximately 41%. Effects were significantly higher for SUVs than for cars. ESC reduced single-vehicle crash involvement risk by 49% for SUVs and 33% for cars. Based on all fatal crashes in the United States during four years, ESC was found to have reduced single-vehicle fatal crash involvement risk by 56%. Again, effectiveness estimates were higher for SUVs than for cars-59% for SUVs and 53% for cars, but these differences were not statistically significant. Multiple-vehicle fatal crash involvement risk was reduced by 32%-37% for SUVs and 25% for cars." (Farmer, 2006).

In the US, ESC will become standard by government regulation in all cars from 2012. In 2004 the installation rate for new car registrations was 36% in the European Union, with Germany having the highest ESC adoption (64%) (source: Bosch). In December 2006 91% of the new cars sold in Sweden were equipped with ESC, Vägtrafikinspektionen (2007).

The following figure and table illustrates the effect of ESC (Figure 5.11 and Table 5.2). When a driver starts a turn with excessive speed and the vehicle starts to loose stability, the inner rear wheel is decelerated, and stability regained. During a manoeuvre aiming at avoiding an obstacle both front and rear wheels are decelerated, and the driver can keep the vehicle control. The obstacle is symbolized by the red object in the figures in Table 5.2. The wheel decelerated is encircled in white and turning direction shown with a green arrow. From the left to the right the figures should be seen as a time sequence (symbolized by the large white arrows below the pictures).

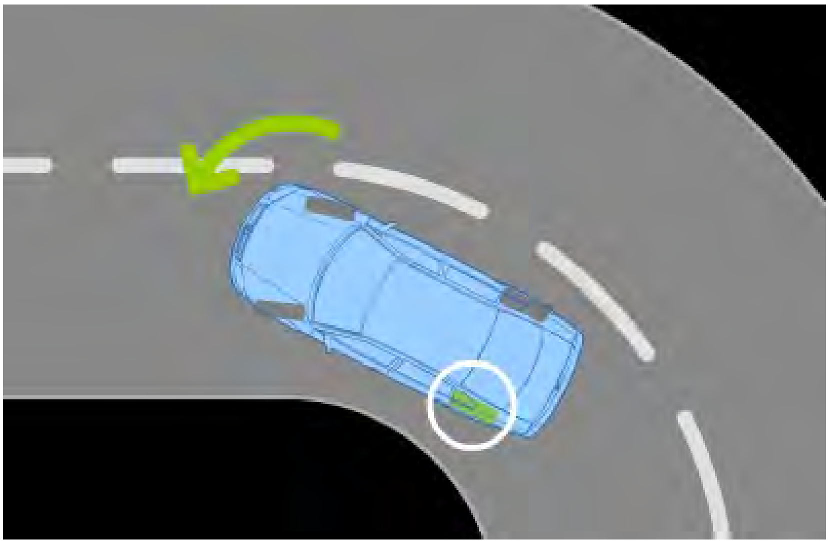
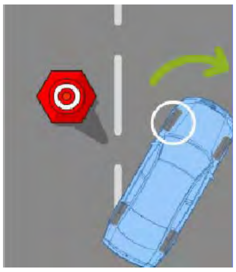
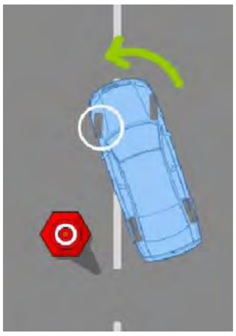


Figure 5.11 ESC applied during a left turn. The wheel decelerated is encircled in white, turning direction shown by a green arrow. The stability of the car is maintained by applying the brake on the left rear wheel.

Table 5.2 ESC applied during obstacle avoidance on straight road. The obstacle is symbolized by the red object. The wheel decelerated is encircled in white and the turning direction is shown with a green arrow. From the left to the right the pictures should be seen as a time sequence (symbolized by the large white arrow below the pictures).

Driver starts to avoid the obstacle (red object in picture) at high speed by turning first to the right.	ESC prevents skidding by applying the brakes first on the rear right wheel, then the front left wheel (white circles around the wheel decelerated by ESC system).	Driver starts to re-enter own lane after avoiding the object, ESC decelerated front left wheel.	Driver re-enters own lane. ESC still decelerating front left wheel to prevent skidding.	Driver again in own lane finalizing obstacle avoidance manoeuvre. Car maintained stability during the obstacle avoidance manoeuvre.
				

A variety of sensor inputs provide data to the ESC system, such as steering angle, wheel angle, gyro, yaw rate as well as lateral and longitudinal acceleration. New systems act, beside on wheel braking, even on traction and suspensions. For example, the engine power is reduced to decrease speed, and suspensions are set to give more friction to the wheel to decelerate.

Most car manufacturers offer ESC as standard in their higher priced cars, some manufacturers provied ESC for the whole range of cars (for example Toyota). ESC as option is available for most cars, excluded some high performance sports cars, heavy duty vehicles, and lowest price segment cars. Since government agencies working with traffic regulations have recognized the importance of ESC in reducing the number of road crashes, it is probable the ESC might be found in most cars in the near future.

Roll stability control can be seen as a variant of ESC, designed to prevent rollover in vehicles with higher centre of gravity. It was first seen in a Volvo sport utility vehicle in 2004, and was then adopted by Ford and a few other manufactures.

There are additions to ESC systems, for example Bosch has introduced a system in which ESC adapts its operation according to the load and its distribution. The system estimates the total mass of the vehicle and its centre of gravity by evaluating responses to braking and accelerating. The system is mainly aimed at light commercial vehicles carrying cargo (Bosch, 2006).

Compared with early systems, improvements have been significant, and modern ESC systems are interlinked with and act on a range of vehicle dynamics. Electronic stability control has proven to be one of the most effective ITS in terms of crash number reduction, and will become standard on all cars in the US from 2012.

5.12 Blind Spot Detection Systems

Blind spot detection systems aid the driver in detecting objects in the “blind spot” (the side of the car where the back or side mirrors are ineffective). The system is mainly aimed at enhancing safety while overtaking or being overtaken. The first manufacturer with this system in series-produced cars was Volvo. The Volvo BLIS (Blind Spot Information System, introduced in 2004) uses cameras on the side mirrors and provides a visual warning when another vehicle is in the blind spot, as described in Figure 5.12 (schematic) and Figure 5.13 (rear mirror with warning light visible). General Motors is developing a system where the blind spots are monitored by 24GHz radars instead of cameras. It is expected that other manufactures could possibly start introducing the system in 2008.

In addition to monitoring the side of the car, the BLIS system monitors the back of the car too, and a warning is provided through visual signals in the mirrors augmented by an acoustic warning if another vehicle gets too close. One rear camera is facing downwards, and monitors small objects behind the car. Camera images can be shown on a video monitor to the driver.

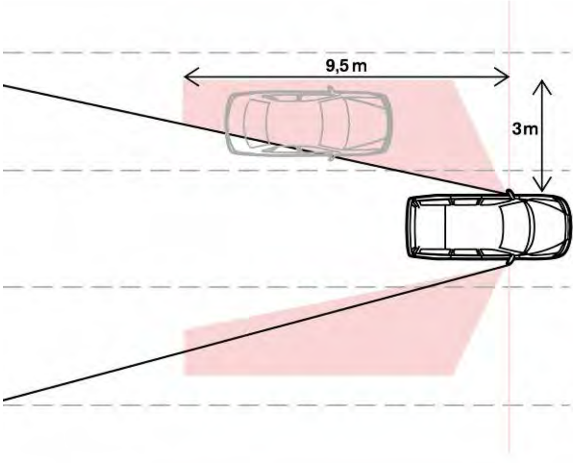


Figure 5.12 Schematic view of Volvo BLIS system with range estimation and active monitored area. (Volvo Car Corporation Newsroom.)

Figure 5.13 Volvo BLIS system in a situation where the driver would receive a warning that other vehicles are on the side of the car. Warning light is visible in orange. (Volvo Car Corporation Newsroom.)

The BLIS system is available on the whole Volvo car range as optional. More research is needed to assess in which way the system helps to reduce the number of crashes. On the US market, Cadillac is expected to offer blind-spot monitoring system in 2007.

Summing up, blind spot detection is found in a number of cars nowadays, and its effectiveness has still to be proven once enough data is available. Whether the system will be seen in several car brands in the future is unclear.

5.13 Pre-collision, collision avoidance and obstacle detection systems

High price range cars offer since a few years back advanced pre-collision systems. Sometimes these systems are called “forward collision warning systems”, and are related to obstacle detection systems. A detailed technical description of the principles of the systems can be found in (Seiler et al., 1998) and (Lee & Peng, 2005). These systems aim at avoiding crashes and reducing the severity of imminent crashes. Mitigating crash severity and avoiding crashes are closely related, since an early action to decelerate the vehicle can lead to crash avoidance, or to a crash with lower impact speed, and thus less severe consequences. Imminent collision can be detected by radar or camera system, and the system is usually integrated with other systems such as obstacle detection. The system will warn the driver once an imminent crash is detected, and even apply the brakes in order to reduce the speed. Mercedes, Lexus, Honda and Nissan offer such systems. For example in the Mercedes S class vehicles the system warns the driver if a forward collision is likely (by visual and auditory warnings). In case the collision danger reaches a certain threshold, the system (Pre-Safe system) automatically closes the windows and the sunroof, finally it activates positioning systems designed to ensure optimal positioning of the occupants in their seats in case of crash. In detail the system will set the seats more upwards, close windows and sunroof, tension safety belts and fill the seats with pressurized air to allow better lateral occupant restrain, if imminent collision is expected.

The Honda system (called Collision Mitigation Brake System – CMS) predicts imminent front collision and assists brake operation to reduce the impact. The system determines the likelihood of a collision based on driving conditions, distance to the vehicle ahead, and relative speeds, and uses visual and audiotory warnings to prompt the driver to take preventive action. First, when the system detects a possible collision, a buzzer sounds, and a warning light is activated. Should the driver take no action, then the safety belt is tensioned repeatedly and light braking is applied. If the driver notices the danger at that stage and hits the brakes, CMS lends support with a brake assist function. If the driver fails to respond altogether, however, CMS goes into the third and final stage which is 'collision damage reduction' when the belt retracts fully and the brakes are applied to provide up to 0.6g brake force (ResearchAndMarkets, 2004; Honda, 2005).

The collision warning system found in the new Volvo range of cars (high segment models, like Volvo S80) uses a radar sensor to scan the road ahead for vehicles (or large objects) which can pose a danger to the driving (the principle is shown in Figure 5.14 below). In case the vehicle approaches another vehicle and a crash situation is possible, a visual warning is given to the driver. When the crash is imminent the vehicle activates brake support, but does not brake autonomously. The system cannot detect small objects or pedestrians. There is the technical possibility to apply autonomous real braking instead of only brake assistance on the named car, but the company has not introduced it yet. In the near future this may change, as other manufacturers start with systems which brake autonomously in similar situations. It is interesting to note that only 10 years ago the implementation of collision mitigating braking systems in cars was seen as highly unlikely (Bishop, 2007).

In Japan Honda, Nissan and Toyota are the major car manufactures with collision mitigating braking systems, on the US and the Europe market Mercedes and Lexus play the major role.

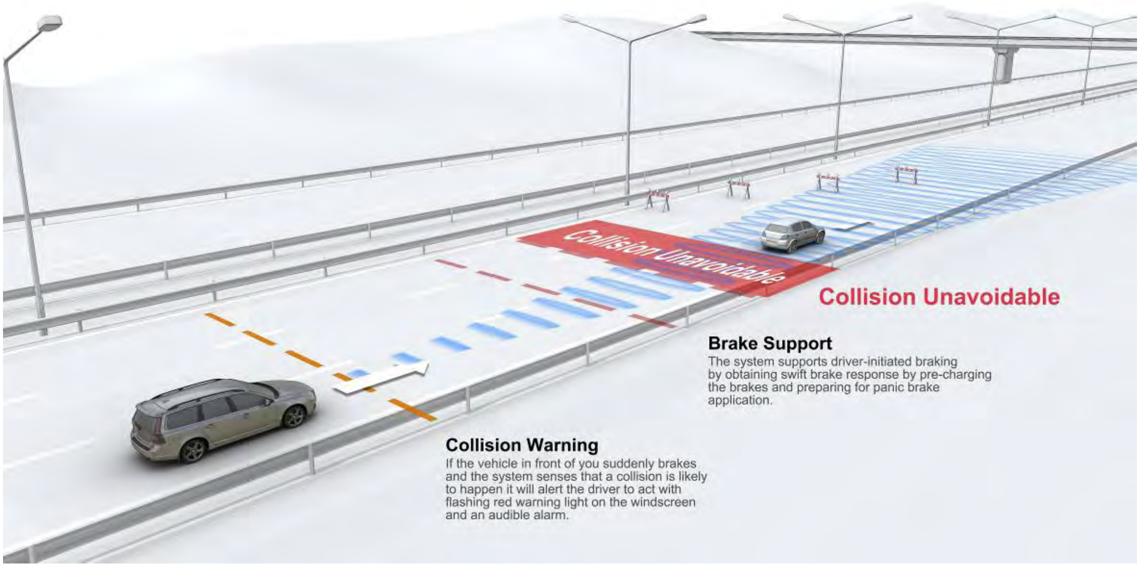


Figure 5.14 Collision warning as found in Volvo S80, autonomous braking with full auto is not yet found on series-produced Volvo cars, but is expected to be available in less than 2 years. (Volvo Car Corporation Newsroom)

Systems aimed at protecting from rear crashes (when a vehicle is impacting the car in front from behind) are found as whiplash effect reduction systems (see chapter 5.16 on page 52). Rear camera systems are available from Honda, Acura, Lexus, Toyota, Infinity, Audi, Mercedes, BMW, and as aftermarket gadget they can be fitted to any car (RearViewSystems, 2006).

In heavy trucks forward collision warning system are present to a larger extend than in passenger cars, where they now start to appear. In the US over 80,000 such units to mount on trucks are used, and the first systems were already installed in 1993. For a overview please consult Federal Motor Carrier Administration (2005). In general it seems that the truck industry is in advance when it comes to introduction of advanced ITS.

In Japan blind curve warning systems for collision avoidance were tested. The cars equipped with the system were able to present the driver with an auditory and visual warning when approaching a blind turn, where a queue was present but not visible. Preliminary results showed a great reduction in the amount of collisions by the warning system. This system, and other systems such as highway merging assistance and vehicle to vehicle and vehicle to infrastructure communication, will be presented in the “Smartway 2007” presentation in Tokyo, Japan in October 2007 (Highway Industry Development Organization, 2007).

Development is ongoing to develop systems that autonomously detect obstacles (such as pedestrians) on the road. Basically this is possible with radar, Lidar (coherent Doppler laser radar), ultrasound, and with cameras. Advanced obstacle detection found in cars on the market uses input from radar or cameras to scan the road ahead and detect objects which will necessitate driver action. There are systems which only use radar, integrated in the front bumper of the car (or a similar location), and a few systems which add camera vision to detect obstacles too small for the radar. The camera can be aided by infrared projectors to allow night use.

Once the obstacle detection system has sensed an object which may pose a danger, there are several alternatives:

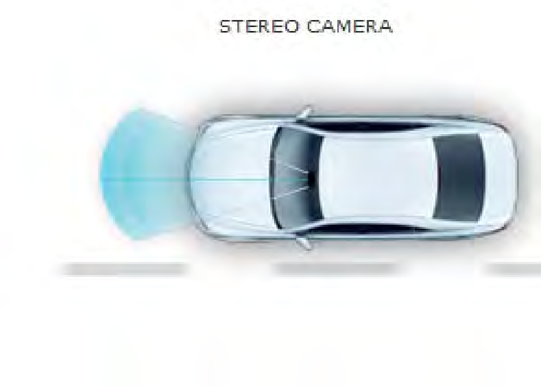
1. Warning the driver by acoustic, visual or other signals.
2. Preparing the vehicle for a possible impact by acting on brake assist systems or vehicle dynamics.
3. Autonomously braking to certain extent.
4. Emergency braking.
5. Activating other safety systems such as whiplash protection, pretension belts, etc.

The pictures in Table 5.3 show an example of a system with both radar and camera as found in some Lexus cars (for example model LS460). Radar is shown in the upper left picture, camera vision in the upper right picture, infrared lights in the lower left picture, and the combined system in the lower right picture.

Table 5.3 Obstacle detection principle, (figures adapted from www.lexus-europe.com). Radar is shown in the upper left picture, camera vision in the upper right picture, infrared lights (integrated in the headlights) in the lower left picture, and the combined system in the lower right picture.

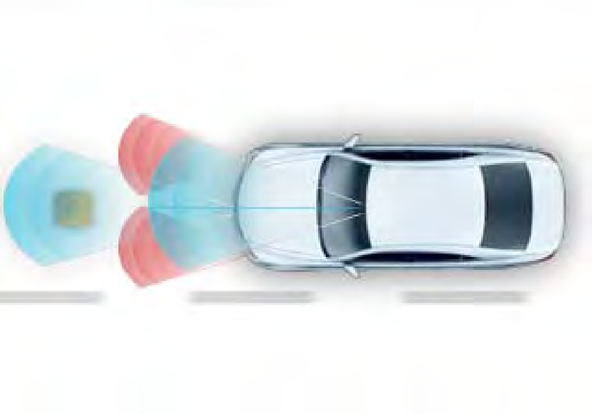
1) A forward facing radar scans the road ahead; the range can be up to 200 meters. Goal is to detect obstacles.

2) A camera helps to detect smaller objects. A “stereo” camera is used because this allows distance estimation.



3) Infrared lights aid the camera during night hours (shown in red below).

4) Obstacles ahead (here the small square in front of the car) are detected and evasive action by driver and/or system is required.



Obstacle detection was first used in conjunction with ACC (automatic cruise control); the input needed from the sensors is quite similar. Many manufactures are active in developing systems related to obstacle detection; please consult Appendix 1.

Forward collision warning was first made available in 2003 in Japan on the Honda Inspire and Odyssey models and on some Nissan models. The Honda system, called “collision mitigation brakes,” is based on millimetre-wave radar and gives drivers audible, visual, and tactile warnings of forward collision hazards. When an impending collision is detected, the system is designed to apply extra braking pressure and to pre-tension the safety belts. Most Japanese car manufacturers are planning to introduce similar systems aimed at warning against forward collisions, but there have also been reports that they are reluctant to bring the technology to the US market until product liability issues are resolved (Hara, 2004). Volvo offers a collision warning system with brake support (note: only brake support, not emergency braking) on the S80 model. The Mercedes version, called PreSafe, is standard equipment on the company’s line of S-class sedans, M-class SUVs, and on some other models

There are also aftermarket systems and nomadic devices for obstacle detection, which can be mounted on vehicles, and provide warnings to the driver (Eye™, 2007), and the high number of players in the field show the high interest from the car industry (McGuffie-Schyhol, 2006). A list of manufacturers and companies developing obstacle detection systems is presented in Appendix 2.

The emergency braking assist system from Mercedes Benz (which is described in another chapter) was recently enhanced by a forward collision warning system: The system is based on radar technology and registers the distance from vehicles ahead, warns the driver if the gap is too small and calculates the necessary brake force assistance if a rear-end collision is likely. If traffic tails back and the driver is obliged to operate the brake pedal, the Brake Assist PLUS instantly builds up the braking pressure required to manage the situation. While reflex-like operation of the brake pedal is necessary with a conventional Brake Assist system, the new system already detects the driver’s braking intention when the pedal is depressed and automatically optimises the brake pressure. This meets one of the major conditions for preventing rear-end collisions, namely the best possible deceleration for the situation in hand (this is what Mercedes Benz states). The system uses two radar sensors, a close-range radar based on 24-Gigahertz technology works together with a 77-Gigahertz radar of the DISTRONIC PLUS (ACC by Mercedes). The 77-Gigahertz radar is configured to monitor three lanes of a motorway to a range of up to 150 metres with a spread of nine degrees, the 24-Gigahertz radar registers the situation immediately ahead of the vehicle with a spread of 80 degrees and a range of 30 metres (as shown in Figure 5.15 below). In the CL model line of Mercedes automatic partial braking is found, which activates the brakes when collision is imminent even if the driver does not react. Braking force applied reached 0.4 g, which is around 40% of the total available braking power. If the driver then activates the brake pedal (even slightly) the car will brake with 100% braking power.

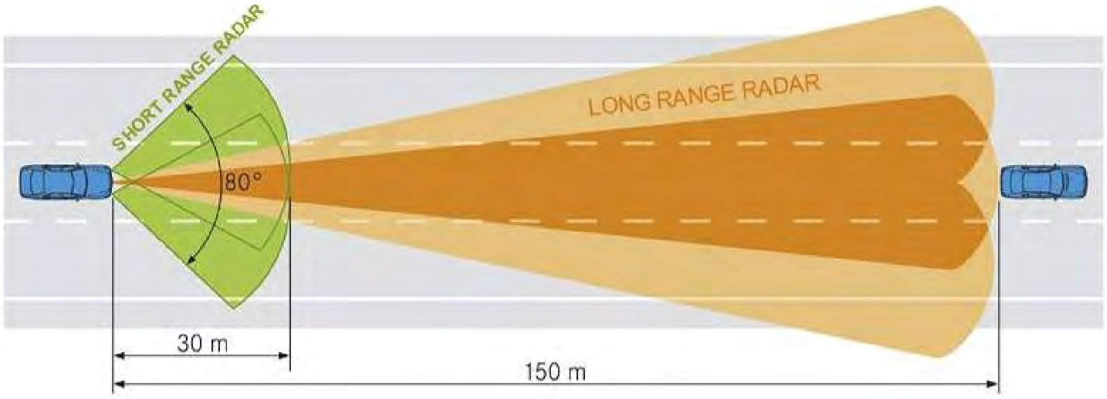


Figure 5.15 Brake Assist PLUS from Mercedes Benz, which combines forward collision warning and emergency braking assistance. The range is depicted in the figure. The narrow range radar (green) has a wider field of view, while the far range radar (orange) has a narrow field of view. The DISTRONIC ACC system works in addition in combination with both radars. Figure adapted from www.mercedes.com

Mercedes Benz writes that the system is a major contribution to safety, mentioning a study in Europe and the US: "One-hundred male and female drivers took part in a series of tests in the driving simulator. They each completed a 40-minute journey with several critical situations on motorways and country roads. It was only possible to avoid crashes by hard braking. Thanks to the new Brake Assist PLUS system, the crash rate during this test series fell by three quarters compared to the average of 44 per cent with conventional brake technology. The new technology demonstrated its advantages particularly well when driving in a line of traffic at 80 km/h on a country road: when the vehicle ahead was suddenly braked, the radar-based Brake Assist system prevented a crash in 93 per-cent of cases – while more than one in two test drives ended in a rear-end collision without the system. Even in situations where a collision was unavoidable owing to a late response by the driver, the new system helped to reduce the severity of the impact. This was confirmed by the measured impact speed, which was reduced from an average of 47 to 26 km/h thanks to Brake Assist PLUS. More than 200 male and female drivers took part in practical trials in Europe and the USA, covering a total of more than 450,000 kilometres in 24 test cars. These journeys were recorded with the help of the latest measuring and video technology. Evaluation of the data and video sequences showed that Brake Assist PLUS also makes a major contribution to safety under real conditions." Note that this is information from the car manufacturer itself, the original study was not found at the time of writing.

Pedestrian detection is another form of obstacle detection, with the peculiarity that pedestrians are detected as such, and their path is for exampled calculated in order to determine if manoeuvres are needed to avoid impacts. Mobileye (Mobileye, 2007a) is developing OEM (original equipment manufacturers) systems for pedestrian detection, for which the company already has a patent request pending (Mobileye, 2007b).

Forward collision mitigation braking systems are offered by Honda, Nissan and Toyota for cars on the Japanese market, and by Lexus and Mercedes for cars on the US and European market.

Research has found positive aspects of collision avoidance systems. In 1997 Suetomi and Kido described positive effects of collision warnings systems in terms of reduced braking response time and reduced number of collisions. The study was performed in a driving simulator (Suetomi & Kido, 1997). In another simulator study of 1997 related to effect of collision warning systems in foggy weather conditions. Saroldi et al. (1997) found that "...driving behaviour is modified in the direction of increasing safety, and the system is well accepted and considered to be useful". Ben-Yaacov et al. (2002) state: "…Results showed that drivers tend to overestimate their headway, and those systems that alert drivers to unsafe temporal headways (collision avoidance systems) are useful in teaching drivers to estimate headway more accurately. Subjects responded properly to the warnings, both under conditions of true and of false alarms." and "…practical implications of these results are that the use of an IVCAWS (in-vehicle collision avoidance systems) should be considered for inclusion in driver education and training programs". Note that the articles did not use real crash data. In a simulator study on effects of warning to the driver by rear-end collision avoidance systems Brown et al. (2001) found that: "…warning enhanced (…) collision avoidance performance. Receiving a warning as the accelerator was released reduced the accelerator-brake reaction time by 50%." (Brown et al., 2001). In a simulator study on headway choice with auditory warning from collision avoidance systems (Hurwitz & Wheatley, 2001) found that participants tent to leave a larger headway with such systems, which can be considered safety enhancing. Lee et al. (2002) confirmed the positive effects of rear-end collision warning systems in a simulator study. In an earlier study from 1997 Lee et al. stated. The collision avoidance performance of subject drivers was compared to the behaviour of drivers in a baseline condition where no collision warning display was present. Relative to the baseline condition, results indicate that drivers using the collision warning display (a) showed significantly fewer crashes in the shorter headway condition, (b) collided with the lead vehicle at significantly slower impact speeds, (c) released the accelerator significantly faster, and (d) had longer headways both at accelerator release and brake initiation." (Lee et al., 1997). Takada and Shimoyama (2001) found driver workload to be reduced by ACC and collision warnings systems in a driving simulator study. Here driver workload was measured by psychophysiological signals (Takada & Shimoyama, 2001). Yamada and Wakasugi (2003) found positive effects of collision warning systems, especially in combination with roadside message information. The study was performed in a driving simulator with 20 participants (Wakasugi & Yamada, 2000).

In short, systems aimed at detecting imminent collisions with obstacles on the road are entering the market, and already a number of cars with these systems are on the market. There is a large interest from the research community and the industry to further develop and evaluate the systems. Interlinking with other ITS, such as ESC, is likely in the future, and already present in a few cars. Preliminary research results indicate a significant benefit in terms of decreased number of collisions. The systems still have to become more affordable in order to face large scale introduction.

5.14 Emergency braking assist

Braking assist systems aid the driver in optimizing the vehicle retardation in emergency situations. This is done by maximising the pressure in the braking circuits, aiding the possible too weak brake pedal pressure of the driver, and by acting faster than the driver. A number of car manufactures offer such systems. In Mercedes car models (with the Brake Assist System (BAS) Plus system) the system uses radar to calculate the proximity to other vehicles; and if the gap gets too small or the closing speed is too high the system will warn the driver first. If an impending collision is likely the system will calculate the optimal braking power to avoid the crash, and as soon as the brake pedal is applied by the driver (even lightly) the optimal braking is immediately applied. The system adapts to the driver behaviour by analysing braking habits, and calculates optimal braking assistance in emergency situations (Kerr, 2006). It is integrated with the other safety systems in the car, taking advantage of ABS and ESC systems (described in another chapter of the report). Furthermore brake function is assisted by brake drying and priming to minimize stopping distance: Brake drying removes moisture that can accumulate on brake discs in wet conditions, and priming positions the brake pads close to the brake disks as soon as the driver lifts the foot from the accelerator pedal.

Why is this system important for traffic safety? In a statement cited from Mercedes-Benz this is explained as follows: "…even experienced drivers may not apply full brake force in emergency situations. In fact, 99 percent of drivers were slow to apply the brakes or only applied full brake pressure when it was too late. Brake Assist applies the brake fully and quickly to stop the car in as short as distance as possible. For many drivers, this means the Mercedes BAS system can provide 45% shorter stopping distances. Even the most skilled drivers find about a 15 % improvement…" (Kerr, 2006). In line with this, according to Mercedes Benz, in 1992 it was found that while the majority of drivers operate the brake pedal rapidly in an emergency situation, they often do not do so with sufficient force. The braking performance is therefore not used to the full, and the braking distance is considerably increased. These findings led to the development of Brake Assist, which first entered series production in 1996 and has been standard equipment in all Mercedes cars since 1997. The technology interprets a certain speed with which the brake pedal is depressed as an emergency braking situation, and builds up the maximum braking assistance autonomously. This significantly shortens the vehicle's braking distance – by up to 45 percent at 100 km/h on a dry road surface, for example (data from Mercedes Webpage information). Again according to Mercedes, the safety advantage was shown in a study in a driving simulator: 55 male and female drivers were asked to drive through a town, and a child suddenly ran into the road. A crash could only be avoided by emergency braking. The result was that drivers with the benefit of Brake Assist had significantly fewer accidents than those without the system. The crash rate was reduced by 26 percentage points with Brake Assist. Note that this data comes from the Mercedes Benz webpage, the actual study was not found at the time of writing.

Researchers found positive effects of brake assist systems: Kassaagi et al. (2006) used an experimental approach to estimate the reduction in stopping distance for cars equipped with brake-assist systems. Ninety-five drivers drove on a test track in a car-following situation, where the vehicle in front would release a trailer which decelerated strongly. The cars equipped with brake-assist showed a reduction in stopping distance between 2 and 9 meters compared to cars without brake assist (Kassaagi et al., 2006).

Emergency braking assist is usually combined with obstacle detection systems, and aids in quick vehicle deceleration if need arises. There are systems which only prime the braking systems and await driver action, other brake autonomously to a certain level, and a few systems brake with full force. This last group is the most challenging in legal and technical terms, and the future may well witness further adoption of them. Not much research has been found on the systems, but the available publications are positive towards the systems.

5.14.1 Notes on autonomous braking

Systems where a car autonomously brakes to a certain extend are already available, for example the Mercedes CL line-up, which has autonomous braking up to 40% of maximal braking power, and Lexus LS600h models (see chapter 5.8 and 5.13). At the present time no cars which autonomously brake with maximal braking power are available (note that a number of cars assist the driver with maximal braking power when the brake pedal is activated even slightly in imminent-collision situations). The advantage which autonomous braking systems able to stop a car in an emergency situation (example: imminent forward collision) have is clearly that they potentially *avoid* the collision, while brake assist systems or autonomous braking systems braking with only partial braking power only *mitigate* the collision. The systems are expected to brake faster and more efficiently than a driver. According to what is known about future development, Volvo is working on a system able to decelerate the car with full braking power and Mercedes and Lexus are developing similar systems. Once one manufacturer presents a system (and the response is positive) other manufacturers might possibly follow; this development is expected for 2008.

5.15 Systems acting on a range of vehicle dynamics

The interaction between systems is becoming more and more important, and advanced safety systems are acting on various levels based on data from several sensors. This makes classification of the system itself more difficult, but is a small problem compared to the potential of the system. For example: The Lexus LS460 is equipped with an "advanced pre-crash system" which detects obstacles by radar and infrared camera and warns the driver by acoustical and visual signals. Furthermore ABS, ESR, ASR, suspensions and servo steering are prepared for eventual impact and in case of imminent impact the safety belts are pretensioned and the vehicle brakes with up to 0.7 g.

The obstacle detection system identifies obstacles ahead by radar, and then assesses the likelihood of collision based on the position, speed, and trajectory of the obstacle. If the collision probability is high, a warning buzzer and a red "BRAKE!" alert on the display are activated, and before imminent collision the brakes are activated (note: brake-assist by priming the brake system and positioning the brake pads on the brakes is done already before). Before a collision the suspensions are "prepared" by stiffening the dampers, which improves response of the vehicle. In a similar manner, the model LS600 adds a driver monitoring system (which detects distraction by cameras monitoring the drivers head) and a rear pre-crash system, which for example repositions the head rest to minimize whiplash in case of imminent rear crash. The emergency steering assist acts on the steering control, making it easier for the driver to perform abrupt steering manoeuvres (in terms of force to apply and steering wheel angle to wheel angle ratio). The system thus warns the drivers for potentially hazardous events (obstacles on road), assists in emergency manoeuvres (steering assist during emergency manoeuvres and assisted maximal braking) and reduces the crash consequences (whiplash reduction). Lexus states: "After testing the reactions of a number of drivers, Lexus engineers determined the best engagement timing for all functions to improve the chances of the driver reacting in time to prevent the collision happening." However, no data is available on this study. Pre-crash seatbelt pretensioners are also activated if the vehicle's yaw rate goes above a certain threshold at speeds of more than 9.5mph (15 km/h). Note that this is only partial emergency braking, as the full brake force is not applied, and only reduces impact severity.

5.16 Active whiplash injury risk reduction

Many car manufacturers put great efforts in minimizing the risk of whiplash injury by adapting head restraint and seat design. Some cars offer a safety system which *actively* acts to prevent whiplash injuries. The “rear pre-crash” (whiplash injury risk reduction system) by Lexus (Toyota, 2007) monitors the rear of the car by radar. If the system detects an imminent rear-end crash, the head restraint is repositioned towards the head of the driver. In doing so, the expectation is that risk of whiplash injuries is reduced. Figure 5.16 and Figure 5.17 show how the head rest is repositioned in case of imminent rear-end crash.

BMW has also an “active whiplash protection”. In this case the system is activated when a collision is registered, and moves the head restraint towards the driver’s head before the crash.

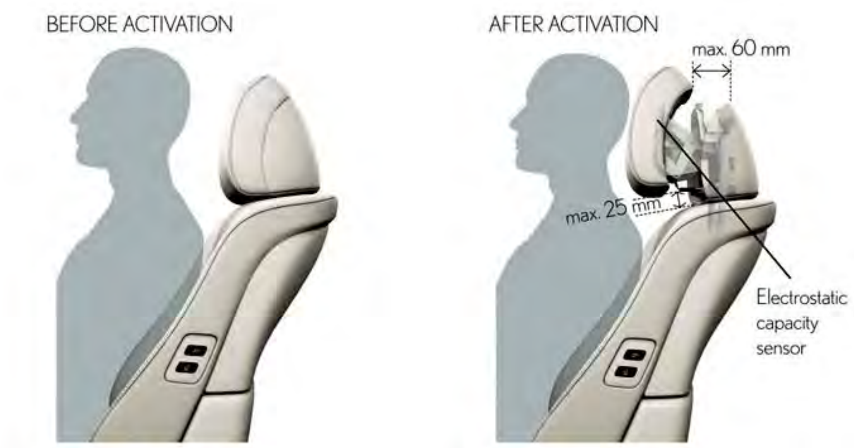


Figure 5.16 Whiplash reduction by head restraint reallocation. Left picture is standard driving, right picture shows headrest repositioning before rear-end crash. Figures adapted from www.lexus-europe.com.

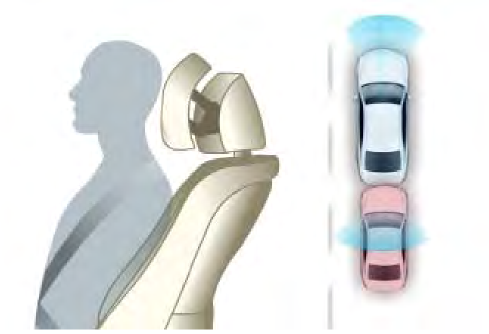


Figure 5.17 System activation before imminent rear-end crash. The head restraint moves toward the driver’s head to reduce the risk of whiplash injuries. Figures adapted from www.lexus-europe.com.

5.17 Airbags

Airbags are recognized as an important safety feature in cars. The airbag deployment is started by pyrotechnical devices which inflate the airbags. In order to protect the occupant in a high severity crash a large bag needs to be inflated in a fraction of a second. Advanced airbags are able to adapt the deployment power according to severity of the collision (example Mercedes, Audi, BMW, Lexus, etc.). Some systems adapt even to the mass of the driver.

Ongoing research efforts are focussed on variable-force airbags with sensors to determine the severity of a collision and, in turn, the force with which to deploy the front airbags. Nissan's Technical Centre Europe (NTCE) is one of several automotive organisations involved in the bone-scanning project called Bone Scanning for Occupant Safety (BOSCOS) (Hardy et al., 2006). The aim is to develop technology which can adjust the deployment of on-board safety systems (for example airbags) to account for the density of the occupants' bone structure. It has been found from real world crashes that injuries such as fractured ribs and sternum result can occur from the deployment of airbags and the high forces that are applied when seatbelts are used. In particular, older drivers and passengers who have weaker bones or medical conditions such as osteoporosis can suffer from fractures as a result of the deployment of airbags and seatbelts. The bone scanning system works by using ultrasound technology to analyse the bone density of the occupants and it can then adjust the force of the airbag and seatbelt pre-tensioners to maximise the protection offered by those devices, and at the same time help to keep the risk of injury to a minimum as a direct result of their deployment. To analyse the bone density, occupants place their finger in an aperture upon starting the car and an ultrasound reader measures their bone density. With the results recorded, the various safety devices will calculate the optimum level of deployment to protect the occupants, whilst keeping to a minimum risk of injury.

Airbags are, together with seat belts, the most common safety systems in cars, and the technical development presented above shows that there is still space to improve airbags. Adaptation to crash severity and driver characteristics are the main scopes and cars with such adaptive airbags are already in the market.

5.18 Pedestrian impact mitigating

Advanced pedestrian impact mitigating systems are still rare in today’s cars. These systems aim at minimizing the injury causing forces on the pedestrian in the event of a vehicle-pedestrian collision.

Jaguar has a system with deployable bonnet in the XK model range. In the event of a pedestrian impact, the deployable bonnet lifts up a few inches, to create a cushioning effect between the engine and the bonnet (shown in Figure 5.18 below). This helps to isolate the pedestrian from hard points in the engine. The bonnet deployment is achieved pyrotechnically. Other manufacturers with deployable bonnets are Citroen (C6 model) and Honda (Legend model). In the Jaguar car a sensing system is mounted in the front bumper to help to discriminate between a pedestrian collision and any other possible front-end collision. The deployable bonnet system can lift the bonnet (which weighs 18 kg) in around 30 milliseconds. The device is mechanically fastened to the bonnet and the chassis. When activated, the pyrotechnic charge inflates a woven polymer tube, lifting the bonnet upwards. The mesh then collapses back. This design allows the bonnet to be closed and latched again after deployment. This differs from the Citroen system which uses sprung–loaded bolts: these remain in the extended position, preventing closure. Jaguar states: “The complex system has been extensively researched across wide-ranging scenarios, using 120 man-years and thousands of computer simulations, as well as tested in practice at Jaguar’s Engineering Centre. While all pedestrian impact research has been carried out using virtual tools, analysis of previous 'real world' incidents has played an important part in the development process” (Jaguar Cars Ltd, 2007). No references on this interesting study are given. In the Honda Legend model three sensors located inside the front bumper and a vehicle speed sensor determine if an impact with a pedestrian has occurred and signal an actuator to raise the rear portion of the engine bonnet (by 10 cm). This provides a space between the bonnet, the engine and other hard components to reduce pedestrian head injuries. Use of the pop-up bonnet for pedestrian safety can cause approximately a 40% reduction in head injury values (Honda statement, but without reference to studies).

Figure 5.18 Jaguar deployable bonnet system. Bonnet is seen lifted in case of impact with pedestrian (figure from Jaguar press release).

There is a number of ongoing projects aimed at developing similar, but more advanced systems: Flexpoint Sensor Systems is working on sensors placed in the front bumper which are able to distinguish between a collision with a human (human leg) and a collision with an inanimate object. The input from the sensor could then be used to control a deployable bonnet (Flexpoint Sensor Systems Inc, 2007). Siemens VDO is working on a sensor for pedestrian collision detection, working with fibre optic sensors (mirror-coated fibre optic conductor, when impacted, the mirror coating is broken allowing a precisely defined amount of light to escape). It determines the position of the object struck, intrusion speed and energy, and mass physical variables. Electronics then identify critical data from the difference between the specified and actual amount of light travelling across the fibre over a period of time, such as deformation, velocity, mass and size of the object involved in the crash. The sensor has been designed for a speed range of 20 to 60 km/h. The data is then used by the electronics system to distinguish precisely the nature of the object struck, detecting whether it is a cyclist, a small child or a lamppost. (Hoffmann et al., 2002).

5.19 Post-crash systems and eCall

Post-crash systems aim at protecting the driver once a crash has occurred and at notifying emergency services. Only a few advanced systems are yet on the market. In the Mercedes Post-Safe system cutting points are marked to show rescue teams where to use cutting equipment, and automatic partial opening of the windows allow ventilation of the interior. Furthermore there is automatic door unlocking, and automatic engine and fuel supply cut off. Emergency lights are activated too.

The eCall stands for emergency call and is funded by the European Commission. It is a system aimed at performing emergency calls to deploy emergency assistance in case of road crash or acute need. The goal is to improve notification of traffic accidents, speed up emergency service response, and lower the effects on fatalities, severity of injuries and traffic flow. The eCall project is among other described in the eSafety Support website (eSafety, 2007) in the eCall Toolbox section. The project is also supported by the European Automobile Manufacturers Association (ACEA), and can be seen as an evolution of the ONSTAR technology in North America (for additional information on the ONSTAR system see http://en.wikipedia.org/wiki/OnStar).

The emergency call can be performed manually by the driver, or automatically by the vehicle (actuated by in-vehicle sensors responding to airbag activation for example). Automated call procedure is relevant in cases where the driver is not able to perform the call manually. When the call to emergency service is established (for example in Sweden by that the emergency number 112 is dialled), simultaneous data is sent, including key information about incident time, location, vehicle characteristics, etc. Data can also be sent back to the caller.

It is planned to have the eCall system as standard option in new vehicles by 2011. For in-vehicle emergency calls first data requirements and data transfer protocol, interface specification and routing and handling procedures have to be developed and accepted by the member countries adopting the system. Training of personnel will also be required. The project is limited to Europe, and will use the standard 112 emergency service lines.

In this report eCall is classified as post-crash system, since it is actuated after a critical incident has happened. It could be grouped together with similar telematics systems such as breakdown call (when there is a vehicle failure), remote diagnostics (in case of vehicle problems), vehicle tracking (for locating stolen vehicles), remote immobilization (in case of crime situation where a car has to be stopped), remote lock-unlock (for example when keys are lost). It is out of the scope of the report to describe all these systems in detail.

Apart from the eCall project described above, there are already manufacturers who provide similar systems in series-produced vehicles. Mercedes-Benz has the TELE AID system, which enables drivers to contact assistance, sending for example GPS position of the vehicle (and other data). A red button, easily reachable by the driver, starts the system. There are additional features related to the system, such as remote unlocking, stolen vehicle tracking, remote guiding assistance, etc. More information about TELE AID is found in the reference TELE AID (2007). BMW has a similar system, called BMW Emergency Call (BMW Emergency Call homepage, 2007), and Audi offers such a system, just to name a few.

5.20 Other systems

There is a large number of systems related to ITS, which are not reviewed in this study in detail. Reason for this is the mentioned focus on advanced in-car systems available in series-produced cars with potential to decrease the number of road accidents. In this sub-chapter a few other systems will be listed which are somehow related to traffic safety and ITS, but which were not presented in detail above.

Navigation systems with dynamic traffic control can display information related to road works and queues, allowing the driver to react early and be prepared for possible dangerous situations. Some systems are able to present the location of traffic lights, which can aid a driver to prepare for a traffic light where he or she would not expect one, or in poor visibility. Such systems are available on a wide range of car models nowadays. Here the human factor aspect would be interesting to study, in order to see how such information is best presented to the driver.

Tyre pressure monitoring is available in a number of car models. They monitor the air pressure in the tyres, warning if the pressure is too low. These systems are expected to gain importance in the next years, as advanced systems go beyond air pressure measurement: it is possible to measure tyre imprint on road, vehicle lateral inclination and centre of gravity (Cavaciuti, 2007). All this information can be very valuable for the Electronic Stability Control (ESC).

Volvo offers as optional a remote unit with a built-in fingerprint sensor that identifies the vehicle operator. It can communicate with the vehicle, whereupon the car automatically adjusts the steering wheel, seating position and more to the settings of that particular driver. Additionally, the system can be programmed to perform a number of telematics functions, such as emergency notification in the event of a crash. Even a heart beat sensor to control for possible intruders hiding inside the car is available.

Vehicle to vehicle communication or vehicle to infrastructure communication is expected to increase in importance in the next years, as major manufacturers are planning such systems. The systems will allow drivers to know for example the position and direction of other cars in hidden turns or intersections, with potential benefit for traffic safety. Combination with available safety systems is possible and likely, and the technical possibilities are vast. Such systems are not found in series-produced cars nowadays (note that vehicle to infrastructure communication systems less related to ITS and traffic safety are available, for example automatic payment systems for toll roads). An interesting presentation on this issue is found in the following reference (Underwood, 2007) and the "Vehicle Infrastructure Integration Initiative" to be found in http://www.vehicle-infrastructure.org. Several links related to cooperative vehicle-infrastructure systems can be found in (Cooperative Vehicle-Infrastructure Systems, 2007).

Systems for traffic sign recognition are under development, for example Siemens VDO plans to offer such a system in 2008. It can be used to provide the driver with warnings when the speed exceeds the speed limit on the actual road, even automatic speed adaptation is possible (ACC integration). Such systems would use camera inputs to scan the vehicle surroundings for traffic signs, the data would then be compared with information from the digital map of the navigation system (The Intelligent Highway, 2006).

Intersection collision avoidance systems are in a development phase. They require some form of vehicle to vehicle communication for ideal functioning. Their potential to increase traffic safety is estimated to be high: Briest and Vollrath (2006) analyzed crash data from 4500 accidents in Braunschweig (Germany), and report (based on information process models concerning the underlying errors and their psychological causes) that: "The analysis reveals three main areas where ADAS (advanced driver assistance systems) could prevent accidents:

1. An intersection assistance system which recognizes drivers and cyclists from different directions having right of way could prevent 26.1% of all severe accidents. The psychological causes often lie in a lack of perception. Thus, a warning system might already be effective.
2. A collision avoidance system with situation dependent distance and speed control which recognizes stationary vehicles and supports the driver's braking manoeuvre. Such a system could prevent 17.5% of all severe accidents. Due to the fact that these accidents are caused by wrong decisions of the drivers, active support of the driver is essential.

3. A system for the situation dependent speed control with additional lateral control could prevent 20.4% of severe accidents.” (Briest & Vollrath, 2006).

Summarizing, the range of available ITS related to comfort and safety is rapidly expanding, and the near future may present important developments. Research is needed to assess the safety advantages (or problems) which the systems have.

5.21 Overview American market

This subchapter shows the ITS development on the American market, which sometimes differs from the European and Japanese markets. These three regions are the main players in the ITS sector.

Table 5.21 gives an overview of ITS available on the American market (Peirce & Lappin, 2006). ITS availability on the European market is somewhat similar, even if car makes are often adapted to market regions, and availability of certain brands and models is very different between American and European market. This fact influenced the market penetration.

Table 5.21 ITS on the American market, adapted from (Peirce & Lappin, 2006). For certain systems also the Japanese market is mentioned.

System	Availability	Notes
Back-up camera	widely available in US	Available in 2004 on Acura MDX, Honda Odyssey, Toyota Sienna, Lexus RX330, Lexus LS430, and other models.
Night vision	limited availability	Discontinued by Cadillac. Available on some Lexus models and upcoming on BMW 7-Series and Mercedes S-Class.
Adaptive headlights	limited availability	Available on 2006 Range Rovers and a few other high-end vehicles.
Blind spot monitoring	limited availability	Digital camera-based system available on some 2006 Volvo models as $500 option. Expected to be offered in the US by other makers in model year 2007 (Cadillac DeVille, STS, Escalade; Buick LeSabre). Production cost is approximately $400 to $500 for 24 GHz radar system in both side mirrors.
Object detection	available in US	Ultrasonic systems for parking assistance widely available (e.g. Mercedes Parktronic); also some radar-based systems.
Parking assistance	limited availability	Toyota “intelligent parking assist” on 80% of Priuses (sold in Japan as $2,200 option).
Antilock braking; brake assist	widely available in US	ABS widely available and offered on 65% of new cars sold in 2004. More advanced brake assist systems on some models, including Mercedes.
Traction control	widely available in US	Widely available.
Electronic stability control	widely available in US	ESC offered on 73 vehicles in North America in 2004 model year. GM: StabiliTrak ESC system available now on one-fifth of models (priced $200-800 as option), with plans to install on all SUVs and vans by 2007, and on all GM vehicles in North American market by 2010. Ford is adding ESC to Explorer and SUV models; DaimlerChrysler to add ESC on all Chrysler SUVs by 2006.

Roll stability control	limited availability	Introduced on 2004 Volvo SUV and now available on 5 Ford models.
Adaptive cruise control	widely available in US	Option on models from Mercedes-Benz, Infiniti, Jaguar, Lexus and a few other makers. System cost is estimated at $3,000 for Mercedes version. Nissan and Toyota developing ACC variants with stop-and-go/low-speed modes.
Lane/road departure warning	limited availability	3 Japanese Toyota models, with production volume about 80,000, have Lane Monitoring System. First US vehicle with Lane Departure Warning is 2005 Infiniti FX (camera-based system). PSA Peugeot Citroen will offer LDW on 2005 C4 coupe. From 2002, Honda Accords sold in Japan offer HIDS (Honda Intelligent Driver Support system), a radar- and camera-based system providing both lane-keeping assistance and adaptive cruise control. Option priced around €5000.
Forward collision warning	limited availability	2006 Acura RL and 2007 Mercedes S-class will have collision mitigation brake systems. Since 2003, Honda Inspire and Odyssey models sold in Japan have optional “collision mitigation brakes.”
Pre-crash safety	available in US	Available on Mercedes (PreSafe) and Lexus (Pre-Crash Safety) models and in development at many other automakers.
Rear-end impact prevention	development phase	Concept in development at Volvo; nothing on market yet.
Tyre pressure monitoring	limited availability	Available on several Mercedes models and a handful of Audi, Ford, VW models. All new US-sold vehicles to be equipped by 2008 to comply with federal law. NHTSA estimates cost at $48-$70 per vehicle.
Workload managers	limited availability	Saab “Dialogue Manager” suppresses certain info displays under demanding driving conditions. First introduced on 9-5 sedan in 1997-98; standard on 9-3 beginning 2003. Volvo IDIS (Intelligent Driver Information System) delays incoming messages during certain driving conditions. In development at other OEMs, including BMW, Daimler Chrysler, Fiat, and Toyota, and among suppliers Delphi and Motorola.
Driver condition monitoring (fatigue, distraction)	limited availability	Not currently available in North America, but expected on Lexus models in Japan in 2006. Volvo’s “co-driver” (in development) may include fatigue monitor measuring eyelid movement/position. Saab developing distraction monitor using infrared cameras, possibly linked to mapping software – no decision yet on putting into production.
Vehicle-to-vehicle and vehicle-to-infrastructure safety systems	development phase	Nothing on market yet. OEMs pursuing research in advance of decision point, circa 2008, about whether to proceed with public-private partnership. Japanese government plans to install sensors in expressways that can communicate with in-car GPS systems to warn of dangerous conditions (fiscal 2007). Also developing vehicle-to-vehicle communication systems.
Event data recorders (EDR)	widely available in US	30-40 million US vehicles equipped, including 65% of new cars sold in 2004. Aftermarket systems ($140-$425) connect to EDR for analysis and/or driver feedback.

5.22 Development of ITS in Japan, US, and Europe

The Japanese market is in some aspects heading the ITS development, and might continue to do this in future. Reason for this may well be the advantage in legislation terms for testing new systems, which are less restrictive than in US and European countries. This is especially true for fields such as elderly driver assistance systems.

In the ADASE report (ADASE Consortium, 2004c) the following statement is found, and describes well the situation in Japan, Europe and the US: ”As we have seen, market introduction is following different paths in the different areas, and tangible differences are present due to different cultural and legislative approaches. In many cases the first introduction of a new system arrives in Japan; however, this often corresponds to a more simple system compared to what would be accepted in Europe or USA. This is because the Japanese market seems to have a different approach in the relationship with the customer, that allows Japanese OEM to introduce more quickly new systems on the road. The Japanese drivers seem to be more used to test new systems in his car, and less demanding on the performances. On the other side, in Europe the human centred design approach requires longer development time, coming at the end with a system that has to satisfy more requirements and that is therefore in general more complex. Finally, introduction in USA is strongly influenced by liability issues and regulations. For that reason, often systems are introduced in USA as after market products, that have smaller liability constraints on the vehicle manufacturer.”

Very little data on ITS market penetration is exists for other parts of the world (for example Russian Federation, Africa, South America, India, China, etc.). The number of vehicles is increasing at fast pace in those regions, but sometimes safety standards are not the first priority, as could be illustrated with for example the crash test performed with the Chinese vehicle Brilliance by ADAC (2007) where the structure of the vehicle provided limited protection for the occupants.

5.23 The effects of ITS on traffic safety

In this section the estimated impact of ITS on traffic safety are summarized. The basis for the data is the papers and reports by Vaa et al. (2006), Penttinen & Virtanen (2005), Elvik & Vaa (2004) and Vaa (2006) in addition to other research literature consulted.

For some systems, especially ABS and ESC the penetration rate is large, and quite a number of evaluation studies have been performed, showing the impact on traffic safety. However, for most advanced ITS crash data is still lacking, which makes conclusions on impact difficult. Vaa et al. (2006) stated that: ”…What we have today are a lot of studies on behaviour parameters, but we do not really know the effects on accidents of these systems. Some effects have been estimated “by proxy” or surrogate methods, but we really do not know yet how these systems will perform in real traffic.” Table 5.23 below lists systems in which research has been performed, and the type of impact analyzed. Behaviour is by far the most common research area, and ABS and ESC are the systems evaluated most commonly.

Table 5.23 Availability of studies on different ITS, adapted from Vaa et al. (2006). The studied impact of each system is noted in the first row of the table.

System	Effect on behaviour	Effect by proxy?	Single accident studies?	Effect on accident types?	Meta-analysis	Overall effect
Antilock braking system (ABS)	■ ■		■ ■	■ ■	■	■
Electronic stability control (ESC)			■ ■	■ ■		
Adaptive cruise control (ACC)	■ ■	■				
Blind spot detection	■					
Collision avoidance systems	■ ■	■				
Side collision avoidance systems	■ ■					
Driver vigilance / fatigue monitoring	■ ■					
Lateral control- lane keeping /warning	■ ■	■				
Pedestrian warning (laser-radar)	■					
Black-spot warning (heavy vehicles)			■	■		

■ = yes, one study
■ ■ = yes, more than one study

Note: ”by proxy” means assessed by methods such as mathematical modelling and simulator studies.

5.24 Classification of systems as convenience or safety systems

In chapter 4 different classification options for ITS were presented. The car manufacturing industry classifies many of the reviewed systems either as safety system or as comfort or convenience system. What criteria delimit this classification is not totally clear. Taking automatic cruise control (ACC) as an example, the system was first regarded as a tool with potential to increase traffic safety, but is nowadays marketed as a convenience system rather than a safety aid (Jagtman & Wiersma, 2003). According to some authors the reason for this is the fear of potential lawsuits following accidents (Marsh, 2003). How the car owners look upon the systems was analyzed in an NHTSA report (Llaneras, 2006): “Although many ACC system owners (41%) perceive the system as solely a comfort and convenience device (consistent with how the systems are marketed), most owners recognize the important safety benefits of the system. A considerable percentage of owners (34%) regard the ACC system as primarily a safety feature, and the overwhelming majority of ACC system owners (84%) feel the system improves safety over conventional cruise control.”

From the information given by Volvo Car Corporation (2007) the following description was presented under the heading “Other active safety systems in use and on the way” …”ADAPTIVE CRUISE CONTROL, ACC, is a convenience system that co-operates with the Collision Warning System. It uses a radar sensor to continuously monitor the vehicle in front, and is designed to automatically adjust the speed to maintain a comfortable distance." Audi (2007) provide the following information about the ACC "Adaptive cruise control: The intelligent convenience system constantly monitors the distance between the car and the preceding vehicle, and adapts the car's own speed accordingly by manipulating the accelerator and brakes. The Audi development engineers have deliberately limited the intensity of possible acceleration and that of brake intervention and very definitely designed the distance control as a convenience system. The adaptive cruise control system is configured such that when another vehicle that is travelling at a completely different speed is approached, the driver is alerted both visually and acoustically to the need for a conscious, situation-appropriate response."

In order to identify ITS systems with the largest safety benefit either among systems labelled with the same acronym or in comparison between different systems in order to promote and support the best performing systems it is of importance to evaluate its traffic safety effects.

5.25 Driver behaviour

The effect of technical systems that are designed to support the driver can be hampered if the driver is unable to handle them correctly. Therefore, the driver behaviour is an important issue when in the implementation of ITS. This chapter on driver behaviour is a summery of a part of a literature review on ABS and ESC (Linder et al., 2007).

There are many models of driver behaviour in the literature. The models handle a vast area of human capacity, reaching from limitations of the driver (due to limitations of the human mind; Shinar, 1993) to models on driver motivation (i.e., subjective vs. objective risk levels; Klebelsberg, 1977). Not all of these models serve to enhance the understanding of the driver's interaction with safety systems and handling of critical traffic situations. In order to understand "Use and misuse of safety systems by drivers", the concept of "Situation awareness", "Violation" and a model on human error will be explained in this section. Situation awareness is a concept used in a range of domains to describe an operator's ability to handle a given situation; violation and human error are two ways of explaining human interaction with a system. In addition, the effect of a system can be reduced by risk compensation or long-terms changes in behaviour.

5.25.1 Situation awareness

A fundamental aspect of driving or handling any kind of complex system is situation awareness, SA. SA refers not only to (in this case) the drivers knowledge on how the car works and skills for driving the car, but also to the drivers' knowledge and understanding of the traffic situation. Being aware of the existence and functionality of safety systems in the car is a crucial part of SA and a prerequisite for ultimate handling of traffic situations.

From the driver behaviour point of view, the evaluation of active safety systems could be done by studying following issues: Use and misuse of safety systems by drivers such as human errors and violations, drivers' theoretical and practical knowledge of safety systems and effect of the systems on driver behaviour – specific case 'Adaptation problematic'.

5.25.2 Use and misuse of safety systems by drivers

Human error

In complex systems there are often different sources of errors. In a car, the car and/or its systems can fail technically but the driver can also fail in relation to the car/systems. Adopting Reasons' reasoning (1990), human errors are classified according to the driver intention and have three levels. The definition of the type of errors made originates from what level of ability the driver has achieved. According to level of ability, the driver is able to behave and react in different ways. Three levels has been identified, namely; knowledge-based, rule-based and skill-based behaviour. Knowledge-based behaviour is the first level of a novice handling a system. The system handling is slow and conscious and new problems are solved when they arise. In the second level, the rule-based, the driver has an experienced pattern, prepared rules and solutions for problems that occur. In the skill-based level the driver knows the system and is able to supervise automated, routine tasks.

Violation and misuse

In contrast to human error, violations are conscious breaking of formal rules and regulations. Misuse can be seen as a corresponding aspect of violation. Misuse is related to the drivers' knowledge about active safety systems (Harless & Hoffer, 2002). One cause of misuse is that the driver does not understand the real effect of the systems and at the same time that the systems are not enough transparent to be understood. A study performed on collision avoidance system (Jagtman et al., 2001) where it was possible to adjust the level of warning found that the systems understanding by the drivers was decisive and that the Human Machine Interface (HMI) issues greatly influences the driver's behaviour (references cited by Jagtman et al., 2001).

5.25.3 Drivers' knowledge of safety systems

Theoretical knowledge

Some authors believe that safety systems won't achieve full scale effect until driver knowledge levels will increase (Broughton & Baughan, 2002; Seymour, 2003). Drivers with good knowledge are benefiting from technology whereas those with less or no knowledge may misuse the system.

Practical knowledge (training, experience)

A survey study by Seymour (2003) concluded that effects of active safety systems are still limited because drivers have too little knowledge concerning how the systems work and how to use them. Large differences were observed among different drivers population, about the degree of knowledge concerning different safety systems (Seymour, 2003). Seymour compared vehicle safety knowledge between younger and older drivers. Older drivers had less knowledge about vehicle safety systems; they were also less willing to have driver's airbag or ABS brakes into their vehicle. When purchasing a car, safety issues were named by only 11% of participants, which is ranked 7 out of 10.

5.25.4 Identified gaps in the driver behaviour research area

Different methods such as survey or field study have been used to identify the effect of ESC and ABS on driver behaviour. There are however many factors, e.g. short/long term effects, learning, to take into account in order to understand effects of safety systems. Data are missing as to show the existence if driver adaptation or risk compensation when using active safety systems such as ESC and ABS.

For ESC and ABS the literature review showed that most drivers have little knowledge of the function of active safety systems as well as how they shall be handled. This lack of correct knowledge could influence the driver behaviour, and thus limit the positive effects on traffic safety.

5.26 Methods for estimation, evaluation and verification of traffic safety impact

Relating to the loop with the seven steps introduced in Chapter 1 (repeated here as Figure 5.26) examples on different techniques used in order to evaluate ITS can be identifies.

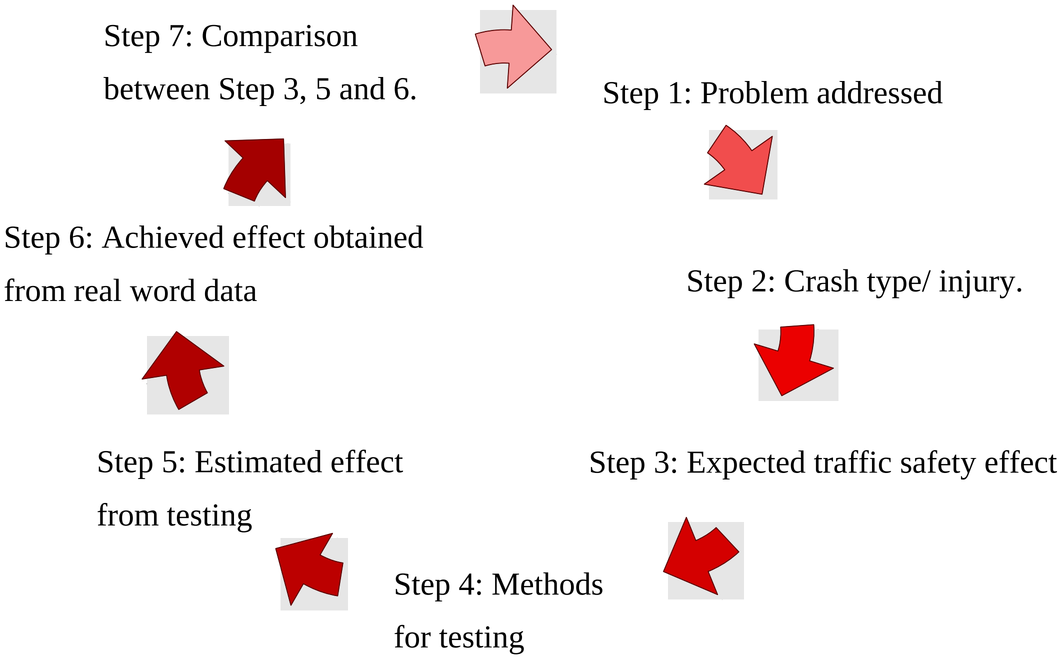


Figure 5.26 The loop with 7 steps from identification of problem to evaluation of achieved effects and comparison of these to expected and estimated traffic safety effects of intelligent transport systems.

Driving simulators are widely used early in the design process when for example different concepts are compared to each other. The design process occurs in Step 1–3 of the steps in Figure 5.26.

Step 4, testing can be both performance test such as the suggested fish hook manoeuvre for the testing of ESC and/or Field Operational Test (FOT). FOT is performed by logging of data from vehicles that are driven in regular traffic and by analysis of this data the effect of systems are assessed.

Step 6 can either be performed by applying statistical methods to accident data (among many others Lie et al., 2004) or by observations of traffic (Krafft et al., 2006).

5.27 Conclusions

In this chapter 20 different ITS systems or groups of systems which are already present on series-produced cars nowadays are described. New technology development provides vast opportunities to support the driver in the driving task. Many systems are promising in terms of improving traffic safety, and some have shown effect in reducing the number of traffic accidents, such as ESC. On the other hand much research is still needed in order to assess the safety implications of many of these systems. For example is the adaptation effect debated i.e. if and if so to what extend drivers adapt new driving characteristics when increased support is given from the vehicle in order to perform the driving task. In addition, safety benefits from increased vision during night time driving could decreased if enhanced vision result in higher driving speed. Statistical methods to evaluate safety effects making use of different data and methods to estimate expected effects are presented in the next two chapters.

6 Statistical methods using accident data to estimate the safety effects of ITS

This chapter deals with different statistical methods to estimate effects on traffic safety of various ITS after the systems are introduced on the market. Focus has been on methods found in the literature using data from real life accidents to estimate a systems safety effect. By estimated safety effect we mean a statistical relationship between a certain ITS and the accident outcome and not a causal relationship.

After a new safety system is introduced into the car fleet, it is important to estimate its crash and injury prevention effectiveness based on data from accidents. Compared to the tests and evaluations done before the safety system is introduced to the market, many more driving factors and road situations could be experienced and these may have an adverse or positive effect on causality reduction. Using data from accidents makes it possible to evaluate the combined effect of the technical performance of the systems and how it interacts with humans in real traffic.

In the first section of the chapter the method used is described and different problems when analyzing accident data are discussed. In section 6.2, different statistical methods used to analyze benefits of a new safety system are described. The chapter ends with a conclusion and suggestions of future work.

6.1 Background

This part of the report focuses on published studies about statistical methods used to estimate safety effects of different ITS after having been introduced on the market. The literature described below are mainly about ABS and ESC. It was difficult to find published studies about other safety systems effects based on accident data. One reason might be due to that evaluations are restricted to systems that are introduced on its own and it could be difficult to distinguish possible safety effects of a certain system when several systems are introduced at the same time. In addition, information on optional equipment in vehicles is not always easily available.

6.1.1 Problems when analyzing accident data

By analyzing trends in the accident statistics, it is possible to estimate safety effects of new safety systems introduced to the market. This analysis is however seldom a straightforward approach.

Before a new safety system is introduced on the market, different tests and simulations are done to ensure that the system performs as expected. This issue is beyond the purpose of this study and is not covered here.

Initially, when a new safety system is introduced in a small extent of the market, there are few accidents to analyse in a statistical evaluation. An initial approach to obtain an estimate of expected safety effects is to use expert knowledge about the ITS and what type of accidents the system are expected to reduce or remove. A reasonable initial estimate of the expected benefit of the system is to assess whether the accident maybe would have been prevented if the cars have had a certain ITS system. This approach is used by Sferco et al. (2001), who use in-depth analysis data from the European Accident Causation Survey (EACS) to obtain an expected estimated benefit of ESC. By studying the outcome from 1674 accidents, in five European countries, experts were asked to record their judgement in a five graded scale with terminal points: 1 = ESP would have definitely not influenced the accident and 5 = ESP would have definitely avoided the accident. If the accidents were classified in categories 3–5, it was thought that the accident outcome would have been influenced by the presence of ESP. The experts judged that 67% of the fatal accidents and 42% of all injury accidents for accidents involving loss of control would have been influenced by ESP. The estimated results for all kind of accidents showed that in 18% of all injury accidents and 34% of fatal accidents, ESP would have a certain positive influence.

A similar approach is described in Langwieder et al. (2003), where Institute for Vehicle Safety Munich (IFM) investigated the potential effect of ESP by retro perspective analyzing data from real life accidents from several accident databases to judge whether an accident could have been prevented or mitigated by an ESP system or not. Langwieder et al. (2003) found that loss of control could be identified in approximately 25–30% of all car accidents involving personal injury.

An approach to combine and compare this introductory information based on expert judgements with evidence extracted from real life accidents is discussed in Section 6.5.

One example when the expected savings failed to materialise in practice was when ABS was introduced into the car fleet in the 1980s. The safety effect of ABS was promising based on results on test tracks where the tests has shown decreasing braking distances during slippery road conditions at the same time allowing the driver to steer and brake simultaneously. Although one can not conclude that the same improvement as estimated in a testing situation fully occurred in real traffic. When evaluations of ABS based on data from real life accidents was carried out, the estimated safety effects were much smaller than expected, (Delaney, 2004; Evans, 1995, 1996 and 1998; Farmer, 1997 and 2000 and Kullgren et al., 1994). Possible explanations can be that ABS did not work in the same way in a real road situation as on the test track due to, for example, differences in the road surface, or the fact that the driver might have changed his or her behaviour so that the technical benefits from ABS vanish in a way so that the traffic safety is not increased or that the crash circumstances were different from those expected.

ESC systems came to the attention of the car buyers in the late 1990s. For ESC, the expectations were more or less confirmed by the evaluations based on accident data. Even though the size of estimated effectiveness of ESC in the different studies can differ, a significant positive effect is shown in most studies (Lie et al., 2004 and 2006; Thomas, 2006; Green & Woodroffe, 2006; Page & Cuny, 2006; Grömping et al., 2004; Dang, 2004; Farmer, 2004 and 2006 and Aga & Okada, 2003). Until now, ESC systems have become widespread, it is estimated that 60% of new cars sold in Germany (Thomas, 2006) are equipped with ESC. In December 2006 in Sweden, 91% of the new cars sold are equipped with ESC, Vägtrafikinspektionen (2007).

When a new ITS system is introduced on the market, the system is usually first introduced in so called up-market car models. There is a possibility that safety effects that are estimated in the beginning are influenced by that the drivers only represent one category of drivers with a non representative driving behaviour compared to the whole driver population. As described above, even very positive results in the beginning can be misleading since the long term effects might be different. The writers in most of the articles studied here are well aware of the problem that new safety devices address certain drivers. To limit such effects to a certain extent, several studies (mainly studies about ABS and ESC here) have restricted the cars to be included in the case and control groups to cars that changed from no ESC availability to ESC as standard equipment in subsequent model years. It is further assumed that no other significant design changes have been made between the model changes, see Farmer (2006 and 2004), Lie et al. (2004 and 2006), Page & Cuny (2006), Green & Woodroffe (2006) etc. In Lie et al. (2004 and 2006), the cars equipped with ESC in the analysis were predominantly Mercedes Benz, BMW, Audi and Volkswagen and consequently so called up-market models, but they also considered broader market cars. The cars in the case and control group studied in the analysis were cars of similar makes and models with and without ESC. Farmer (2004) compared vehicles equipped with ESC as standard from 2000 or 2001 year model with vehicles without ESC that was assumed to be identical and argues that model years with identical designs have identical platforms and the same safety equipment. Aga & Okado (2003) estimated the effectiveness of Vehicle Stability Control (VSC) by analysing accident data in Japan. To establish that characteristics of vehicles and drivers did not differ too much, Aga & Okado (2003) used three common Toyota vehicles in the study.

Green and Woodrooffe (2006) investigated the age-of-vehicle effect by studying the effect of ESC in three different situations:

1. Cars of similar makes and models with and without ESC (FARS data)
2. Cars, not older than three years (similar makes and models with and without ESC, FARS data)
3. Vehicles with different makes and models, but similar model years (GES data).

A general problem when analyzing the benefit of a specific safety system is the problem of obtaining sufficient data. Often information about safety systems fitted in the vehicles are insufficient or even absent in the accident databases and in the vehicle registration register. These limitations lead to that only a limited amount of ESC-equipped cars can be identified correctly and therefore used in the analysis. This problem seems to be the same in most countries. In a study done in France (Page & Cuny, 2006), the problem of obtaining sufficient information whether a car is equipped with ESP or not led to that only a very limited set of cars which include information about ESP was selected to the study. Only one make and model was used, namely the Renault Laguna. Two sets of Lagunas, those without ESP (Laguna 1, produced before mid 2000) and those with ESP (Laguna 2, produced after 2001 with ESP as standard equipment) were included in the study. Drawbacks with this limited selection of cars, expect the obvious lack of information of how other car models are affected of ESC, were for example that Laguna 2 benefited from other active and passive safety improvements compared to Laguna 1. This is further discussed in Page and Cuny (2006).

6.2 Different approaches to estimate safety improvements

This section describes some of the methods found in the literature about estimating safety effects from accident data. The most common methods (mainly studies about ABS and ESC) have similarities since most of them were based on ratios of different accident-ratios. Some methods were more detailed than others, restricting the analysis to certain groups of cars, accidents and road surfaces, while others used available information more generally. Though some overlap, the methods could be classified as:

- induced exposure methods/simple odds ratios
- odds ratios combined with logistic regression
- methods originating from epidemiology where expected counts are compared to observed counts.

In the sections below, the most common methods used are described in more detail.

6.2.1 Induced exposure methods – simple odds ratios

In general, it is rather difficult to obtain information about the exposure of a vehicle with a certain ITS-system, since such information is not included in the accident data bases or in the vehicle registers. One key issue is how to measure the exposure of ESC equipped cars and that there are no direct way of register accidents that did not occur. To overcome such difficulties, induced exposure methods can be used to estimate the true exposure. One critical assumption is that it is possible to identify at least one type of accident not sensitive to the ITS system. The evaluation methods are inspired by the *double pair comparison method* developed by Evans (1986), see Appendix 4.

The induced exposure methods are very similar to a case-control approach, and therefore the method is described in terms of cases and controls. (The description does not follow strictly the definition given in medical and epidemiological literature.)

In a case-control approach subjects with a particular condition (the cases) are selected for comparison with subjects without the condition (the controls). Cases and controls are compared with respect to attributes believed to be relevant to the condition under investigation. As an example, cases can be those vehicles involved in single-vehicle crashes and controls can be restricted to vehicles involved in multi-vehicle crashes. Cases and controls can then be compared with respect to the presence or absence of a certain ITS, for example ESC. In a case-control study, the vehicles of interest should be as similar as possible, expect for the presence or absence of ESC, so that any measured effect most likely is attributed to the presence of ESC.

The following description is based on Grömping et al. (2004), Page & Cuny (2006) and Lie et al. (2004 and 2006). Let the population be all vehicles in use and use the following notation:

- D = accidents sensitive to ESC (Cases).
- $\overline{D}$ = accidents not sensitive to ESC (Controls).
- E = the vehicle was equipped with ESC
- $\overline{E}$ = the vehicle was not equipped with ESC.

In Table 6.2.1, the probabilities used to express the odds ratios are described.

Table 6.2.1 Description of the probabilities in a case-control approach used in Grömping et al. (2004).

	E	$\overline{E}$
D	$P(D \mid E, x)$	$P(D \mid \overline{E}, x)$
$\overline{D}$	$P(\overline{D} \mid E, x)$	$P(\overline{D} \mid \overline{E}, x)$

The odds that a vehicle is involved in an accident, provided that the vehicle was equipped with ESC, can be estimated by:

$$odds_D \mid E = \frac{P(D \mid E, x)}{P(\overline{D} \mid E, x)}$$

and the odds, given that the vehicle was not ESC-equipped, are:

$$odds_D \mid \overline{E} = \frac{P(D \mid \overline{E}, x)}{P(\overline{D} \mid \overline{E}, x)}.$$

The corresponding odds-ratio which describes the factor, by which the odds of having an accident of interest with an “unexposed vehicle” is multiplied to find the odds for an “exposed” vehicle:

$$OR_D = \frac{odds_D \mid E}{odds_D \mid \overline{E}} = \frac{\dfrac{P(D \mid E, x)}{P(\overline{D} \mid E, x)}}{\dfrac{P(D \mid \overline{E}, x)}{P(\overline{D} \mid \overline{E}, x)}}$$

If the odds-ratio equals 1, then ESC is assumed to have no influence on the odds of having an accident of interest.

Under certain conditions, this odds-ratio-ratio can be estimated by observing the following frequencies:

Table 6.2.2 Distribution of accidents for the estimation of odds-ratio OR.

	ESP equipped cars	Non-ESP equipped cars
Accidents sensitive to ESP	A	B
Accidents not sensitive to ESP	C	D

The effectiveness E is defined as : E = 1 – OR and estimated by:

$$E = 1 - OR = 1 - \frac{A/C}{B/D} \qquad (1)$$

where A, B, C and D are described in Table 6.2.2.

If all counts in the odds-ratio (1) are assumed to Poisson distributed then statistical inference can be done in several ways. An estimate of the standard deviation is:

$$s = OR \cdot \sqrt{\frac{1}{A} + \frac{1}{B} + \frac{1}{C} + \frac{1}{D}}.$$

Logistic regression methods can be applied to adjust for different confounding factors. Disadvantages are that no absolute reduction in risk can be estimated and that there is a high bias risk due to selection of controls and selection of confounders.

Methods to estimate effectiveness of ESC based on odds-ratios have been used by Lie et al. (2004 and 2006), Dang (2004), Page & Cuny (2006), Bahouth (2005), Green & Woodroffe (2006) and Grömping & Mentzler (2003).

Effectiveness of ABS by means of odds-ratios are treated in the following studies: Delaney and Newstead (2004), Evans (1995, 1998), Evans & Gerrish (1996), Farmer (2001), Farmer et al. (1997) and Kullgren et al. (1994).

Grömping & Mentzler (2003) extended the traditional case-control approach to a new approach called a split register approach. This approach is further described in Linder et al. (2007).

As mentioned earlier, one critical assumption is that it is possible to identify at least one type of accident not sensitive to the ITS system.

Similar methods have also been used to study the effect of passive safety systems. In Lie & Tingvall (2002), a paired comparison of car-to-car crashes is done to investigate how EuroNCAP results correlate with real life injury risks. It was concluded from the study that cars with three or four stars were found to be approximately 30% safer when compared with cars with two stars or cars without a EuroNCAP score.

6.2.2 Odds-ratios obtained by logistic regression

If information about other parameters such as driver age and gender, age of the car, etc. are available in the accident database or a corresponding database, it is possible to include such information of covariates in a case control approach by the use of logistic regression.

Logistic regression is a method for modelling probabilities of a certain event depending on other variables, so called covariates, see for example Dobson (1990).

Define the binary random variable Z as:

$$Z = \begin{cases} 1 \text{ if the output is a success} \\ 0 \text{ if the outcome is a failure} \end{cases}$$

with $P(Z=1)=\pi$ and $P(Z=0)=1-\pi$. Assume *n* independent such variables $Z_1, Z_2, \ldots, Z_n$ with $P(Z_i=1)=\pi_i$. The general logistic model is formulated as:

$$\text{logit}\pi_i = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \mathbf{x}_i^T \beta ,$$

where $\mathbf{x_i}$ a vector of covariates and/or dummy variables and β is the parameter vector.

As we can see below, the coefficients have an interpretation as the logarithm of odds ratios.

Suppose that the only variable included in the model is a dummy variable describing whether the car is ESC equipped or not, i.e.:

$$I_{ESP} = \begin{cases} 1 \text{ if the vehicle is equipped with ESP} \\ 0 \text{ if the vehicle is without ESP} \end{cases} .$$

The logarithm of the odds described in the logistic regression model is:

$$\log\left(\pi_{ESP} \big/ 1-\pi_{ESP} \right) = \beta_0 + \beta_1 I_{ESP} .$$

If we compare the odds for vehicles with and without ESC we can see that

$$OR = \frac{odds_{ESP}}{odds_{nonESP}} = \frac{\exp(\beta_0 + \beta_1)}{\exp(\beta_0)} = \exp(\beta_1) \text{ meaning that} \log(OR) = \beta_1 .$$

The following studies are examples of studies where the method of simple odds-ratios are extended to logistic regression methods: Page and Cuny (2006) and Dang (2004).

Another extension of the pure case-control approach has been done by Green and Woodroffe (2006), where a generalized additive method (GAM) was fit to the data to assess the effects of age and gender. A GAM can fit smooth terms such as smoothing splines to continuous variables such as age. The models are described further in Hastie and Tibshirani (1990). In their study, Green and Woodroffe assess the effects of age, gender and ESC.

6.2.3 Expected and observed counts

Farmer calculated crash involvement rates per vehicle registration. If ESC had no effect on crash risk, then crash rates per registration should be the same for vehicles with and without ESC for each model. Farmer calculated the expected crash risk for each of the vehicles in the study and compared with the observed crash risk. The expected crash counts for the ESC-equipped version were derived as the product of the crash rate for the non-ESC version and the registration count for the ESC version. This was done for every vehicle included in the analysis and thereafter a risk ratio was computed. The risk ratio was calculated as the sum of the observed crash counts for ESC-equipped vehicles divided by the sum of expected crash counts. Several risk ratios for different levels of injuries and different accident types were calculated. Confidence intervals (95%) were calculated using a formula derived in Silcock (1994). The lower and upper limits are calculated as follows:

$$lower = \beta_{0.025}(O, E+1) \Big/ 1 - \beta_{0.025}(O, E+1)$$

$$upper = \beta_{0.975}(O+1, E) \Big/ 1 - \beta_{0.975}(O+1, E) ,$$

where O is the sum of observed crash counts, E is the sum of expected crash counts and $\beta_p(x, y)$ is the pth percentile in the β-distribution with parameters x and y.

6.2.4 Conclusions

The methods described above certainly have advantages and disadvantages. The methods based on odds-ratios require that the accidents can be classified into accidents sensitive to the ITS system and accidents not sensitive to the system. This might be a crucial point. Advantages of these methods are that factors such as driver age and gender, age of the car etc. can be included in the analysis by means of logistic regression. It is also positive that a misclassification of for example ESC equipped cars, whether in the case or control group will tend to underestimate the effectiveness of ESC.

The methods comparing observed and expected counts do not require the identification of sensitive accidents, but has on the other hand not the same possibility to include covariates as logistic regression. It is further important to point out that all the methods described above only estimate safety effects, they do not show any causal relationship between ESC and the accident outcome.

Before a recommendation of which method to use, it would be very interesting to compare different statistical evaluation methods on the same set of data in order to quantify their differences. It would also be an interesting approach to use the same evaluation method on different data sets.

6.3 Estimated safety effects on the number of accidents

For ABS and ESC the following data for estimated reduction of traffic accidents is found in the literature (Vaa et al., 2006; Lie et al., 2004; Dang, 2004; Farmer, 2004) (see Table 6.3 for effect of ABS and 6.4 for effect of ESC). ABS does not only have a positive effect on the number of accidents, as seen in Table 6.3. As pointed out earlier, these results are estimates of effects and not illustrating any causal relationship.

Table 6.3 Estimated effects of ABS on the number of accidents (table adapted from Vaa et al., 2006). Percent change in the number of accidents and the types of accidents which were affected.

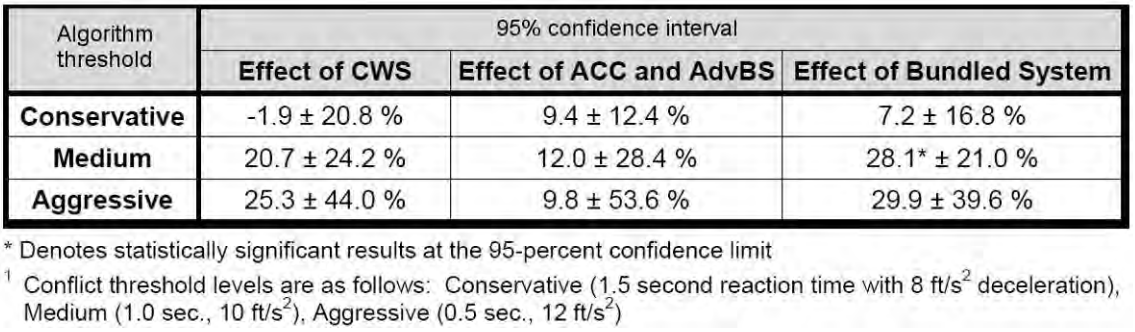
Level of injury	Percent chance in number of accidents		
	Affected accident types	"Best" estimate	95% confidence interval
ABS brakes in car			
All vehicles	All	-4	(-5; -3)
Injury accidents	All	-5	(-8; -2)
Fatal accidents	All	+6	(+1; +12)
Effects on specific accident type			
Unspecified (all types)	Overturning accident	+22	(+11; +34)
Unspecified (all types)	Single vehicle accident without overturning	+15	(+9; +22)
Unspecified (all types)	Intersection accident	-2	(-5; +1)
Unspecified (all types)	Rear-end collision	-1	(-5; +3)
Unspecified (all types)	Collision with fixed objects	+14	(+11; +18)
Unspecified (all types)	Collision with turning vehicles	-8	(-14; -1)
Unspecified (all types)	Collision with pedestrians, cyclists, or animals	-27	(-40; -12)

Table 6.4 Estimated effects of ESC on the number of accidents. Percent change in the number of accidents Lie et al. (2006), Dang (2004) and Farmer (2006) and description on the types of accidents which were affected.

	Percentage change in the number of accidents		
Study	Accidents types that are affected	Point estimate	95 % CI
Lie et al (2006)	All	-16.7	(-26.0, -7.4)
-“-	Single/oncoming/overtaking (fatal/serious) accidents on dry surface	-24.8	(-50.8, 1.2)
-“-	Single/oncoming/overtaking (fatal/serious) accidents on wet surface	-56.2	(-79.8, -32.6)
-“-	Single/oncoming/overtaking (fatal/serious) accidents on snow/ice	-49.2	(-79.4, -29.0)
Farmer (2006)	Single accidents	-41	(-48, -33)
-“-	Fatal single accidents	-56	(-68, -39)
-“-	Fatal accidents US, all	-34	(-45, -21)
Dang (2004)	Single accidents-passenger cars	-35	(-41, -29)
-“-	Single accidents-SUVs	-67	(-74, -60)
-“-	Fatal accidents – passenger cars	-30	(-50, -10)
-“-	Fatal accidents - SUVs	-63	(-81, -44)

It is interesting to compare the passenger car sector with the heavy truck sector. In the truck industry, Volvo estimated the safety effects of *collision warning systems*, *adaptive cruise control* and *advanced braking system* in the framework of the ”Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test”, prepared for the US Department of Transportation in January 2007 (Battelle, 2007). From the report the three systems are described as follows: ”The collision warning system is based on forward radar sensors. The forward sensor transmits a radar beam out from the front bumper and receives signal reflections to measure the following distance between the host (or subject) vehicle and the lead (or target) vehicle. If the system detects a potential crash, a warning system notifies the driver to take corrective action through in-cab visual displays and audible alarms. When there is no detected vehicle ahead, ACC maintains a given preset speed similar to conventional cruise control. The ACC system does not actuate the service braking system to maintain the gap setting. ACC can be bundled with collision warning system as an integrated, complementary package. Advanced braking system, which includes air disc brakes and an Electronically Controlled Braking System (ECBS), is designed to enhance the tractor’s stopping performance, and therefore has the potential to reduce the frequency of rear-end crashes by reducing the stopping distance of the vehicle. However, there is potential that the improved braking could also increase drivers’ aggressiveness.” The evaluation was performed by an independent company, not by Volvo itself. The estimations in Table 6.5 and Figure 6.1 are calculated from mathematical models based on historical data, onboard driving, fleet operational records, and surveys. Three thresholds of the algorithms are used (conservative, medium and aggressive, based on deceleration). Expected results in terms of reduced crash number are interesting, as the following Table 6.5 and Figure 6.1 show (Battelle, 2007). The table and the plot show that the overall effect is positive, but the confidence range of the analysis gives questions about possible negative aspects as well. Note that the results are for trucks, not passenger cars, and that they are estimated with mathematical methods.

Table 6.5 Estimated percent reduction in rear-end crashes attributable to deployment of ITS technologies for heavy trucks. Estimation calculated with three different algorithms, for more detail please consult the reference (Battelle, 2007), from which the table was adapted. The acronym CWS is collision warning systems, ACC is adaptive cruise control, and AdvBS is advanced braking system.



Algorithm threshold	95% confidence interval		
	Effect of CWS	**Effect of ACC and AdvBS**	**Effect of Bundled System**
Conservative	-1.9 ± 20.8 %	9.4 ± 12.4 %	7.2 ± 16.8 %
Medium	20.7 ± 24.2 %	12.0 ± 28.4 %	28.1* ± 21.0 %
Aggressive	25.3 ± 44.0 %	9.8 ± 53.6 %	29.9 ± 39.6 %

* Denotes statistically significant results at the 95-percent confidence limit

[1] Conflict threshold levels are as follows: Conservative (1.5 second reaction time with 8 ft/s^2 deceleration), Medium (1.0 sec., 10 ft/s^2), Aggressive (0.5 sec., 12 ft/s^2)

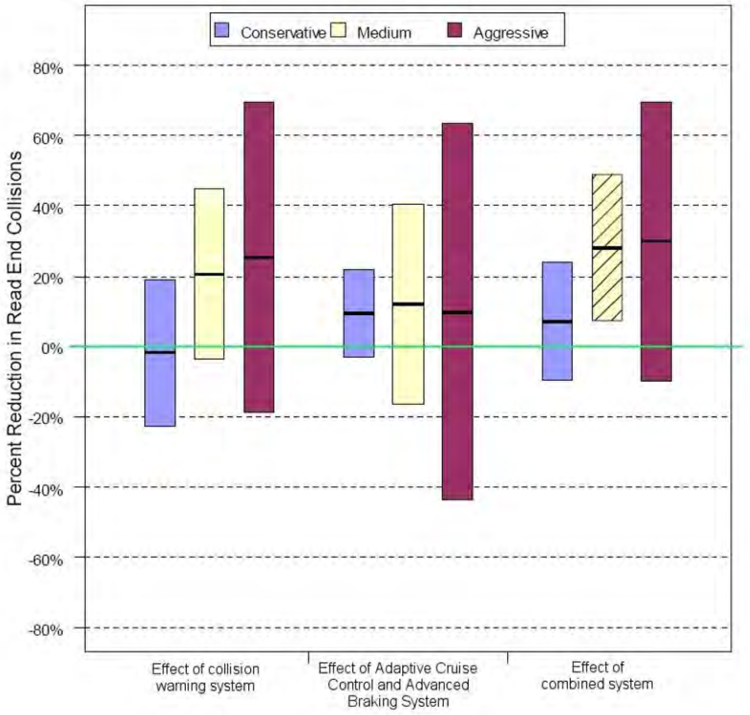


Figure 6.1 Volvo Intelligent Vehicle Initiative Field Operational Test (heavy trucks). Plot of estimated reduction in rear-end crashes attributable to deployment of ITS technologies. Bars show the 95% confidence interval. Collision warning systems, ACC and advanced braking system, and effect of combined system is plotted. Blue bars for conservative algorithm, yellow for medium, and red for aggressive algorithm. Figure adapted from (Battelle, 2007).

6.4 Are expected savings overestimated?

When a new ITS is introduced on the market, the introduction has been preceded by different tests and simulations to ensure that the system performs as expected and to obtain an estimate of the expected safety benefits. These test situations are of course very controlled and not exactly comparable to what will happen in a real traffic situation. When the system is introduced on the market, it is not sure that the expected savings coincide with the observed outcome from real crashes. When ABS was introduced to the market in the 1980s, the expected savings failed do materialise in practice. This became evident when evaluation studies based on accident data began to appear and estimated effects differed between studies. In Table 6.3, the results concerning ABS are rather different for different accident types and different injury classes. Some estimated effects are positive and some are negative. Studies such as Evans (1995), Evans and Garrish (1996), Farmer et al. (1997) and Farmer (2001) also show rather different results. The studies by Farmer showed that ABS had little effect on fatal crash involvement and that ABS-vehicles were slightly more involved in fatal crashes, particularly single-vehicle crashes. However, both studies by Evans show a positive effect for crashes on wet roads, while Evans (1995) show no significant improvements on snow or ice compared to crashes on dry roadway.

Can we expect that high expectations prior to real life experience are more correct when it comes to ESC? So far, as can be seen in Table 6.4, the results concerning ESC are more in accordance with each other which indicate that the overall effect is positive. However, long term effects are not yet studied and might show different results.

Another difference between ESC and ABS is that ESC requires no special knowledge of the driver about the system, while for ABS it is required that the drivers know how to use the system for it to work properly.

6.5 An approach to combine expert judgements with accident data

An alternative approach, not used in any of the articles studied above is to combine the information obtained from expert judgements with the information obtained from the initial accidents on the roads.

As described above, Sferco et al. (2001) and Langwieder et al. (2003) studied different accident databases and judged whether an accident would be influenced by the presence of ESC or not.

In Langwider et al. (2004) a three step evaluation method is suggested:

- "Investigation of potential safety
- Pilot studies on effectiveness with trend analyses
- Subsequently, large-scale statistical studies to confirm the effect and, where applicable, the extent of the influence on accident statistics".

Here, we suggest how to deal with the initial accident data and how to compare and combine this information with expert judgements:

The expert judgements like Sferco et al. (2001) and Langwieder et al. (2003) can be thought to represent a probability distribution. This distribution can be called posterior predictive distribution. To check whether this distribution coincide with the observed accident distribution several approaches described in Gelman et al. (2004) can be used.

Assume that the expert judgements can be summarised in a probability distribution. One simple example is to define two stochastic variables, X and Y, where

- X = the number of accidents for cars without a certain ITS system, X is Poisson distributed with mean μ.
- Y = the number of accidents for cars with a certain ITS system, Y is Poisson distributed with mean $\alpha\mu$.

α describes the difference between vehicles with and without the ITS system (for a certain type of accidents).

When the ITS system is introduced on the market and data from accidents on the roads start to appear it is possible to compare these two sources of information by *posterior predictive checks* to see if the observed data fits the distribution obtained from expert judgements. One basic technique to do this is described in Gelman et al. (2004).

First, draw simulated values from the posterior predictive distribution and compare these samples to the observed accident data. Different methods to do this comparison are described in Gelman et al. (2004). Some examples of methods are:

- Calculation of classical or posterior predictive p-values to compare tail-area probabilities.
- Graphical methods
  - Direct display and compare the data
  - Display different data summaries (means, standard deviations, quartiles etc)
  - Graphs of residuals or other discrepancy measure.

Before the idea described above can be realized, a rather extensive work to obtain a proper database and a reasonable distribution of the expert judgements must take place and this is not within the scope of this project.

6.6 How to obtain a database

No matter of which evaluation method to use, the first important step is to obtain a proper database containing all the relevant information. Looking at the situation in Sweden, the accident database to use is STRADA. Important facts to use when evaluating effects of any ITS system and that can be obtained from STRADA are:

- Type of accident
- Type of road
- Road state
- Injury extent
- Passenger position
- Sex of occupants
- Element type
- Speed limit
- Traffic environment

A more detailed description of the facts obtained from STRADA is found in Appendix 5.

However, the information from STRADA is not enough to select and classify cars with a certain ITS system. In STRADA, it is possible to identify a reference number (Vehicle info ID), that leads to a table with the following vehicle information:

- Car make and model
- Model year and/or production month
- Kerb weight including driver's weight
- Total weight
- Airbag
- Engine capacity
- Fuel type
- Width and length
- etc.

The vehicle information is obtained from the vehicle register in Sweden. An example of a table with vehicle information is given in Appendix 6.

From this vehicle information an extensive work still remains in order to identify which ITS a specific vehicle is equipped with.

In Kreiss et al. (2005) some of the steps above are described and different difficulties to obtain a proper database are discussed They describe the importance of classifying and select accident situations where the safety system of interest is likely to have some effect and accident situations where the system definitely has no effect. All other accidents should be excluded. Then the selection of cars to be included in the study takes part. As described earlier it is important to be able to decide whether or not these cars are equipped with the safety system of interest. Usually it is possible to separate the following groups:

- Cars most likely equipped with the safety function
- Cars most likely not equipped with the safety function
- Cars for which the equipment is not known.

Kreiss et al. stress that cars where information about the safety equipment is not available must be excluded from the study. It is also important to ensure that the cars with and without the safety system are as similar as possible and about the same age. The problem of misclassifying cars and/or accidents is also discussed in Kreiss et al (2005). A misclassification leads in any case to an underestimation of the safety equipment. In Thomas (2006) it is also described that a misclassification of ESC equipped cars, whether in the case or control groups, will tend to underestimate the effectiveness of ESC.

7 Estimating expected effect

This chapter deals with the question of how different industry areas such as the pharmaceutical and food industry have estimated the expected effect of a product, material or solution before it is introduced. It is of interest to know how similar estimations have been made in businesses comparable to ITS, concerning evaluation of obtained effects. The question this chapter tries to address is: What could be learned from other industries that is applicable on the introduction of ITS in the traffic safety area? The overview of different industry areas is done on the Swedish market and thus describes the structure in place in Sweden. In section 7.1 references for ITS evaluation guidelines are given, whereas sections 7.2–7.7 deal with other industries. In section 7.8, parallels between the traffic safety area and other areas are drawn.

7.1 Evaluation guidelines for ITS

Comprehensive evaluation of ITS is vital in order to assess the effects on traffic safety, mobility, efficiency and environment. Here follows examples of some guidelines for evaluation of ITS from a variety of countries. The US Department of Transport’s ITS program gives comprehensive information on ITS evaluation in a number of documents available online (ITS, 2006). Their ITS evaluation guidelines serve in assessing expected and achieved safety effects of ITS as one goal area (besides mobility, efficiency, productivity, energy and environment). The Finnish VIKING ITS evaluation guidelines (Kulmala et al., 2002) can be found as downloadable version under http://www.ibec-its.de/viking.pdf. Here indicators and evaluation methods are described in detail for several aspects of ITS. The Swedish Road Administration offers a report on ITS evaluation (PLUTO (Vägverket, 2002)) which contains practical hints on ITS evaluation in several aspects, including practical examples, and descriptions of methods for evaluations ranging from statistics to qualitative methods. Please note that the PLUTO report is written in Swedish. In Norway Sintef has written guidelines for evaluation of ITS projects (Knudsen, 2005). This report is more an overview of ITS evaluation methods, and often takes the PLUTO report as source of information. The Swedish framework for ITS evaluation is shown in Figure 7.1 below. Detailed description of the framework is found in Dörge (2006) which also contains an overview of the usage of ITS in the road infrastructure from the countries Finland, Sweden, Denmark, Norway and North Germany. In this report examples on how ITS applications such as traffic management, road pricing, variable speed limits and parking information have been evaluated is described.

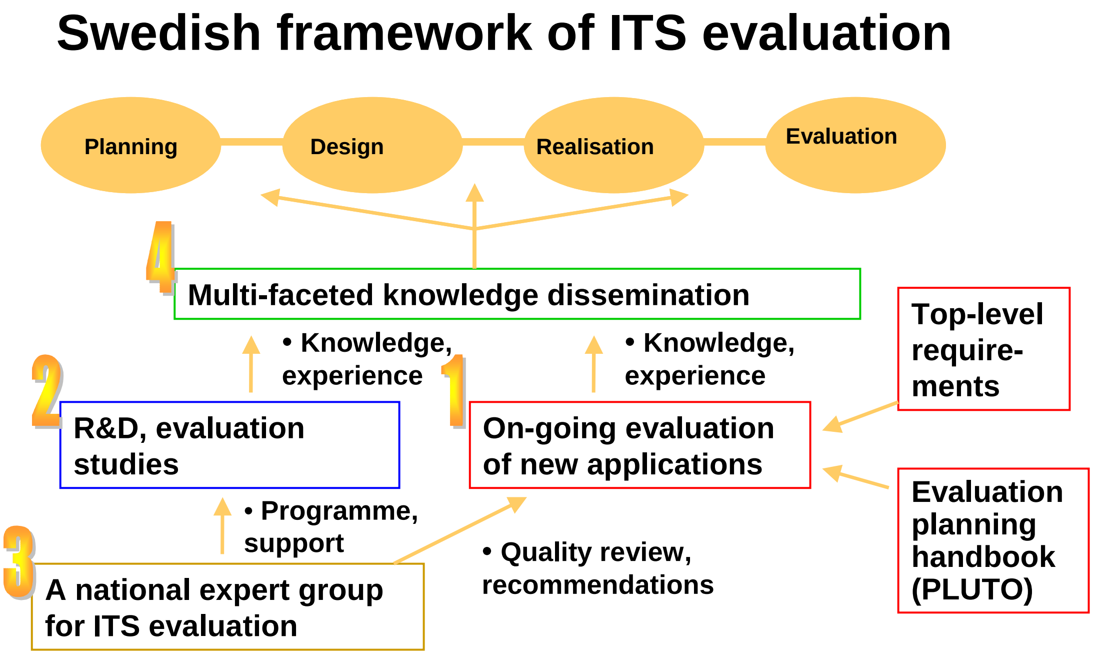


Figure 7.1 Swedish framework for ITS evaluation.

Within the European Commission several large projects are run that address evaluation and assessment of ITS in relation to traffic safety and socioeconomic aspects. One example is the ADVISORS final report, which gives insight into assessment methodologies of several driver assistance systems (ADVISORS, 2007). The HUMANIST project has a number of reports (deliverables) related to ITS system assessment, all available for download (HUMANIST, 2007). From HUMANIST especially the deliverable 2 of task force B comprehensively summarizes available ITS and their effect on traffic safety, referencing to several studies. The eSafety project describes several aspects of ITS in a number of reports, and lists as well other relevant projects in the area of ITS and traffic safety on its web site (eSafety, 2007) and in a report by the traffic safety working group (eSafety Working Groupd on Traffic Safety, 2002).

Other web sites listing reports on effects of ITS for traffic safety are:

- Intelligent Transportation Systems webpage by the US Department of Transportation (US Department of Transportation, 2007b).
- Benefits Database for ITS from the Intelligent Transportation Systems webpage by the US Department of Transportation (US Department of Transportation, 2007a).
- Intelligent Vehicle Initiative report collection (Intelligent Vehicle Initiative (IVI), 2005).
- Bishop Consulting collects several reports and presentations related to ITS in the IVSource webpage (Bishop Consulting, 2007).

7.2 The pharmaceutical industry

7.2.1 Authority control

In Sweden the Medical Products Agency (Läkemedelsverket, 2007) has the responsibility of medicine safety and is the authority that can permit clinical tests and grant selling of medicine. The responsibility of medicine safety includes collecting and evaluating reports on side-effects, periodic safety reports and measures due to safety problems. The agency inspects production, distribution and clinical tests, gives information about the medicine to health and medical services and to the public, and it also performs random sampling of the medicine.

7.2.2 The research process

When a new medicine is introduced, it has gone through a complex research process over several years. The process can, in short, be presented in the following way:

- Finding a causal connection between cause and disease.
- Analysing and testing numerous chemical substances.
- Further testing and refinement of possible chemical substances for medication.
- Testing of substances in different disease models for determining safety and efficiency.
- Tests on healthy human beings in a small scale.
- Small scale clinical tests on sick patients to examine the effectiveness on the disease.
- Large scale tests on sick patients to see what supplement the new medication brings compared to already existing treatments.
- Sending an application to the authorities for permission to introduce the medicine into the market.
- Introduction of the medicine into the market.
- Continuous clinical tests to increase knowledge about the medicine and its use.

Before the medicine is tested on human beings, pre-clinic studies are carried out. In order to find a causal connection between cause and disease, the scientists use all information available on the area and combine it with personal experience. Some scientists identify proteins and enzymes that are believed to be involved in a certain disease process and others analyse which role they have. So called in-vitro studies, where tissue from humans or animals is being examined in test tubes, is one way to see if the substances are suitable. Tests on laboratory animals are carried out to test if the substance is active and has the desired effect on relevant organs and the whole body. It is controlled if the substance affects foetus and fertility and if it can cause cancer.

Working together, scientists from different disciplines determine the connection between exposure of the substance, effect and time of efficiency. Calculations of how fast the medicine is probable to disappear from the body, in what forms and in what way it will happen, are carried out. An expert group, consisting of all scientists involved, meets to evaluate the research results from the pre-clinic studies. The scientists present their results and together they make a decision on the possibilities of the model substances. An application is sent to the Medical Products Agency that can give permission to carry out clinical tests. If there is a suitable medicine candidate, the concept is tested on human beings; first on healthy persons, and finally on sick patients. Ultimately, the Medical Products Agency can pass the medicine for selling, continuing to perform inspections and random sampling of the medicine. (Astra Zeneca, 2007; Pfizer, 2007; Läkemedelsverket, 2007).

7.2.3 Time and cost aspects

The typical time for a new medicine to be developed is about 12 years, which includes the pre-clinic phases (≈ 4,5 yrs), the clinic phases (≈ 6 yrs) and approval from the authorities to introduce the medicine into the market (≈ 1,5 yrs). The typical cost would sum up to about US$ 897M, where the clinic phases stand for the most part. After the introduction of the medicine, continuous clinical tests to increase knowledge about the medicine and its use are carried out. This process is schematically described in Figure 7.2.

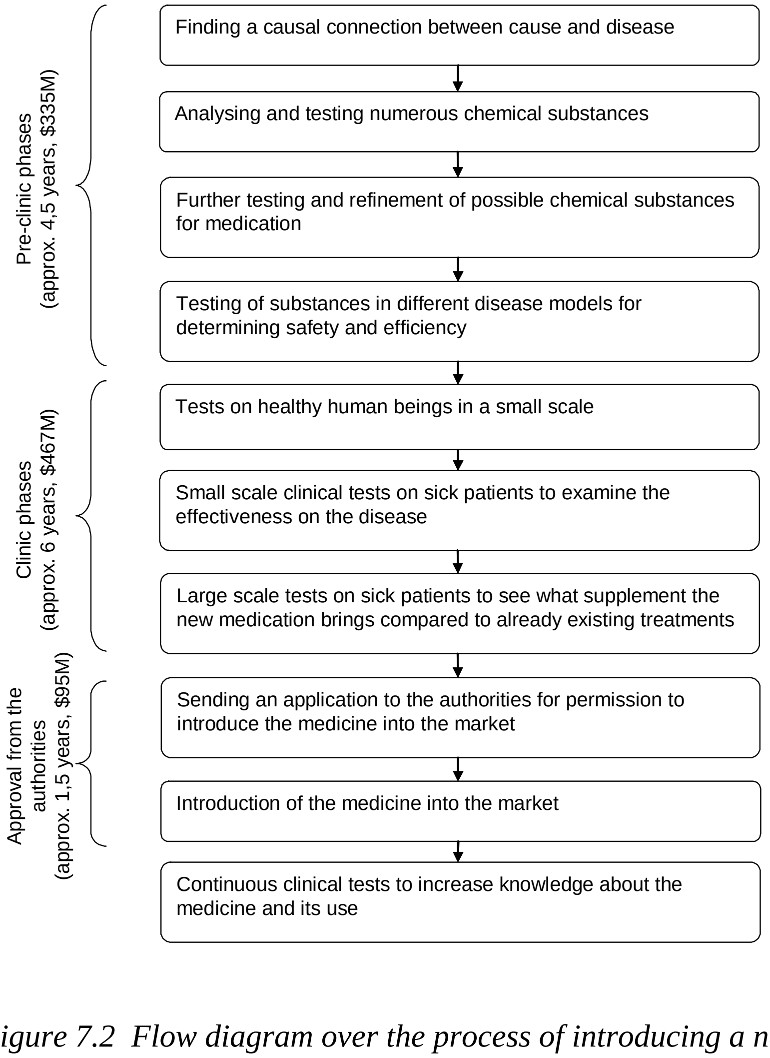


Figure 7.2 Flow diagram over the process of introducing a new medication (Astra Zeneca, 2007; Pfizer, 2007).

7.3 The Food industry

7.3.1 Authority control

The responsibility of food control in Sweden is shared between the National Food Administration (Livsmedelsverket, 2007), the county administrative boards and the local authorities. The National Food Administration controls about 600 establishments and the local committees for environmental and health protection control the rest of the establishments. The National Food Administration leads and co-ordinates the local authority control together with the county administrative boards.

The Medical Products Agency approves on what medicines are allowed to be given to animals, the Swedish Chemicals Agency gives permission on use of pesticides, the National Food Administration has the responsibility for control of meat, milk, eggs, honey and fish and also determines the time that should pass between that an animal has been given medicine until it can be slaughtered.

The National Food Administration shall:

- Influence the food regulations.
- Make sure that the food regulations are followed.
- Make sure that the food at restaurants, in industries and markets is controlled.
- Make local authorities, county administrative boards and the National Food Administration co-operate.
- Inform about everything essential related to food.
- Work for safe food and good eating habits in the way defined by the government and the parliament.
- Carry out food investigations.
- Co-operate with other countries, in particular the EU countries.

The National Food Administration should actively work for safe food and good eating habits. The European Union has an overall common legislation about marking of food products. From this, the National Food Administration develops guidance for controlling authorities, such as the local environmental authorities. Studies of eating habits for different consumer groups are regularly performed, in order to build up a basis for recommendations on good eating habits for different consumer groups, such as pregnant women, small children and old people (Livsmedelsverket, 2007).

7.3.2 Requirements for food manufacturers

Every food manufacturer must carry out self-monitoring in order to follow the requirements in the food legislation and to avoid and restrict that food is processed with bad quality or make people ill.

In self-monitoring the following tasks are included:

- To identify possible dangers and risks in the production
    - investigate where in the production the dangers may exist
    - determine where in the process the dangers can be handled

- To establish systems for surveillance
  - measure temperature and time, for example
- To verify that the system works
  - make tests and evaluations separate from the systematic surveillance
- To establish routines for documentation.

A self-monitor programme is a document describing which routines the food manufacturer has performed to meet the requirements in the food legislation.

Self-monitoring is supplemented with control from supervision authorities that judge whether the food manufacturers' systems for self-monitoring secure that the requirements in the food regulation are fulfilled. The supervision is often carried out by the local committees for environmental and health protection, and sometimes by the National Food Administration. Documented routines, work instructions and results from measurements, analyses, protocols and complaints are gone through and observations from the operation are made (Livsmedelsverket, 2003).

7.3.3 Introduction of novel food

Novel food is a notion for food that has not been eaten to a larger extent within the EU before May 15th 1997 (Livsmedelsverket, 2007). When novel food is introduced, it must be approved after a preliminary examination according to a specific procedure to be sold in the market within the EU.

The basic rules are that food included in the regulation should not:

- imply any risks for the consumer. To control this, a safety estimation is made
- mislead the consumer. Special demands for marking can be made
- differ so much from "normal" food that it brings nutritional disadvantages to the consumer.

To obtain approval on novel foods, there are mainly two procedures to undertake:

- the evaluation procedure
- the announcement procedure.

When using the evaluation procedure, the applicant has the responsibility to prove that the novel food is safe and that it does not involve nutritional disadvantages for the consumer.

The flow diagram in Figure 7.3 schematically shows the different steps a novel food has to go through in the evaluation procedure until it is approved for use. The steps are further detailed below:

- **Application documents (by the applicant)**
  To help the applicant, there is an advisory document given out by the European Commission (97/618/EG). The application document should contain specific data in order to make it possible to make a judgement of safety and of nutrition value. There are certain questions that must be answered scientifically and in a specific order. The application document should also contain conclusions and a summary.

- **Evaluation report (by the food authority in the member state where the product is to be introduced first)**
  The Commission's advisory document also contains advice for how to formulate the evaluation report. The evaluation report should be presented within three months, after which the Commission distributes the report to the other member states.
- **Opinions (from other member states)**
  Comments and motivated objections to letting the product out on the market should be given within two months.
- **Draft on decision for approval/rejection (by the Commission)**
  The Commission, together with the applicant, should handle the opinions of the member states. If there are objections from the member states concerning risks, the Commission can ask the European Food Safety Authority (EFSA) for advice. The Commission can decide on solutions, for example by proposing special demands on marking.
- **Decision for approval/rejection (by SCFCAH)**
  The SCFCAH is the Standing Committee on the Food Chain and Animal Health. With a qualified majority voting the SCFCAH decides on approval or rejection of the product. The decision includes the extent of the permission.

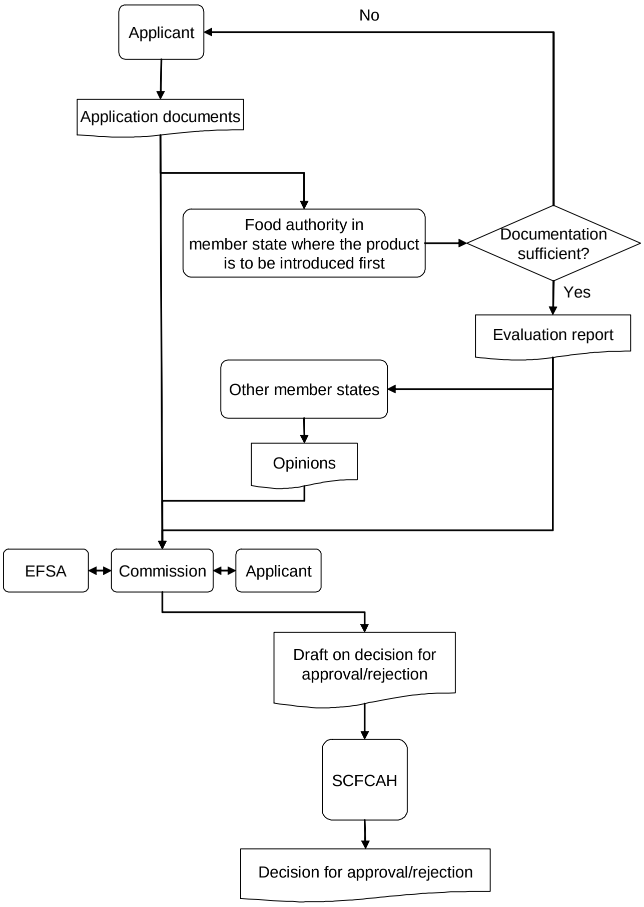


Figure 7.3 Flow diagram over the application process for a novel food, using the evaluation procedure.

For a novel food to be approved in Sweden, the authority to which to send the application document is the National Food Administration. The costs for handling the application depends on the time for handling (725 SEK/h in April 2007), and costs for travel and allowances for expenses. If there are other investigations necessary to perform in order to handle the application, there can also be investigation costs.

The announcement procedure is used when the novel food in substance corresponds to a product that already exists concerning composition, nutritive value, metabolism, intended use and content of undesirable substances. The person announcing a novel food must prove that this is the case.

For genetically modified products other rules apply (Livsmedelsverket, 2007).

7.4 Security equipment and alarms

Concerning security equipment, the consequences if anything breaks or must be replaced are important to analyse. It is often more difficult to make new security equipment work together with existing equipment than the change the whole system simultaneously. A new camera system could for instance affect the alarm system.

7.4.1 Risk analysis

In general, a risk analysis is carried out before any security equipment is installed. A risk analysis means that the consequences of every failure are examined and consists of the following parts:

- Identifying all possible risks present or risk that may pose in the future.
- Estimating the probability for such a risk to occur.
- Identifying what consequences each risk will have if it takes place.

The estimation of risk probability and consequence is often made based on previous experiences. The probability for a risk (PROBABILITY) and its consequences (CONSEQUENCE) if it occurs are usually categorized into small, medium or large and given a number 1, 2 or 3 in a matrix as described in Figure 7.4. From the product between PROBABILITY and CONSEQUENCE, the total risk is determined. For example, if the probability of the risk is considered medium (PROBABILITY = 2), and the consequences if the risk occurs are considered large (CONSEQUENCE = 3), the product PROBABILITY × CONSEQUENCE = 2 × 3 = 6, and the total risk is considered very high.

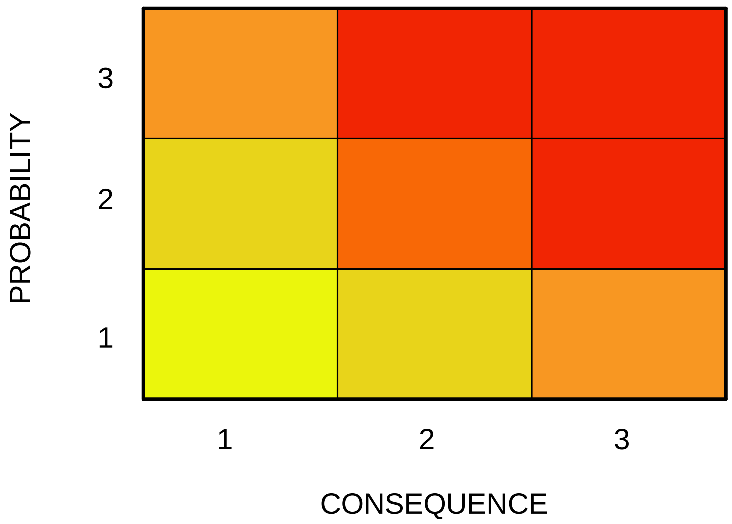


Figure 7.4 Schematic graph for risk determination.

Risk analyses are usually carried out by the constructor of a device or system. The commissioner of the equipment can also carry out the risk analysis itself or with help from, for instance, a consultant. Sometimes it is valuable that both the manufacturer and the commissioner of the equipment carry out separate independent risk analyses to see if the results are the same (Nygårdhs, 2007).

7.4.2 An example of risk analysis

An example of a risk analysis being carried out is a project at a Swedish nuclear power plant in which one person (a consultant) is constantly working with risks in the course of the project. The consultant, among other things, investigates the risk of finding a Viking ship where it is supposed to be an excavation for a new barrier or building. What would such a discovery mean for the project? Some of the aspects to take into consideration are illustrated in Figure 7.5.

- Will it be delayed?
- What do the authorities that have demanded that the project should be carried through say?
- What are the economical consequences?
- Is it possible to take in external people (in this case: archaeologists) in the area from a safety perspective?
- Are there other, alternative solutions?
- etc.

A certain amount of imagination skill is required here.

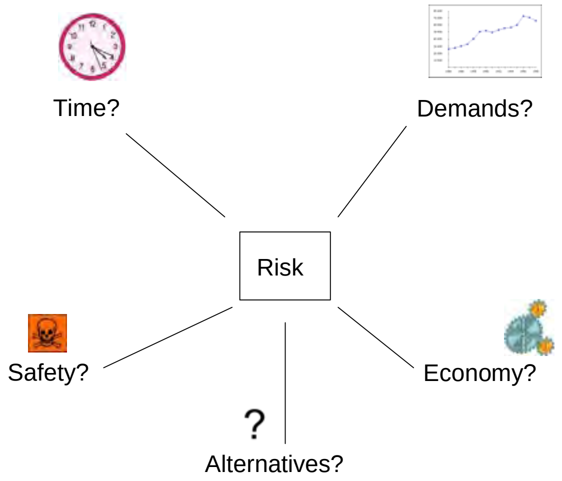


Figure 7.5 Schematic graph of some of the subjects to consider in a risk analysis (Nygårdhs, 2007).

7.4.3 Self-monitoring and redundancy

Self-monitoring is used for examining activities. An example could be that a camera should start when an alarm is signalling. At self-monitoring this function is tested to see if it exists.

Regarding personal alarms, for instance at solitary work where it is important to contact other people if something happens, redundancy is important. This means that there should be at least two ways of contacting others, such as two numbers to call or two mobile phones to handle etc. (Nygårdhs, 2007).

7.5 The nuclear power industry

7.5.1 Authority control

Nuclear activities in Sweden are mainly regulated by the Act on Nuclear Activities. This means that the holder of a licence to conduct nuclear activities has the full responsibility for the safe operation of the facility.

The Swedish Nuclear Power Inspectorate (SKI) supervises all nuclear activities, such as nuclear fuel fabrication, nuclear power plant operation and the operation of other technical facilities, transport and waste management. The SKI also works for safety work development. SKI activities are financed through a fee paid by the licensees. However, the government and the parliament determine the cost and direction of SKI's activities. On certain issues, the SKI co-operates with the Swedish Radiation Protection Authority (SSI).

The SSI issues radiation protection regulations and ensures compliance with them. The SSI supervises and measures activities including radiation, carries out research on radiation, informs about radiation and radiation protection and takes part in international co-operative work. Both SKI and SSI are regulatory and supervisory authorities that report to the Ministry of the Environment (Statens Kärnkraftsinspektion, 2007; Statens Strålskyddsinstitut, 2007).

7.5.2 Safety through analyses

Safety is crucial for the nuclear power industry. There is a massive protection against accidents, where the protection is built upon different independent barriers to prevent radioactive discharge. The barriers are protected by independent security systems, instructions and routines. This way of building up the safety is called the nuclear power plant’s defence in depth. This means that all barriers will have to leak before radioactivity leaks out to the environment. To make sure that all parts of this protection work, different analysis methods are used; deterministic and probabilistic analyses. The idea of both methods is to analyse the probability for one or more errors in different environments. Fundamentally, the nuclear power plant is theoretically exposed to various chains of error and then the probability for this to happen is estimated (Österberg, 2007; Statens Kärnkraftsinspektion, 2007).

7.5.3 Deterministic analyses

Deterministic analyses try to predict disturbances that may occur. The barriers in the defence in depth for the nuclear power plant (Figure 7.6) are constructed to be proof against both expected and more unusual disturbances using deterministic safety analyses. Every barrier is analysed separately in order to manage all disturbances (Statens Kärnkraftsinspektion, 2007).

7.5.4 Probabilistic analyses

Probabilistic analyses regard all barriers and their way of working in connection to different disturbances. Probabilistic Safety Assessment (PSA) is a tool used for instance to:

- calculate the frequency of events that may lead to damage on the core
- find the disturbances, component errors and mistakes that would give the largest contribution to the total frequency of damage on the core
- find possible measures of security improvement and prioritize between them.

Figure 7.6 A nuclear power plant. Photo: OKG (2007).

PSA can be carried out on three levels:

- Level 1: Risk of damage on the core.
- Level 2: Risk of radioactive discharge.
- Level 3: Risk for the environment.

In Sweden, only the first two levels are carried out. PSA can also be used in daily security work to estimate both disturbances and suggested changes in construction and operation procedure. A description of level one is given in the following:

A PSA of level one, risk of damage on the core, is initiated by examining the construction of the plant and previous operation experiences. By doing this, a number of possible initial events that may lead to an undesired end condition are identified. The initial events are grouped together from several aspects: equality of course of events, what demands the events put on separate systems and the influence of the events on the use, performance and operator situation of system functions. Finally, the groups' frequencies are quantified from collected statistics on component failure, fire and tube burst data.

The next step of level one is to describe the course of the breakdown after the initial event. Safety functions that are needed for avoiding damage on the core or limiting the consequences of an initiate event are identified and modelled in an event tree, and help systems necessary for the function of the safety systems are identified. A matrix showing dependencies between different safety and help functions is constructed to analyse the logic succession of events. In the event tree, every safety function or help system correspond to a function event that is either success or failure. Different branches in the tree lead to different end conditions that indicate consequence from the extent of the meltdown (Statens Kärnkraftsinspektion, 2007; Börefelt & Lundberg Fredriksson, 2007).

7.6 The aircraft industry

When introducing new functions in the aircraft industry, a holistic approach is used. First, an interesting functionality is decided. Then the criticality, i.e. risks connected to the functionality, is determined. When this is done, the functionality can be designed. Sometimes, the function can be separated into different parts, where one part is implemented in software and the other part in hardware (Börstell et al., 2007).

7.6.1 Authority control

The manufacturer of an aircraft has product responsibility and is controlled by the authorities. The Swedish Civil Aviation Authority has the collected responsibility for civil aviation in Sweden and is financed through fees. Their main task is to promote a safe, cost efficient and environmentally safe civil air traffic. This includes working out regulations, issuing permissions and supervising the civil aviation.

The European Aviation Safety Agency (EASA) is responsible for type-certification of specific models of aircraft, engines and parts approved for operation within the European Union. EASA performs inspections, training and standardisation programmes to make certain that the European aviation safety legislation is implemented in all EU member states and it collects data, performs analyses and research to improve aviation safety.

The authorities control that certain demands for safety are fulfilled but they do not control any customer demands. The customer can demand that the number of risks of breakdown at a million flight hours should not be higher than a certain maximum. Every equipment group (for instance the fuel group) estimates the contribution for breakdown risk by using the product of failure frequency and breakdown frequency in case of failure. For every part of the system a system report is written. The system report contains what tests have been carried out, what limitations and restrictions there are, together with flight system safety information and the system contribution for breakdown risk. All separate system reports are summarized for the entire aeroplane and a certification is applied for. EASA can give permission for type-certification and thereafter, changes are made by the customer. The whole process is well documented in every step of the way (EASA, 2007; Luftfartsstyrelsen, 2007; Börstell et al., 2007).

7.6.2 Examples of safety systems in aircrafts

An example of a safety system in an aeroplane is the ground proximity warning system. Radar is used for measuring the distance to the ground and warns the pilot. Stored databases of the terrain are used and a steering system takes over if the plane comes too close to the ground. This could happen if the pilot is unconscious, but if he or she is able and wants to, the pilot can force the aircraft to fly deeper.

However, there are problems with the safety systems in aircrafts, such as pilots using the warning systems as guidance. This means that they trust the safety systems so much they use them to their critical limits. Functions crucial for safety can be subjects to accustoming. The ground proximity warning system is an example of a safety system that can be used to the limit by pilots. How could this be avoided? For now, the pilots are instructed in the manual that computer-controlled information can not be used for taking extra risks. Dangerous modes are also trained periodically in a flight simulator (Börstell et al., 2007).

7.6.3 Redundancy

For critical systems, redundancy is very important. Gyros are examples of systems where there is triple redundancy at the primary level, which means that two out of three parts must fail before there is a failure on the primary level. If there is failure on the primary level, a secondary level that also has triple redundancy takes over. The primary level and the secondary level are written in different programming languages and by different persons to avoid the same mistakes twice. Less critical systems, such as navigation, can have double redundancy. Due to good operation experience, however, the engine has double redundancy instead of triple (there are only two motors, not three) (Börstell et al., 2007).

7.6.4 Testing of new materials

When interesting new materials come into the market, these are tested for breakage for a long time. Attempts are made to break them and continuous struggles of bending and application of all kinds of forces are used for a much longer time than the material is meant to be used. If a good result is achieved, manned simulations are made and finally the material is tested in the air and mass simulations are carried out (Börstell et al., 2007).

7.6.5 Software

Software in aircrafts should be developed and validated according to the standard RTCA-DO178B, level A, B, C or D. The different levels correspond to specific levels of criticality, where level A is most critical and a failure would have catastrophic consequences. Systems for steering are examples of systems included in level A. In commuter aeroplanes the probability of contribution from every single catastrophic error must be less than 10^{-9} (one of a billion). Level B is defined as having severe, level C as major and level D as minor consequences. If a part of a system certified at level D is bought, with a complete operating system, the full insight of the system is lacking, and the overall system can not be upgraded to any higher level. For level A, full insight to every single line of programming code is needed. The choice of level for a system is a question of how critical it is (higher level means more critical), how much it costs (higher level means higher cost) and how much will be desired to alter later on (higher level means more difficult to alter). A system for increased comfort may not be critical and could also be less expensive because there is no need to master the total programming code, which means that programs ready for use can be bought. Also, combinations of systems can determine what level of safety effect is at hand: If a pilot is lost and the fuel begins to run out, the situation is not catastrophic as long as the radio works so he or she can call for help. If the radio stops to work but the navigation is working properly, the situation is considered having major safety effects, because of the large amount of air traffic. If both navigation and radio cease to work, however, the situation is catastrophic (Börstell et al., 2007).

7.6.6 Hardware

Hardware is analysed using FMEA (Failure Mode and Effect Analysis) which is a systematic method of predicting possible failures, evaluating the consequences of failure and to suggest actions to prevent failures. In short, it is a systematic method to find critical sources of error and it is carried out on different levels, down to component level. Preferably, the FMEA should be carried out by a group of people in order to have a collected knowledge that is as large as possible. The group also has to know the analysed system well. The FMEA must be updated whenever changes and modifications are introduced in the system. The following subjects could be contained in an FMEA form (see for example Johansson, 2003):

- Possible way of failure
- Possible effect from failure
- Possible cause of failure
- Present state
    - Existing controls
    - Probability of occurrence
    - Severity
    - Probability of discovery
    - Risk priority rating
- Recommended action.

7.7 Forensic equipment

At the Swedish National Laboratory of Forensic Science (SKL), the validation procedure is determined by the accreditation. How a certain validation procedure is carried out depends on the specific method or technique planned to be introduced.

It is common to introduce the new method or technique parallel to the present, and compare to new one with the present equipment or method, which is known to function appropriately (Törnström, 2007).

7.7.1 An example of introducing a new technique

An example of introducing of a new technique is the so called FTA technique for taking of DNA specimens, Figure 7.7. It was introduced in connection to the new legislation for DNA that came into effect in 2006 and which states that DNA should be taken from a saliva specimen.

Figure 7.7 Kit for taking of specimens with the FTA technique. Photo: Marcus Andrae/SKL.

The saliva specimen method has several advantages compared to the blood sample method:

- Personnel
    - Blood samples demanded nursing staff, because it was considered as body examination.
    - The saliva sample can be taken by a policeman.
- Automation
    - With blood samples, most routines were carried out manually, such as double checking the samples by supervision, measuring and extracting DNA.
    - With a saliva specimen, the process has been automated and a digital demand is made immediately, in which the policeman fills in the social security number and other data in the computer. When the sample arrives to SKL, everything is prepared and the specimen is taken care of by a robot.
- Reliability
    - 1 DNA analysis was made per blood sample.
    - A robot punches a small disc out of the saliva specimen two times during a day and both discs are analysed separately by different persons. If the samples do not agree an error is detected, which means that the results are more reliable than with the previous method.
- Time
    - The blood sample analysis required two weeks.
    - The saliva specimen analysis takes two days.

When the FTA technique was to be introduced, SKL made risk analyses and own tests to see if the technique worked as expected, which it did. It was also necessary to design a new kit for taking of specimens, to learn the individual policeman how to use it, to make sure that the communication (the digital demand for analysis) worked between the police authorities and SKL, to make sure that the sample was physically sent to SKL in a safe way and that a totally new line for identification, sample preparation, analysis and evaluation as well as hit reporting worked. At the same time twofold analyses of every sample were made (Törnström, 2007).

7.8 Conclusions

In most of the industries described in this chapter, detailed control is carried out by a governmental authority. This applies to the pharmaceutical industry, the food industry, the nuclear power industry and the aircraft industry.

Early in the **pharmaceutical research process**, a scientist in charge can have the responsibility to gather all available information on the specific area and together with personal experience to make judgements of how to proceed. In later stages, expert groups are used. These groups often consist of experts from various areas. The scientists present and evaluate the results from their research and a joint judgement is done before introducing the medicine to human beings.

This method might be of use in the traffic safety area. Before the introduction of a new system, an expert group could be gathered together to estimate the traffic safety effects, based on research carried out and on personal experiences. This method is in use at individual car manufactures but might be applied on a societal level. How this should be organized exactly might be worth considering since then expected traffic safety could be estimated and maybe gaps in the development identified.

In the **food industry**, self-monitoring is used for food manufacturers, supplemented by occasional control from the authorities. Currently self control carried out by the car manufactures is applied to the safety effect of ITS introduced in passenger vehicles.

Concerning risk assessment in the area of **security equipment and alarms**, estimations of probability risks and consequences are often based on previous experience. Self-monitoring is also used for examining activities in a security system. It might be interesting to let experts estimate the probability of risks and consequences of ITS in new car systems before introduction.

In the **nuclear power industry**, two methods for analyses are continually used: deterministic and probabilistic analyses. This could also be applicable for traffic safety systems to try to predict possible disturbances that may occur and analyse every part separately – then regard all parts of the system and their way of working in relation to different disturbances.

In the **aircraft industry**, it all comes down to a methodology – a structured way of carrying out the work. Regulation, methodology and tools are the principal points. Software should be developed and validated according to a specific standard and hardware is analysed using Failure Model and Effect Analysis (FMEA). Every step of the process is well documented. The manufacturer of the aircraft has a product responsibility, but is controlled by the authorities. To avoid failure, redundancy is very important and secondary levels take over if the primary level fails.

In **forensic equipment**, it is common to introduce a new method or technique parallel to the present one and make double checks to ascertain that it works adequately. Risk analyses and tests are also used.

8 General conclusions and recommendations for future studies

An overview of intelligent traffic systems with the potential to improve traffic safety has been performed and described in this report. Focus was on systems already available in series-produced passenger vehicles. A large variety of available systems was identified, but the search for scientific research on safety aspects of the systems (in terms of reduced number of traffic accidents) was less proficient. Limited number of publications related to long term effects and human factors aspects before and after introduction of new ITS on the market was found in the literature overview. One reason might be that data is not yet available in sufficient amount, since the systems have been introduced recently. Another explanation might be the market penetration: if a new system is only installed in a small number of upper segment cars, data might not be representative and therefore not sufficient.

From the literature and market overview two car manufacturer stand out in terms of safety systems included: the upper segment Lexus sedans (for example Lexus LS600h) and Mercedes cars (for example Mercedes CL class). In these cars a large variety of systems aimed to assist and protect the driver were found.

It is difficult to forecast how ITS will develop in the future, however, the trend is that drivers will witness the shift from *crash effect reduction* systems to *crash avoidance* or mitigation systems, and this trend has already started. System integration is likely to become a major topic: a system might combine road information (ex. slippery road), traffic information (ex. queue ahead), driver information (ex. age), information from other vehicles (vehicle to vehicle communication), and possibly more to assist the driver in concluding the journey safely. Research on methods for evaluation of safety benefits of new ITS is vital, and needs to be increased in order to be able to follow the rapid technical innovation development.

In the area of statistical methods the induced exposure or case-control approach was from the literature review found be the most common to estimate safety benefits from ITS. A big challenge when estimating safety effects of different safety systems in vehicles is how to obtain a proper database including all the necessary information of the accidents and safety equipment of the vehicles. It is also a very difficult task, sometimes even impossible, to isolate the effects of one certain ITS, since often several improvements of vehicles are made between consecutive year models.

To develop statistical methods that can give an early indication whether the accident data seems to coincidence with the expert judgements or not, it would be of great value to carry through and develop the evaluation method outlined in Section 6.5. However, this must be preceded by a rather extensive work to obtain a proper database and a reasonable distribution of the expert judgements.

In the overview of other areas than traffic various techniques and methods were identified. The methods identified were:

- Single experts using available information together with personal experience making evaluations and judgements.
- Using expert groups consisting of people from different disciplines. Together they evaluate results and estimate safety effects, based on what they know at the time, i.e. research carried out and personal experiences.
- Self-monitoring supplemented by control from the authorities.

- Performing risk analyses: probabilistic and deterministic.
- Using redundancy when developing systems.
- Account of documentation of all steps in the development process.

Questions that have been raised during the writing of this report and suggestion to future studies are:

- » In the area of mechanical testing: Who performs the tests and in what form? In a structure as NCAP testing or by manufacturers?
- » What infrastructure development are linked to the ITS development in vehicles? How is it ensured that the techniques developed in vehicle and infrastructure work in the best possible way together in order to maximise traffic safety in the road transport system?
- » Driver adaptation: Following up of the usage of systems in vehicles by logging signals of for example duration of braking in order to identify behavioural changes during long exposure (years) of a systems.
- » Driver behaviour: Testing of short-term changes in behaviour such as cognitive workload changes and driver distraction from ITS.
- » Which role do/could/should different agencies and companies play in the evaluation and monitoring of introduction and assessment of traffic safety performance?
- » It would be interesting to compare different statistical evaluation methods on the same set of data in order to quantify their differences. Another interesting approach would be to use the same evaluation method on different data sets.

References

Abele, J., Kerlen, C., Krueger, S., Baum, H., Geißler, T., Grawenhoff, S., Schneider, J. & Schulz, W.H (2004). Exploratory Study on the Potential Socio-Economic Impact of the Introduction of Intelligent Safety Systems in Road Vehicles, MST NEWS 6: 44–46.

Abele, J., Kerlen, C., Krueger, S., Baum, H., Geißler, T., Grawenhoff, S., Schneider, J. & Schulz, W.H. (2005). Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles, SEiSS final report. VDI/VDE Innovation + Technik GmbH and Institute for Transport Economics at the University of Cologne, available at: http://www.esafetysupport.org/download/intelligent_vehicle_reports/Final_SEiSS.pdf

ABI Research (2005).Vehicle Safety Systems Report, ABI Research, NY, USA: February 2005.

ABI-Research (2006). Automotive Obstacle Detection Systems, available at http://www.abiresearch.com/products/market_research/Automotive_Obstacle_Detection_Systems.

ABI-Research (2007). Automotive Night Vision Has the Potential to Become a Mainstream Application, available at http://www.abiresearch.com/abiprdisplay.jsp?pressid=805.

ABI-Research. (2007). Automotive Night Vision Systems, available at http://www.abiresearch.com/products/market_research/Automotive_Night_Vision_Systems.

ADASE Consortium (2004). State of Practice in ADASE, IST-2000-28010. Deliverable D2B - Version 2.1.

ADASE Consortium (2004) ADASE project information, Fifth EU Framework Programme, f available at: http://www.adase2.net/.

ADASE Consortium (2004). ADASE2 Roadmap for advanced driver assistance systems in Europe, available at: http://www.adase2.net/docs/index.asp?id=7977&domid=695&sp=D&addlastid=&m1=7940&m2=7977.

ADVISORS (2007). Action for advanced Driver assistance and Vehicle control systems Implementation, Standardisation, Optimum use of the Road network and Safety, available at: http://www.advisors.iao.fraunhofer.de/.

Aga, M. & Okada, A. (2003). Analysis of vehicle stability control (VSC)'s effectiveness from accident data, Proceedings of the 18th ESV Conference, paper number 541, Nagoya, Japan.

Astra Zeneca (2007). Jakten på nya läkemedel, available at: www.astrazeneca.se (Accessed 2007-02-16).

AutoMotoPortal (2006). Lexus LS 460, available at: http://www.automotoportal.com/article/Lexus_LS_460_achieves_world_first_in_preventive_safety.

Audi (2007). available at: http://www.audiworld.com/news/02/a8launch/content7.shtml (Downloaded: 2007-08-17)

Bahouth, G. (2005). Real world crash evaluation of vehicle stability control (VSC) technology, 49th Annual Proceedings Association for the Advancement of Automotive Medicine.

Barton, A. D., Farrelly, J. O. & Nicholas, A. (2005). Oversteer steering assistance controller, United States Patent 6895318. TRW-Limited. USA.

Battelle (2007). Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test. Washington, D.C, U.S. Department of Transportation - DTFH61-96-C-00077, available at http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/14352.htm.

Ben-Yaacov, A., Maltz, M. & Shinar, D. (2000). Driver performance with a collision avoidance system, Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium'.

Ben-Yaacov, A., Maltz, M. & Shinar, D. (2002). Effects of an in-vehicle collision avoidance warning system on short- and long-term driving performance, Human Factors 44(2): 335–342.

Bishop Consulting (2007). IVSource - Information collection related to ITS, available at: http://www.ivsource.net/.

Bishop, R. (2002). Liability Issues in the U.S. for Intelligent Vehicle Systems, available at: http://ivsource.net/public/ppt/0211xx_IATSSBishop.ppt.

Bishop, R. (2007). Futures of Intelligent Vehicle Safety Systems. Seminar on IVSS, Linholmen Science Park, Göteborg, Sweden

BMW Emergency Call homepage (2007). available at: http://www.portal-me.com/BMW/services/Assist/index.asp.

BMW (2006). Brake Force Display, available at: http://www.bmwworld.com/technology/brake_force_display.htm.

BMW (2007) Adaptive Headlights, available at: http://www.bmw.com/com/en/index_narrowband.html?content=http://www.bmw.com/com/en/newvehicles/5series/sedan/2007/allfacts/ergonomics/adaptive_light.html.

BMW (2007). High-beam assistant, available at: http://www.bmw.com/com/en/index_narrowband.html?content=http://www.bmw.com/com/en/newvehicles/5series/sedan/2007/allfacts/ergonomics/highbeam_assistent.html

Bosch (2006). Automotive Equipment - LAC - Press release, available at: http://www.bosch-presse.de/TBWebDB/en-US/Presstext.cfm?CFID=1354040&CFTOKEN=&ID=2847.

Briest, S. & Vollrath, M. (2006). When do driver errors occur? Using in-depth accident analysis to derive requirements for Advanced Driver Assistance Systems [In welchen Situationen machen Fahrer welche Fehler? Ableitung von Anforderungen an Fahrerassistenzsysteme durch in-depth-Unfallanalysen], VDI Berichte(1960): 449–463.

Brook-Carter N, Parkes, A., Burns, P. & Kersloot, T. (2003). An experimental assessment of an urban adaptive cruise control (ACC) system, TRL ANNUAL RESEARCH REVIEW (2003/07): 51–59.

Broughton, J. & Baughan, C. (2000). A survey of the effectiveness of ABS in reducing accidents, Report 453, Transport Research Laboratory, Crowthorne, England.

Broughton, J. & Baughan, C. (2002). The effectiveness of antilock braking systems in reducing accidents in Great Britain, Accident Analysis & Prevention 34, 347 355.

Brown, T. L., Lee, J. D. & Hoffman, J. (2001). The effect of rear-end collision warnings on on-going response, 45th Annual meeting of the Human Factors and Ergonomics Society.

Börefelt, C. & Lundberg Fredriksson, S. (2007). Ekonomiska konsekvensanalyser av komponenthaverier i kärnkraftverk – En metod för att systematiskt utvärdera och rangordna ekonomiska konsekvenser, Examensarbete Teknisk – naturvetenskaplig fakultet, UTH-enheten. Uppsala University, Sweden.

Börstell, Stig (Saab AB), Lindell, Håkan (Saab AB) & Sjöblom, Hans (Saab AB). Personal communication, June 2007.

Cavaciuti, C. (2007). Speciale Telematica. Automobilismo. 7-2007: 168–175.

Cooperative Vehicle-Infrastructure Systems (2007). CVIS links, available at: http://www.cvisproject.org/en/links/.

Cummings, P., McKnight, B. & Weiss, N. S. (2003). Matched-pair cohort methods in traffic crash research, Accident Analysis and Prevention, 35, 131–141.

Dang J. N. (2004). Preliminary results analyzing the effectiveness of electronic stability control (ESC) systems, Report no. DOT-HS-809-790, U.S. Department of Transportation, Washington, DC. USA.

Delaney, A., & Newstead, S. (2004). The effectiveness of anti-lock brake systems; a statistical analysis of Australian data, Proceedings Road Safety Research, Policing and Education Conference, Road Safety Council of Western Australia, Perth, Australia.

Demel, H., & Hemming, F. (1989). ABS and ASR for passenger cars – Goals and limits, SAE Paper 890834.

DIATS Consortium (1999). DIATS Final Report - Deployment of Interurban ATT Test Scenarios, EU 4th Framework Programme Funded Project: RO-96-SC.301.

Dinges, D.F., Mallis, M.M., Maislin, G. & Powell, J.W (1998). Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and the Basis for Alertness Management, U.S. Dept. Transportation, National Highway Traffic Safety Administration, DOTHS 808 762, USA.

Dobson, A. J. (1990). An introduction to generalized linear models, Chapman & Hall.

Dörge, L., Kulmala, R., Lind, G., Rydmell, C., Wold, H. & Sage, D. (2006). Euro-Regional Project VIKING – MIP VIKING Overview of evaluations, MIP2005, available at: http://tempo.austriatech.org/fileadmin/library/60/VIKING_MIP2005_%20D8_2_Overview%20of%20evaluations%20ver1_0.doc.

EASA (2007). The European Aviation Agency, www.easa.eu (Accessed 2007-06-26).

Elvik, R. & Vaa, T. (2004). The Handbook of Road Safety Measures. Elsevier, Oxford.

Englund, N. (1982). Spectral Analysis of heart rate variability as an indicator of driver fatigue, Ergonomics 25(7): 663–672.

Engström, J., Agnvall, A. & Markkula, G. (2006). Towards the next generation Intelligent Driver Information System (IDIS): The Volvo car Interaction Manager concept. ITS World London, available at: http://www.cedes.se/handouts/070301%20RB.pdf.

Eriksson, M. & Papanikolopoulos N. P. (1997). Eye-tracking for Detection of Driver Fatigue, IEEE Intelligent Transport System Conference 1997.

eSafety (2007). eSafety Support Web page. http://www.escope.info/en/welcome.htm eSafety Support is a European Commission funded project coordinated by ERTICO – ITS Europe.

e-Safety Working Group on Traffic Safety (2002). Final Report of the eSafety Working Group on Road Safety. Project funded by the European Commission, available at: http://www.escope.info/download/documents/finreport_RMaps_WG.pdf.

European Commission (1997). 97/618/EG. 1997, http://eur-lex.europa.eu/

European Space Agency - GALLANT Pilot Project (2002). GALLANT – Galileo safety-of-life applications for driver assistance in road transport, available at: http://ec.europa.eu/dgs/energy_transport/galileo/doc/galileo_pp_gallant.pdf.

European Space Agency (2002). GALILEO Services and Applications, available at: http://ec.europa.eu/comm/space/doc_pdf/warsaw-musmeci_en.pdf.

Evans, L. (1986). Double pair comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes, Accident Analysis and Prevention, 18, 217–227.

Evans, L. (1995). ABS and relative crash risk under different roadway, weather, and other conditions, SAE technical paper 950353, Society of Automotive Engineers, Warrendale, PA.

Evans, L. (1998). Antilock brake systems and risk of different types of crashes in traffic. Proceedings 16th international technical conference on enhanced safety of vehicles, 1, 445-61, National Highway Traffic Safety Administration, Washington DC, USA.

Evans, L. (2004). Traffic safety, Science Serving Society, Bloomfield Hills, Michigan.

Evans, L. & Gerrish, P. H. (1996). Antilock Brakes and Risk of Front and Rear Impact in Two-vehicle Crashes, Accident Analysis and Prevention, 28, 315–323.

Eye™, E. (2007). The Eagle Eye System, available at: http://www.tst-eagleeye.com/.

Farmer, C. M. (2001). New evidence concerning fatal crashes of passenger vehicles before and after adding antilock braking systems, Accident Analysis and Prevention, 33, 361-9.

Farmer, C. M. (2004). Effect of electronic stability control on automobile crash risk, Traffic Injury Prevention, 5, 317–325.

Farmer, C. M. (2006). Effects of electronic stability control: An update, Traffic Injury Prevention 7(4): 319–324.

Farmer, C. M., Lund, A. K., Trempel, R. E. & Braver, E. R. (1997). Fatal crashes of passenger vehicles before and after adding antilock braking systems, Accident Analysis and Prevention 29(6): 745–757.

Farmer, C., & Lund, A. (2006). Trends over time in the risk of driver death: what if vehicle design had not improved? Traffic Injury Prevention, 7: 335–342.

Federal Motor Carrier Administration. (2005). Concept of Operations and Voluntary Operational Requirements for Forward Collision Warning Systems (CWS) and Adaptive Cruise Control (ACC) Systems On-board Commercial Motor Vehicles, available at: http://www.fmcsa.dot.gov/facts-research/research-technology/report/forward-collision-warning-systems.htm.

Flexpoint Sensor Systems Inc (2007). Pedestrian Impact Detection, available at: http://www.flexpoint.com/sensorApps/automotive/pedestrianImpactDetection.htm.

Floudas, N., Amditis, A., Keinath, A., Bengler, K. & Engeln, A. (2004). Review and Taxonomy of IVIS/ADAS applications, AIDE Deliverable 2.1.2. available at: http://www.aide-eu.org/pdf/sp2_deliv/aide_d2-1-2_summary.pdf.

Ford Global Technologies (2003). Drowsy driver monitoring and prevention system. United States Patent. US 7,138,922 B2.

Foret-Bruno, J. Y., Faverjon, G., Brun-Cassan, F., Tarriere, C., Got, C., Patel, A. & Guillon, F. (1990). Females more vulnerable than males in road accidents. XXIII FISITA Congress. Torina, Italy.

Gelman, A. Carlin, J., Stern, H. & Rubin, D. (2004). Bayesian data analysis, Chapman and Hall.

Grace, R., Byrne, V.E., Bierman, D.M., Legrand, J.-M., Gricourt, D., Davis, B.K., Staszewski & J.J.Carnahan, B. (2001). A Drowsy Driver Detection System for Heavy Vehicles, Proceedings of the 17th Digital Avionics Systems Conference, Seattle, USA.

Green, P. E. & Woodrooffe, J. (2006). The effectiveness of electronic stability control on motor vehicle crash prevention, IN UMTRI (Ed.).

Grömping, U., Weimann, U. & Mentzler, S. (2004). Split register study: A new method for estimating the impact of rare exposure on population accident risk based on accident register data, 1st International ESAR Conference Hannover Medical School, Germany.

Hara, M. (2004). Japanese carmakers find themselves in a race to introduce new safety technologies, Automotive Industries online magazine.

Hardy, R. N., J. W. Watson, Cook, R. & Zioupos, P. (2006). Development and Assessment of a Bone Scanning Device to Enhance Restraint Performance, available at: http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0245-O.pdf.

Harless, D. W. & Hoffer, G. E. (2002). The antilock braking system anomaly: A drinking driver problem? Accident Analysis and Prevention 34(3): 333-341.

Hastie, T. J. & Tibshirani, R. J. (1990). Generalized Additive Models, Chapman & Hall.

Highway Industry Development Organization. (2007). SMARTWAY 2007 – the state-of-art ITS service trial. Tokyo, Japan, available at: http://www.smartway2007.jp/index_e.htm.

Hoffmann, J., Kretzschmar A. & Blundell, M. V. (2002). Investigation into the use of adaptable car structures concepts for pedestrian impact protection, Vehicle Safety, IMechE: 28-29 May 2002, London, available at: http://www.siemens-restraint-systems.de/de/xt_download/IMechE_2002_IPPS.pdf.

Hollnagel, E. & J. E. Kallhammer (2003). Effects of a Night Vision Enhancement System (Nves) on Driving: Results from a Simulator Study. Driving Assessment 2003: The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Park City, Utah, USA.

Honda (2005). Honda Press Release - New Safety and Environmental Initiatives, available at: http://www.hondanews.com/categories/889/releases/2417.

HUMANIST (2007). HUMAN centred design for Information Society Technologies, Reports and deliverables available at: http://www.noehumanist.org/news.php.

Hurwitz, J. B. & D. J. Wheatley (2001). Driver choice of headway with auditory warnings, Proceedings of the Human Factors and Ergonomics Society, pp. 1637–1640, Minneapolis, USA.

IIHS (2006). Update on two Effective Safety Features, Insurance Institute for Highway Safety Status Report Vol. 41(5).

Inside ITS (2001). Inside ITS Reports Impressive Results from Eaton VORAD Units on Truck, available at: http://ivsource.net/archivep/2001/mar/010324_InsideITS_EVresults.html#article.

InsideITS (2006) Magazine. Siemens VDO introduces system to detect and combat drowsy driving. Inside ITS. 1: 7.

Intelligent Vehicle Initiative (IVI) (2005). Several reports on projects related to ITS and ITS effects, available at: http://www.its.dot.gov/ivi/ivihf/reports.html, and http://www.its.dot.gov/ivi/ivi.htm.

Jagtman, H. M., Marchau, V. A. J. W. & Heijer, T. (2001). Current knowledge on safety impacts of collision avoidance systems (CAS), Critical Infrastructures – Fifth International Conference on Technology, Policy and Innovation, Lemma, Delft, The Nethrelands.

Jaguar Cars Ltd (2007). Jaguar Pyrotechnic Pedestrian Deployable Bonnet, available at: http://media.ford.com/article_display.cfm?article_id=21557&make_id=95.

Johansson, P. (2003). Feleffektanalys – Failure Mode and Effect Analysis (FMEA). 2003 09 17. TMKT 31 Kursmaterial – FMEA. LiTH/IKP/Maskinkonstruktion. Linköpings Universitet, available at: www.machine.ikp.liu.se/publications/fulltext/fmea.pdf.

Kallberg, V. P. (1991). The Effects of Reflector Posts on Driving Behaviour and Accidents. Traffic Management and Road Safety, PRTC European Transport, Highways and Planning, 19th Summer Annual Meeting, University of Sussex. Vol P350, page. 181–192, (note: later published in Transportation Research Record 1403, pp. 57–66 as "Reflector posts–signs of danger").

Kassaagi, M., Bouslimi W., Clément, V., Jean-Marc Bersac, J.-M., Moessinger, M. & Page, Y. (2006). Effectiveness of Emergency Brake Assist in Rear-end Accident Scenarios, FISITA 2006, Yokohama, Japan, F2006D062, abstract available at: http://www.fisita2006.com/programme/programme/F2006D062.

Kerr, J. (2006). Mercedes-Benz Brake Assist, CanadianDriver.com, available at: http://www.canadiandriver.com/articles/jk/at_010501.htm.

Klebesberg, D. (1997). Das modell der subjektiven and objektiven sicherheit. *Schweizerische Zeitschfrift für Psychologie und ihre Anwendungen, 36, 285–294,* in Vogel, K. (2002). Modeling driver behaviour - a control theory based approach. *Linköping studies in Science and Technology, dissertation No. 751.*

Korse, M.J., Schermers, G., Radewalt, N.M.D., de Hoog, A. & Akim, T. (2003). Resultaten van de proef met het Lane Departure Warning Assistant systeem. (Results of the trial with the Lane Departure Warning Assistant-system) Adviesdienst Verkeer en Vervoer (AVV) Traffic Research Centre – Rotterdam, Holland.

Krafft, M., Kullgren, A., Lie, A., & Tingvall, C. (2006). The use of seat belts in cars with smart seat belt reminders - Results of an observational study, Traffic Injury Prevention, Vol 7(2), pp 125–129.

Kreiss, J-P., Schüler, L. & Langwieder, K. (2005). The effectiveness of primary safety features in passenger cars in Germany, Proceedings of the 19th ESV Conference, paper No 05-0145, Washington, USA.

Kullgren, A., Lie, A. & Tingvall, C. (1994). The effectiveness of ABS in real life accidents, Folksam Research, Stockholm, Sweden.

Langwieder, K., Gwehenberger, J. & Hummel, T. (2003). Benefit Potential of ESP in real accident situations involving cars and trucks, Proceedings of the 18th ESV Conference, Nagoya, Japan.

Langwieder, K., Gwehenberger, J. & Hummel, T. (2004). International Field Experiences With Electronic Stability Program (ESP) in Cars, 2004 FISITA World Automotive Congress. Barcelona, Spain.

Langwieder, K., J. Gwehenberger, J. & Hummel, T. (2001). Benefit Potential of ESP in real accident situations involving cars and trucks, Proceedings of the 18th ESV Conference, Nagoya, Japan.

Lee J, McGehee, D.V., Thomas A. Dingus, T. A. & Wilson, T. (1997). Collision Avoidance Behaviour of Unalerted Drivers Using a Front-to-Rear-End Collision Warning Display on the Iowa Driving Simulator, Transportation Research Record 1573(1997): 1–7.

Lee J. D., McGehee D. V., Brown, T. L. & Reyes, M. L. (2002). Collision Warning Timing, Driver Distraction, and Driver Response to Imminent Rear-End Collisions in a High-Fidelity Driving Simulator, Human factors. Vol. 44(2): 314–334.

Lee, J., McGehee, D., Brown, T. & Dawn, M. (2006). Effects of Adaptive Cruise Control and Alert Modality on Driver Performance, Transportation Research Board 85th Annual Meeting, pp 49–56, Washington, USA.

Lee, K. & Peng H. (2005). Evaluation of automotive forward collision warning and collision avoidance algorithms, Vehicle System Dynamics 43(10): 735–751.

Leen G. & Heffernan D. (2002). Expanding automotive electronic systems, IEEE Computer 0018-9162/02, available at: http://grouper.ieee.org/groups/1616/ARTICLEVehicleNetworks.pdf.

Lexus (2007). Emergency Steering Assist, available at: http://www.lexus.co.uk/about_lexus/news_and_events/paris_2006_safety_technology.asp.

Lie, A. & Tingvall, C. (2002). How do EuroNCAP Results Correlate with Real-Life Injury Risk? A paired comparison Study of Car-to-Car crashes, Traffic Injury Prevention, 3, 288–293.

Lie, A., Tingvall, C., Krafft, M. & Kullgren, A. (2004). The Effectiveness of ESP (Electronic Stability Program) in Reducing Real Life Accidents, Traffic Injury Prevention, 5, 37–41.

Lie, A., Tingvall, C., Krafft, M. & Kullgren, A. (2006). The effectiveness of electronic stability control (ESC) in reducing real life crashes and injuries. Traffic Injury Prevention, 7, 38–43.

Lie, A., Kullgren, A., Krafft, M. & Tingvall, C. (2007). Intelligent Seatbelt Reminders: Do They Change Driver Seat Belt Use in Europe, 20th ESV Conference, Paper no 07-0388-O, Lyon, France.

Linder, A., Dukic, T., Hjort, M., Matstoms, Y., Mårdh, S., Sundström, J., Vadeby, A., Wiklund, M. and Östlund, J. (2007). Methods for the evaluation of traffic safety effects of Antilock Braking Systems (ABS) and Electronic Stability Control (ESC) – A literature review, VTI rapport 580A.

Livsmedelsverket (2003). Egentillsyn ger trygghet och kvalitet, Karlstad. Sweden.

Livsmedelsverket (2007). The National Food Administration, www.slv.se (Accessed 2007-02-16).

Luftfartsstyrelsen (2007). The Swedish Civil Aviation Authority, www.luftfartsstyrelsen.se (Accessed 2007-06-26).

Läkemedelsverket (2007). The Medical Products Agency, www.lakemedelsverket.se (Accessed 2007-06-25).

Ma, R. & Kaber, D. B. (2005). Situation awareness and workload in driving while using adaptive cruise control and a cell phone, International Journal of Industrial Ergonomics 35(10): 939–953.

McGuffie-Schyhol, D. (2006). What's new in obstacle detection, available at: http://fleetowner.com/equipment/whatsnewin/fleet_whats_new_obstacle/.

Mercedes-Benz. (2007). Distronic Plus Information, available at: http://www2.mercedes-benz.co.uk/content/unitedkingdom/mpc/mpc_unitedkingdom_website/en/home_mpc/passenger_cars/home/products/new_cars/S-Class_Saloon_2006/overview/safety.0010.0003.html.

Mobileye (2007). Patent on Pedestrian Detection,World Intellectual Property Organization. WO/2005/098739.

Mobileye. (2007). Mobileye company information and products, available at: http://mobileye-vision.com/.

NHTSA (1998). References on drowsy driving, available at: http://www.nhtsa.dot.gov/people/injury/drowsy_driving1/drowsyref.html.

Nygårdhs, M. (2007). SecTec Consulting, Personal communication March–June 2007.

OKG (2007). OKG Aktiebolag, Oskarshamn.

Page, Y. & Cuny, S. (2006). Is electronic stability program effective on French roads? Accident Analysis and Prevention, 38, 357–364.

Page, Y. & S. Curry (2004). Is ESP effective on French Roads? 1st International ESAR Conference, Germany.

Papelis, Y., Brown, T. Watson, G., Holtz, D. & Weidong, P. (2004). Study of ESC assisted driver performance using a simulator, D. n. N04-003-PR. Iowa, University of Iowa, USA.

Pearl, J. (2004). Causality - Models, Reasoning, and Inference, Cambridge University Press, Cambridge.

Peirce, S. & J. Lappin (2006). Private Sector Deployment of Intelligent Transportation Systems: Current Status and Trends, U.S. Department of Transportation – Research and Innovative Technology Administration.

Penttinen, M. & N. Virtanen (2005). An inventory of available ADAS and similar technologies according to their safety potentials. BVTT-070105-R1-DB2. Deliverable 2 of Task Force B. Delivered under EC-project HUMAN centred design for Information Society technologies Network of Excellence, VTT Building and Transport, Finland.

Pfizer (2007). Från idé till verklighet, www.pfizer.se (Accessed 2007-02-16).

PReVENT (2007). Code of Practice for the Design and Evaluation of ADAS, document number PR-11300-SPD-060811-v16-CoP.doc V1.6, Available at: http://www.prevent-ip.org/.

Rakha H, Hankey, J., Patterson, A. & Van Aerde, M. (2001). Field evaluation of safety impacts of Adaptive Cruise Control, ITS JOURNAL 6: 1–35.

RearViewSystems (2006). Rear view camera systems, Available at: http://www.rearviewsystems.com/info.html.

Reason, J. (1990). Human Error, Cambridge University Press, Cambridge.

Rekveldt, M. G. C. & Labibes, K. (2003). Literature survey on in-vehicle safety devices, TNO Report 03.OR.BV.037.1/MRE, Available at: http://www.vv.se/filer/39176/in_vehicle_safety.pdf.

ResearchAndMarkets (2004). Collision Avoidance – Forecasts to 2010, available at: http://www.researchandmarkets.com/reports/227935.

Riecken, D. (1997). What makes an intelligent user interface intelligent? Proceedings of the 2nd international conference on intelligent user interfaces, Orlando, Florida, United States, ACM Press New York, NY, USA.

RTCA-DO178B (1992). Software Considerations in Airborne Systems and Equipment Certification. SC-167. 12/01/1992.

Rudin-Brown, C.M. & Noy Y. I. (2002). Investigation of Behavioral Adaptation to Lane Departure Warnings, Transportation Research Record, (1803): 30–37.

Saroldi, A., Bertolino, D. & Sidoti, C. (1997). Driving in the Fog with a Collision Warning System: a Driving Simulator Experiment, Proceedings of the 4th World Congress on Intelligent Transport Systems, Berlin, Germany.

Sato, T., Akamatsu, M., Takahashi, A., Yoshimura, K., Shiraishi, Y., Watanabe, T. & Sugano, T. (2005). Analysis of driver behaviour when overtaking with adaptive cruise control, Review of Automotive Engineering 26(4): 481–488.

Schumann, J., Lowenbau, J. & Naab, K. (1996). The Active Steering Wheel as a Continuous Support for the Driver's Lateral Control Task, Proceedings of Vision in Vehicles V, Glasgow, Scotland.

Seiler, P., Song, B. & Hedrick, J. K. (1998). Development of a Collision Avoidance System, SAE Paper 98PC417.

Seymour, R. (2003). Vehicle safety knowledge and older driver decision making, Road Safety Research, Policing and Education Conference, Sydney, Australia.

Sferco, R., Page, Y., Le Coz, J. Y. & Fay, P. (2001). Potential effectiveness of the electronic stability programs (ESP). What European field studies tell us? Proceeding of 17th ESV Conference. Amsterdam, The Netherlands.

Singh, S. and N. P. Papanikolopoulos (1999). Monitoring driver fatigue using facial analysis techniques, International Conference on Intelligent Transportation Systems, Tokyo, Japan.

Stanton, N.A. & Young, M. S. (2005). Driver behaviour with adaptive cruise control, Ergonomics 48(10): 1294–1313.

Stanton, N. A. &Young, M. S. (1998). Vehicle automation and driving performance, Ergonomics 41(7): 1014–1028.

Statens Kärnkraftsinspektion (2007). The Swedish Nuclear Power Inspectorate, www.ski.se (Accessed 2007-03-01).

Statens Strålskyddsinstitut (2007). The Swedish Radiation Protection Agency, www.ssi.se (Accessed 2007-06-26).

Suetomi, T. & Kido, K. (1997). Driver Behavior under a Collision Warning System: A Driving Simulator Study, SAE Transactions 106 (6): 424–458.

Sullivan, J.M., Bargman, J., Adachi, G. & Schoettle, B. (2004). Driver Performance and Workload Using a Night Vision System, UMTRI Report Nr. 2004-8. University of Michigan - Transportation Research Institute, USA.

Suzuki, K. & Jansson, H. (2003). An analysis of driver's steering behaviour during auditory or haptic warnings for the designing of lane departure warning system, JSAE Review 24(1): 65–70.

Takada, Y. & Shimoyama, O. (2001). Evaluation of Driving-Assistance Systems Based on Drivers' Workload, Driving Assessment 2001: The First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design., Aspen, Colorado, Available at: http://ppc.uiowa.edu/Driving-Assessment/2001/Summaries/TechSession5/takada_yuuji.pdf.

Tapio, J., Pirtala, P. & Ernvall, T. (1995). The accident involvement and injury risk of car models, Publications of Road and Transport Laboratory, Report No 32, University of Oulu, Finland.

TELE AID (2007). TELE AID homepage. http://www.teleaid.com/index.html.

The Intelligent Highway (2006) magazine. Siemens VDO pro. pilot Initiative Produces Driver Assistance Products, The Intelligent Highway 1: 6.

Tingvall, C., Krafft, M., Kullgren, A. & Lie, A. (2003) .The effectiveness of ESP (Electronic Stability Program) in reducing real-life accidents, 18th ESV Conference, paper no 261, Nagoya, Japan.

Tingvall, C., M. Krafft, Kullgren, A. & Lie, A. (2004). The effectiveness of ESP (Electronic Stability Programme) in reducing real life accidents, Traffic Injury Prevention 5(1): 37–41.

Toyota (2007). Lexus Advanced Safety, Available at: http://www.lexus-europe.com/lexus_cars/ls/ls460/showcase/index.asp.

Trent Victor - Volvo Technology (2003). Driver Awareness Support – online presentation, Available at: http://www.volpe.dot.gov/hf/roadway/saveit/docs/may04/victor.pdf.

Törnros, J., Peters, B & Östlund, J. (2000). Heart rate measures as drowsiness indicators, Report no 38A, Swedish National Road and Transport Research Institute, Linköping, Sweden.

Törnström, EvaMarie (2007) (SKL, The Swedish National Laboratory of Forensic Science). Personal communication, March–April 2007.

Underwood, S. E. (2007). Cars and Highway Talking to Each Other: New Approaches to Safety, Seminar for Journalists - Foundation for American Communications, Available at: http://www.facsnet.org/tools/biz_econ/Underwood010607.pdf.

Unselt, T., Breuer, J., Eckstein, L. & Frank, P. (2004). Avoidance of "loss of control accidents" through the benefit of ESP, FISITA Conference, paper no F2004V295, Barcelona, Spain.

US Department of Transportation (2007). Benefit Database. Database on impact of various ITS, Available at: http://www.itsbenefits.its.dot.gov/.

US Department of Transportation (2007). Intelligent Transportation Systems webpage. Several documents on ITS effects, Available at: http://www.its.dot.gov/evaluation/docs.asp.

US Department of Transportation (2006). An overview of the 100-car naturalistic study and findings, Available at: http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/100Car_ESV05summary.pdf.

US Department of Transportation (2006). The 100-Car Naturalistic Driving Study. Phase II – Results of the 100-Car Field Experiment, Available at: http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/100CarMain.pdf.

Vaa, T. (2006). Intelligent Transport Systems (ITS): An overview of effects on behaviour and accidents, Institute of Transport Economics, Oslo, Norway, TØI-report no 845/2006.

Vaa, T., Gelau, C., Merja, P. & Ioanna, S. (2006). ITS and effects on road traffic accidents – state of the art, 13th World Congress and Exhibition on Intelligent Transport Systems and Services, London, UK.

Wakasugi, T. & Yamada K. (2000). Driver reaction time to forward vehicle collision warning - effectiveness of warning system under low awareness level, 7th World Congress on Intelligent Transport Systems, Turin, Italy.

van Zanten, A. (2002). Evolution of Electronic Control Systems for Improving the Vehicle Dynamic Behaviour, 6th International Symposium on Advanced Vehicle Control, AVEC, Hiroshima, Japan.

Web Publications Pty Limited (2007). Autoweb information from http://www.autoweb.com.au/cms/A_53414/title_Volvo%20Safety%20Concept%20Car%20(SCC):%20The%20Car%20That%20Catches%20the%20Eye/newsarticle.html.

Wierwille, W., Fayhey, S. E., Fairbanks, R.J. & Kirn, C.L. (1995). Research on Vehicle-Based Driver Status/Performance Monitoring. National Highway Traffic Safety Administration Report, DOTHS 808-299, NHTSA, USA.

Vincent, A., Noy, I. & Laing A. (1998). Behavioural adaptation to fatigue warning systems. Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles., Ontario – Canada, DOTHS808759, Available at: http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/Esv/esv16/98S2P21.PDF.

Volkswagen (2006). New Touran Press Release, from http://www.volkswagen.co.uk/company/press/dec06_touran.

Volvo Car Corporation (2007). Volvo Cars Homepage, www.volvocars.se , http://www.volvocars.com/corporation/NewsEvents/News/news.htm?item=%7BAAD586FE-CD82-4FC5-BC50-5467AFD3718F%7D (Accessed 2007-08-17).

Vägtrafikinspektionen (2007). Omkomna i vägtrafiken 1996–2006, Publication 2007-06, The Road Traffic Inspectorate, Sweden.

Vägverket (2004). Pressmeddelande – Vägverket rekommenderar antisladdsystem på ny bil, Available at: http://www.vv.se/templates/Pressrelease____10136.aspx.

Vägverket (2005). Effekten av ESP i verkliga olyckor, available at: http://www.vv.se/filer/24496/esp_presskonf.pdf.

Österberg, Anders (OKG). Personal communication, February 2007.

Companies developing obstacle detection systems

Source: ABI-Research (Automotive Obstacle Detection Systems), 2006

Aisin Seiki’s Driver Assistance Systems
Audi
Bendix
BMW
Robert Bosch
Cadillac
Cambridge Consultants SoftCar
Canesta
Citroën
Continental
DaimlerChrysler
Delphi
Denso
Eaton
Ford
Fujitsu Ten ACC System
GM
Groeneveld Groep RoadEye
Hella
Hitachi Sensors
Honda
Ibeo ALASCA
IEE
Iteris
M/A-Com
Mercedes
Micron Technology
Mitsubishi Electric
Mobileye
MTS Sensors
Nissan
Omron
Siemens VDO Driver Assistance Systems
Subaru
Toyota
Trico
TRW Automotive
Valeo
Valeo Raytheon Systems
Visteon Technology
Volkswagen
Volvo

Companies developing night vision systems

Source. ABI-Research (Automotive Night Vision Systems), 2007.

BMW
Chrysler
Ford
GM
Honda
Mercedes
Nissan
Toyota
Autoliv
Automotive Lighting
Bendix
Bosch
Delphi
Denso
Hella
L-3 Infrared Products
Panasonic
Siemens VDO
Valeo
Visteon
Canesta
FLIR Systems
International Electronics and Engineering
Mobileye

List of terms used for the literature search

(pre-accident* AND system* AND vehicle* dynamic*)
(weight sensor* AND air bag*)
(weight sensor* AND safety belt*)
active restraint*
Active safety system*
active steering
active suspension system*
Adaptive cruise control*
ADAS
advanced driver support*
alcohol detection advisor*
alcohol interlock*
automatic-dimming rearview mirror*
automatic crash notification*
autonomous brak*
belt pre-tension*
blind-spot warning*
brak* assist*
brake priming
collision avoidance system*
collision avoidance warning*
collision* warning*
congestion avoid* system*
crash avoid* system*
crash warning*
cruise control*
distraction warning
driver assistance
driver condition* warning*
drowsiness detection*
drowsiness warning*
e-safety
electronic brak* assist*
electronic* driv* aid*
electronic* driv* licenc*
electronic* licenc*
electronic* skid* protect*
electronic* stability control*
electronic* stability program*
emergenc* brak* assist*
emergenc* notification*
esafety
fatigue monitoring
fatigue warning*
Following Distance Warning*
forward collision warning*
forward protection system*
headway warning*
intelligent airbag*
Intelligent Cruise Control*
intelligent restrain*
intelligent speed*
ITS AND traffic
lane chang* collision* avoid*
lane chang* collision* warning*
lane departure warning*
lane keeping assistance*
lane keeping system*
lane keeping warning*
night vision system*
Obstacle* Warning*
pre collision sensor*
pre crash sensor*
precrash sensor*
road* condition* warning*
route guidance*
safety* AND (crash OR accident*) reduction
safety belt* interlock*
seat belt* interlock*
seat belt* reminder*
seatbelt pre-tension*
seatbelt* interlock*
seatbelt* reminder*
Smart restraint*
speed alert*
speed limiter*
speed warning*
steering assist*
tire pressure monitoring system*
tyre pressure monitoring system*
vehicle monitoring*
vigilance monitoring
vision enhancement system*

Double pair comparison method

The double pair comparison method was developed by Evans and described in Evans (1986, 1988a, 1988b, 2004). This description is from Linder et al. (2007). The method enables us to make inferences about a certain type of accidents without information about the external exposure measure. To describe the method, we use the original example by Evans (1986), where the fatality risk of a belted driver is compared to the fatality risk of an unbelted driver.

The method used two classes of occupants: subject occupants and control occupants. The fatality risk was compared in two sets of crashes, referred to as the first and the second comparison. The subject occupant was the driver and the control occupant was a right front passenger travelling with the driver. In the first comparison the driver was belted and the passenger unbelted whiles in the second comparison both the driver and passenger were unbelted. It is important to emphasize that the conditions for the control occupant were the same in both comparisons.

Evans used the following notation:

a = number of crashes where a belted driver was killed but unbelted passenger survived.

b = number of crashes where a belted driver survived but unbelted passenger was killed.

c = number of crashes where both belted driver and unbelted passenger was killed.

a + c = total number of belted drivers killed

b + c = total number of unbelted passengers (travelling with belted drivers) killed

This can be illustrated in Table A4.1 below.

Table A4.1 Data to be used in the first comparison in the double pair comparison method.

		Unbelted passenger	
		Fatal	Non-fatal
Belted driver	Fatal	c	a
	Non-fatal	b	**X**

j = number of crashes where unbelted driver was killed but unbelted passenger survived.

k = number of crashes where unbelted driver survived but unbelted passenger was killed.

l = number of crashes where both unbelted driver and passenger were killed.

j + l = total number of unbelted drivers killed

k + l = total number of unbelted passengers (travelling with unbelted drivers) killed.

This is illustrated in the same way as when the driver was unbelted, see Table A4.2.

Table A4.2 Data to be used in the second comparison in the double pair comparison method

		Unbelted passenger	
		Fatal	Non-fatal
Unbelted driver	Fatal	l	j
	Non-fatal	k	**X**

In the first comparison the belted driver to unbelted passenger fatality ratio r_1 was calculated:

$$r_1 = \frac{a+c}{b+c} = \frac{d}{e} \qquad (1)$$

and in the second comparison the unbelted driver to unbelted passenger ratio r_2:

$$r_2 = \frac{j+l}{k+l} = \frac{m}{n} \qquad (2)$$

Since the driver and passenger may be subject to different forces, the interpretation of these ratios might not be precise. Compared to a traditional case-control approach, we can see that the numerator and denominator in (1) respectively (2) are dependent due to that *c* and *l* occur in both.

The purpose of the calculations was to compare the risk for a fatal accident for a belted driver compared to an unbelted and this risk was given by

$$R = \frac{r_1}{r_2} \qquad (3)$$

It is worth to notice that asymmetry effects that can be present in (1) and (2) is cancelled in (3) since the asymmetries operate in opposite directions in (1) and (2).

The same calculations as above can be made for different sets of control occupants, say belted passengers, passengers in different age categories etc. Each calculation provides an independent estimate, R_i of the fatality risk of a belted driver compared to an unbelted driver. The double pair comparison method enables us to combine these estimates into a weighted overall average value $\overline{R}$ and calculate the associated error for this estimate.

Rather than calculating a usual arithmetic average $(R_1+R_2)/2$, Evans (1986) used a more appropriate measure. Let

$z = \log(R)$

and study the weighted average $\overline{z}$. The estimate of $\overline{R}$ is then obtained as $\overline{R} = \exp(\overline{z})$.

Evans (1986) discuss that the error is thought to consist of two different errors: one error intrinsic to the method σ_μ and one error due to random fluctuations in the fatal accidents, σ_z. The total standard error σ consists of those two parts: $\sigma^2 = \sigma_\mu^2 + \sigma_z^2$.

Based on previous experience, a judgement estimate of $\sigma_\mu = 0.1$ is motivated in Evans (1986). Under several assumptions and first order approximations Evans showed that

$$\sigma_Z^2 = \frac{1}{n} + \frac{1}{d} + \frac{1}{m} + \frac{1}{e} \qquad (4).$$

As mentioned earlier, the components *d (= a+c)* and *e (= b+c)* are dependent as well as *m (= j+l)* and *n (= k+l)*. This estimate might therefore be given more consideration to obtain a more accurate estimate. This dependence leads to that σ_z was underestimated, this is however not further investigated in Evans (1986), but treated in an article by Cummings et al. (2003), where an alternative variance estimator is suggested.

If we have a number of different estimates of R (R_i, $i = 1, 2, \ldots$) each with standard error σ_i, $i = 1, 2, \ldots$, then the error in the estimate of $\overline{R}$ can be approximated by:

$$\Delta\overline{R} = \overline{\sigma}\overline{R}$$

where $\frac{1}{\overline{\sigma}^2} = \sum_i \frac{1}{\sigma_i^2}$.

The method described above is mainly based on the following key assumptions:

1. For crashes with identical severity, the probability that the passenger is killed does not depend on whether the driver is belted or not.
2. The populations of belted and unbelted drivers do not differ in ability to survive identical crashes when all other factors are the same.
3. The distribution of crash type (or direction) is the same for crashes of the same severity in both the first and second comparison.

Information from STRADA (in Swedish)

Value_TypeOfAccident (Olyckstyp)

Huvudgrupper

Kod	Olyckstyp
S	Singelolycka
M	Mötesolycka
O	Omkörningsolycka
U	Upphinnandeolycka
A	Avsvängningsolycka
K	Korsandeolycka
C	Cykel/Moped i koll m motorfordon
F	Fotgängarolycka
V	Övrigt/Okänt
W	Viltolyck
G	Cykel/Moped
J	Tåg/Spårvagn

Undergrupper (om inget annat anges avses motorfordon)

Kod	Beskrivning
S0	Singelolyck. specialfall
S1	Singel, primv rakt fram
S2	Singel, sväng från primv
S3	Singel, sekv rakt fram
S4	Singel, sväng från sek.v
M0	Mötesolyck. specialfall
M1	Kollision mellan mötande
M2	Möte m avkörn/koll m ann
M3	Mötesol, konfl på sekväg
O0	Omkörningsolyck. spec.f.
O1	Omkörn.ol. koll m möt el
O2	Koll m omkört el avkörn
U0	Upphinnandeol. spec.fall

Kod	Beskrivning
U1	Upph.ol. konfl på primv.
U2	Upph.ol. konfl på sek.v
A0	Avsvängningsol. spec.f.
A1	V-sväng, konfl bakomvar.
A2	H-sväng, konfl bakomvar.
A3	V-sväng, konfl möte rakt
A4	V-sväng, konfl möte sv.
A5	V-sväng sek.v - bakomvar
A6	H-sväng sek.v - bakomvar
A7	V-sväng sek.v - möt rakt
A8	V-sväng sek.v - möt sv.
K0	Korsandeolyck. spec.fall
K1	V-sväng - ford på sek.v
K2	H-sväng - ford på sek.v
K3	Rakt fram - v rakt fram
K4	Rakt fram - h rakt fram
K5	V-sväng sek.v - h rakt f
K6	V-sväng sek.v - v rakt f
K7	H-sväng sek.v - v rakt f
C0	C/M - motorfordon spec.f
C1	C/M - mf. möteskonflikt
C2	C/M - mf. omkörn/upphinn
C3	C/M - mf. avsv samma ben
C4	C/M - mf. avsv motr. ben
C5	C/M - mf. kors. ej sväng
C6	C/M - mf. kors. m sväng
C7	C/M uppställd - motorf.
F0	Fotgängarolyck. spec.f.
F1	Fotg kors - mf fr vänst.
F2	Fotg kors - mf fr höger
F3	Fotg gående på v sida
F4	Fotg gående på h sida

Kod	Beskrivning
F5	Fotg korsar före vägskäl
F6	Fotg kors e vägsk, f rak
F7	Fotg kors e vägsk, f vsv
F8	Fotg kors e vägsk, f hsv
F9	Fotg stillastående - mf
V0	Övrigt
V1	Djur, ej klövvilt - mf
V2	Spårfordon - annat ford
V3	Trakt/mredsk-ford/gående
V5	P/uppst fordon - fordon
V6	Backning,vändning, mf-mf
W1	Rådjur, dov- & kronhjort
W2	Älg
W3	Ren
W4	Annat vilt
W5	Tamdjur
G0	Gående singel
G1	Cykel singel
G2	Moped singel
G3	Cykel - Gående
G4	Cykel - Cykel
G5	Cykel - Moped
G6	Moped – Gående
G7	Moped – Moped
J0	Spårvagn singel
J1	Spårvagn – Spårvagn
J2	Spårvagn – Gående
J3	Spårvagn - Cykel/Moped
J4	Spårvagn – Motorfordon
J5	Spårvagn - Övrigt fordon
J6	Tåg - Cykel/Moped
J7	Tåg – Motorfordon
J8	Tåg - Övrigt fordon

Kod	Beskrivning
J9	Tåg - Spårvagn/Gående

Value_TypeOfRoad (Vägtyp)

Kod	Vägtyp
1	Motorväg
2	Motortrafikled
3	Annan allmän väg
4	Gata
5	Enskild väg
6	Övrig väg
9	Uppgift saknas
99	Okänt

Value_InjuryExtent (Skadegrad)

Kod	Skadegrad
1	Dödad
2	Svårt skadad
3	Lindrigt skadad
4	Oskadad
9	Uppgift saknas

Value_PassengerPos (Passagerarplats)

Kod	Passagerarplats
1	Förarplats
2	Passagerarplats fram
3	Passagerarplats bak
4	Förarplats höger
5	Passagerarplats vänster fram
9	Övrig/okänd plats/Ej relevant

Value_RoadState (Vägförhållanden)

Kod	Vägförhållanden
0	Okänt
1	Vägbanan torr
2	Vägbanan våt/fuktig
3	Tjock is / packad snö
4	Tunn is, vägbanan synlig
5	Lös snö / snömodd
9	Uppgift saknas

Value_PrimaryElemtype (Primärelementtyp, huvudgrupper)

Kod	Elementtyp
1	MotorVehicle
2	OtherVehicle
3	BicycleMoped
4	RailVehicle
5	Pedestrian
6	Animal
7	Trailer

Value_SubElemtype (Elementtyp, undergrupper)

Kod	SubElemtype
1	Personbil
2	Tung lastbil
3	Lätt lastbil
4	Buss
5	Tung motorcykel
6	Lätt motorcykel, skoter
7	Moped klass 1
8	Moped klass 2
9	Motorfordon av okänd typ
10	Fordonskö
11	Moped (okänd klass)

Kod	SubElemtype
12	Cykel
13	Gående
14	Ryttare
15	Hästekipage
16	Motorcykel (okänd viktklass)
17	Lastbil (okänd viktklass)
21	Traktor
22	Motorredskap
24	Terrängvagn
25	Terrängskoter
27	Övrigt fordon med motor
28	Ensamt släp
29	Övriga ej motordrivna f.
31	Tåg, rälsbuss, dressin
32	Spårvagn
51	Älg
52	Rådjur
53	Ren
54	Dovhjort, kronhjort
57	Vildsvin
59	Övrigt & okänt vilt
61	Häst
62	Nötkreatur
69	Övriga tamdjur
79	Okänt djur
99	Uppgift saknas

Value_Sex (Kön)

Kod	Kön
1	Man
2	Kvinna
9	Uppgift saknas

Value_SpeedRestriction (Hastighetsbegränsning)

Kod	Hastighetsbegränsning
20	20 km/h
30	30 km/h
50	50 km/h
70	70 km/h
90	90 km/h
110	110 km/h
999	Uppgift saknas
9	Okänt
Xxx	Egen inskriven hastighet

Value_TrafficEnvironment (Tättbebyggt område)

Kod	Tättbebyggt område
0	Okänt
1	Tättbebyggt område
2	Ej tättbebyggt område
9	Uppgift saknas

Vehicle information in STRADA (in Swedish)

Fabrikat_typ	Aarsmode	Bredd	laengd	Motoreffek	Drivmede	Tjvikt	Totalvikt	Besiktndatum	Krockkudde	illverkningsmaanad
NISSAN ALMERA	9999	171	420	66	1	1270	1710	20041019	0	200101
BMW 320 I TOURING	9999	170	445	110	1	1440	1850	20040310	0	999999
FIAT PUNTO 55 S	9999	163	380	40	1	930	1310	20030129	0	199909
SCANIA R144GB6X2NB460	1999	260	980	339	2	13140	27000	99999999	0	999999
VOLVO 745-896 GLT 16 VA	1990	175	495	114	1	1530	1950	20051021	0	999999
LEXUS RX400H	9999	185	480	155	1	2120	2510	99999999	1	200503
HYUNDAI ATOS 4-D GLS M	9999	150	350	40	1	930	1320	20060228	0	200002
K SETRA S 315 GT	1998	250	1200	250	2	12340	17590	20070315	0	999999
VOLVO L + V70	1997	182	485	142	1	1770	2160	20041005	0	999999
ARCTIC CAT WILDCAT EFI	1993	115	310	9999	1	300	480	99999999	0	999999
HYUNDAI TRAJET GLS V6	9999	184	470	127	1	1860	2440	20001024	1	200010
YAMAHA XT 600	1993	999	99999	20	1	180	350	20050706	0	999999
FORD BWY MONDEO	9999	182	480	107	1	1500	2030	20010619	0	200106
FORD SIERRA 2,0I GL KAT	1988	170	445	74	1	1220	1650	20040115	0	999999
VOLVO 945-811 S 2.3	1995	175	495	99	1	1540	1940	20051205	0	999999
TOYOTA COROLLA DLX	1987	164	400	54	1	1030	1400	20021120	0	999999
MITSUBISHI GALANT HATC	1990	170	455	80	1	1330	1730	20040414	0	999999
PEUGEOT 206 XSI 1,6	9999	168	385	80	1	1130	1560	20020920	1	200209
TOYOTA LAND CRUISER (1	9999	188	490	120	2	2260	2850	99999999	1	200311
YAMAHA YZF R1	2000	999	99999	110	1	195	395	20040608	0	999999
VOLVO 244 OMBYGGD BIL	9999	171	500	60	2	1460	1850	19971110	0	999999
FORD ESCORT 1,6 LX	1985	164	410	48	1	990	1350	20041007	0	999999
VW SHARAN 2.0I	9999	182	475	85	1	1780	2400	20021212	1	999999
SAAB 900I AB45J-SR-KAT	1988	169	480	81	1	1320	1670	20051129	0	999999
VOLVO 855-512 SE 2.5	1996	177	485	106	1	1550	1970	99999999	0	999999
VW GOLF GL 1,8 I	1996	170	405	66	1	1150	1520	20040415	0	999999
HYUNDAI TRAJET GLS 2,0	9999	184	480	100	1	1820	2400	99999999	1	200306
MAZDA 2 5D 1,4	9999	168	395	59	1	1170	1500	20030422	1	200304
SSANGYONG MUSSO 3.2	9999	185	475	161	1	2190	2520	20010115	0	999999
SAAB 9000 I16 CC55D	1987	177	475	96	1	1410	1780	20041005	0	999999
VW JETTA 2,0 FSI	9999	179	455	110	1	1480	1930	99999999	1	200512
FOBO 1300 CM	1988	223	505	9999	99	360	1300	20030714	0	999999
VW GOLF 1,8 GL	1994	170	405	66	1	1220	1540	20040616	1	999999
VOLVO B10M/CARRAS STA	1997	255	1200	265	2	13700	18000	20041029	0	999999
SAAB 9000 I16 CC45B-PO	1992	179	500	110	1	1520	1980	20040518	0	999999
SAAB 900 S 5D 2.0I TALLA	1997	172	465	96	1	1420	1840	20041101	0	999999
VOLVO FL612 4X2	1997	260	715	132	2	8210	11900	20061010	0	999999
FORD ESCORT 1,6I CLX HC	1993	170	430	66	1	1240	1620	20060127	0	999999
SAAB 9-5 LINEARSPORT S	9999	180	485	136	1	1680	2130	20060808	1	200306

www.vti.se
vti@vti.se

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VTI is an independent, internationally outstanding research institute which is engaged on research and development in the transport sector. Our work covers all modes, and our core competence is in the fields of safety, economy, environment, traffic and transport analysis, behaviour and the man-vehicle-transport system interaction, and in road design, operation and maintenance. VTI is a world leader in several areas, for instance in simulator technology. VTI provides services ranging from preliminary studies, highlevel independent investigations and expert statements to project management, research and development. Our technical equipment includes driving simulators for road and rail traffic, a road laboratory, a tyre testing facility, crash tracks and a lot more. We can also offer a broad selection of courses and seminars in the field of transport.

HUVUDKONTOR/HEAD OFFICE
LINKÖPING
POST/MAIL SE-581 95 LINKÖPING
TEL +46(0)13 20 40 00
www.vti.se

BORLÄNGE
POST/MAIL BOX 760
SE-781 27 BORLÄNGE
TEL +46 (0)243 446 860

STOCKHOLM
POST/MAIL BOX 6056
SE-171 06 SOLNA
TEL +46 (0)8 555 77 020

GÖTEBORG
POST/MAIL BOX 8077
SE-402 78 GÖTEBORG
TEL +46 (0)31 750 26 00