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MANAGING TRAFFIC SAFETY -AN APPROACH TO THE EVALUATION OF NEW VEHICLE SAFETY SYSTEMS

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ABSTRACT

Road traffic crashes are killing more than one million road users per year, worldwide. Preventive measures to decrease this number are warranted. Relevant measures can be to introduce systematic road traffic safety management and to improve the safety properties of components in the road transport system. The so called Vision Zero, a holistic system to improve road safety, is built around the general idea to build a ‘‘safe system” based on knowledge regarding human capacity and where no predicted crash or collision results in death or serious injury. A Vision Zero model for safe traffic has been developed to illustrate how different system components interact.

The aim of this thesis was to investigate how two vehicle safety systems, electronic stability control (ESC) and intelligent seat belt reminders (SBR), could deliver improved road traffic safety. Further the Plan-Do-Check-Act approach was investigated as a systematic mean for the evaluation of effects of new safety technologies.

The studies were mainly based on data in the form of police records and field observations. For some aspects, in depth studies of fatal road crashes were used.

ESC systems were focused in two studies. The first study only investigated crash involvement independent of injury outcome level. In that study, a positive effect of ESC was found both overall and for accidents on wet, icy, and/or snowy roads. In a later study with a larger data set, the effect of ESC in crashes with various injury severities was investigated. The overall effectiveness on all injury crash types was found to be 16.7% (95% C.I. 7.4–25.0%), while for serious and fatal crashes, the effectiveness was 21.6% (8.8–34.4%).

The highest effects were found on serious and fatal loss-of-control type crashes on wet roads where the effect was 56.2% (32.7–79.7%) and on roads covered with ice or snow where the effect was 49.2% (19.0–79.4%). It was estimated that for Sweden, that at the time had a total of around 500 vehicle-related deaths annually, 80-100 fatalities could have been avoided if all cars had had ESC.

The effect of SBRs to increase the use of seat belts was studied in eleven cities in Europe, five of them in Sweden. The seat belt use rate in cars without SBR ranged from 69.6% to 96.9%. In cars with SBR, the seat belt wearing ranged from 92.6% to 99.8%. Considering all data, SBR increases seat belt use in traffic with 82.2% (73.6-90.8%).

The fourth study includes an analysis of how safety aspects can be put into the Vision Zero model for safe traffic. An important finding was that the model was helpful in the understanding of how road traffic safety aspects performed and interrelated.

In the last study, fatal crashes of modern cars were studied. The focus was on ESC and SBR. ESC reduced fatal loss-of-control crashes with 74%. Of the nine, loss-of-control cases in cars with ESC, only one occurred under normal driving conditions. The other cases were related to very low friction, loss-of-control initiated beside the road surface, or related to extreme speeding. Seat belt use in fatal crashes was 74% for cars without SBR and 93% for cars with SBR.

The studies in this thesis illustrate how important it was to follow the introduction of new safety technologies, and this from many aspects, all the way to the ultimate goal to eliminate fatalities and serious injuries. The Vision Zero model was helpful in defining how safety parameters interact. Plan-Do-Check-Act was found to be a valuable approach. As safety systems become more sophisticated and fatality rates diminish, better evaluation processes will be needed.

SAMMANFATTNING

Globalt dör fler än en miljon trafikanter i vägtrafikolyckor varje år. Förebyggande åtgärder för att minska denna förlust är befogade. Nollvisionen bygger på grundidén att man kan utveckla ett säkert system utifrån kunskap om människans förmåga. I ett sådant system leder inga olyckor till dödsfall eller allvarliga skador. I en modell för säker trafik i Nollvisionens anda illustreras hur olika systemkomponenter samverkar. Denna avhandligs syfte var att undersöka hur två bilsäkerhetssystem, antisladdsystem (ESC) och intelligenta bilbältespåminnare (SBR), kan ge förbättrad trafiksäkerhet. Vidare undersöktes hur den systematiska Plan-Do-Check-Act-metoden kan användas för att utvärdera nya säkerhetssystem.

Studierna bygger huvudsakligen på information från polisrapporterade olyckor samt fältobservationer. Djupstudier av dödsolyckor användes som grund för vissa analyser. Två studier fokuserade ESC. I den första studien undersöktes bara olycksfrekvensen oberoende av skadenivån i olyckan. I denna studie identifierades en positiv effekt av ESC i alla olyckor liksom för olyckor på våta, isiga eller snöiga vägbanor. I den senare studien, som hade ett större grundmaterial, undersöktes effekten av ESC i olyckor av olika skadegrad. Den övergripande olycksminskningen på alla typer av personskadeolyckor var 16,7 % (95 % C.I. 7,4–25,0 %). För allvarliga och dödliga olyckor var effekten 21,6 % (8,8–34,4 %). De högsta effekterna identifierades för allvarliga och dödliga olyckor i vilka föraren tappat kontrollen på våta vägbanor. I sådana olyckor var effekten 56,2 % (32,7–79,7 %) och på vägar täckta med is eller snö var effekten 49,2 % (19,0-79,4 %). Det skattades att i Sverige, som vid den tidpunkten hade sammanlagt cirka 500 fordonsrelaterade dödsfall årligen, skulle 80–100 dödsoffer kunna sparas om alla bilar hade ESC.

Bilbältespåminnares förmåga att öka bilbältesanvändning studerades i elva europeiska städer, fem av dessa i Sverige. Bilbältesanvändningen i bilar utan SBR varierade mellan 69,6 % och 96,9 %. I bilar med SBR varierade bilbältesanvändning mellan 92,6 % och 99,8 %. Detta visade att SBR överlag ökade bilbältesanvändningen i trafik med 82,2 % (73,6–90,8 %).

Den fjärde studien är en analys av hur indikatorer kan användas i Nollvisionens modell för säker trafik. En viktig slutsats var att modellen var användbar för att förstå hur egenskaper relaterade till trafiksäkerhet förändras och hur de kan relatera till varandra.

Dödsolyckor med moderna bilar, nyare än 2003 års modell, studerades i det sista arbetet. ESC visade sig minska dödliga olyckor där föraren tappat kontrollen över bilen med 74 %. Av nio dödsolyckor där föraren tappat kontrollen initierades bara en enda under vad som kan betraktas som normala körförhållanden. De andra fallen var relaterade till mycket låg friktion, att föraren tappat kontrollen bredvid körbanan eller så var de kopplade till extrem fortkörning. Bilbältesanvändningen i dödsolyckor visade sig vara 74 % för bilar utan SBR och 93 % för bilar med SBR.

Studierna i denna avhandling illustrerar vikten av att nära följa introduktionen av nya säkerhetssystem från många aspekter. Man bör studera effekten, hela vägen till det slutliga målet att eliminera dödsfall och allvarliga skador. Nollvisionens modell för säker trafik var till hjälp för att definiera hur säkerhetsegenskaper samverkar. Plan-Do-Check-Act konstaterades vara en värdefull metod. Vartefter säkerhetssystemen blir mer sofistikerade och dödsoffer i trafiken minskar, kommer en mer systematiskt utvärderingsmetodik att behövas.

LIST OF PUBLICATIONS

I. Lie A, Tingvall C, Krafft M, Kullgren A. The Effectiveness of ESP (Electronic Stability Program) in Reducing Real Life Accidents. Traffic Injury Prevention, Vol. 5:1 pp 37-41. 2004

II. Lie A, Tingvall C, Krafft M, Kullgren A. The Effectiveness of Electronic Stability Control (ESC) in Reducing Real Life Crashes and Injuries. Traffic Injury Prevention, Vol. 7:1 pp 38-43. 2006

III. Lie A, Kullgren A, Krafft M, Tingvall C. Intelligent Seat Belt Reminders. Do They Change Driver Seat Belt Use In Europe. Traffic Injury Prevention, Vol. 9:5 pp 446–449. 2008

IV. Tingvall C, Stigson H, Eriksson L, Johansson R, Krafft M, Lie A. The properties of Safety Performance Indicators in target setting, projections and safety design of the road transport system. Accident Analysis and Prevention. Vol. 2010, No. 42, pp 372-376. 2010

V. Lie A. Nonconformities in real world fatal crashes - electronic stability control and seat belt reminders. Traffic Injury Prevention. Accepted for publication, 2011

CONTENT

List of abbreviations

EC	Commission of the European Communities
ESC	Electronic Stability Control
ESP	Electronic Stability Program
ETSC	European Transport Safety Council
EU	European Union
Euro NCAP	European New Car Assessment Programme
EuroRAP	European Road Assessment Programme
ISO	International Organization for Standardization
NHTSA	National Highway Traffic Safety Administration
OECD	Organisation for Economic Cooperation and Development
PDCA	Plan-Do-Check-Act
SBR	Seat Belt Reminder
SPI	Safety Performance Indicator
SRA	Swedish Road Administration (Vägverket)
WHO	The World Health Organization

DEFINITIONS

In this thesis, road safety is defined as conditions and factors related to road traffic crashes and other road traffic incidents that impact, or have the potential to impact on death or serious injury of road users (From ISO 39001)

Serious injury is defined as an injury with a long term health impact or non-minor harm caused to a person’s body or its functions arising from a road traffic crash (From ISO 39001)

1 INTRODUCTION

1.1 THE GLOBAL TRAFFIC SAFETY SITUATION

The relative un-safety of the road transport system is causing significant health problems. Already in 2004, the United Nation's World Health Organisation (WHO) identified that 1.2 million people die in road traffic crashes every year and up to 50 million people are injured (Peden et al., 2004). Projections indicated that these figures would increase by about 65% over the coming 20 years unless there is new commitment given to road traffic fatality prevention (Peden et al., 2004). Lack of such preventive measures were predicted to move road traffic injuries from a 9th rank in the list of loss of DALYs (Disability-Adjusted Life Years) in 1990 to a 3rd rank in 2020 (Peden et al., 2004).

In 2004 the WHO and the United Nations put road traffic safety on their policy agenda (Peden et al.,2004; United Nations, 2004). As an effect of the growing number of traffic fatalities, especially in developing countries, the United Nations stress the need for concerted action to improve road safety, in a resolution of May 2010 (United Nations, 2010). In this resolution, the period 2011-2020 was proclaimed as the "Decade of Action for Road Safety". In the resolution, United Nations "Calls upon Member States to implement road safety activities, particularly in the areas of road safety management, road infrastructure, vehicle safety, road user behaviour, including distractions in traffic, road safety education and post-crash care, including rehabilitation for people with disabilities, based on the plan of action" (United Nations, 2010. Page 4).

The road traffic safety problem is growing in developing countries while the situation is slowly improving in industrialized countries (Peden et al., 2004). Today, 90% of the global road safety casualties occur in developing countries (Make Roads Safe, 2011). An example of the development in highly motorized countries is the development over the last years in the European Union (EU). In the countries of Western Europe the fatalities decreased by 61% between 1970 and 2005 (OECD, 2008). In many industrialised countries, the number of road fatalities initially increased along with an expanding motorization up to around 1970 (Trafikanalys, 2011; Statistics Finland, 2008). Since then, the number of fatalities per 100,000 inhabitants has been reduced in some countries by more than 80% (Touring Club Suisse, 2008).

To tackle road safety it is common practice to set numerical targets for the reduction of road fatalities (OECD, 2008). Many jurisdictions are aiming at a 50% reduction of fatalities in a ten-year time span. In 2001 the EU the Commission of the European Communities (EC) set the target to halve the number of road deaths between 2001 and 2010 (EC, 2001). In that time period, road deaths in EU 27 were cut by 43%. In the EU15 countries, which originally set the road fatality reduction target, road deaths were cut by 48%. Latvia, Estonia, Lithuania, Spain, Luxembourg, Sweden, France, and Slovenia all reached the EU 2010 target (ETSC, 2011). Sweden, in the same period, reduced the road death toll to a historically low level with a road mortality of 28 people per million inhabitants in 2010 (ETSC, 2011).

Already in the 1960's, William Haddon Jr. developed the so called Haddon matrix. The aim of the matrix was to aid in resource allocation analysis, strategy identification, and planning in the field of injury prevention. The matrix, as well as different prevention strategies, was described in the work "Advances in the epidemiology of injuries as a basis for public policy" (Haddon, 1980). The matrix differentiates between three factors; the human being, the vehicle, and the environment. It also contains three phases; pre-event, event, and post event. The matrix has been extensively used and been helpful in the analysis of crashes and injuries. The original idea was to have a systematic and holistic approach to injury prevention in the field of road traffic safety.

The Council of the European Union has identified the lack of cooperation between road authorities and vehicle manufacturers as an obstacle to improved road safety (Council of EU, 2010). In the communication, they state the following: the Council of the European Union "encourages a strong cooperation between the bodies responsible for the infrastructure in the Member States and the vehicle industry in order to support the deployment of promising in-vehicle safety systems that can contribute to save lives on the European road-network. New technical solutions of which the effect is proven can contribute to make it possible to deal with problems like speeding and impaired driving (such as driving under the influence of alcohol, drugs and fatigue)" (Council of EU, 2010. Page 6). This statement is an indication of how the European Council sees the value in a holistic and integrated approach to vehicle and road safety. It also illustrates how vehicle technology is assumed to be able to make a contribution to some areas that today mainly are addressed via information, training and police enforcement.

1.2 THE VISION ZERO

Over the last decades, a holistic approach to road traffic safety has developed. A new safety paradigm has been formulated, Vision Zero. The Vision Zero road safety policy was first presented in 1995 by the Swedish National Road Administration (Tingvall, 1995; Vägverket, 1996), when Tingvall for the first time shared the idea of an inherently safe road transport system. Vision Zero has taken inspiration from injury prevention strategies in medical care but also from occupational health and safety cultures (Johansson, 2009).

The Vision Zero ideas have been extensively accepted. In some jurisdictions the name has been changed to Safe Systems Approach to avoid the strong focus on zero (OECD, 2008).

The Vision Zero and Safe Systems Approach traffic safety programs are both based on a systems perspective and the design of the road traffic system to the failing human. It is clearly stated that the peoples' need for transportation should not be associated with a risk of fatal or impairing injuries. The Vision Zero involves ethical, political, and scientific issues. A clear ethical standpoint is that it is not acceptable that people are killed or seriously injured in the road transport system, and that such events must be eliminated and not only reduced. A corner stone of the Vision Zero is the concept of shared responsibility. The vision states that the responsibility for the safety of the road transport system falls primarily on the designers of the system, while the user in general is supposed to follow the rules. If this is not achieved, the designers and managers of the system must act to keep the road user within the safe limits. The scientific part of the Vision Zero states that it is the human tolerance to forces and energy in combination with the failing human being that constitutes the limiting parameter of a sustainable system (Swedish Government, 1997a, 1997b; Swedish Parliament, 1997).

The Vision Zero and the Safe Systems Approach are based on energy management in the road traffic system. Travel speed is defines the initial energy level. The human tolerance to mechanical forces is the limiting factor. Road design, vehicle design and the design of protection systems can reduce the potential energy of a crash down to survivable levels (Tingvall et al., 2000). In a safe system all predicted crashes and collisions have tolerable health losses (Johansson, 2009).

The Commission of the European Communities has in its White Paper on transports set out the goal “By 2050, move close to zero fatalities in road transport. In line with this goal, the EU aims at halving road casualties by 2020. Make sure that the EU is a world leader in safety and security of transport in all modes of transport” (EC, 2011. Page 10).

Beside traffic safety authorities, other actors in society are also picking up the Vision Zero principles. Vehicle manufacturers are formulating their visions of a safe system. One explicit example is the Volvo Car Corporation’s vision 2020 stating: “Volvo Cars has a vision of no serious injuries or deaths in or by a Volvo car by the year 2020, in line with a long tradition focusing on safety” (Volvo Car Corporation, 2009. Page 6). Also other car manufacturers have stated Zero as the long-term target. Nissan Car Corporation states: “In the area of safety, we have established Vision Zero, the goal of which is to reduce the number of fatal accidents to zero.” And continues “To achieve this, we have set a series of milestones, including cutting the 1995 fatal accident figure in half by 2015” (Nissan Car Corporation, 2005. Page 46). Toyota Car Corporation is taking a firm standpoint. “In terms of safety, Toyota is aiming for the complete elimination of traffic deaths and injuries and is advancing initiatives for traffic safety by viewing people, vehicles and the traffic environment as an integrated whole.” (Toyota Motor Company, 2008. Page 14). Volvo Car Corporation is unique in giving a specific time for the achievement of the vision of no fatalities or no serious injuries in Volvo cars. It is worth noting that their vision of no serious injuries or deaths is to be reached by the year 2020, a point in time only a couple of vehicle generations away.

The ethics of the Vision Zero is further elaborated in the Tylösand declaration (2008). That declaration includes the following five clauses:

1. Everyone has the right to use roads and streets without threats to life or health
2. Everyone has the right to safe and sustainable mobility: safety and sustainability in road transport should complement each other
3. Everyone has the right to use the road transport system without unintentionally imposing any threats to life or health on others
4. Everyone has the right to information about safety problems and the level of safety of any component, product, action or service within the road transport system
5. Everyone has the right to expect systematic and continuous improvement in safety: any stakeholder within the road transport system has the obligation to undertake corrective actions following the detection of any safety hazard that can be reduced or removed. (Tylösand declaration, 2008. Page 6)

The last paragraph of the Tylösand declaration points at the basics of modern quality management systems. The Tylösand Declaration was presented at the Tylösand annual safety seminar in 2008. Several individuals and organisations signed the Tylösand declaration there.

1.3 MANAGING TRAFFIC SAFETY

Traffic safety management is under constant development. Recent works from the OECD (OECD, 2008) and the World Bank (Bliss and Breen, 2009) are showing how systematic approaches are developed and stress the importance of effective management within the field of traffic safety. For instance, Bliss and Breen stress how the essential institutional management functions should initiate interventions, which in turn produce results.

The United Nations are stressing the same aspects in the resolution of May 2010 (United Nations, 2010). The resolution is proclaiming the period 2011-2020 as the “Decade of Action for Road Safety”. In the resolution United Nations “Calls upon Member States to implement road safety activities, particularly in the areas of road safety management, road infrastructure, vehicle safety, road user behaviour, including distractions in traffic, road safety education and post-crash care, including rehabilitation for people with disabilities, based on the plan of action” (United Nations, 2010. Page 4).

Moreover, the Council of the European Union, in their comments to the European Commission’s program for traffic safety 2010 "Towards a European road safety area: policy orientations on road safety 2011-2020" invited “the Commission and the Member States to stimulate the development and use of safety management systems, in order to promote responsibility for road safety among all relevant stakeholders” (Council of EU, 2010. Page 5).

Management system standards have been used extensively for management of the quality of products and services. The International Organization for Standardization (ISO) has developed several management system standards. The ISO 9000 family of quality management standards, was first developed in the mid 1980s. ISO 9001 (Quality management systems – Requirements) and ISO 14001 (Environmental management systems – Requirements with guidance for use), which give the requirements for, respectively, quality management and environmental management systems, are among ISO’s most well-known and widely implemented standards ever. They are used worldwide by businesses and organizations, large and small, in public and private sectors, by manufacturers and service providers. In December 2008, almost one million companies were certified to ISO 9001 and almost 180,000 were certified to ISO 14001 (ISO, 2009).

Naveh and Marcus (2007) have shown that systematic traffic safety work in line with ISO 9000 improves safety performance. The same study indicates that the financial performance of ISO 9000 certified companies are better than that of the non-certified companies.

In 2008, ISO decided to initiate the work to develop a management system standard for traffic safety (ISO, 2008). The standard is called “ISO 39001 Road traffic safety (RTS) management systems – Requirements with guidance for use”. The Draft International Standard version was released in June 2011 (ISO, 2011). The final international standard will be released in late 2012. ISO 39001 is based on the structure of other management standards, using the Plan-Do-Check-Act (PDCA) model as described by Deming (Deming, 1986). ISO 39001 is using “road traffic safety performance factors” as a means to assist organisations to focus objectives and targets to safety areas of relevance. The safety performance factors identified are (ISO, 2011. Page 16):

- Road design and safe speed especially considering separation (on-coming traffic and vulnerable road users), side areas and intersection design.
- Use of appropriate roads depending on vehicle type, user, type of cargo and equipment.
- Use of personal safety equipment especially considering seat belts, child restraints, bicycle helmets, motorcycle helmets, and means to see and be seen.
- Using safe driving speed also considering vehicle type, traffic and weather conditions.
- Fitness of drivers especially considering fatigue, distraction, alcohol and drugs.
- Safe journey planning including consideration of the need to travel, the amount and mode of travel and choice of route, vehicle and driver.
- Safe vehicles especially considering the occupant protection, protection of other road users (vulnerable as well as other vehicle occupants), road traffic crash avoidance and mitigation, road worthiness, vehicle load capacity and securing of loads in and on the vehicle.
- Appropriate authorization to drive/ride the class of vehicles being driven/ridden.
- Removal of unfit vehicles and drivers/riders from the road network.
- Post crash response and first aid, emergency preparedness and post crash recovery and rehabilitation.

2 BACKGROUND

2.1 THE PLAN-DO-CHECK-ACT MODEL

In modern management systems, the so called Plan-Do-Check-Act (PDCA) process is common practice (Deming, 1986). The process is also called PDSA since some user want to emphasis on the "study" of results more than on "check". The PDCA approach is used in several ISO management standards. The general idea is to get a systematic process supporting effective and reliable delivery of desired qualities through continuous improvements.

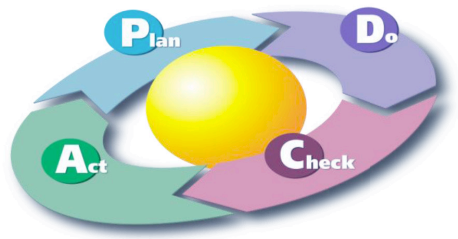

Figure 1. The Plan-Do-Check-Act model.

The PDCA model can be described in brief as follows (ISO, 2011):

- Plan: establish the objectives and processes necessary to deliver results in accordance with interested parties' requirements and the organization's policies.
- Do: implement the processes.
- Check: monitor and measure processes and product and services against policies, objectives and requirements and report the results.
- Act: take actions to continually improve process and performance.

One focus in this thesis is the study of how the PDCA approach can be used to enhance road traffic safety, especially when analysing the safety effects of new safety technologies.

2.2 A MODEL FOR THE DRIVING PROCESS.

An integrated safety chain model (Figure 2) can be used to describe how the driving process potentially can lead up to a crash (Kanianthra, 2007; Tingvall, 2008). The model is driving-oriented and holds some important steps between the normal driving state and the potential crash. The model is linked to modern vehicle safety strategies since it contains a time and space horizon between the steady state, normal driving, and a potential crash. This and similar models have a widespread use in vehicle industry (Nissan, 2004; Schoeneburg and Breitling, 2005; Eugensson et al., 2011).

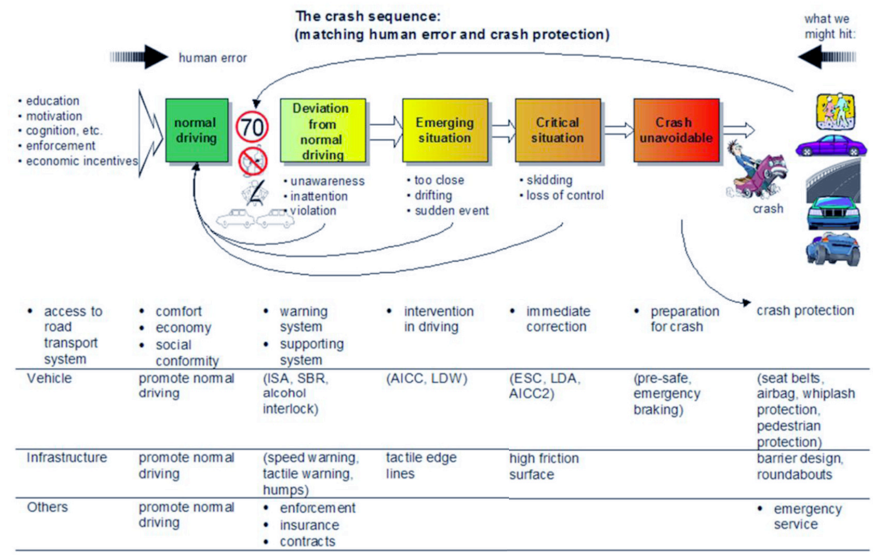

Figure 2. The integrated safety chain model (Tingvall, 2008. Page 606).

The integrated safety chain model illustrates how safety approaches can be applied at different times in the driving/crash time flow (Figure 2). It begins with "Normal Driving", a state under which the driver has the driving under control. Tingvall (2008) stresses that the most important factors to have under control in the normal driving phase are to support the driver to keep to the posted speed limit, to drive with less than the prescribed legal blood alcohol concentration, and to ensure seat belts are used. This "support" can be achieved by information, by education, by enforcement or by technical support systems. In the first step towards a potential crash the driver may leave normal driving conditions, a deviation from normal driving. This can occur because of distraction, inattention, or violations. Often the driver can return to normal driving by him/herself or after a warning from in vehicle support systems. However, if in this phase not enough action is taken, the situation can emerge further, leading to a critical situation or potentially to a crash. In a critical situation, the time span for corrections is small. Autonomous systems can today act by braking or steering (Schoeneburg and Breitling, 2005; Eugensson et al., 2011). As a final phase before a crash, the car can prepare for crash by pre-deploying some safety technologies such as seat belt pre-tensioners or moving the driver's seat into an optimal position for a potential crash (Schoeneburg and Breitling, 2005).

As described above, many crashes can be avoided by reverting the car into normal driving conditions. A plethora of modern vehicle safety systems are aiming at that. The systems can use warning signals at early stages in the process. In the later stages the systems are often autonomous. In the model as described by Tingvall (2008) there are many barriers and filters between normal driving and a crash. In the event of a crash the protection systems come in to play. The energy level coming into the crash depends on the conditions for normal driving and how much of the initial energy has been absorbed between the normal driving conditions and the crash. The time scale of the different phases is not fixed. A crash is over in about 100ms, the phase when a crash is unavoidable is around one second from the crash. The one second frame is used by Volvo Cars in their autonomous braking system (Coelingh et al., 2007). If systems demand that the driver is in the loop to take action, longer time periods are needed to ensure appropriate driver action.

Volvo Car Corporation have used the integrated safety chain model to illustrate to what degree a modern car, released in the next few years, can be expected to protect its occupants in different crash situations (Eugensson et al., 2011). The results were presented as acceptable speed limits in different traffic/crash situations. Volvo claims for instance that a modern car with modern safety equipment can handle frontal crashes with an initial travel speeds up to 80 km/h. Some of the kinetic energy of the car is reduced by braking the car just before the crash. Volvo estimates that the modern car can robustly and autonomously reduce the travel speed by around 20 km/h. The residual 60 km/h can be handled by the crash safety of the vehicle. At higher speed limits road design must ensure that head on collisions do not occur.

2.3 THE VISION ZERO MODEL FOR SAFE TRAFFIC

In the planning of operations of a safe road transport system, the design parameters in the above mentioned Vision Zero perspective are needed (Tingvall, 1995; Tingvall et al., 2000). The design demands can be put on the vehicle, on the road, or on the road users. The Swedish Road Administration (SRA) has developed a Vision Zero model for safe traffic (Figure 3), presented in 1996 (Tingvall et al., 2000). The idea was to illustrate elements around safe vehicle travel. The model is trying to encompass the energy control in the system. Furthermore, the model takes account of the biomechanical properties of humans, the behaviour of users, the vehicle, the road and the speed in the system. The model can be used to set design parameters and establish conditions for safe use. The hypothesis underlying the model is that fulfilment of the predefined sets of factors would generate an inherently safe system. In the description from 1996 there were no attempts to define elements and criteria for the design factors.

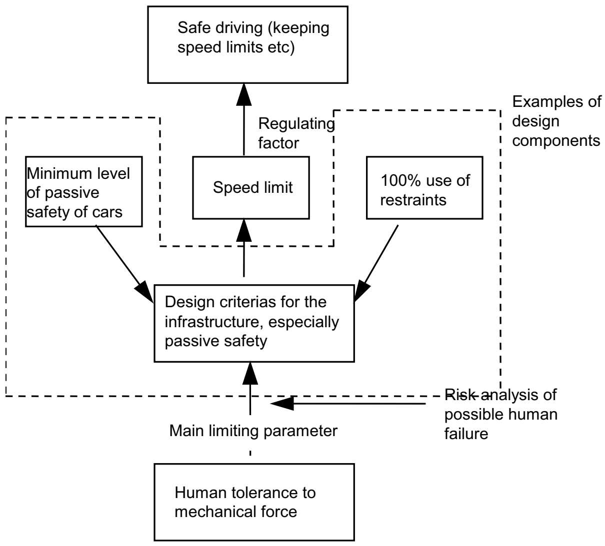

Figure 3. A multidimensional model for safe travel in a vehicle (Tingvall et al., 2000. Page 67).

The above mentioned Vision Zero model for safe driving and the driving process model can help in the planning process of a management system for traffic safety, especially in the design parameter setting and in the understanding of potential crashes. It can further be of use in identifying potential problem areas. However, when first presented, many of the factors of the model were not clearly specified. The only factor specified was 100% restraint use (Tingvall et al., 2000). The Vision Zero model for safe traffic has since then been filled with elements and criteria by SRA (Linnskog, 2007). In Study IV of this thesis, vehicle elements and criteria are defined together with elements and criteria for safe road and safe road user (Figure 4). An example of the use of elements and criteria is how the factor "Safe vehicle" contains the element *vehicle safety as measured by Euro NCAP* and the criterion *5 stars*. Another example is in the factor "Safe road user" that is having *"Wears seat belt"* as element and *100% fulfilment* as criterion. Stigson et al. have used this model to evaluate the safety on Swedish roads (Stigson et al., 2008; Stigson, 2009; Stigson et al., 2011).

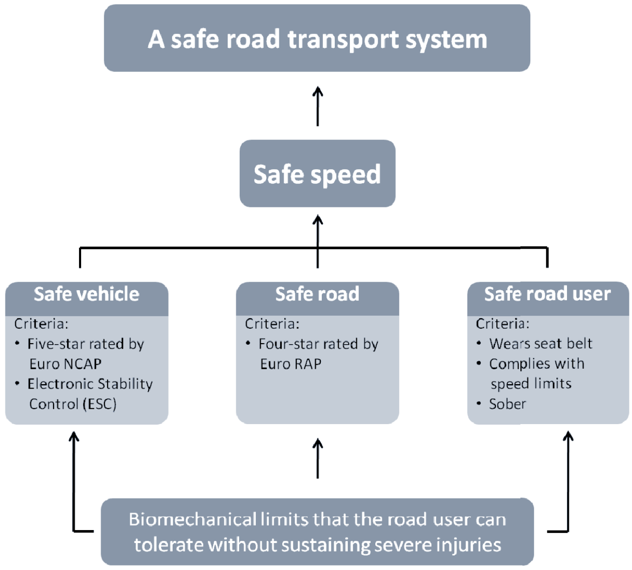

Figure 4. The multidimensional model for safe travel in a vehicle with factors, elements and criteria. (Study IV. Page 373).

Tingvall et al. and Stigson both used the same elements and criteria when using the multidimensional model for analysis (Tingvall et al., 2010; Stigson et al., 2008; Stigson, 2009). The elements and criteria set were for cars, being rated by Euro NCAP to have 5-star occupant protection and equipped with ESC. Roads were considered to be safe when living up to 4-star demands in the EuroRAP program. EuroRAP provides independent safety ratings of roads in Europe (Lynam et al., 2003). Road users lived up to the safety demands when using the seat belt, following the speed limits, and being sober. Stigson et al. (2008) analysed 215 fatal crashes occurring in Sweden 2004. The study showed that the model was useful to classify all crashes except 18 of the 248 fatally injured occupants in the data.

In this thesis, the model for safe traffic with defined elements and criteria was used to assess crashes with fatal outcome.

2.4 THE SAFETY PERFORMANCE INDICATORS (SPI) CONCEPT

In the management of road traffic safety, setting quantified, time-limited targets regarding the reduction of fatalities and injuries, has been a common approach in many countries (OECD, 2002; OECD, 2008). However, a long period of time can elapse between countermeasures being taken and their final outcomes in terms of fewer casualties, and it is difficult to manage an effective road safety strategy based on causality reduction targets alone. Casualties are relatively rare events and are not suited as a base for follow up of everyday operations. Except from the random outcome in crash events there are too many other factors, for example, fluctuating economic trends, which can influence the outcome in terms of casualty reductions. It is, therefore, becoming more common to use Safety Performance Indicators (SPI) (ETSC, 2001; Elvik, 2008; ISO, 2011; OECD, 2008; Vägverket, 2008a; Gitelman et al., 2007) as a way of effectively linking safety countermeasures with final outcomes in terms of fewer casualties. In general terms, SPI has been defined as "measures (indicators), reflecting those operational conditions of the road traffic system, which influence the system's safety performance" (Gitelman et al., 2007. Page 19). SPIs are used to measure and establish traffic safety-related aspects since the final outcome of un-safety in the shape of fatalities are rare and seldom directly linked to any organisations everyday activities. SPIs can be used to ensure that different countermeasures are combined in order to achieve results. SPI can also for the basis for safety projections (Vägverket, 2008a).

In management of improved safety, SPIs vary in number from less than 10 to more than 20 (Elvik, 2008; OECD, 2008). In this context, SPIs are understood to represent certain operational conditions that are related to traffic safety, often expressed as the proportion of the traffic volume that fulfils the condition. One example could be "the proportion of car occupants using seat belts"; another example is "the proportion of the traffic volume travelling on divided roads". The SPI, therefore, represents both a certain safety aspect (seat belt use, divided roads) as well as a value (proportion of traffic volume) of how this aspect has penetrated the traffic system. It is implicitly understood that the SPI should have a proven and well-documented relation to the number of casualties, and could be seen as an intermediate measurement of the traffic safety level for that specific aspect. The combination of several SPIs would then also be an intermediate measurement of traffic safety, representing current or future final outcomes in terms of the number of fatally and severely injured (Elvik, 2008; Gitelman et al., 2007).

In Sweden since 2010 the following SPIs are used to monitor the traffic safety situation (Vägverket, 2008a);

- Number of fatalities on the roads
- Number of persons seriously injured on the roads
- Percentage of traffic volume within speed limits, national road network
- Percentage of traffic volume within speed limits, municipal road network
- Percentage of traffic volume with sober drivers
- Percentage of those wearing a seat belt in the front seat of passenger cars
- Percentage of cyclists wearing a helmet
- Number of new passenger cars with the highest Euro NCAP score.
- Percentage of new heavy vehicles with automatic emergency braking system
- Percentage of traffic volume on roads with speed limits of more than 80 km/h and median barrier
- Percentage of safe pedestrian, cycle and moped passages in the municipal road network
- Percentage of safe crossings in main municipal road network for cars
- Average time from alarm to satisfactory rescue and care
- Percentage of drivers stating they have fallen asleep or almost fallen asleep while driving
- Valuation of road safety

For the majority of SPIs, there are several countermeasures that could contribute to their improvement. Taking the examples of seat belt use, the improvement could, for example, follow as a result of information and education, seat belt legislation and enforcement, a demerit point system, occupational health and safety regulations, or intelligent seat belt reminders in isolation or in combination.

In this thesis mainly two important Safety Performance Indicators for vehicles are investigated; Electronic Stability Control (ESC) and Seat Belt Reminders (SBR). Some general aspects of SPIs are also analysed.

2.5 VEHICLE SAFETY

One essential component in achieving road safety improvements is the vehicles. Vehicle safety has improved ever since Ralph Nader put focus on the vehicles in the book "Unsafe at any speed" in 1965. Vehicle manufacturers, legislators and consumer crash test programs have in recent years developed significant improvements.

The vehicle plays a significant role in the achievement of stringent and demanding traffic safety targets in the society. About one quarter of the target set for year 2020 in Sweden is estimated to come from enhanced vehicle safety (Vägverket, 2008a; 2008b). The vehicle today plays a role also in achieving positive development for seat belt use (seat belt reminders), speeding (intelligent speed assistance), fit driving (fatigue and alcohol detection) and emergency response (eCall). Many new vehicle technologies have been introduced to enhance road traffic safety and predictions of their benefits are being made (eImpact, 2008; van Ratingen et al., 2011).

Based on analysis of 105,000 crashes in Sweden between 2000 and 2008 Folksam has identified that the safety level of cars has improved substantially over time. The risk to get an impairing injury is reduced with 25% in a car from 2003 or later, compared to cars from 1983-1992 (Folksam, 2009, press notice). Euro NCAP is an independent organisation crash testing cars to assess vehicle safety. Kullgren et al. (2010) have evaluated the effects of good Euro NCAP occupant protection scores on injuries in almost 34000 police reported real life crashes occurring in Sweden between 1995 and 2008. The study showed that 5-star rated Euro NCAP cars have a lower risk of all types of injuries compared to 2-star rated cars (5-star cars had 10± 2.5% lower risk than 2-star cars). For fatal and serious injuries, the difference was 23± 8%, and for fatal injuries alone the difference between 2-star and 5-star cars was 68± 32%.

New vehicle safety technologies are rapidly entering the market. Enhancements are seen in crash protection but many new safety systems are also aiming at avoiding crashes (van Ratingen et al., 2011). The systems are addressing all stages in the driving process model. Some safety technologies are acting very close to the crash, like tensioning the belt prior to crash or autonomous braking. These are acting without intervention from the driver. Other systems are active close to the normal driving situation, for instance lane departure warning. Since the situation then is less time critical, the driver can be warned to avoid the potential crash.

2.6 ESC AS KEY ELEMENT OF SAFE VEHICLE

For safe journeys it is essential that cars do not loos control as an effect of low friction. A technical system aimed at diminishing loss-of-control crashes is Electronic Stability Control (ESC also known under Bosch's brand name ESP). ESC helps the driver keep or regain control of the vehicle also when the vehicle is close to losing control because of insufficient friction (Sferco et al., 2001). The function of ESC is to revert the driving to normal conditions once the situation has become critical.

ESC operates normally with both brakes and engine management. If the car, at micro level, loses control, defined as when one wheel or more is moving faster or slower than calculated from the steering input and turning angle, braking is applied to one or more wheels, and the engine power might be reduced(Sferco et al., 2001). Several groups (Langwieder et al., 2003; Papelis et al., 2004; Zobel et al., 2000) have claimed that ESC also might change the orientation of the vehicle prior to impact.

Since 1998, when the first mass-produced car with ESC as standard equipment was launched, the market for cars with ESC has grown quickly (Høye, 2011). However, ESC is not standard on all vehicles, and in 2011there were still a number of car models where ESC was not available. In Europe in 2011, around 65% of all new cars sold had ESC. In China the corresponding figure was 15% (eSafety Aware, 2011).

In Sweden since 1998, the market for cars with ESC has grown quickly. The proportion of new car sales equipped with ESC in Sweden has grown from 15% in March 2003 to 69% in December 2004 and reached 98% in December 2008 (Krafft et al., 2006; Høye, 2011).

Australia, Canada, the European Union, and the USA have all taken regulatory action to make ESC mandatory in vehicles. In the US, legislation was passed in 2007 making ESC mandatory standard equipment for all passenger cars, multipurpose vehicles, trucks and buses with gross vehicle rating of 4,536 kg or less from model year 2012 (NHTSA, 2008). In the European Union, the Regulation No 661/2009 of the European Parliament and of the Council of 13 July 2009 makes ESC mandatory. According to that regulation, from November 2011 all new passenger cars and commercial vehicle models registered in the European Union will have to be equipped with ESC. From November 2014, this will then apply to all new vehicles including old models. (eSafety Aware, 2011).

In 2001, Sferco et al. (2001) used in-depth data to calculate a projection of the potential effect of ESC. They analysed 1,674 crashes occurring between 1995 and 1999 in five European countries. The results of the projection suggested that for 67% of fatal and 42% of injury only loss-of-control accidents, ESC would have had a probable or definite influence. The estimated proportion of all injury crashes that would be addressed was 18% and for fatal accidents, 34%.

An early study of the effect of ESC was performed in Japan. Aga and Okado (2003) followed a cohort of three Toyota models with ESC for around 390,000 vehicle years and compared to a similar cohort of 980,000 cars without ESC. The study showed that all crashes dropped by 30% to 35% and the severe and fatal crashes with 40% to 50%.

In Germany a fleet of about 390,000 cars with ESC was compared to a 980,000 cars fleet without ESC (Breuer, 2002). The aim was to identify effects of ESC in Mercedes cars on German roads during the years 2000 and 2001. The author followed a fleet of

Mercedes cars with ESC and compared to other cars (without ESC) and found that the ESC-fleet had 10.6% to 10.7% loss-of-control crashes while the reference fleet had 14.5 to 14.3% loss-of-control crashes.

NHTSA in the USA made an early preliminary study of the effects of ESC in 2004 (Dang, 2004). The study was based on American crash data from the years from 1997 to 2003. They identified crashes with around 15,000 ordinary cars with ESC and compared to 21,000 cars without ESC. They also identified around 3,700 SUVs with ESC and compared with 7,000 SUV without ESC. They further identified around 400 fatal crashes with cars having ESC and compared those with 500 fatal crashes with cars without ESC. Similarly 128 fatal SUV crashes with cars having ESC were compared to 328 fatal crashes in SUVs without ESC. The findings indicated that single vehicle crashes were reduced by 35% in passenger cars and by 67% in SUVs. Similarly, fatal single vehicle crashes were reduced by 30% in cars and by 63% in SUVs.

ESC has since then been evaluated in many different studies showing significant benefits (Chouinard and Lécuyer, 2011; Erke, 2008; Farmer, 2004; Farmer, 2006; Ferguson, 2007; Høye, 2011).

As illustrated above, studies have also shown that ESC is more efficient in reducing more severe accidents by conducting the analysis on injury crashes and all crashes separately. Chouinard and Lécuyer (2011) analysed a Canadian data set of crashes occurring in Canada between 2000 and 2005. In the study regression analysis was used looking at 18,000 crashes with cars having ESC and comparing their crash experience with 1.1 million cars without ESC. The study found ESC effective for single-vehicle ESC-sensitive crashes, both for all severities of crashes (18.6% effectiveness) and injury crashes only (49.3% effectiveness).

An American study from Insurance Institute for Highway Safety (Farmer, 2010) was evaluating the effect of ESC on fatal crashes in the USA, based on data covering ten years (1999-2008). The study compared fatality crashes per vehicle years for cars with and without ESC. The study found a reduced fatal crash involvement risk by 33% — 20% for multiple-vehicle crashes and 49% for single-vehicle crashes.

The effects of ESC have been evaluated through meta-analysis. This was first done by Erke (2008) and later updated by Høye (2011). The meta-analysis made by Høye "indicates that ESC prevents about 40% of all crashes involving loss of control. The greatest reductions were found for rollover crashes (−50%), followed by run-off-road (−40%) and single vehicle crashes (−25%). These results are however likely to be somewhat overestimated, especially for non-fatal crashes" (Høye, 2011. Page 1148).

The European research project eImpact (2008) is after analysis of several safety systems ranking ESC highest in a list of 11 innovative safety technologies, when it comes to saved lives.

The ESC system is a technical system assisting the driver to keep control of the vehicle in critical situations. It is a system that the driver can adapt to and drive closer to the limit of handling. It is important to understand this element of driver adaptation. Høye has commented this; “No empirical results are available directly related to behavioural adaptation. However, several of the results from meta-analysis may give some indication of whether or not behavioural adaptation is likely to occur. The results indicate that a large proportion of all crashes involving loss-of-control are prevented by ESC and that the total number of crashes is at the worst unchanged. This means that behavioural adaptation does at least not overcompensate for the safety effects achieved by the engineering effect of ESC“ (Høye, 2011. Page 1158).

When looking at the model for safe traffic, ESC is a typical example of a system that is reverting a critical situation to normal driving. In some circumstances where the system cannot prevent the crash it can also change some characteristics of crashes. Because the system is preventing skidding, it can potentially change some side impacts to frontal impacts (Langwieder et al., 2003; Papelis et al., 2004; Zobel et al., 2000).

In the Vision Zero model for safe traffic, ESC is an element in vehicle safety. The safe road design is based on the properties of the crashes that occur. ESC affects both frequency of crashes and crash properties. In the model with elements and criteria, ESC is made a prerequisite for safe vehicles.

Even if ESC effects have been evaluated on a higher level, no studies have presented indications on what specific property of the system is generating the positive effects. Understanding the properties of loss-of-control crashes with cars equipped with ESC is one aim of this thesis.

2.7 SEAT BELT USE AS KEY ELEMENT OF SAFE VEHICLE

The aim of the seat belt is to keep the occupants of a vehicle in position in a crash. It is protecting from hard contacts with the vehicle interior and prevents potential ejection. It is widely recognised that the seat belt is one of our most important safety inventions. Kahane (2000) estimates the fatality risk reduction associated with seat belts in cars to be 45% in passenger cars and 60% in light trucks. The current seat belt wearing rate saves thousands and thousands of lives every year according to Kahane.

Most countries have legislation requiring mandatory use of seat belts. In the European Union, there is a seat belt use directive. Nevertheless, despite these laws, the seat belt use is not 100% in those countries. In 2003, the seat belt wearing rate for drivers and front seat passengers in Europe was estimated to be on average 76% (ETSC, 2003). For passengers in the rear seat the use rate estimate was 46%. The variations in seat belt wearing rates between countries are significant. For front seat occupants in Europe in 2004 it varied from 59% and 96% (ETSC, 2006a, 2006b).

It has been known for a long time that seat belt use rates in severe crashes is lower than could be expected when comparing to seat belt use in everyday traffic. In fatal crashes occurring in Sweden in 2005-2009, only 58% of the occupants in cars, trucks and buses were belted (Trafikverket, 2010; Tingvall et al., 2010).

In the USA in 1973, the National Highway Traffic Safety Administration (NHTSA) mandated seat belt starter interlocks in cars of model year 1974 (The National

Academies, 2004). The legislation mandated that all passenger vehicles not providing automatic protection should be equipped with an interlock system, which prevented the engine from starting if any front-seat occupant was not buckled up (Kratzke, 1995). Many consumers opposed the interlock because they believed that it infringed their personal freedom and reported difficulties experienced with the system (e.g. in emergency situations). In 1974, the US Congress withdrew the legislation. As a consequence of this experience, recent seat belt reminder systems in the USA have tended to be less aggressive (ETSC, 2006a, 2006b).

After some initial work performed by Folksam research in Sweden (Kamrén et al., 1994), the Swedish Road Administration, together with Swedish car manufacturers and research institutes, in 1995 begun to cooperate regarding a modern and improved seat belt reminder systems. These joint efforts resulted in a shared understanding that improved seat belt reminders could play an important role in increasing seat belt use (Turbell et al., 1996).

A seat belt reminder is a system using audio and visual signals to remind occupants to put the seat belt on. Evaluations of the potential of SBRs started with the motives claimed by non-seat belt users. Dahlstedt (1999) in 1998 stopped almost 500 unbelted drivers in traffic to make an interview about their motives not wear the seat belt. The interviews revealed very imprecise arguments for not using the seat belt from the majority of the nonusers in Sweden. Dahlstedt further found that only a very small fraction (less than 0.1% of the whole population and approximately 1% of the nonusers) were against seat belts as a matter of principle. The most common reasons for not using seat belts were simply that they were forgotten or that the trip was short in time or distance. The high acceptance for seat belts and the weak arguments against them lead to the conclusion that reminders could have a relatively mild reminder signal and still achieve high belt use levels. This was verified by Young et al. (2008) using field operational tests.

There are similar results from the USA, where it has been reported that only approximately 4% of the drivers are against using a seat belt and 87% strongly agree that they would want to be wearing a seat belt in a crash (TRB, 2004). Ferguson et al. (2006) found in interviews that nearly 90% of drivers having cars with seatbelt reminders would like one in their next car.

Based on the Swedish experience, the European Enhanced Vehicle-Safety Committee (EEVC) initiated work on seat belt reminders. The Working Group 16 (EEVC/WG16) reported a set of recommendations in 2002. These recommendations formed the basis for Euro NCAP, the consumer crash protection programme in Europe, when developing the first seat belt reminder protocol. A relatively mild reminder signal is demanded in the Euro NCAP protocol which has been the basis for modern seat belt reminders.

Euro NCAP has rewarded car models having seat belt reminders since 2002. The requirement to get the seat belt reminder reward is that a loud and clear light and sound signal should be active for at least 90 seconds if the seat belt is not worn. Euro NCAP analyses and gives credit to the driver seat, the front passenger seats and the rear seats separately. The requirements for the rear seats are lower and do not demand an audio signal.

In June 2002, the first car with a seat belt reminder system living up to the Euro NCAP demands was introduced. That car model had a SBR for the driver. It was quickly followed by other car models with seat belt reminder systems also monitoring the passenger seats. In all, Euro NCAP has given SBR points to almost 300 car models (February 2012). In 2005 ETSC estimated the proportion seat belt reminders in new cars sold in EU to be 56% (ETSC, 2006b). ETSC found large variations between the different countries. In Sweden almost 70% of the new cars sold in 2005 had seat belt reminders and the Czech Republic only some 30%. Legislation demanding new cars to have seat belt reminders came into play in 2005 in Japan and 2011 in Europe.

The European Transport Safety Council (ETSC, 2006a, 2006b) has calculated the potential fatality reductions associated with seat belt reminders. In the European Union (EU-15), another 7,600 lives could be saved per year bases on the fatality rate in 1996 if all car occupants used seat belts. In the USA, the potential is also big and it has been shown that another 8000 lives would have been saved if all car occupants used seat belts (Glassbrenner, 2003). Even in countries with a high seat belt use, the remaining potential is high. In Sweden with a 96% seat belt use, almost 40% of those killed as car occupants were unrestrained (Trafikverket, 2010; Trafikverket, 2011). In Australia, with an overall seat belt use of 95%, 33% of those killed in car crashes were unrestrained (Fildes et al., 2002). In the USA in 2005 less than half of the occupants in road crash fatalities were belted (Hedlund et al., 2008).

Ford Motor Company has introduced a seat belt reminder system in the USA (Ford, 2005). The Ford Belt Minder system is monitoring the seat belt use for the driver. If the driver remains unbuckled, the system chimes and flashes a warning lamp for six seconds every 30 seconds for five minutes or until the driver buckles up, whichever comes first (Ford, 2005). The user's appreciation of the Ford Belt Minder system was evaluated by Williams and Wells in 2003. The study is based on interviews with 405 drivers of Ford cars with belt minder systems. Two thirds of the driver had had the reminder activated once or more times, 73% said that the last time this happened they fastened their belts. The study indicated that the system was appreciated. 78% of the drivers said they liked the reminder system, and 79% said they wanted a reminder system like this in their next vehicle. Williams et al. (2002) also have performed a study on seat belt use in cars with seat belt reminders. By observing driver seat belt use as vehicles were brought to dealerships for service they could estimate the effects of the system. They compared 1,500 cars without reminders to 800 cars with seat belt reminders. Overall use rates were estimated at 71% for drivers in vehicles without the reminder system and 76% for drivers in vehicles with belt reminders.

Krafft et al. (2006) reported a study on the effect of SBR seat belt use reminders in Sweden in 2005. That data set containing observations of seat belt use of over 3,000 drivers is used in the analyses of Study III of this thesis. The analysis showed that seat belt reminders made a significant difference in seat belt use in Sweden. The seat belt use for cars not equipped with seat belt reminders was 82.3± 1.9%. For cars with seat belt reminders, the seat belt use was found to be 98.9± 0.8%. Ferguson et al. (2006)

reported in 2006 a study done in the USA on the seat belt use in Honda cars. The observed the cars when the driver came to service points. They compared the seat belt use in models without seat belt reminders from 2002-2004 and cars with seat belt reminders 2004-2006 model year. About 800 cars with reminders were included and compared to a group of similar size not having reminders. The research showed a change in seat belt use from 84% to 90% in cars with seat belt reminders.

In Australia a field operational test of a seatbelt reminder system has been preformed (Young et al., 2008). In the study a fleet of 23 cars was followed for at least 16,500 km as part of their everyday driving. In cars without reminders 32% of the occupants were unrestrained during any part of a trip. When the SBR system was activated, this percentage reduced significantly to 17%, representing a 47% reduction.

Farmer and Well (2010) have made a calculation of the benefits of seat belt reminders in the USA. The systems there are less intrusive than the ones in use in Europe. The study analyses fatal crash rates for car models that can be indentified with and without SBR. They used data from fatality files from the years 2000-2007. In all over four million vehicle years with cars having SBRs were compared to over five million vehicle years of cars without SBRs. The result showed a 2% reduced fatality risk in cars with SBRs. However, the result was not significant.

When considering the model for safe traffic, SBR is a system related both to normal driving and to the crash. The user cannot be expected to put on the belt during the crash therefore, it must be put on from the start of the journey. In the Vision Zero model for safe traffic, SBR is related to the safe road usage part where 100% seat belt use is specified as element and criterion. Designing a safe road transport system for unbelted user would put high demands on the roads and result in low speed limits.

The specific properties of crashes in which users were unbelted in cars with seat belt reminders are important in the development of better SBRs, the proper maintenance of SBRs and targeted information about the importance of seat belts.

3 AIMS

The overall aim of this thesis was to evaluate the safety effects of ESC and SBR from the market introduction to observed benefits in fatal crashes. Another aim was to use the Vision Zero model together with defined elements and criteria to identify non-conformities in fatal crashes. The analysis of the properties of SPIs used as elements and criteria in the model was a further aim. The last aim was to present a methodology based on the PDCA cycle for follow up of the safety effects of new safety technologies.

Studies I to III analyse the effects of ESC and SBR. In Study IV the Vision Zero model for safe traffic were developed to contain specified elements and criteria for the safe usage, the safe vehicle and safe roads. The properties of some of the SPIs were also investigated. In Study V the Vision Zero model for safe traffic, developed in Study IV, was used together with the elements and criteria to identify nonconformities in fatal crashes. The specific aims of the different studies are presented below.

3.1 STUDY I

The primary aim of the study was to present a method for analysis and to apply the method to estimate the influence of ESC on accidents in Sweden and to give an estimate of the potential injury reduction.

3.2 STUDY II

Two years after the first study a second analysis of stability programs (ESC) was performed. The more significant exposure made it possible to evaluate the benefit of ESC in more accident scenarios and at different injury levels. Over and above the aims in Study I the aim in Study II was to estimate how ESC can reduce real life crashes with injuries and crashes with serious and fatal injuries separately.

3.3 STUDY III

The aim of the study was to evaluate if the presence of a smart seat belt reminder (SBR) increases the driver seat belt use in traffic in some European cities.

3.4 STUDY IV

One aim of this study was to study the properties of some SPIs. The SPIs' independence, linearity and correlation were studied. Another aim of the study was to check if crashes that fulfilled the elements and criteria the Vision Zero model for safe traffic also resulted in safe traffic.

3.5 STUDY V

One aim of this study was to analyse fatalities in modern cars with respect to stability control systems (ESC) and modern seat belt reminders (SBR). The second aim was to characterize the cases where SBRs and ESC have not delivered the expected benefit. The third and final aim of the study was to use the Vision Zero model for safe traffic to analyse nonconformities in in relation to ESC and SBR in fatal crashes.

4 MATERIALS AND METHODS

The five studies included in this thesis use different data materials and methods. Study I and II are based on data from Swedish police reported crashes. In Study III and IV field observation data were used. Studies IV and V were based on data from in-depth investigations of fatal crashes in Sweden.
An overview of the data can be seen in Table 1.

Table 1. Overview of the studies

	Study				
	I	**II**	**III**	**IV**	**V**
Aim	Effect of ESC on accidents	Effect of ESC on accidents of different severity levels	Effect of SBR in traffic	Properties of SPIs. Elements and criteria in model for safe traffic	Effects of ESC and SBR in fatal crashes. Properties of nonconformities
Data	Data about police reported crashes in Sweden	Data about police reported crashes in Sweden	Field observations of seat belt use from 6 cities in Europe and 5 cities in Sweden	Data from in-depth studies of fatal crashes in Sweden	Data from in-depth studies of fatal crashes in Sweden
Number of cases (cases/controls)	110/499	1,942/8,242	3,498/6,739	217 vehicle fatalities on rural roads	138 crashes with 152 fatalities. ESC 68/70 SBR 75/77
Time period that the data covers	2000-2002	1998-2004	Europe 2006 (May) Sweden 2005 (July)	2004	2004-2010

4.1 STUDIES I AND II

These two studies are using a case/control approach to investigate the effects of ESC. From vehicle model codes the car models with ESC were specified. In Study I a number of 15 distinct car models were identified having ESC. Eleven matched controls were identified also by the model codes. The controls were selected to be as close as possible to the case vehicles.
The first study was based of police-reported crashes between 2000 and 2002 in Sweden. In all, 442 crashes with ESC equipped vehicles were identified. The control fleet contained 1,967 crashes. For car-to-car crashes, information was also obtained about whether the vehicle under study was the striking or struck part. The actual speed limit at each crash site was used to calculate the average speed limit at the crash sites.

The second study uses police-reported crashes from the years 1998 to 2004 in Sweden. The data set contained fatalities (42 case and 179 controls), severe injury cases (294 case and 1,319 controls), and minor injury crashes (1,609 cases and 6,774 controls).

In these two studies on the effect of ESC, induced exposure is used to estimate the exposure to crashes for cars equipped and not equipped with ESC. This is a method used in situations when it is not possible to calculate the true exposure (Evans, 1998).

Effectiveness was calculated by:
$E = (A_{ESC} / N_{ESC}) / (A_{nonESC}/ N_{nonESC})$
Where E is the effectiveness of ESC on accidents sensitive to ESC, A is the number of accidents sensitive to ESC, and N is the number of accidents that are not considered to be sensitive to ESC.

The method is based on the identification of at least one type of event that is not expected to be affected by ESC. In these studies rear-end crashes was considered not to be influenced by ESC. In the material, not only type of crash but also the road surface conditions were used to estimate possible effects.

4.2 STUDY III

The study on seat belt reminders was an observation study. The aim was to evaluate the change in seat belt use for drivers in real traffic. One single observer visited several sites. Data was collected from city traffic in five Swedish cities in July 2005 and in six European countries in May 2006 (Table 6). Distinct car models with (n=21) and without (n= 18) seat belt reminders were identified in advance and were used for the study. In total 10,237 cars were observed and the seat belt use of the driver was noted. Statistical tests were carried out comparing the proportion of seat belt usage (student's t-test for proportions). Gauss's approximation for the variance of ratios was used to calculate confidence limits for the effectiveness of SBR.

4.3 STUDY IV

The Vision Zero model for safe traffic was described. Elements and criteria for the different safety factors were established. In this study both empirical data as well as observational data were used. The empirical data consisted of all in-depth investigated fatal crashes occurring in Sweden in 2004 on the state road network (more or less the same as outside built-up areas). In all, 217 fatally injured car occupants fatally injured and data concerning them was studied. This sample was used to analyse the independence between the SPIs for drunk driving and seat belt use. Long time series of observational data were used to analyse the linearity of the SPI seat belt use. Here, a data from SRA's in-depth studies of fatal crashes between 1997 and 2007 were used. This was combined with data on seat belt use in traffic from the Swedish National Road and Transport Research Institute (Vägverket, 2008a).

Fatality cases occurring in 2007 (n=217) were used to evaluate the effect of simultaneous, 100% fulfilment of the SPIs *divided roads, seat belt use, sober driving and non-excessive speed.* This was combined with observational data for travelling on divided roads outside built-up areas, seat belt use in traffic, proportion of traffic over the legal alcohol limit and the proportion driving more than 30 km/h over the posted speed limit.

4.4 STUDY V

The Swedish Transport Administration has collected in-depth data from fatal crashes since 1998. This data set was used to analyse ESC and SBR. For this study all fatal crashes involving cars of model year 2003 and onwards were used. Data from Euro NCAP was used to identify if the car had SBR. The Swedish Transport Administration has since 2003 followed the introduction of ESC into the Swedish vehicle fleet. This data set together with the inspector's observations has been used to identify if a specific vehicle has been equipped with ESC.

The study was performed using case-by-case analysis of the collected data. A classification was made into two groups, depending on if the crash was ESC/loss-of-control group relevant or not for the case vehicle. Based on the field data the seat belt use was coded. The Vision Zero model for safe traffic in combination with the elements and criteria defined in Study IV was used to find nonconformities.

All fatal crashes occurring from first of January 2004 to the end of June 2010 were analysed. In all 138 crashes were analysed since they contained a fatality of a driver or passenger in a car built from model year 2003. The effect of ESC in reducing fatal loss-of-control crashes was calculated from the material using the same methodology as in Studies I and II.

5 RESULTS

5.1 STUDY I

The results are based on the assumption that rear-end collisions on dry roads are not, or only slightly, affected by the presence or absence of ESC. A higher average speed of one of the groups would result in an overrepresentation as a bullet car in rear-end collisions. In such cases, the calculated effectiveness would be wrong. One way of controlling this factor in rear-end crashes is if ESC cars were more involved as bullet cars in relation to being the target car. Inspection of the data revealed that the bullet to target distribution of cars with and without ESC was almost identical (44% and 47% respectively as target car).

Average speed limits at the location of the crashes for cars with or without ESC were similar, around 65 km/h. The highest value was recorded in the group of small front wheel drive non-ESC cars at 69 km/h and the lowest for ESC equipped large rear wheel drive cars at 63 km/h. Within group the largest difference between cars with and without ESC was 3km/h.

The risk of crash was reduced, in all crashes except rear-end crashes, with 22.1% if all road states were included. On dry roads the reduction was 9.3%, on wet roads 31.8% and on roads covered with ice or snow 38.2% (Table 2).

Table 2. Effectiveness, in percent with 95% confidence intervals, of Electronic Stability Control in reducing crashes for different road conditions.

Accident type	*Effect*
All accidents excluding rear-end	22.1± 21.0%
Accidents on dry roads	9.3± 28.3%
Accidents on wet roads	31.8± 23.4%
Accidents on snow/ice roads	38.2± 26.1%

When analysing the effectiveness of ESC for three car types: small and large front wheel drive as well as large rear wheel drive it can be seen that ESC significantly reduced the number of "all accidents" for large rear wheel drive cars. In addition, there was a significant reduction in low friction accidents for both the large car types. For small front wheel drive cars the reduction was not significant at the 95% confidence level (Table 3).

Table 3. Effectiveness, in percent with 95% significance tests, of Electronic Stability Control in reducing crashes for different vehicle types.

Type of car	*All accidents*	*Accidents on low friction*
Small front wheel drive	28.0% n s	24.5% n s
Large front wheel drive	21.4% n s	58.9% s
Large rear wheel drive	44.8% s	46.0% s

s=significant, n s=not significant

5.2 STUDY II

In the second study, the methods used in the Study I were expanded from the accident level to different injury levels. The method developed was working and significant results were found. The study shows a positive and consistent effect of ESC overall and in circumstances where the road has low friction. The overall effectiveness on all injury crash types, except rear-end crashes, was 16.7%, while for serious and fatal crashes; the effectiveness was 21.6%. The corresponding estimates for crashes with injured car occupants were 23.0% and 26.9% (Table 4).

Table 4. Effectiveness, in percent with 95% confidence intervals, of Electronic Stability Control in reducing crashes for different crash conditions.

Crash type	*Effect*
All crashes excl rear-end	16.7± 9.3%
All crashes excl rear-end, car occupants	23.0± 9.2%
Serious/fatal crashes excl rear-end	21.6± 12.8%
Serious/fatal crashes, excl rear-end, car occupants	26.9± 13.9%
Single/oncoming/overtaking casualty crashes	31.0± 10.2%
Single/oncoming/overtaking serious/fatal crashes	40.6± 15.1%
Single serious/fatal crashes	44.4± 19.6%
Single/oncoming/overtaking crashes, dry surface	24.8± 26.0%
Single/oncoming/overtaking crashes, wet surface	56.2± 23.6%
Single/oncoming/overtaking crashes ice/snow surface	49.2± 30.2%

For serious and fatal loss-of-control type crashes on wet roads, the effectiveness was 56.2% and for roads covered with ice or snow the effectiveness was 49.2% (Table 4).

It has been mentioned earlier (Langwieder et al., 2003; Papelis et al., 2004; Zobel et al., 2000), that ESC could have an effect on the direction and location of impact. A higher proportion of crashes would be expected to be frontal rather than lateral. No difference in deformation pattern was found for cars with or without ESC (Table 5).

Table 5. Deformation patters for cars with and without Electronic Stability Control.

Deformation	*Cars with ESC*	*Cars without ESC*	*Quote*
Cars deformed in the front	710	2,828	0.251
Cars deformed in the sides	265	1,046	0.253
Cars deformed in the rear	407	1,564	0.26

It was estimated that for Sweden, with at the time a total of 500 vehicle related deaths annually, 80–100 fatalities could be saved annually if all cars had ESC.

5.3 STUDY III

A significant difference in seat belt wearing rate was found. For all observations, the total seat belt wearing rate was 97.5% in cars with SBR, while it was 85.8% in cars without. The highest wearing rate in cars with seat belt reminders was found in Paris, 99.8%, and the lowest in Brussels, 92.6% (Table 6).
The study indicates that the effectiveness of SBR in terms of increasing the seat belt use for nonusers is in the range of 80% (82.2±8.6%). The effectiveness is a bit lower in Berlin and Brussels but higher in Paris and Sweden. The results indicate that many lives could be saved each year if all cars were equipped with SBRs.

Table 6. Seat belt use for cars with and without Seat Belt Reminders.

Region	*Total number*	*Belted number*	*Belt Use % (95% confidence intervals)*
Belgium/Brussels			
Cars with SBR	526	487	92.6±2.2%
Cars without SBR	869	605	69.6±3.1%
Denmark/Copenhagen			
Cars with SBR	326	319	97.9±1.6%
Cars without SBR	652	580	89.0±2.4%
France/Paris			
Cars with SBR	512	511	99.8±0.4%
Cars without SBR	897	869	96.9±1.1%
Germany/Berlin			
Cars with SBR	446	431	96.6±1.7%
Cars without SBR	1044	932	89.3±1.9%
Italy/Milan			
Cars with SBR	463	452	97.6±1.4%
Cars without SBR	894	770	86.1±2.3%
Spain/Barcelona			
Cars with SBR	491	484	98.6±1.0%
Cars without SBR	757	690	91.1±2.0%
Sweden/5 Cities			
Cars with SBR	734	726	98.9±1.1%
Cars without SBR	1,626	1,339	82.3±1.9%
Total			
Cars with SBR	**3,498**	**3,410**	**97.5±0.5%**
Cars without SBR	**6,739**	**5,785**	**85.8±0.8%**

5.4 STUDY IV

The result of the analysis of independence of SPIs shows a clear indication that, at least in the example seat belt use and alcohol impaired driving, the assumption about independent SPIs is not fulfilled. The conditional probability that a drunk driver is not restrained is far greater than for a sober occupant, and the probability that an unrestrained driver is drunk is higher than expected (Table 7). This shows that a method estimating combined effect by simply multiplying probabilities (1-SPI_1) (1-SPI_2) etc. cannot automatically be applied to all SPIs. The seat belt use levels in all crashes were 60% and the level of alcohol involvement 25%.

Table 7. Relations between seat belt use and alcohol-related fatal crashes.

	Restrained	*Unrestrained*
Not alcohol-related	97	65
Alcohol-related	33	22
Total (n=217)	130	87

The analysis of the linearity of seat belt use when comparing the results showed that while seat belt use in traffic had increased from 88% in 1997 to 96% in 2007 the rate of unbelted drivers in fatal crashes remained at 40%. This indicates that an increase of an SPI among the general population might not lead to an improvement of the final outcome.

The Vision Zero model for safe traffic was developed to contain elements and criteria. The model was used for SPI analysis. The 100% fulfilment of the SPIs, divided roads, seat belt use, sober driving and non-excessive speed combined simultaneously are shown in Table 8. The table shows the observational data from everyday traffic and the data from the fatal crashes. The table illustrates how drivers under the influence of alcohol are present in 0.2% (99.8/100) of the traffic but are involved in more than 25% (161/217) of the road fatalities. The 33.2% of the traffic with sober and restrained drivers who do not speed and travel on divided roads, only are involved in 5% of the fatalities.
Almost half of the 185 fatalities among car occupants on undivided roads occurred with 100% fulfilment of the SPIs. The equivalent figure for divided roads was one third of the fatalities.

Table 8. Sober driving, speeding, seat belt use and divided road fatal crashes.

	Percentage of traffic flow	*No. of fatally injured (%)*
Rural roads	100%	217 (100%)
Sober driver (99.8%)	99.8%	161 (74%)
Sober driver (99.8%) + non-speeding (99%) [a]	98.8%	143 (66%)
Sober driver (99.8%) + non-speeding (99%) [a] + restrained (96%)	94.8%	100 (46%)
Sober driver (99.8%) + non-speeding (99%) [a] + restrained (96%) + divided roads (35%)	33.2%	11 (5%)

[a] Below 30 km/h over the speed limit.

5.5 STUDY V

Based on studies of fatal crashed it was found that in cars equipped with ESC 13% of the cases were related to loss-of-control (Table 9). For cars without ESC the same proportion was almost three times higher (36%). The effectiveness of ESC to reduce fatal loss-of-control crashes was 74%.

Of the 152 occupants fatally injured under study 15 individuals were related to suicides. 84% of the occupants with known seat belt use were using the seat belt when seated in a seat with a seat belt reminder. In the material 69 occupants were using seats without seat belt reminders. Out of these 72% used the seat belt in the fatal crash. After the exclusion of the suicide cases 62 individuals were using a seat with a seat belt reminder (Table 10). With suicides excluded, 93% of the occupants of seats with seat belt reminders living up to Euro NCAP's standard used the belt. Only 74% of the occupants used the belt in seats without a seat belt reminder.

Table 9. Electronic stability control in loss-of-control fatal crashes.

ESC results	*The car was equipped with ESC*	*The car was not equipped with ESC*	*Unknown ESC equipment*
ESC/Loss-of-control relevant	9 (13%)	22 (36%)	2
Not ESC/Loss-of-control relevant	59	38	8
ESC sums	68	60	10

Table 10. Seat belt reminders in fatal crashes.

SBR results excluding suicide	*The car was equipped with SBR*	*The car was not equipped with SBR*	*Unknown SBR equipment*
Belted occupants	55 (93%)	48 (74%)	4
Unbelted occupants	4	17	2
Unknown belt use	3	4	
SBR sums	62	69	6

Taking a management or quality management system approach, the 9 loss-of-control cases for cars with ESC can be considered as nonconformities. The same goes for the 4 unbelted occupants in seats with seat belt reminders (suicides excluded). Characteristics of these cases are described below.

In only one case, a car with ESC has lost control on the road surface under normal conditions. In three cases the cars have lost control beside the road in the road side area. All the cars have initially drifted of the road surface with a small angle. Two of the cars have lost control on the road surface under extremely low friction circumstances. The last three cases were all related to extreme speeding.

For the four cases of unbelted drivers in cars with SBR no clear common factor, beside gender, has been identified. Euro NCAP protocols allows a delay of the start of the reminder signal. One case could have happened within this 60-seconds timeframe. All the others happened outside urban areas and at a significant time after the start of the journey. From the material it has not been possible to verify if the reminder systems were de-activated or not.

6 GENERAL DISCUSSION

Studies I to III in this thesis have used mass data in the form of police reports and field observations to analyse the effects of ESC and SBR. Significant positive effects were identified. In Study IV the Vision Zero model for safe traffic was developed to contain specified elements and criteria for the safe usage, the safe vehicle and safe roads. The properties of some of the SPIs were also investigated. In Study V the Vision Zero model for safe traffic was used together with the elements and criteria to identify nonconformities in fatal crashes. Below the papers are discussed first individually, later a methodological reflection and after that follows some reflection on how to use a systematic approach when analysing new safety systems. Finally in this section some future research needs are identified.

6.1 STUDIES I AND II

ESC is an on-board car safety technology that should help drivers to maintain control of their vehicle in critical situations.

Study I was the first study ever published in peer-review press, assessing the potential effectiveness of ESC in real life traffic. The results are clear but the confidence in some of the findings was low because of the limited material size. The first study contributed to the knowledge regarding ESC effectiveness at an early stage of the introduction of the system. However, the results needed to be verified from other studies, especially as the study was done in a small country, with a limited number of accidents, consequently limiting the possibility to draw firm conclusions. Furthermore, weather conditions in Sweden are different from those in many other countries, limiting the possibility to generalise the results from this specific study to the rest of the world.

In the time span between Study I and Study II several studies (Dang, 2004; Farmer, 2004; Farmer, 2006; Langwieder et al., 2004; Page, 2006) had demonstrated positive effects of ESC. While the results have been related to studies with varying selection criteria, methodology and effectiveness estimates, all studies showed a positive and large effect. The data had been collected in different countries and regarding different set of vehicles. The number of studies and the clear and consistent results show, however, that there is no fundamental problem in evaluating primary safety system effectiveness with robust statistical techniques. At least as long as the safety effects are of a certain magnitude.

Studies I and II, as well as studies from others, show clearly that ESC has a very high potential in saving lives and injuries. In Study II, which was focused on the number of crashes where car occupants were severely injured or killed, the effectiveness of ESC to reduce these crashes was over 25%. In crashes that are more ESC sensitive, like single/oncoming/overtaking crashes on wet or icy roads, the reduction was in the order of 50%. In Study V the analysis of fatal crashes reveals a 74% effect of ESC in reducing fatal loss-of-control crashes. It is clear that the effects are highest when the analysis is focused on the functional target of a system.

Statistical analyses of mass data do not allow an analysis on the actual function of the system, and in what sequence of driving, ESC has its major safety effects. ESC can potentially work as an intelligent system to warn the drivers about low friction. It can also have a direct function in the driver-vehicle loop in critical manoeuvres, either in controlling stability and/or in reducing speed. It has not been possible to identify the exact cause of the safety benefit in these studies.

At the early stage, evaluations could only be made on the basis that all ESC systems and for all car models, have the same effectiveness. Two studies from the USA (Dang, 2004; Farmer, 2004) had been able to separate passenger cars from SUV, but it is likely that there are also other important differences. There is a development ongoing in making ESC more sophisticated and covering more situations. This is done without knowing what characteristic of ESC that is mostly safety related, and therefore the understanding of the impact of more sophisticated systems must be done by empirical evaluation of real life crash data.

In the studies, only vehicles where ESC was standard equipment were included. In most cases, where ESC was an option, the car model was excluded to minimise selective bias. On the other hand, this method meant that cars otherwise identical with and without ESC were not used out in traffic in parallel time with identical age of the cars. Other studies should try to pick up this factor. The fact that ESC has been introduced on fairly up-market car models is a restriction in generalising the results. Some control vehicles were car models different from ESC cars, which were sold at the same time. This should reduce the type of bias mentioned above. Today (2012) when almost all new vehicles have ESC the problem is instead to find relevant control cases.

In Sweden already in 2003, a firm recommendation was given by the Swedish Road Administration that consumers should choose cars with ESC, especially in countries with wet and icy road conditions. The recommendation was based on the findings in Study I. At that stage, the rate of fitment of ESC on new cars was 15%. In September 2004, 16 months later, the fitment rate was 58%, and a stronger recommendation was given. In December 2004, the fitment rate on new cars had grown to 69%. In December 2006, the fitment rate came up to 92% and two years later to 98% (Krafft et al., 2009). This is probably one of the highest introduction rates in the world when it comes to vehicle safety technologies. The findings in Study 1 were probably important for the rapid introduction. There was at an early point no reason not to recommend all consumers to choose a car with ESC, and to advise car manufacturer to as soon as possible only market cars with ESC.

6.2 STUDY III

The seat belt is one of the most important safety devices in a modern car. There is still a huge additional potential for saving lives or preventing injuries. By getting all occupants in the cars and trucks belted many thousand lives could be saved. Setting the seat belt use target at 100% seems the only logical way ahead. Dahlstedt (1999) and Young et al. (2008) have identified that few car occupants directly oppose seat belt use at least in Sweden and Australia..

Based on mass data it is hard to identify seat belt use levels in crashes. Police records in Sweden do not contain data about seat belt use. For this reason the estimate of the effects of SBR was studied using road side observations.

The observations on belt use for this study were made inside several European cities. While the control group would have had a higher use if the observations were conducted outside built up areas, the use of seat belts for those in a car with SBR would probably not be lower. Dahlstedt (1999) found the lowest seat belt use rates in small towns and cities.

SBRs are playing an important role in changing the user's pattern of seat belt use. This study showed that more than 80% of the non-seat belt wearers did put their belts on in cars with seat belt reminders. This indicates that the approach for seat belt reminders used in Europe is working well. The systems are using a clear visual signal accompanied by a loud and clear acoustic signal. The effects are larger than the effects in the study of seat belt reminders in the USA of Williams and Wells. They identified a seat belt use increase of around 20%. One probable reason is the more mild reminder signal used in American cars.

Over the last few years, an increase in seat belt use has been seen in Sweden (Trafikverket, 2011). To some extent this can be explained by a higher market penetration rate of car models with seat belt reminders. Already in December 2006, almost 80% of the new cars sold in Sweden had seat belt reminders for the driver that fulfilled the Euro NCAP's demands (Vägverket, 2007). In late 2008, the market penetration rate in new cars was 84% and in 2010 it was 95%. From 2011, all new car models sold in Europe must have SBRs for the driver. In 2011, all cars tested by Euro NCAP had SBRs for both the driver and the front seat passenger.

This study looked at seat belt use in traffic. Previous studies as well as Study IV have shown a major difference in rates of seat belt use between traffic and serious crashes (Trafikverket, 2010; Trafikverket, 2011; Fildes et al., 2002; Hedlund et al., 2008). It was found important to perform studies of actual seat belt use in crashes for cars with SBR. This was later done in Study V.

The positive effects of SBRs in Europe depend on an already existing relatively high acceptance for seat belts in the general public. High positive effects of SBRs have also been found in Australia and the USA (Young et al., 2008; Williams et al., 2002). On other markets with a more limited knowledge about and acceptance of the positive effects of seat belts less positive effects could be expected. The successful introduction of SBRs and other driver support technologies depending on the drivers, needs a basis of knowledge, acceptance and potentially even legislation. When the USA in the early 1970s regulated seat belt starter interlocks there was a significant backlash and the systems were taken out of the regulation after a short period (TRB, 2004). This might illustrate how the technology in itself is not enough to change driver behaviour.

6.3 STUDY IV

Safety Performance Indicators can be used both to detect deficiencies in the level of safety, as well as guide progress towards a safe system. In the most radical use, the simultaneous fulfilment of a set of SPIs could illustrate a system that is inherently safe.

Elvik (2008) and the Vägverket (2008b) use SPIs in a broad sense, where SPIs are utilised to both set targets and also to predict the outcome of improvements. In both cases, SPIs are used for the calculation of combined effects. To combined calculations the nature of SPIs must be understood. From this study it is clear that for at least two commonly used SPIs, the assumption of statistical independence must be rejected. The conditional probability that a drunk driver is not restrained is far greater than for a sober occupant. The implication is that simple multiplicative treatments of SPIs to estimate effects of multiple improvements should be treated with some care. The result from the present study is not unique, in the sense that seat belt use and drunk driving are associated.

The study showed further that a substantial improvement of an SPI, e.g. seat belt use, might not necessarily lead to an improved final outcome, implying that assuming a linear relationship between an SPI and a final outcome could be highly incorrect. The above finding stresses that it is important not only to collect and analyse SPIs in traffic, but also with regard to fatalities and severe injuries. This is something that needs to be addressed. It is also essential that the actual countermeasure, or countermeasures directed towards a specific SPI, is followed up. Improved seat belt use, increased enforcement and intelligent seat belt reminders might have different final outcome effects, as they might target different populations with different risk profiles (Study III). The understanding of the weak relation between seat belt use in normal traffic and in fatal crashes inspired study V in which the effects of SBRs in fatal crashes was investigated.

In the most far-reaching use of SPIs, i.e. the simultaneous effect of 100% fulfilment of relevant SPIs, it is clear that combining only a few SPIs can lead to a dramatic reduction in risk. While this finding is based on partly weak data, the direction of the results is promising. The results must be further investigated. In the present example (cases relating to more than 30% of the traffic flow on the state network, where more than 200 car occupants were fatally injured, fulfilling four basic SPIs simultaneously) only 11 fatalities occurred.

In Study IV, the SPIs were put in the context of the Vision Zero model for safe traffic as elements and criteria. This was found to be attractive for the evaluation of safety systems. The developed elements and criteria were used in Study V to identify nonconformities.

6.4 STUDY V

Traffic safety work is more and more taking a systems perspective on the road transport system. Modern management systems knowledge can improve the efficiency in achieving stringent traffic safety goals.

The Vision Zero model for safe traffic and a nonconformity approach can give rapid feed-back when new safety systems are put on the market. The relations between elements and criteria in the model for safe traffic can explain nonconformities and/or focus the non-expected outcome. In Study V nine cases were identified as nonconformities when looking at ESC and four cases were considered nonconformities in relation to seat belt use and seat belt reminders.

In Study V it was found that ESC reduced fatal loss-of-control crashes with 74%. This was in line with study II that showed better ESC effects in more severe crashes. Farmer (2010) found a 49% reduction from ESC when looking at fatal single vehicle crashes in the USA. It is logical that the findings in study V show a higher effect of ESC since not all single car crashes are related to loss-of-control. The 74% reduction level calculated is including the eight non conformities identified. If these nonconformities were excluded the effect of ESC to reduce fatal loss-of-control crashes would rise to almost 100% (97.5%).

Electronic Stability Control has shown to be very effective in reducing crashes. In this study only one case was identified in which the system together with the driver could not keep the car under control on the road surface with some friction. In two ESC related cases drivers lost control of cars with ESC on extremely slippery roads. It is still not evident what specific property of the ESC system that gives these high effects. The ESC system is having the driver in the loop and many factors can influence beside the pure technical capacity to prevent loss-of-control.

This paper is using the method to look at the characteristics of loss-of-control type crashes with cars having ESC. This is a useful method to verify that hypotheses about benefits for ESC systems are valid all the way to fatal crashes. It was found that the majority of the loss-of-control cases were related to load conditions not normally verified or tested during development of ESC systems. The ESC-equipped vehicles in loss-of-control type crashes are having special characteristics of importance to feedback into the design of both the ESC systems and the design parameters of the road infrastructure. The maintenance standards and assurance of sufficient road friction are found to be essential and could potentially be an element in the Vision Zero model for safe traffic.

The analysis of seat belt reminders gave a mixed picture with no typical technical conditions identified in the study. It was not possible to investigate the technical status of the seat belt reminder system in cars where occupants have not used the seat belt. It is strongly recommended that this is done in conjunction with the data collection. It is important to know whether it is the function of the reminder system that is failing to achieve the goal to get occupants to put the belt on, or if the users or workshops disconnect the systems. If there is a problem with significant disconnection or tampering of the seat belt reminder system the vehicle inspection programs should put control of seat belt reminders on their inspection scheme.

Potential suicide was a factor in a significant proportion of the cases where occupants were unbelted in cars with seat belt reminders. It is not likely that these individuals are easy to reach with technical means to increase seat belt use.

The identified seven percent of unbelted occupants (when suicides are excluded) in seats with seat belt reminders differ significantly from the predictions in earlier about seat belt use in cars with SBR. That research was based on road-side studies and that identified only 1.1% of unbelted drivers (see Study III). In fatal crashes (excluding suicides) the seat belt use went from 74% to 93% if the seat was equipped with a SBR. This is in line with previous roadside studies (Study III) indicating that 80% of the unbelted drivers did put the belt on in cars with seat belt reminders.

The analysis of effects of SBRs in fatal crashes gives a far more positive picture that the results presented by Farmer and Wells (2010). Their calculations indicated only a 2% reduction in fatality risk. In USA the general seat belt use is lower, potentially indicating more firm resister to seat belt. These resisters are hart to convince with technical means. The reminder systems in the USA have a weaker reminder signal.

One should be aware of the fact that the observed seat belt use rate in crashes is influenced by the protective effects of the seat belt. In theory all fatally injured would be unbelted if the protective effect of the belt would be 100%.

6.5 METHODOLOGICAL REFLECTIONS

In this thesis Electronic Stability Control systems and Seat Belt Reminders have been studied in close relation to their large scale introduction on the market.

A challenge for real life follow-up is to properly separate vehicles with a specific safety feature from vehicles without the same feature. For the studies on ESC and SBR, this was done based on information from motoring magazines, press releases from vehicle importers and through analysis of equipment sheets from car sales material. This is a manual method with potential to include errors. It would be valuable if there were information accessible linked to each car individual in a central register. In Sweden, preparations have been made for a system where vehicle importers can report the safety equipment level of individual cars to the central vehicle register. Such a system could give valuable safety information to consumers, to insurance companies, and for evaluations of safety effects. The system has not yet been made operational.

Modern vehicles carry a multitude of possibilities to register information from normal driving conditions and from potential crashes. These systems can significantly improve data quality and quality. A good cooperation between vehicle industry and the society is essential to get good value out of these new possibilities (Eugensson et al., 2011). The higher precision in the data collection can make a more rapid evaluation and mass market introduction possible. Kullgren and Lie (1998) have shown the safety conclusions based on weak field data risk to offset the focus of safety development. To better assess the change of velocity in crashes a simple crash pulse recorder was developed in the mid 1990s (Kullgren, 1998). This has given unique possibilities to assess for instance the risk of whiplash related injuries as a function of change of velocity in crashes (Kullgren and Krafft, 2008). Modern vehicles and their level of computer power make this kind of approaches possible, even trivial.

It should be understood, that new vehicle technology is not brought into the market in a way that would guarantee a scientific evaluation in terms of a randomised controlled study. First of all, the technology is not randomly equipped to vehicles, and there is probably a selective recruitment to such technology (Høye, 2011). ESC seems to have been brought to the market initially on more up-market car models, and vehicles in high-performance versions. Attempts have been made in these studies to overcome this problem, but there are still some lingering doubts about how the technology is picked up by consumers. The novelty of the technology might even lead to changes in behaviour such that drivers of cars with the technology will provoke the system to act more frequently than expected. These phenomena are very hard to control for, but might modify the long-term effectiveness of ESC or similar technologies.

The studies of ESC and SBRs were performed over a short period of time and the results would be expected to changes over time as the technologies penetrate further into the fleet and the users potentially change their behaviour.

If the road transport system is managed in line with Vision Zero, the aim is the elimination of death and serious injuries as an effect of crashes. Frequently in vehicle safety studies fatality related cases are excluded, which can be relevant if general risk reduction is in focus. For risk elimination every crash in focus contains important information.

A study from the USA (Bean et al., 2009) was investigating 122 fatalities occurring in cars of model years 2000 and 2007 between the years 2000 and 2007. All 122 car occupants were using seat belts in cars with air bags. The following conclusion is found in the abstract of the study "Aside from a substantial proportion of these 122 crashes that are just exceedingly severe, the main reason people are still dying is because so many crashes involve poor structural engagement between the vehicle and its collision partner: corner impacts, oblique crashes, impacts with narrow objects, and underrides" (Bean et al., 2009. Page i). The design of vehicles was in focus for the study. The design of the roads and the speed limits were factors not analysed in that study. The Vision Zero model for safe traffic can be a useful tool for this kind of analyses since it is giving a framework where elements and criteria are given. Safety failures are best understood when they are put into a framework where the relations between the safety relevant components of the road transport systems are identified.

Without a model the complex factors around road traffic crashes can be hard to understand, evaluate or tackle. Models of traffic and crashes can be of significant help. One model frequently used is the Haddon matrix with its components; the human being, the vehicle, and the environment (Haddon, 1980). The Haddon matrix does not contain a clear model of safe driving or a resolution in a process leading up to a crash. NHTSA have added a "crash imminent" phase between the environment and the crash to complement the original model and to illustrate where some safety system have their main function (Maddox, 2011). Often the Haddon matrix has been used to divide research areas or responsibilities. Even if the main components of road safety are identified in the Haddon matrix it has not been widely used to elaborate a truly holistic view of a safe system (Stigson, 2009).

The method to look at failures of the safety technologies can give important feedback long before accurate statistical analysis of the effects of the system can be performed. Vision Zero is aiming at elimination of defects as the goal is set at elimination of fatal and severe injuries. All nonconformities contain valuable information and severe crashes with a new safety system should therefore be analysed in detail. However it is challenging to know whether individual cases found early in the evaluation process are typical and meaningful to base actions on.

Most road safety data collection systems are not prepared for the system approach used in this study. The data collection set up would gain from using the Vision Zero model with the specified elements and criteria. Further, the data collection should be adapted to the elements in the model.

It must be understood in the analysis if the road users are violating the safe usage envelop of the system. One cannot expect ESC to keep control of the vehicle under extreme speeding or when the friction is extremely low. Nor can SBRs be expected to make suicide candidates to put the seat belt on. It has become very clear that a precise specification of the aim of a technical system is a part of the "Plan" part of the introduction of a new safety system. That specification is also a cornerstone when the effects of systems are calculated and discussed.

Many studies have claimed that the vast majority of road crashes are caused by users making "errors". A figure often cited is that 90% of the road crashes are caused by user errors (Peden et al., 2004). Sudden failures of roads or vehicles, being the complements to user errors, are rare. The clear picture that the users are the problem can lead to the conclusion that changing user behaviour is the best way ahead. Changing the properties of the systems can be more efficient than focus on changing human behaviour (Peden et al., 2004). Focus on driver errors can potentially mislead the focus from the basic idea of Vision Zero, to design a road transport system that can absorb user errors and thus deliver improved safety. However, when analysing road traffic crashes, it is important to distinguish between errors and violations.

In the Study IV of this thesis three common violations are identified, all related to safe road usage. The elements and specified criteria analysed were, the use of seat belts, compliance with speed limits and that the driver is sober. These criteria are often identified as key criteria for safety (Peden et al., 2004; ETSC, 2010). They have also been identified as the main contributing factor for France's rapid traffic safety improvements (ETSC, 2011). In the analysis the legal limit for blood alcohol content is used to set limit for being sober. Exceeding the speed limit with more than 30 km/h was used to define non-compliance of the speed limit. To use 30 km/h gave a significant margin between normal driving and "speeding". It was estimated that 94.8% of the normal traffic on rural roads was performed without violations of any of those three criteria. The 5.2% not fulfilling the criteria were, however, related to 54% of the fatal crashes. The properties of the crashes with sober drivers, using their seat belts and that are keeping the speed limit are extremely important to adjust road design, speed limits and vehicle design properties. In the last study of this thesis cases of that kind were identified having ESC and SBR in focus of the analysis.

6.6 TOWARDS A SYSTEMATIC APPROACH

A systematic approach is needed to tackle the challenge to rapidly improve road traffic safety. That is also what the United Nations, the World Health Organisation and the Commission of the European Communities have called for (UN, 2010; Peden et al., 2004; EC, 2011).

PDCA (plan–do–check–act) is an iterative four-step management method used for the control and continuous improvement of processes and products. The PDCA method is used by ISO in the managements system standard 39001 (ISO, 2011). In the following the separate components of the PDCA-process are discussed.

6.6.1 "Plan" part of the PDCA process

6.6.1.1 The vision is the elimination of death and serious injuries

Road traffic safety is a multi facetted field with stakeholders from many different areas of society. A shared vision can be the most important factor when many actors are to work together towards a common goal.

The Vision Zero approach to road traffic safety has been accepted by many organisations and jurisdictions. The most important part of the Vision Zero that is picked up is the ideas about a road transport system that can absorb human errors in a way that is eliminating death and serious injury as outcome from road crashes.

There are fundamental policy and strategy differences between aiming at reductions of errors and aiming at zero errors. For elimination every residual case must be understood. This is well known from industrial production that has aimed at zero defects for some time. When, as in this case, the focus is on zero fatalities or severe injuries, every single crash resulting in a fatality or serious injury contains important information for improvements. As the injury rates in focus are diminishing a continuously increased understanding of the fewer remaining fatal crashes is essential.

It seems that elimination of death and serious injuries is a shared vision to base traffic safety activities on.

6.6.1.2 Models

Without a model the complex factors around road traffic crashes can be hard to understand, evaluate or tackle. Models of traffic and crashes can be of significant help. Studies in this thesis have used two complementing key models to make systematic analysis possible; "The Integrated safety chain model"(Figure 5) and the Vision Zero model for safe traffic"(Figure 4).

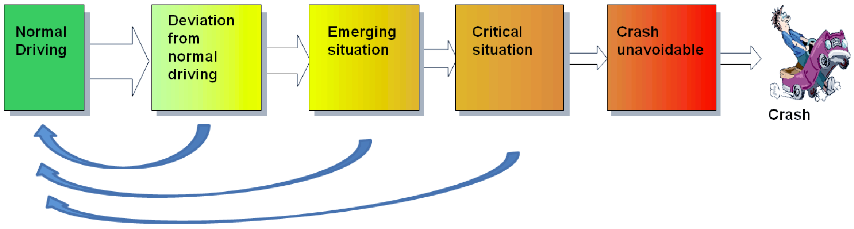

Figure 5. Integrated safety chain model, adapted from Tingvall 2008.

The integrated safety chain model is describing a process leading up to a potential crash. It contains several steps from the “Normal driving” situation to the “Crash”.

Safety technology acting close to normal driving will be active and function more frequently than the systems acting in close relation the crashes. An important approach for elimination of injuries is for systems to revert the deviations back to normal driving as early in the process as possible (Eugensson et al., 2011). Even if the crash protection is good, every avoided crash is reducing the risk of injury. A safety technology can also aim at influencing the incident in a way that is beneficial to the next phase of a potential crash.

Technologies that are active close to normal driving can have the driver as an important agent, but in or close to the crash, systems will have to be autonomous to give significant benefits. The integrated safety chain model can be used to better understand the role of the driver in relation to safety technologies and in different phases of a potential crash. As identified by Young et al. (2008) the level of acceptance and understanding of new safety technology can be crucial for its benefits. If warning systems are calibrated in a way that it is not accepted by the driver, there is a high risk that the system is rejected and turned off.

A weakness of the integrated safety chain model is that it does not in itself define safe levels of performance. Essential conditions around normal driving influence the absolute safety level of crashes. The human tolerance to forces is the deciding factor for safety in the crash. It would be valuable if these factors were defined more in detail. Specifying the normal driving condition regarding driver capacity, travel speed and potential crash configurations is important for design of safety systems. It is also essential to define how severe a crash can be and still not result in fatalities or severe injuries.

Volvo Cars Corporation and the Swedish Transport Administration analyse traffic safety and crashes together to better develop product and services that the safety demands of tomorrow’s road transport system (Eugensson et al.,2011). This work can provide a good picture of the limitations of today’s and tomorrow’s vehicles and feed that back into road design principles and speed limit systems.

The Vision Zero model for safe traffic illustrates components of a road transport system by the definition of key factors of safety (Figure 4). A set of elements and criteria have been specified as a development of the initial model (Study IV). These elements and criteria were essential for the use of the model in evaluations of road transport system of today. The identified and specified elements and criteria have been used for such evaluations of ESC and SBR in Study V of this thesis and by Stigson (Stigson et al., 2008; Stigson, 2009; Stigson et al., 2011) for analysis of road design.

In the specified elements key factors for road safety are used. If all the factors and their criteria are completely fulfilled the aim of no fatalities or serious injuries should under ultimate conditions be achieved. However, the model is a simplification, based on today's knowledge. It also focuses only on main factors. Even if the decided elements criteria are based on solid knowledge further development of the model should be performed. In Study V for instance road friction was identified as an element of importance. Extremely low friction inhibited ESC to avoid loss-of-control. The model should be revised occasionally when new knowledge emerges and when new safety systems are identified as significant. Already established SPIs are good candidates to include in the model. It is also important to keep the model relatively simple. A model is a representation of reality used to simplify analysis and understanding of a complex question.

The combination of the integrated safety chain model and the Vision Zero model for safe traffic is helpful when preparing the evaluation of new vehicle safety systems. The safety chain is well suited for problem identification when developing or analysing modern vehicle safety technologies. The Vision Zero model for safe traffic is more holistic and sets some more normative values, such as minimum levels for user compliance with rules. The two models are connected in the way that the Vision Zero model identifies parameters for "normal driving" but is also identifying biomechanical forces as the ultimate limiting factor for a "safe" crash. The clear identification of problems and parameters is essential for analyses in the "Check" phase.

6.6.1.3 Safety performance indicators

Using Safety Performance Indicators (SPI) is an established way to monitor the traffic safety situation (Elvik, 2008; Gitelman et al., 2007; ISO, 2011; OECD, 2008; Vägverket, 2008a). A continuous development of new SPIs is encouraged by researchers (Stigson, 2009). It would simplify analysis of road traffic safety and vehicle technologies if SPIs were developed based on the integrated safety chain model and the Vision Zero model for safe traffic in focus. A well defined SPI is a good candidate to be an element in the Vision Zero model for safe traffic. As new safety solutions emerge the existing SPIs should be revised. A good example of such a revision is the introduction of ESC as an element in the Vision Zero Model for safe traffic.

6.6.1.4 Preparations for data collection

When system is put out in traffic there are significant benefits in preparing data systems to be able to follow the equipment level of individual cars. Data collection system should also be prepared. In Study I and II there can be classification errors since ESC equipment level were decided and handled in a manual way. In Study V information about SBR and SBR function was missed in the data.

Modern vehicle holds possibilities to store data on factors around normal driving, safety system activations and crash data. There are substantial benefits possible if these possibilities were used for evaluation of new safety systems.

6.6.2 "Do" " part of the PDCA process

6.6.2.1 Implementation

After the planning process the implementation should start. In road traffic safety the SPIs often are used to guide and focus activities (ETSC, 2001; Elvik, 2008; ISO, 2011; OECD, 2008; Vägverket, 2008a; Gitelman et al., 2007). They are identified to tackle essential safety areas.

In the past introductions of many vehicle safety features were regulation driven. On the other hand, some vehicle manufacturers and some customers of new cars have had internal safety standards containing significantly higher goals than what regulation demands. Most car manufacturers see the positive advantages of ensuring their vehicles achieve the highest possible result in public consumer test programs such as Euro NCAP (van Ratingen et al., 2011). The test programs support consumers in the selection of safe vehicles. The open information about test procedures and safety levels also supports the safety departments of vehicle manufacturers in focusing important safety areas. Over the last decade vehicle safety has become a significant aspect on the vehicle market. Safety sells, at least to a significant part of new car buyers (Koppel, 2008).

The introduction of ESC on the mass market was mainly driven by industry. The aim was to reduce loss-of-control crashes and to increase stability. Mercedes A-class was a small car having ESC as standard at an early stage and changed the implementation strategy for many other vehicle manufacturers. Also Volvo Car Corporation made ESC standard equipment in Sweden at an early stage changing the market situation.

The seat belt reminder systems were to a large extent brought into the market by safety advocates in the society. The starting point was the understanding of the significant differences between seat belt use in road side observations and in severe crashes. Another key element in the push for reminders was the understanding that a large proportion of the drivers were seat belt part time users (Dahlstedt, 1998).

No study in this thesis is specifically looking at the implementation process. It can, however, be noted that the studies included in this thesis were likely influential in how Sweden got the quickest introduction of ESC in Europe (Høye, 2011; Krafft et al., 2009)). Research in close conjunction to the introduction of a new safety technology can influence market introduction significantly.

6.6.3 "Check" part of the PDCA process

6.6.3.1 To follow the introductions of new safety technologies

As new safety systems enter the road transport system they should be monitored. Mass data and in-depth data are complementary. Based on mass data effect studies can be performed. From in-depth studies the function of the system can be verified. Rapid feed-back can come both from mass data and in-depth studies.

6.6.3.2 Mass data analysis

Studies I and II on the effect of electronic stability control systems show that the highest effect in reducing crashes were in situations with low friction. Loss-of-control crashes are more common on roads with low friction. The police data cannot in an efficient way identify cases related to loss-of-control. Based on the evaluation of police records in isolation, ESC can hardly be considered a system that is eliminating loss-of-control type crashes. More information than what is available in police record was needed for a better conclusion. Without an idea of the function and target of a safety system there is a significant risk that the analyses will be weak and even potentially misleading. Only with clear hypotheses of targets and functions a precise and rapid analysis can be performed.

6.6.3.3 In depth data analysis

To complement the studies based on police data and field observations, in-depth data was used. The Swedish Transport Administration is collecting data from crashes with fatal outcome. The data stored contains information from all fatal crashes occurring in Sweden. The data set was used to look at properties of crashes with modern cars.

The Vision Zero model was used to classify the crashes into the cases where the system under study failed and when it was other aspects of a safe system that failed. This was done in line with the nonconformity concept.

The concept of "Nonconformity" is essential in modern management systems. Nonconformity is defined as a; non-fulfilment of a requirement (Requirement; need or expectation that is stated, generally implied or obligatory). To identify nonconformities a reference point is needed. The Vision Zero model for safe traffic formed such a basis in the analyses in this thesis. To make the model more useful, elements and criteria have been identified and introduced. Fatalities occurring even though all the elements are under critical levels are extremely important to identify areas that should be improved to enhance safety on the roads or to improve the model. Other fatalities can occur because one or several elements of the model do not live up to the specified criteria.

In Study V, the nonconformity aspects related to ESC and SBR were analyzed. When safety technologies are put out in traffic it is important to have an idea of what specific problem the system are to solve. That is part of the "Plan" in the PDCA cycle. Only if this is properly done the research of effects can precisely identify nonconformities. Valuable insights came from the analysis of in-depth cases that contains detailed information about the crash circumstances. A mass data analysis could not have given the same clear answers no matter the size of the data set.

In this thesis, in-depth data was used to show that ESC has eliminated fatal loss-of-control crashes with one single exception. That case occurred on a wet road surface and the driver lost control of the vehicle in an emergency manoeuvre. From available information it was not possible to confirm the status of the ESC system. It can potentially have been switched off. All other fatal crashes were outside what was considered the design target of the system. Even if that has not been explicitly stated, ESC was considered to address only loss-of-control crashes on a road surface with a certain minimum friction. Loss-of-control on extremely slippery snow and ice cannot be expected to disappear only because of ESC. Using the Vision Zero model for safe traffic revealed that the effect of ESC was almost 100% reduction of loss-of-control crashes for drivers driving as expected in the model. It became clear that many loss-of-control cases started outside the road surface. This finding illustrates that modern lane departure warning/assist systems have a potential to give high effects together with ESC. Guard rails are also helping to avoid this specific crash type.

In study V, the seat belt use in cars with and without SBRs was studied. In the study it was found that even in cars that according to registers should have SBRs there were unbelted drivers killed. The properties of these remaining few cases are important for further development of SBRs and the maintenance of the functionality of the SBR systems. Since the data collection systems were not prepared for this question, the data about whether the SBRs were disconnected is missing.

6.6.4 "Act" part of the PDCA process

Timely and accurate feedback from crashes in the road transport system is important. The use of SPIs to monitor elements and criteria is essential (Gitelman et al. 2007; ETSC, 2001). SPIs give the possibilities to follow safety related aspects of road safety closely related to management and activities. The management system approach to study nonconformities is also a valuable element since it can put nonconformities into a holistic systems perspective. As fewer fatalities occur in traffic, more actions should be based on the proper understanding of the properties of few crashes.

Getting the new technology out on the market rapidly is important to gain the safety benefits. However, the basis for society to support new technologies is dependent on scientific evidence of the benefits of the technology. Larger data sets have the potential to make more rapid analysis possible. In Europe today few international, co-ordinated and systematic evaluations of new safety systems are performed. However, an attempt to merge police data from several countries for the analysis of ESC systems has been made (MUARC, 2011). The approach was successful and a paper presenting the results is under development.

Robust knowledge about the performance of safety technologies is also important feedback for the vehicle manufacturers and their suppliers. The enhanced knowledge should in a timely manner be fed back into the development of coming generations of the technologies.

6.6.5 Systematic traffic safety work

The possibility to work through the PDCA cycle in a systematic way results in several benefits. A high precision in knowledge about new safety technologies can guide users and society towards the most important safety features. A rapid answer about the effects of newly introduced systems can make the systems introduced in large scale at a quicker pace and hence give safety effects earlier. The potential nonconformities can be used to improve relevant components of the road transport system and further develop the safety technology in itself. A holistic view of the road transport systems and its components can open up for constructive cooperation between different traffic safety stake holders.

The management systems standard ISO 39001 gives organisations the possibility to identify important safety factors and monitor the organisation's output in relation to these factors. The management standard is based on PDCA.

Development of the safety of the road transport system is a step-by-step process. For rapid improvements every new step must build on knowledge generated from previous steps. The foundation for every step must be solid but also generated at a rapid pace. The systematic use of PDCA can help to progress towards Vision Zero.

6.7 FUTURE RESEARCH NEEDS

The Vision Zero model for safe traffic is multidimensional and can be further elaborated. The model can be changed to another balance between the road usage, the road design and the vehicle design and the effect of such changes should be evaluated. The studies in this thesis all focused on car occupants. There is a need to develop the model for other kinds of road users as well.

Many of today's vehicles carry a multitude of safety technologies. The integrated safety chain model is a valuable tool to understand how these different safety technologies interact towards the elimination of death and serious injury. More research is needed to understand effects of individual safety technologies, but to an even higher degree to understand how more complex safety systems interact.

In study IV some properties of SPIs were investigated. It became clear that some factors are clearly correlated. It was also found that seat belt use in traffic and fatal crashes had a non-linear function. More research is needed about how commonly used SPIs are related. For more SPI a better knowledge should also be generated about how fulfilment levels in traffic observations are related to fulfilment levels in severe and fatal crashes.

Any analysis of safety systems will have be based on available data. It is important to further investigate how data supply can be more efficient. More research is needed on how data registers can contain information about safety technology levels of individual vehicles. As new safety technologies are introduced it is important to better understand necessary new data to collect, both in mass data and in in-depth studies.

Data from a small country, like Sweden, is limited. Methods to pool data from several jurisdiction is a potential way ahead but more knowledge on how that can be done is needed. Methods for meta-analysis of pooled data would therefore entail the possibility to obtain faster and more accurate answers on effectiveness of new safety technologies.

Modern vehicles hold completely new possibilities to collect and store data. Significant research is needed to be able to use that possibility for evaluations of safety technologies. There are both technical and integrity issues related to this that should be understood. For investigation all the vehicles of a certain model can be used, or a special cohort equipped with special equipment and capabilities to collect data. The equipment can potentially make reconstructions of individual cases possible. This field is being researched to some degree in several Field Operational Tests (FOT studies). That new knowledge should be used also in this field.

Virtually all road safety systems interact with the road users. A good understanding of how users and technology interact for different new systems is valuable. More research is needed in this field. The research could have both the introduction phase perspective and a perspective of the effects of potential long-term user adaptation.

The studies contained in this thesis have evaluated ESC and SBR relatively close in time to the introduction of the systems. It is important to follow the systems over a longer time period to understand whether the same positive effects are sustained.

The ISO 39001 will soon be ready for user implementation. The management standard is based on PDCA. Research on how ISO 39001 have a safety impact on organisations using it will be of significant importance.

7 CONCLUSIONS AND RECOMMENDATIONS

A method based on PDCA for the evaluation of safety effects has been presented and tested. The method spans from early verifications of the safety effect by analysis of mass data to analysis of in-depth studies.

A clear definition of the aim and the target for a safety system is essential for the hypothesis generation prior to evaluation. The integrated safety chain model was found to be a good tool to describe the functions of modern vehicle safety technologies.

It is important to prepare for data collection already when a new system is put on the market. Evaluations are made more simple and precise if there are ways to keep track of which individual cars are equipped with the system under investigation.

Mass data in the form of police data or field observations can be used for analysis of the effects of ESC and SBR. Both systems have high effects on road traffic safety. Police data revealed a crash reduction effect of ESC at around 50% for crashes on roads with low friction. Field observations indicate that SBR reduce the number of unbelted drivers with around 80%.

To fully understand the safety potential of ESC and SBR it was found important to study the properties of loss-of-control crashes that cars with ESC were involved in as well as to understand factors around crashes involving unbelted drivers in cars with SBRs. The data set containing in-depth studies of fatal crashes gave possibilities to do this. It only takes one or a few cases to falsify a precisely put hypothesis. In a situation with fewer and fewer crashes resulting in death or serious injury, every individual case contains important information.

The use of the Vision Zero model for safe traffic made it possible to use a nonconformity approach. It was identified that for ESC equipped cars all loss-of-control crashes except one occurred with one or more other safety factors in the model not being fulfilled. If the other safety factors had been fulfilled the fatal outcome would have been avoided. For SBR if was found that the majority of unbelted drivers were committing suicide. When excluding suicides, 62 drivers were killed in crashes in cars with SBR. Only four of those drivers were unbelted.

Several of the ESC related loss-of-control crashes occurred when the driver was severely violating the traffic rules. When analysing road traffic safety it is important to clearly distinguish between violations and errors. A safe system should absorb errors, but can hardly be built to handle violations in a safe way.

The approach presented in this thesis can be generalised to other safety technologies than SBR and ESC.

It has been found crucial to make safety systems evaluations more precise and rapid to get maximum benefits for road safety. The PDCA approach presented in this thesis is a candidate to make that possible.

Recommendations

- The functional specifications and target of new safety systems should be clearly understood prior to evaluations
- The introduction of new safety systems should be planned and executed in a way to make precise and rapid evaluation of possible safety effects
- Cars should be equipped with possibilities to investigate the function of new safety systems
- The Vision Zero model for safe traffic could be used to identify nonconformities
- In the analysis errors should be separated from violations
- A study of the long-term effects of ESC or SBR should be performed
- The introduction of ISO 39001 should be monitored and the safety effects analysed
- A close cooperation between suppliers and road safety authorities should be encouraged

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