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OCCUPANT CASUALTIES IN BUS AND COACH TRAFFIC

-Injury and crash mechanisms

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Umeå 2005

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To my late grandfather
Kuno

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Preamble

There is a saying that the pen is mightier than the sword. It is possible that this might be valid for this thesis.

Early in the morning on the 26th of November, a coach started from Skellefteå bus station heading towards Umeå. For the people who boarded the coach this morning, many of them being commuters, it was an ordinary Monday with weather typical for the season. Rain mixed with snow was hanging in the air, the temperature was around zero degrees Celsius, and rough winds were tearing leaves off the trees. It was a relief for the passengers to enter the heated coach this morning. When the coach was about halfway to Umeå, it left the main road into a county road and was supposed to make a stop at the village of Robertsfors. Before entering the village, the coach was hit by a heavy cross-wind and the driver lost control of the vehicle.

At 08.18, the ambulance in Umeå was alerted by the dispatch-centre with information stating that a bus crash with about thirty injured had occurred. The author of this thesis was one of the paramedics that were called upon. When arriving at the crash site, a strange feeling entered the paramedics when facing the coach across the small river, was it an exercise or was it for real? When entering the crashed coach, another strange feeling occurred. Contrary to what was expected, there was almost a complete silence amongst the injured occupants. In addition, they were piled on the side windows with the black water from the small river about one meter underneath. A laborious and time-consuming rescue-work was undertaken.

Strangely enough, this event came to be, by different circumstances, both the end of the author's career as a "life-saving" paramedic and the starting point for a new; a life as a Ph. D. student. The experiences from this event have been very valuable and many times during the work with the thesis, reflecting thoughts have gone back to this Monday.....Hopefully, this thesis can live up to the saying that the pen actually can be mightier than the sword so that the author can keep up the "life-saving" business, however, from now on only with the pen.

Pontus Albertsson Umeå 1st March

Abstract

Background: The relevance of conducting this thesis is evident by the fact that bus and coach casualties have been “stubbornly stable” in Europe recent years and a need for investigating if a similar trend could be found in Sweden is therefore obvious. It was also important to add new knowledge to the bus and coach research in Sweden, since many areas were scarcely addressed.

Aims: To describe bus and coach occupants’ injuries, crash and injury mechanisms generated in a traffic environment based on data from the medical sector. Additional aims were to investigate the injury reducing effect of a 3-point belt, the effect of cross-winds, and crucial factors in the emergency- and rescue response.

Material and methods: Injury data analyses were based on a complete ten-year medical data set from a catchment-area with about 130,000 inhabitants. A number of crash studies with the scope in different crash phases were conducted by applying and elaborating the Haddon matrix as a framework. An additional framework, Protocol for Major Incidents was used in order to investigate the emergency- and rescue response to a severe coach crash.

Results: Between the first and second five-year period, the incidence of injured in non-crash incidents was increased by 24%. In non-crash incidents, 54% were injured; 2/3 while alighting from a bus or coach. The pre-crash factor cross-wind, in addition to vehicle design, vehicle speed and road friction, was investigated in ten crashes. It was confirmed that cross-wind, in relation to vehicle speed and slippery road conditions, needs more attention. The importance of goods loading and passengers’ position in the bus, was indicated by the fact that a displacement of the centre of mass rearwards with 10% increased the necessary coefficient of friction with, on average 45%, which in many cases corresponded to dry road conditions. Three Swedish rollover crashes were analysed with regard to the injury outcome, mechanisms and the possible injury reduction for occupants using a safety belt. A considerable increase in safety for occupants belted with 3-point belts was shown through limiting interior contacts, occupant interaction and the possibility of ejection. Crucial post-crash factors in the emergency- and rescue response showed that ordinary ways of working and equipment are not always useful and proper equipment for lifting a coach body is essential in the case of a rollover. Finally, the communication between the hospitals is important, and the telephone systems may be overloaded by calls from worried relatives and media.

Conclusions: *In non-crash events:* Non-crash events constitute a majority of all bus and coach casualties with a high proportion of elderly female occupants among the MAIS 2+ injury cases. Boarding and, especially alighting causes many injuries to the lower extremities.

In the pre-crash phase: Cross-winds do affect the safety of buses and coaches and requires more attention. Seat belt usage among bus and coach occupants has to be increased.

In the crash phase: Rollover and ejection are the major causes behind serious and fatal injuries to bus and coach occupants, consequently, retentive glazing, pillars or rails need more attention. An upgrade from 2-point seat belts to 3-point seat belts yields an increase in the estimated injury reduction from approximately 50% up to 80% for the MAIS 2+ casualties in a rollover crash.

In the post-crash phase: In order to be able to lift a coach body proper equipment originated from experience and development is essential in a rescue operation of a crashed bus or coach. Furthermore, to improve the emergency response inside crashed coaches proper methods originated from experience need to be developed.

Euro NBAP: Based on the results and conclusions generated in this thesis, a European New Bus and Coach Assessment Programme is suggested, which would provide bus and coach occupants with a assessment programme similar to the Euro NCAP.

Svensk sammanfattning

Betydelsen av att ytterligare arbeta med skadepreventiva åtgärder i busstrafik kan visas av att antalet skadefall relaterade till busstrafik i Europa har legat på en konstant nivå, jämfört med dem som inträffat i biltrafik vilka visat på en något sjunkande trend. Det var därför viktigt att undersöka om en liknande trend bland busskadefall kunde återfinnas i Sverige. Det var också viktigt att tillföra ny kunskap till ett flertal områden gällande säkerhet för bussar som hittills i Sverige varit sparsamt utforskade.

Syftet med avhandlingsarbetet har varit att studera krasch- och skademekanismer bland busskadefall. Ett annat syfte har varit att studera busskrascher utifrån ett katastrofmedicinskt perspektiv, med tonvikten på det akuta räddningsarbetet utfört av ambulans- och räddningspersonal. Analysen av skadefallen har utförts med hjälp av ett sjukvårdsbaserat datamaterial från en 10-årsperiod. Även ett antal djupstudier av busskrascher har utförts där passagerarna och räddningspersonalen intervjuats.

Resultaten visar på en ökning av antalet skadefall i det undersökta området med 24 %, sett mellan de två undersökta femårsperioderna. En majoritet (54 %) av alla skadefall tillhör kategorin ”icke-krascher” dvs. en skadehändelse som inträffar när bussen inte kolliderar med något eller någon. Typfallet för en moderat skada eller svårare (MAIS 2+) i en ”icke-krasch” kan beskrivas vara en 57-årig kvinna som skadar benet i ett fall när hon kliver av bussen. Tidpunkten för skadan är att det inträffar en vardagsmorgon i rusningstid under någon av vintermånaderna.

När bussen kraschar mot något annat fordon eller går av vägen blir det i regel flest svåra skador vid singelkrascher ute på en landsväg där hastigheterna i regel också är högre. I dessa singelkrascher är det vanligt att bussen går av vägen åt höger sida, välter och landar på höger sida. Passagerarna löper då stora risker att skada sig och speciellt när rutorna på höger sida krossas. De kan då klämmas fast under bussen med stor risk för svåra eller dödliga skador. Ett 3-punkts säkerhetsbälte ger ett bra skydd för de flesta passagerarna, förutom de som sitter närmast sidan som slår i marken. För dessa passagerare behövs andra åtgärder i form av skyddslister eller ”okrossbara” rutor för att de inte ska skadas. Typfallet för en MAIS 2+ skada vid en busskrasch kan beskrivas vara en 37-årig kvinna som sitter närmast den sida som slår i marken när bussen välter åt höger. När bussen glider över marken krossas sidorutorna vilket gör att personen hamnar under bussen med kroppen.

Det faktum att vinden i kombination med halt väglag är en viktig faktor att ta hänsyn till har påvisats i denna avhandling. Bakgrunden till att det uppmärksammats är att Statens haverikommission i en undersökning av en svår busskrasch med 62 skadade tog initiativet till ett vindtunnelförsök där en beräkningsmodell framtoogs. Denna beräkningsmodell har sedan använts i denna avhandling i en studie av 10 busskrascher där föraren uppgett vinden som orsak till att bussen gått av vägen. Resultaten visar att vinden med stor sannolikhet bidrog till kraschen i samtliga fall. Även placeringen av passagerare och gods i bussen visar sig vara viktigt för förarna och entreprenörer att ta hänsyn till då en lastförskjutning bakåt i bussen ställer större krav på hög friktion jämfört med en normalt lastad buss.

Busskrascher har även studerats ur ett katastrofmedicinskt perspektiv då dessa krascher ofta innehåller många svårt skadade som ställer stora krav på omhändertagandet. Den

trånga och svårarbetade miljön inne i en kraschad buss medför svårigheter att arbeta då ordinarie rutiner och utrustning för omhändertagande av skadade inte alltid kan användas.

De viktigaste slutsatserna i denna avhandling är:

- Det är förhållandevis säkert att åka buss jämfört med andra transportsätt på landsvägar.
- Skador relaterat till busstrafik har dock legat på en envist stabil nivå i Europa och samtidigt kan en ökning av skadefall skönjas i Sverige.
- Data från sjukvården är generellt sett bättre att använda jämfört med den officiella statistiken när skadepreventiva åtgärder ska föreslås.
- Kraftiga sidovindar kan påverka bussar och mer uppmärksamhet bör ägnas åt studier av bussars aerodynamiska egenskaper.

I “icke-krascher”:

- “Icke-krascher” utgör en majoritet av alla skadefall relaterat till busstrafik.
- Det är en stor andel av äldre kvinnor bland de skadade med MAIS 2 + skador.
- På- och avstigning och speciellt avstigning är ett kritiskt moment under en bussresa som är upphov till många skador i de nedre extremiteterna.
- När bussen är i rörelse är häftiga inbromsningar en vanlig skadeorsak.

I pre-krasch fasen:

- Säkerhetsbältesanvändningen bland busspassagerare är låg och fortsatta insatser för att öka användningen är önskvärda i framtiden.

I krasch fasen:

- Vältningar, speciellt vältningar åt höger sida är en vanlig kraschmekanism vid singelkrascher. Vid dessa krascher löper passagerare stor risk att kastas ut och klämmas fast under bussen med svåra och dödliga skador som följd. Följaktligen bör åtgärder för att förhindra denna typ av skador ägnas mer uppmärksamhet.
- Ett 3-punktsbälte ger ett avsevärt bättre skydd för busspassagerare jämfört med ett 2-punktsbälte. Vid vältningar skulle cirka 80 % av alla MAIS 2+ skador reduceras med ett 3-punktsbälte.

I post-krasch fasen:

- Bättre metoder rörande teknik/taktik bör utvecklas för att lyfta en buss liggandes på sidan i syfte att frigöra utkastade och fastklämda personer. Även bättre metoder för omhändertagande av skadade personer inne i kraschade bussar bör utvecklas. Dessa metoder bör baseras på den erfarenhet som finns inom området.

Baserat på resultaten och slutsatserna denna avhandling föreslås ett nytt “star rating” program kallat Euro NBAP gällande för nya bussar liknande det som idag finns för personbilar (Euro NCAP). Euro NBAP programmet skulle kunna fungera som en katalysator för uppmuntrande av säkrare design lösningar vid utvecklandet av nya bussar. Det skulle även underlätta för resenärer och upphandlare av bussresor att ta ställning till vilka bussar de hellre utnyttjar. Ett exempel på säkerhetslösning som kunde uppmuntras är om bussen är utrustad med ett 3-punktsbälte på alla platser.

List of original papers

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals, I-V.

- I. Björnstig, U., Albertsson, P., Björnstig, J., Bylund, P.O., Falkmer, T., & Petzäll, J. (2004). Injury Events among Bus and Coach Occupants – Non-crash Injuries as Important as Crash Injuries. Submitted 2005.
- II. Albertsson, P., Björnstig, U., & Falkmer, T. (2003). The Haddon Matrix, a Tool for Investigating Severe Bus and Coach Crashes. *International Journal of Disaster Medicine*, Vol. 2, pp. 109-119.
- III. Petzäll, J., Albertsson, P., Falkmer, T., & Björnstig, U. (2004). Wind Forces and Aerodynamics, Contributing Factors to Compromise Bus and Coach Safety? *International Journal of Crashworthiness*. Accepted 2005.
- IV. Albertsson, P., Falkmer, T., Kirk, A., Mayrhofer, E., & Björnstig, U. Case study: Three Rollover Coach Crashes in Sweden - Injury Outcome, Mechanisms and Possible Effects of Seat Belts. Submitted 2005.
- V. Backman, K., Albertsson, P., Pettersson, S., and Björnstig, U. Report from a major traffic incident: The Severe Coach Crash in Ängelsberg, Sweden, 2003 (2005). *International Journal of Disaster Medicine*. In press.

Abbreviations

The following abbreviations are used in the text:

ADAS	Advanced Driver Assistive Systems
AIS	Abbreviated Injury Scale
ALP	Ambulance Loading Point
ALR	Automatic Locking Retractor (device in seat belts)
CM	Centre of Mass
ECBOS	Enhanced Coach and Bus Occupant Safety project
E.D.	Emergency Department
FIC	Fire Incident Commander
EHLASS	European Home and Leisure Injury Surveillance System
ELR	Emergency Locking Retractor (device in seat belts)
EU	European Union
HIC	Head Injury Criterion
ITRD	International Transport Research Documentation
IS SWEDE	Information System SWEDE (System for transmission of on-line information from ambulances to hospitals)
KSI	Killed or Seriously Injured
MADYMO	Mathematical Dynamic Model (engineering software tool)
MAIS	Maximum Abbreviated Injury Scale
MEDLINE	Medical Literature, Analysis, and Retrieval System Online
MIC	Medical Incident Commander
OECD	Organisation for Economic Co-operation and Development
PIC	Police Incident Commander
PsycINFO®	Psychological Abstracts
SHK	The Swedish Accident Investigation Board
SNRA	The Swedish National Road Administration
SOS Alarm	The dispatch centre in Sweden receiving emergency calls
STRADA	Swedish Traffic Accident Data Acquisition
SMHI	Swedish Meteorological and Hydrological Institute
SRSA	Swedish Rescue Services Agency
TRIS	Transportation Research Information Services databases
ULTRA	Umeå Local Traffic Corporation
VITS	The Swedish National Road administration's Information system for traffic safety
VVIS	The Swedish National Road administration's Road and Weather Information System

Keywords: Bus, coach, aerodynamics, crash, non-crash, cross-wind, injuries, weight distribution, road friction, restraints, Haddon's matrix, prevention, severe crash, mass casualty, major incident, alighting, boarding, incidents.

The Swedish bus history

In the following section a brief summary of the Swedish bus history is conducted with focus on the two main bus and coach manufacturers Scania and Volvo's history, respectively.

Industrialisation began in England in the mid-18th century and reached Sweden a century later. This evolution came to affect society in many ways. To travel, in a modern sense, became a new phenomenon not only for a privileged few. The industry soon generated a demand to transport raw materials, products and people to and from factories. This fact rather quickly outstripped the present mode of transport; horse and cart. The railway was the first established efficient passenger transport system on land over longer distances. In urban areas, the horse was still holding its position with the horse-drawn omnibus as a comfortable and reliable mode of transport. The Latin word omnibus (meaning "for all") soon became a word denoting a form of transport suitable for all (Nordström & Nyström, 1990).



Figure 1. The first motor omnibus in Stockholm 1899 with iron-shod timber wheels. Photo from the Nordic Museum archives.

The first motor omnibus used in Stockholm came into use in 1899 (Figure 1) but was taken out of use after eight days because of the noise from the iron-shod timber wheels and it was not until 1923 motor buses were operating in the capital's streets again. At that time manufacturers in many countries started to understand the potential of the motor-car. The first two Swedish manufacturers in the automotive industry were Vagnfabriken and Scania (Nordström & Nyström, 1990). Later on, Volvo became another participant in the Swedish omnibus market.

In 1911, Vagnfabriken and Scania merged into one company, Scania-Vabis, in the beginning with the focus mainly on heavy trucks. However, the first real bus equipped with permanent sides, windows, roof and a door, left the factory the same year the companies merged but it was not until 1922 bus production was continuous. The company collaborated with the Swedish Post Office in developing vehi-

cles designed to carry mail in the northern parts of Sweden (Nordström & Nyström, 1990) (Figure 2).



Figure 2. The first Scania-Vabis motor post bus in traffic 1922 between Lycksele and Tvåålund, Västerbotten, Sweden. Here equipped with skis on the front wheels. Photo from Gert Ekström's collection.

Examining the market segments back in 1924, the owners of Volvo realised that they should invest in large commercial vehicles, such as trucks and buses. The first Volvo bus built on a truck chassis left the factory in 1928. Some of these buses were a “saloon” type with a door ahead of each seat (Figure 3). In order to challenge the larger and more expensive Scania-Vabis buses Volvo launched a small, economical and robust bus at a reasonable price. In 1934 Volvo started to build ‘real buses’ on bus chassis although buses built on truck chassis were continued to be produced for many years (Olsson, 2001).

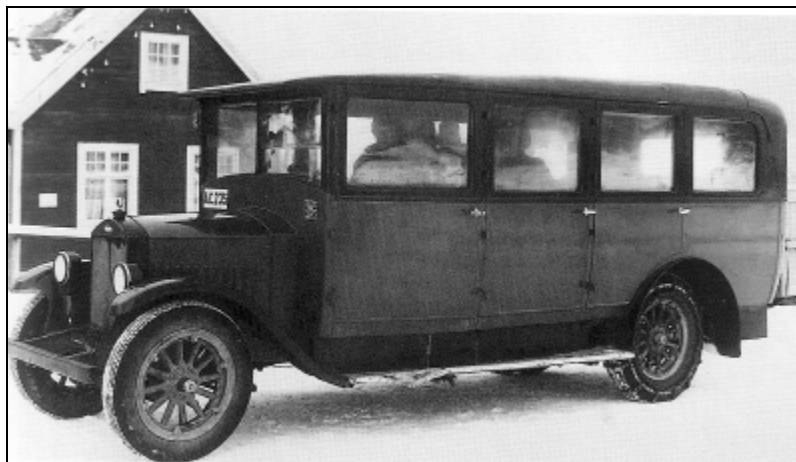


Figure 3. A common model of a four-cylinder Volvo bus built on a truck chassis from late nineteen twenties. Photo from Volvo central archives.

Scania-Vabis and Volvo did not just build their own buses; they also collaborated with other companies and distributed chassis to factories where they developed their own bus models. This collaboration started in the mid-nineteen thirties and is still ongoing for both Scania-Vabis and Volvo. At the end of the nineteen thirties, Scania-Vabis and Volvo were the only Swedish bus manufacturers left.

The Second World War broke out in 1939 and although Sweden remained neutral, major sections of the industry switched to military productions. The bus production for civil use was almost completely shut down in favour of trucks and armoured vehicles needed for military use. The shortage of materials and fuel also affected the bus industry in a negative way. However, at the end of the war, both Scania-Vabis and Volvo experienced a period of expansion in the bus production, due to the priority of truck production during the war. Many new models were introduced with diesel and turbo engines as important milestones. In the mid-nineteen sixties, Scania-Vabis (company name changed to Scania in 1968) concentrated their production to rear-engined models, while mid-engined models became synonymous with Volvo buses (Nordström & Nyström, 1990; Olsson, 2001).

The low fuel prices in the nineteen sixties made the share of buses to expand at the expense of tram and trolley buses in many Swedish cities. A major event that affected bus production at the end of the decade was the switch to right-hand traffic in 1967. Older buses become difficult to use in public transportation due to the doors suddenly being on the “wrong” side. Some older buses were thus modified with doors fitted on the left side but many buses were exchanged for new models with doors on the right side (Nordström & Nyström, 1990).

Scania and Volvo have today expanded and have a world-wide representation, both taking part in developing their own bus models (chassis and bodies) and cooperating with other coach body-builders by delivering chassis. Volvo is today the second largest bus manufacturer in the world, with a product range of city buses, intercity buses and tourist coaches while Scania is on fourth/fifth place in the world with its production concentrated on bus chassis, intended for use as tourist coaches as well as urban and intercity buses.

Background to this thesis

Research process and the relationship between the papers

The research process and the relation between the different papers of this thesis are illustrated in Figure 4. The process started with an identification of the different problems that bus and coach occupants (i.e. driver, member of the crew and passenger) might be exposed to during a journey with a bus or coach and continued with an analysis of a hospital based data set from a ten-year period. The next step was to investigate a number of severe coach crashes and for this purpose a suitable method was used and further elaborated. The final step was to investigate severe coach crashes with focus in the three crash phases, pre-, crash and post-crash phases respectively. Paper V, combined the previously used method with a method used in the disaster medicine discipline. Finally, conclusions were drawn at the end of the research process.

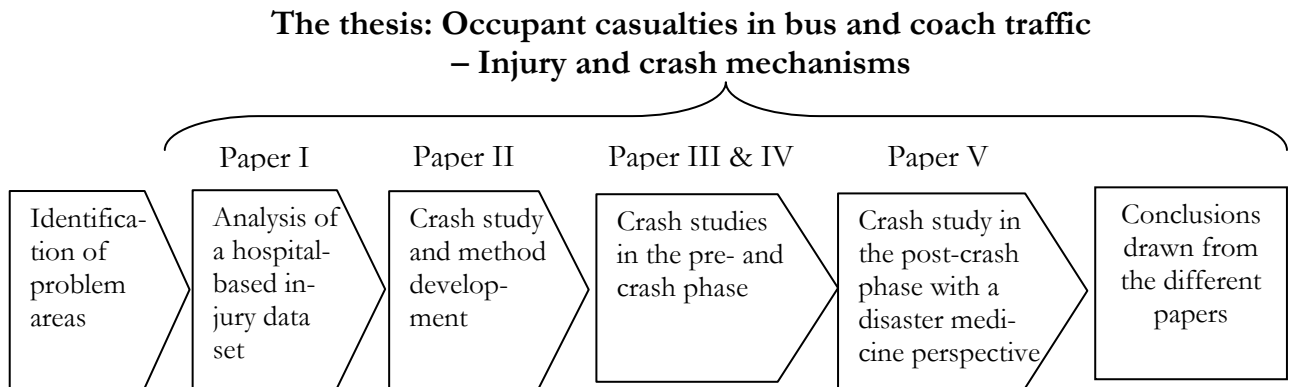


Figure 4. Illustration of the research process and the relationship between the papers.

The thesis in relation to the “Travel Chain Perspective” framework

A bus or coach journey could be seen from a wider perspective, meaning that the entire journey from door to door is taken into account. This perspective is called “The Travel Chain Perspective” (Carlsson, 2002; Iwarsson et al., 2000). Placing this thesis into the “Travel Chain Perspective” framework we find that its scope lies between when occupants are boarding a bus or coach and ends when occupants are alighting from the bus or coach, as shown in Figure 5. More precisely; the first step when boarding the bus or coach is included in this thesis, as well as the step down to the ground when alighting from a bus or coach.

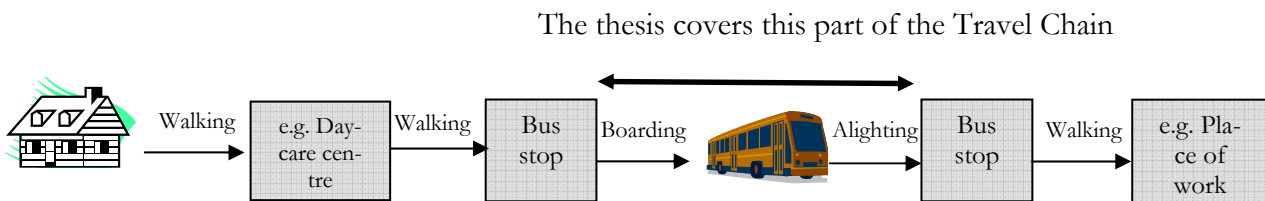


Figure 5. Position of the thesis in relation to the “Travel Chain Perspective”

The main reason for limiting this thesis to cover just this part of the travel chain was that the scope bus and coach occupants comprises a different perspective concerning injury mechanisms, compared to the rest of the travel chain. For example, a pedestrian is facing a certain risk (Forsström, 1982) when taking a journey by foot and this risk is not necessary connected to if the pedestrian is heading for a bus stop or not. A pedestrian heading for a bus stop but not yet at the bus stop will in injury databases (for example Swedish Traffic Accident Data Acquisition (STRADA) and European Home and Leisure Injury Surveillance System (EHLASS) in Sweden and STATS 19 in U.K.) be coded as a pedestrian in case of an injury. Thus, it is difficult to use official databases when searching for pedestrians heading for a bus stop.

Important problem areas in bus and coach research

Data concerning bus and coach incidents are presented in international literature in virtually as many ways as there are articles on the topic, which make it difficult to compare statistics (ECBOS, 2001; Transport Canada, 2002; Albertsson & Falkmer, 2005). One way of solving this problem might be to sort the information into different categories which was done in this thesis, as shown in Figure 6.

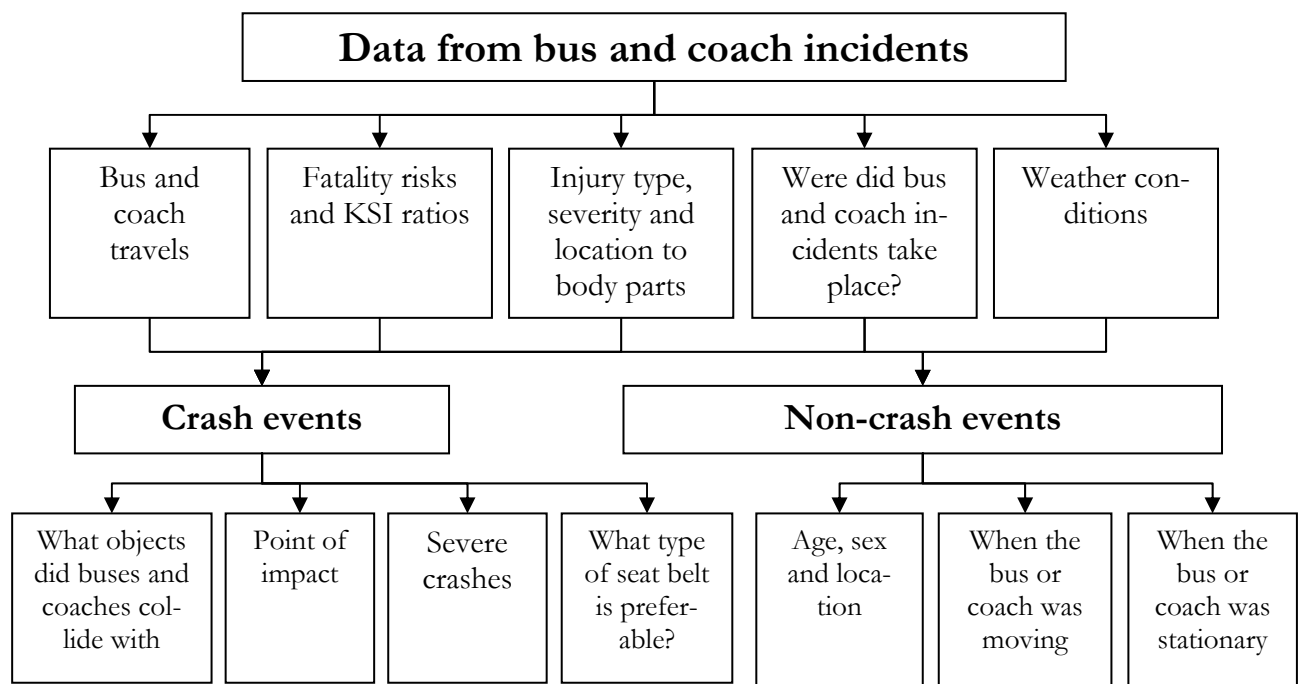


Figure 6. Problem areas in bus and coach related research structured into subheadings (Albertsson & Falkmer, 2005).

The first step in the process was to use the term *bus or coach incident*, in order to cover all types of injury and crash events related to bus and coach traffic. The rea-

son for using this term is that previous research (Falkmer et al., 2001; Falkmer & Gregersen, 2001; Kirk et al., 2001; Simpson, 1997; Wretstrand, 1999) have indicated that injuries occur even though the bus or coach did not crash, i.e. a non-crash event. The next step was to sort the data depending on type of event into their category. The final step was to identify problem areas in the different categories. The subcategories crash and non-crash events are further explained in the following sections.

Crash events

Injuries sustained in a crash event do occur when the bus or coach is crashing into another vehicle or object. Crash events could be further divided into collisions with other vehicles and single crashes. In collisions with other vehicles a bus or coach might collide with a car, lorry or another bus or coach. Collisions with other vehicles might be further divided into different points of impact, like for example, side or frontal.

The injury outcome of a crash is dependent on what type of crash mechanism the bus or coach occupants are being exposed to, e.g. frontal collision or rollover. Botto et al. (1994) investigated injury mechanisms in 47 real world crashes and divided the injury mechanisms into five categories, namely;

1. Projection; occupant interaction with other occupants and the interior of the coach.
2. Total ejection; the occupant being ejected or thrown out of the vehicle.
3. Partial ejection; part of the occupant's body thrown out of the compartment.
4. Intrusion; the occupant being injured inside the vehicle, due to structural deformation or intrusion of an object.
5. Inhalation of smoke following a fire.

This definition of injury mechanisms is frequently used throughout this thesis, and especially in the papers concerning crashes (Paper II-V).

Non-crash events

Injuries sustained in a non-crash event occur when the bus or coach is not crashing into another vehicle or object. Examples of this are injuries sustained when boarding or alighting from a bus or coach. Slipping or tripping on wet or icy steps might be a common reason for these injuries (Albertsson & Falkmer, 2005). Other examples of non-crash injuries are injuries sustained when a driver, due to the traffic situation, is forced to perform harsh braking, which forces the occupants out of their positions, hitting the interior inside of the vehicle (Albertsson & Falkmer, 2005).

Theoretical frameworks for investigating bus and coach crashes

As shown in previous section, there are many potentially important factors in investigations and studies of severe bus or coach crashes, which present significant challenges to researchers. The problem with disparate pieces of information and no coherence on crash data have been discussed in a meeting by a task force on transport incidents at the 13th World Congress on Disaster and Emergency Medicine. The participants particularly highlighted bus and coach crashes, and a suggestion was proposed that a common tool for investigating severe bus and coach crashes would be desirable (Örtenwall, 2003). One reason for having such a tool is that the outcome could be used as a scientific basis in the education and training in disciplines such as emergency and disaster medicine (Lennquist, 2003a). Another reason could be for developing measures that could prevent the crash from occurring in the first place, and also in case of a crash, work out measures that might reduce the outcome of it.

It is thus important to find a framework that is suitable for these purposes and that includes all the stages and factors in a crash. For example, if the cause behind the crash is the objective, the investigation has to be concentrated on the time before the crash took place. Another example is if the objective is to find measures to protect the driver in case of a crash, then the actual crash the area which the investigation has to be concentrated on.

In the following sections three methodological frameworks are presented of which the first two— Haddon's matrix and the Protocol for Major Incidents— are used in this thesis.

Haddon's matrix

Haddon's matrix, developed by William Haddon Jr. (Haddon, 1972), is a relevant framework that has been frequently used for structured analyses of traffic injury events. In the matrix, the contribution of human, vehicle/equipment and environmental factors to the injuries are based on the sequences in a crash where the;

- pre-crash phase, determines whether a crash actually takes place.
- crash phase, determines whether injury occurs and its nature.
- post-crash phase, determines to what extent the personal injuries is limited.

In Table 1 is shown the factors and the phases with examples of factors of interest in each cell.

Table 1. Haddon's matrix (Haddon, 1972).

Factors Phases	Human	Vehicle/equipment	Physical environment	Socio-economical environment
<i>Pre-crash</i>	Driver behaviour	Tyre type	Road design	Company policy
<i>Crash</i>	Injury outcome	Rollover protection	Guard rail	Legislation
<i>Post-crash</i>	First aid	Emergency exits	Weather conditions	Training of ambulance personnel

The matrix can be used in three ways; either to analyse data or to suggest counter-measures or both. In the pre-crash phase an example could be crash avoidance strategies, in the actual crash phase improved crashworthiness measures (Evans, 2002), and in the post-crash phase actions which facilitate emergency response and medical intervention.

Haddon matrix has been frequently used throughout the papers in this thesis. In Paper II it was applied on a severe coach crash and further elaborated and used in Paper III, IV and V with the scope of the Papers in the different phases respectively.

The Protocol for Major Incidents

In Paper V, the prospective standardized methodology *Protocol for Major Incidents*, suggested by Lennquist (2003c) was used. This methodology has its scope focused on the post-crash phase i.e. the initial response of the rescue forces and the receiving hospitals. Alert routines, pre-hospital and hospital resources, communication systems and injury outcome are examples of factors in the protocol. In Table 2 is shown an example of a box that is used in the protocol to gather information.

Table 2. Example of box used in the Protocol for Major Incidents.

Box 4. Hospital alert plan and response (include all involved hospitals in the same table)

<i>Name of hospital</i>	<i>Distance to scene</i>	<i>Hospital alerted (yes/no)</i>	<i>Disaster plan available (yes/no)</i>	<i>Disaster plan activated (yes/no)</i>	<i>Receiving first patient (time)</i>

Important to note is that the protocol gathers all experiences, not only the cases where the rescue work was performed optimally, but also cases where things did not work out as well as planned (Lennquist, 2003b). The main reason to include these experiences in the scientific basis is that it is needed in the education and training in disaster medicine (Lennquist, 2003a).

Jovanis model

Another model or conceptual framework that takes the special conditions for buses into account is the Jovanis et al. (1991) model. It was developed in order to be able to structure, and thereby to compare, crash statistics. While the Haddon matrix includes the four factors, human, vehicle/equipment physical and socio-economical environment, the Jovanis model includes a fifth, namely the “Transit service characteristics and agency policies”.

In the Jovanis model, the four factors, as well as “Transit service characteristics and agency policies” interact to define a particular level of crash risk. This level results in a certain probability of having a crash and when combined with exposure to risk this yields a certain number of crashes (Jovanis et al., 1991). Jovanis et al. (1991) argues that it is practical to separate the four factors from those controlled by the transit agency because, for example, promotions for safe driving may act as a motive for safe driving. The primary shortcoming of Jovanis’ model is that only the driver of all occupants are included, and thus making any analyses of occupant injuries impossible within the model.

How safe is it to travel in buses and coaches?

One way of measuring fatality rates could be to measure the proportion of bus and coach fatalities in relation to all traffic fatalities. It is perhaps the most reliable method for international comparison of bus and coach incidents, since fatalities are normally well investigated and, hence, the information gathered is to be considered reliable. A figure of 0.3% of all road fatalities was reported for Germany, and France both figures being stable over time. Bus and coach fatalities represented on average 0.5% of all road traffic related fatalities in the countries covered by the Enhanced Coach and Bus Occupant Safety-project (ECBOS). However, the differences were large, for example only 0.1% in the Netherlands compared to 1% in Spain (ECBOS, 2001; Albertsson & Falkmer, 2005).

The ECBOS project also calculated KSI rate for different categories of road users in Sweden. The KSI rate for car occupants were about 7-9 times higher and for pedestrians 3-54 times higher compared to bus and coach occupants (ECBOS, 2001; Albertsson & Falkmer, 2005).

Classification and use of buses and coaches

Buses and coaches are generally defined and named after purpose and use, instead of after a common universal definition. In Europe, the term bus is used to describe a city bus used for short term transportation of people on urban streets, carrying standing and seated passengers. Other buses in this category are local buses and transit buses. The inter-city bus describes another type usually carrying seated passengers, but designed with areas for standing passengers and used on both urban

and rural roads. One example in this category is a transfer bus going to and from the airport. Coach is yet another type, which generally covers vehicles transporting seated passengers on long distances on rural roads. They are also called tourist/touring coaches or long distance coaches (Albertsson & Falkmer, 2005). “Double-deck vehicle” is a coach with two superimposed levels and spaces for standing passenger are not provided in the upper deck (Directive 2001/85/EC, 2002). Within the EU, the M-definition was constructed and used, in order to include all road vehicles under a common classification classifying vehicles after seating capacity, usage and weight. M1 are vehicles with no more than 8 passenger seats (the Swedish “mini-buses” are included in this group). M2 are vehicles with more than 8 passenger seats and a mass not exceeding 5 tonnes, while M3 are M2 vehicles but with a mass exceeding 5 tonnes. The M-definitions are further divided into classes (I-III) depending on purpose and use (Directive 70/156/EEC, 1970).

The concept bus translated into the M-classification means M2 or M3 vehicles class I, with areas for standing passengers to allow for their frequent movements. Coach means M2 or M3 vehicles class II and III, where class II are vehicles principally for carriage of seated passengers and designed to allow standing passengers, while class III are vehicles designed for seated passengers, exclusively (Albertsson & Falkmer, 2005). The most common bus type with 47% of all buses in Sweden are buses with room for 70 occupants or more (seated and standing) i.e. a M3 bus class II or III. This bus type is also the most frequent type in crash statistics (72%) (SIKA, 2002b).

Regarding the Swedish bus fleet distribution over year models, it is noticeable that a majority (52%) of all registered M3 buses are not older than five years but one fifth is older than 11 years. Older buses are also used in traffic and they represent 23% of the total annual mileage done by buses and coaches. Buses and coaches are also operating in different traffic environment. As shown in Table 3, 35% of all buses and coaches are operating in rural traffic, while 27% are operating in urban traffic. In tourist and charter traffic, 19% of all buses and coaches are engaged. Together, Volvo and Scania, the two main manufacturers of buses and coaches in Sweden dominated 84% of the market (SIKA, 2002b).

Table 3. No. of buses distributed over type of traffic (SIKA, 2002b)

Type of traffic	No. of buses
Rural traffic	4,500 (35%)
Urban traffic	3,500 (27%)
Tourist and charter traffic	2,500 (19%)
School traffic	1,800 (14%)
Long-distance traffic	400 (3%)
Other traffic	200 (2%)
Summary	12,900 (100%)

Bus and coach journeys in Sweden

Buses and coaches constitute approximately 1% of the vehicle fleet in Sweden, which is a representative share for all 15 European Union member countries in 1996 (OECD, 1996). In Sweden, bus and coach travelling share constitutes 10% of the annual road travelling per person, vehicle and kilometres (Nilsson, 1997), due to the fact that these vehicles are generally built to transport a significant number of occupants.

Travel data from a local district in Sweden were collected from the catchment-area of the University Hospital in Umeå. The data were collected from the local traffic company in Umeå (ULTRA), and from Länstrafiken AB, responsible for the regional bus and coach traffic. It should be noted that the regional journeys cover a larger area and population than the catchment-area of University Hospital in Umeå, but the majority, 75% of these journeys were made to and from the catchment-area, in which half the county's population lived (Å. Larsson, Länstrafiken Västerbotten, personal communication, September 2004). Travel data from the bus company and bus operator showed that the number of local passenger journeys made with ULTRA during a 10-year period was characterized by an increase from 4.7 million journeys in 1994 to a peak in 1998 with 5.4 million journeys, and then a decrease in 2003 to a level almost equal to the number of journeys in 1994. Contrary to this finding, statistics from Länstrafiken AB showed a steady increase from 3.9 million journeys in 1994 to 4.2 million journeys in the year 2003. If data from the two operators are compiled, a slight increase over the years is shown.

A forecast for future coach passenger transports shows that long-distance travels over 100 km are about to increase with 24% over the years 1997-2010, while short journeys up to 100 km done by buses and coaches will increase only by 5% over the same period (SIKA, 2002a).

Travel data, age groups and sex

Women tend to travel more frequently on local buses compared to men. This was shown in a local travel survey conducted by the authorities in Umeå (Umeå municipality, 1999). The travel survey covered 2,540 persons between the ages 16 and 74. The response rate was 79%. In the survey, 47% men and 53% women participated and the responses distributed over age groups corresponded well to the general population in the investigated community, i.e. a population with a mean age of 37 years. The results showed that women used the bus as mode of transport in 12% of their journeys, while the corresponding figure for men was 5%. When the number of journeys was distributed over age groups, the age group 16-17 years had the highest share of bus journeys (30%), while the corresponding shares for the age groups 45-64 and 65-74 was 6% and 5%, respectively (Umeå municipality, 1999). These results correspond well to a travel habit survey done on a national

level (Thulin, 2004). A similar pattern was also found in other European countries. In for example the U.K., women travel longer distances on local buses and also more frequently compared to men. Local bus travel was also more frequent among people aged 17-20, compared to other age groups (Department for Transport, 2000).

Classification of injuries and fatalities

The Abbreviated Injury Scale (AIS) is used in many reports utilizing hospital data and/or medical records (Association for the Advancement of Automotive Medicine, 1998). This classification was also used in this thesis.

The maximum injury severity is abbreviated MAIS. Injury severity according to AIS is, minor injury (AIS=1) e.g. superficial contusions, moderate injury (AIS=2) e.g. concussion, serious injury (AIS=3) e.g. femur fracture, severe injury (AIS=4) e.g. blood in the pleural cavity, critical injury (AIS=5) e.g. intracranial haemorrhage, maximum injury (AIS=6) e.g. decapitation.

The injury categories fatal, serious and slight are often used in official statistics in Europe, but with many differences. For example, in the U.K. the term fatal injury includes the possibility of the victim dying up till 30 days after the incident, while the corresponding time for Spain is only one day. The definitions of a serious injury are also rather disparate, but characteristically a seriously injured person is treated as an in-patient at a hospital. The disparity is also apparent between different countries in the definition of the term slight injury (ECBOS, 2001). Examples of serious injuries are fractures, concussion, internal injuries or crushing, while a slight injury could be a sprain, bruise, or cut. Killed or seriously injured (KSI) is yet another term used in some reports, in which fatal and serious injuries are compiled, see for example Kirk et al. (2001).

Why data from the medical sector are more useful than police data

In this thesis, data from the medical sector was used. The difference in the coverage between injury data from the medical sector and police injury data is the main reason for this decision. This is especially essential when suggesting measures based on injury analyses. For example, in the Swedish part of the ECBOS-project it was noted that only 35% of all injuries reported by the medical sector could be found in police data (ECBOS, 2001). Other sources in Sweden have reported similar results (Björnstig et al., 2001; SIKA, 2001). The police reported statistics cover serious injuries more extensively, but to a lesser extent regarding slight injuries (Bylund et al., 1999). The main reason for not reporting slight injuries is that the police do not investigate all traffic incidents; they only investigate the ones they are called to, which are serious crashes or other events when traffic control and crash investigations are needed.

Legislation and function of seat belts in buses and coaches

In Sweden, compulsory seat belt use in buses equipped with seat belts has been legally regulated since 1986. If the occupant is under fifteen years of age, it is the driver's responsibility to see to it that the law is upheld (Road traffic regulation chap. 4. 10 §). From January 2004 it is compulsory to have seat belts installed in all new buses and coaches in Sweden (except city-buses).

A number of EU-directives declare the technical demands and descriptions of seats, seat belts and seat belt anchorages. These directives are incorporated in each member country's own legislation. In Sweden, the EU-directives are incorporated in Swedish National Road Administrations (SNRA) regulations concerning vehicles and their equipment (SNRA, 2002a).

A seat belt in a bus or coach is usually one of the following types:

2-point (lap belt) is a belt which passes across the front of the wearer's pelvic region.

3-point belt is any belt assembly which is anchored at three points and is a combination of a 2-point belt and a diagonal belt.

The adjustment, extraction and in case of a crash, the locking are managed by a extractor. In buses and coaches, basically two types of extractors are used, technically known as Automatic Locking Retractor (ALR) and Emergency Locking Retractor (ELR) respectively. The ALR is described in Directive 77/541/EEC pp 0095 (1977) as "A retractor allowing extraction of the strap to the desired length and which, when the buckle is fastened, automatically adjusts the strap to the wearer. Further extraction of the strap is not possible without deliberate action on the part of the wearer".

The ELR is described in Directive 77/541/EEC pp 0095 (1977) as "A retractor which, in normal driving conditions, does not restrict the freedom of movement of the wearer of the seat belt. It has a length adjusting device which automatically adjusts the strap to the wearer, and a locking mechanism actuated in an emergency by deceleration of the vehicle, extraction of the strap relative to the retractor or any other automatic means (single sensitive) or any combination of these factors (multiple sensitivity)".

Previous bus and coach projects

A European project, called Enhanced Coach and Bus Occupants Safety, ECBOS, was conducted between the years 2000 and 2003. The project co-ordinator was Technical University Graz while several other universities in Europe were contractors, for example Loughborough University, U.K. and Universidad Politecnica de Madrid, Spain. It was funded by the European Commission and the scope was to identify the correlation between the current test approvals for buses and coaches

and the real-world crash incidents. The reasons for conducting the project were the inadequacy of fatality and injury rates in bus and coach crashes and also the lack of research on general bus and coach safety (ECBOS, 2001). The project also studied rollover bus and coach crashes by considering national data analyses, overall analyses of an in-depth database of cases collected in ECBOS, analyses of computer simulations, test section modelling and individual case analyses (ECBOS, 2002). The project resulted in suggestions for a number of new regulations and written standards. The project recommended for example, strongly the use of seat belts during a rollover and 3-point belts in frontal and rear end collisions. The project also recommended a new regulation concerning partial ejection through side windows and that the contact load with the side (window or structure) should be minimized. In this thesis, a co-operation with members of the ECBOS-project from Loughborough University and Technical University Graz was undertaken in Paper IV incorporating their experiences and results in the paper.

Another project was committed by Transport Canada in 2002. The results of a review of bus occupant protection research and regulatory practices in Canada, the United States, Australia and Europe are described in their report. The focus of the study was on occupant safety in intercity buses and issues for future consideration. The key findings in the review were (Transport Canada, 2002);

- There is no common definition for different types of buses.
- There is little harmony or detail in the classification of bus types in collision data.
- Rollovers and ejections are the major causes of serious and fatal injuries to bus occupants.
- 2-point belts are not the preferred manner of restraint.
- 3-point belts are effective in preventing injuries and ejections.
- Retentive glazing may also reduce the risk of ejections.
- Retrofitting of seat belts is difficult and costly when the floor structure is not strong enough to take the loads.
- Bus seats with integral seat belts are available without weight penalty.
- Regulations in Australia and Europe regarding the strength of the bus's superstructure, seat attachments and seat belts generally reflect real world collision data.

In order to identify and describe a pattern in Europe for bus and coach incident related injuries and fatalities, a literature analysis was performed by Albertsson & Falkmer (2005). The main conclusions of the present literature analysis were that;

- Women travelled more frequently by bus compared to men, and injuries sustained predominantly affected women 60 years of age or older.

- Bus and coach fatalities represented only 0.3-0.5% of all traffic fatalities, it is in fact comparatively safe to go by bus.
- Fatalities were more frequent on rural roads, although a vast majority of all bus and coach casualties occurred on urban roads.
- Boarding and alighting caused about 1/3 of all injury cases.
- Rollovers occurred in almost all cases of severe coach crashes.
- A 3-point belt is the most preferable safety belt in buses and coaches.
- Ejection is the most dangerous injury mechanism in bus and coach crashes, consequently should more attention be given to measures like retentive glazing, pillars, rails or similar systems that prevent occupants from being ejected.

Relevance of this thesis

The relevance of conducting this thesis is shown by the fact that injuries among bus and coach occupants have been “stubbornly stable” in Europe (European Commission, 2002) over the recent years, and a need for investigating if a similar trend could be found in Sweden is obvious. It was also important to add knowledge to several areas concerning the bus and coach research in Sweden, since these areas were scarcely addressed in the literature.

General aims

The aim of the thesis was to describe bus and coach occupants' injuries, injury and crash mechanisms generated in traffic environment based on data from the medical sector and from crash investigations. Additional aims were to investigate crucial factors in the emergency- and rescue response to bus and coach crashes.

Specific aims:

Each of the Papers has a specific aim, namely:

- Paper I. To describe injury epidemiology among bus and coach occupants, involved in both crash and non-crash injury events.
- Paper II. To use the Haddon matrix as an analytical framework and to analyse crash and injury mechanisms in a severe coach crash.
- Paper III. To show that the effect of cross-winds, in addition to velocity and friction, is a contributing pre-crash factor to compromise bus and coach safety.
- Paper IV. To go beyond the ECBOS study by describing and analysing occupant injuries and the corresponding injury mechanisms in a selection of three typical rollover crashes, and furthermore to estimate the possible injury reducing effect of 2-point and 3-point seat belts
- Paper V. To analyse crucial post-crash factors from a disaster medicine perspective, especially organisational, rescue and pre-hospital issues at the emergency scene in one of the most serious coach crashes in Sweden.

In a long term perspective, the aim was to add new knowledge to Swedish National Road Administration's work on rules and regulations concerning safety, security, accessibility and comfort for bus and coach travellers, bus manufacturers, bus spare part manufacturers and bus and coach companies.

Material and methods

The five papers vary with respect to approach, design, material, and interview/questionnaire objects, as shown in Table 4.

Table 4. Approach, design, material, and interview/questionnaire objects used in Papers I-V.

	Paper I	Paper II	Paper III	Paper IV	Paper V
<i>Research approach</i>	Injury data analyses	Method paper	Crash studies with scope in the pre-crash phase	Crash studies with scope in the crash phase	Crash studies with scope in the post-crash phase
<i>Analysis design</i>	Total survey covering 10 years, analyses on group level	Case description, applying the Haddon matrix as framework	Case descriptions, simulations and elaborating the Haddon matrix	Case descriptions, analyses of possible intervention and elaborating the Haddon matrix	Case description from a disaster medicine perspective applying the Haddon matrix and the Protocol for Major Incidents
<i>Type of data</i>	Hospital based injury data	Hospital data, data from interviews and police records	Data from interviews and police records	Hospital data, data from interviews and police records	Hospital data, data from interviews and police records
<i>Interview/questionnaire objects</i>	E.D. Structured questionnaire	Semi-structured questionnaire about injuries, seating position and injury mechanism. Interviews with the rescue and ambulance personnel	Interview with drivers about the cause for the crash	Semi-structured questionnaire about injuries, seating position and injury mechanism	Semi-structured questionnaire to the injured occupants. Interviews with the rescue and ambulance personnel
<i>Number of subjects studied</i>	284 injured bus and coach occupants	34 injured occupants in one crash	10 crashed coaches, 243 occupants	128 injured occupants in three crashes	49 injured in one crash

The specific methods used in Papers I-V are described below in the sections Paper I to Paper V.

Paper I

The hospital based data comprised 284 cases with injuries sustained during a bus or coach journey, including boarding and alighting within the Umeå medical district. The included patients were all treated at the emergency department (E.D.) at the hospital, during the ten-year period 1994-2003. The Umeå university hospital in northern Sweden has a well-defined catchment-area with a radius of 50-60 km, and

a population increasing from 125,000 inhabitants in 1994 to 137,000 in 2003. Winter conditions prevail between October/November through March/April. Data were derived from the data base EHLASS (The National Board of Health and Welfare, 2004) stored at Norrlands University hospital.

At the emergency department both in- and outpatients from the area are treated. At small local medical centres in the area, only a few per cent of those with vehicle related minor injuries are treated (data from the Umeå Accident Analysis Group). All other patients are referred to the hospital. At the E.D. visit, the injured person answers a questionnaire about the injury event, or these data are retrieved later, when convenient. Data from medical records and police investigations are also included in the database. By a control performed through the hospital's compulsory E-number- (external cause) registration for inpatients (The National Board of Health and Welfare, 1987; The National Board of Health and Welfare, 1997), a loss of these cases is unlikely. The dropout of outpatients in the hospitals injury registration is estimated to be only 2-5% (Bylund et al., 1999). Vehicles included in Paper I were M2 vehicles (Directive 70/156/EEC, 1970).

Depending on the type of injury event they have experienced, all the injured case events were divided into two categories, namely crash events or non-crash events. The crash events were further divided into collisions with other vehicles or single vehicle crashes. The non-crash events were, in addition, divided into bus or coach at stand still or moving bus or coach. The main reason to divide the material into subgroups was to facilitate the identification of the underlying causes for the sustained injuries and, additionally, to suggest injury preventive measures.

Paper II

In Paper II, a case study approach was chosen applying the Haddon matrix. A specific coach crash was selected as the subject for the study. All 34 occupants on-board the coach were interviewed about the crash, their injuries and how they sustained their injuries. Medical records concerning ambulance and hospital treatment were collected and examined. Police reports and other documents concerning the vehicle, weather conditions and the road were also examined. Table 5 shows the Haddon matrix with a suggestion of factors that may be investigated in a severe coach crash. The factors written in *italics* are the factors presented in Paper II.

Table 5. The Haddon matrix with the examined factors written in italics.

Haddon Matrix	Human factor	Vehicle/ equipment factor	Physical environment factor	Socio-economical environment factor
<i>Pre-crash phase</i>	<i>Age and sex Driver behaviour Blood Alcohol Concentration (BAC)</i>	<i>The vehicle -vehicle speed -high sided -semi passive 4-wheel steering -engine position -tyre standard -ABS-brakes</i>	<i>Road design -state of the roads Weather - wind condition - temperature -wind and vehicle design</i>	<i>Company policy concerning traffic safety -formal -informal Timetable and scheduled traffic Legislation concerning traffic safety Vehicle control</i>
<i>Crash phase</i>	<i>Kinematics Occupant position Injury type distribution over the occupants' body parts</i>	<i>Points of occupant body contact inside the coach Stiffness of the glass</i>	<i>Guard rail Road side embankment</i>	<i>Legislation - tachograph -safety belt Demands about purchase Company policy</i>
<i>Post-crash phase</i>	<i>The first responder Psychosocial effect Hypothermia -clothing -bearings</i>	<i>Emergency exits Internal rescue environment Fire</i>	<i>External rescue environment</i>	<i>Society rescue work -rescue service -ambulance services/emergency treatment and triage -police Medical attention at hospital/rehabilitation Psychosocial attention</i>

Paper III

Over a ten year period, bus crashes in Sweden were surveyed by using the SNRA's databases VITS and STRADA, in order to identify cases in which the drivers or witnesses claimed that the bus deviated off the road during strong cross-winds and slippery road conditions. In several cases, this was expressed as "an invisible hand steering the bus" and the driver being unable to counterbalance by steering and keep the bus on track. By these criteria, ten cases were identified, all of them taking place during the months November through March i.e. under winter conditions.

Based on data from these ten bus crashes, a mathematical model developed during a wind tunnel test (Torlund, 2000), was utilised to determine whether or not cross-wind forces were a contributing factor to the crashes, additionally to vehicle speed and road friction.

The coefficient of friction between the road and the wheels was needed in the analyses of the crashes. The road surface e.g. water, slush, snow or ice may affect the friction coefficient. The following best practice values for coefficients of friction, shown in Table 6, are set by SNRA for different road conditions (SNRA,

1996). When the coefficient of friction is below $\mu = 0.25$, de-icing measures should be executed on the main road net within 2 hours.

Table 6. SNRA's best practice values for coefficients of friction in different road conditions (SNRA, 1996)

Class	Coefficient of friction
High friction on dry road conditions	$\mu \geq 0.5$
Sufficient friction	$\mu \geq 0.25$
Slipperiness ^a	$\mu < 0.25$
Severe slipperiness	$\mu \leq 0.15$

^a De-icing measures are executed within 2-8 hours depending on road type.

Data concerning the ten crashes were collected from six police records, three case reports and one bus company investigation. Weather condition data at the time of the crashes were collected from the SMHI and SNRA:s Road and Weather Information System (VVIS). The weather stations were located within 5-20 km from the crash sites. Vehicle data i.e. body weight, height, length etc. were collected from the Motor Vehicle Registration Office at SNRA and the longitudinal position of the centre of mass (CM) was calculated at the Royal Institute of Technology (KTH), Stockholm, Division of Vehicle Dynamics. The vehicles in the investigated cases were classified as M3, class II and III vehicles according to the M-classification (Directive 70/156/EEC, 1970).

CM was calculated with the coach actual weight in the crash, i.e. the coach kerb weight, plus the occupants' weights. The occupants' weights were calculated according to the Directive 97/27/EC (1997) regarding the mass of one "statistical based" person, i.e. 71 kg for M3 vehicles Class II and III. Within this weight, 3 kg of luggage is included. The rear bias laden case represents an average case with vehicle weight of 18 tonnes and 1.8 tonnes of goods placed in the rear luggage compartment, or of 25 adult passengers placed behind the CM of the vehicle.

Paper IV

Data collection

Three coach crashes were selected with a typical crash mechanism in a single crash i.e. a 90° rollover to the right. Two of the cases were previously the subject of other in-depth investigations (Albertsson & Björnstig, 2003; SHK, 2004) and the third case was supplemented, in order to get a complete description of the crash and the sustained injuries. The method of collecting data from the occupants' was by interviews over the telephone asking questions related to their seating position, their injuries and how they received their injuries. Moreover, medical records concerning hospital treatment and police records were analysed.

Methods of analysis

The occupants' lateral positions in the coach were categorised as Position 1 - 4, (P1-P4) as shown in Figure 7.

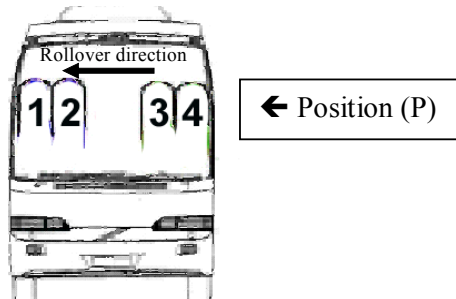


Figure 7. Identification of the occupants' position (1-4) in the coach in relation to the rollover direction.

Position 1 in Figure 7, indicates that the occupant was seated next to the rollover side window. Position 2, in turn, indicates that the occupant was seated next to the rollover side's aisle. Position 3 indicates that the occupant was seated next to the opposite side aisle and position 4 indicates that the occupant was seated next to the opposite side window.

In order to predict the possible injury reduction if a 2-point or a 3-point belt had been used by all occupants suffering an injury classified as MAIS 2+, a model was constructed, as shown in Table 7. The model is based upon the injury mechanism described by Botto et al. (1994) and rollover simulations through 90° to the right conducted by (Rasenack et al., 1996) and in the ECBOS-project (2002). Furthermore, the analysis was completed with information obtained from the interviews about the injuries, injury mechanisms and the occupant's position in the three coaches.

The direction of the diagonal part of the seat belt across the thorax in relation to the rollover impact side is shown in Figure 8, with the upper anchorage point towards the window side. This way of mounting the seat belts is the Swedish bus manufacturers Volvo's, Carrus' and Scania's way.

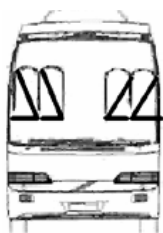


Figure 8. The diagonal part of the seat belt with the upper anchorage point towards the window side.

Table 7. The model used to investigate the potential injury reducing effects in different positions during a rollover crash in 90° to the right.

Position in the coach	P 1 (window im- pacted side)		P 2 (aisle impacted side)		P 3 (aisle opposite impact side)		P 4 (window oppo- site impacted side)	
Type of seat belt	2-point	3-point	2-point	3-point	2-point	3-point	2-point	3-point
<i>Injury mechanism</i>								
<i>Projection inside the coach</i>								
-hitting side window								
-hitting armrest								
-hitting seatback or handle								
-hit by other occupant								
<i>Ejected</i>								
<i>Partly ejected</i>								
<i>Intrusion on the impact side</i>								

A examination of each position was conducted by using the results from numerical occupant simulations performed in the ECBOS-project, which showed the passenger movement and impact load of belted passengers. In Table 7, a + sign was inserted if an injury reduction may have occurred by the occupant being properly restrained by a 2-point seat belt, whereas a ++ sign was inserted if an injury reduction may have occurred if the occupant had been properly restrained by a 3-point seat belt. A – sign was inserted if an injury reduction was not likely to occur.

Paper V

This paper presents a severe coach crash according to the prospective standardized methodology Protocol for Major Incidents, suggested by Lennquist (2003c). To make the analysis comprehensive, Haddon's matrix (Haddon, 1972) was used for structuring all the sequences in a crash i.e. the pre-crash, crash, and post-crash phases.

Data were derived from the crash investigation authored by the Swedish Accident Investigation Board (2004). In this investigation the Division of Surgery at Umeå University contributed with analyses of the injuries and injury mechanisms. Data were derived from interviews with the occupants. Additional data about medical resources, emergency, and disaster planning were collected in collaboration with the administrator of disaster emergency planning in the County Council of Västmanland (2003).

Ethical requirements

According to Swedish law (2003:460), there was no need to apply for ethical approval for the studies included in this thesis since it contains data from voluntary interviews and data registers.

Participation was voluntary (II-V) and the individual data obtained were kept confidential (I-V). The subjects were given written and oral presentations of the purposes of the studies (II-V) and they were told that could leave the interview/end their participation at any time without any explanation.

Results

Paper I

The injury incidence was 2 per 10,000 inhabitants per annum. The median age was 43 years and 3/4 was women. During the winter months, 3/4 was injured and all injury events with five or more casualties happened during these months. Thirty-three percent of the injury cases in this study were reported in the official statistics. A majority was injured in non-crash incidents and a vast majority of those were injured while alighting from a bus or coach. Slippery conditions contributed to these injuries.

Nearly half was injured in crashes; 86 in collisions with other vehicles and 44 in single vehicle crashes. In two winter single crashes involving high built coaches, heavy wind forces and slippery road conditions in combination with high speed caused the crashes. Eighty-four percent of those injured in collisions with other vehicles, were injured in collisions with other heavy vehicles. Rear-end collisions with other heavy vehicles in urban areas caused a high number of neck distortions.

Nearly one third of all injured suffered non-minor injuries (MAIS 2-4). The proportion was highest in single vehicle crashes (48%) and in alighting and boarding (43%) incidents, and was lowest (5%) in collisions. Lower extremity injuries (56%) and neck injuries (71%), respectively, were most common in the two latter groups. Every sixth injured was treated as in-patient on average for five days. Non-crash victims consumed 57% of all in-patient days.

Paper II

The coach went off a road via a guard-rail and landed on the right side, after a 90° rollover position right across a small river. The impact from the crash was greatest in the frontal part of the coach since this part fell three metres from the bridge guard-rail down to the river bank as shown in Figure 9. The rear part of the coach slides on the river bank with less impact as a result.



Figure 9. The front of the coach after the impact to the river bank.

The most frequent injury mechanism was projection i.e. occupants being thrown around inside the bus or coach and/or hit by other occupants. The main reason for the coach to deviate from the road was strong and gusty side winds imposing lateral forces on the coach, making steering impossible. A mathematical model was

Results

used to investigate if cross-winds contributed to the crash (SHK, 2001). The results showed that a coach of the type in question driving 70 km/h and being hit by a gusty wind of 20 m/s from an unfavourable direction (approximately an angle of 30°) could lead to the coach losing its tyre grip on the road. At this particular crash, the coach was driving 90 km/h in a slight left curve, meaning that the wind forces on the coach were supported by radial forces instigated by the turning of the coach. The fact that most of the side windows remained in position after the crash probably prevented many occupants from receiving serious and fatal injuries caused by ejection or partial ejection.

Paper III

Ten crash cases, six of them rollovers, were investigated in this paper. Each of the included crashes is briefly described in Table 8.

Table 8. A brief description of the ten investigated crashes.

Crash no.	Vehicle body height and length (m)	Actual vehicle weight* (kg)	Wind gusts (m/s)	Resulting approach angle of the wind (β)	Nos. of injured occupants with minor/non-minor injuries
1	3.8/14.6	16,350	16	26	2/-
2	4/12.2	21,190	15	32	31/11
3	4.3/15	19,500	9	32	10/-
4	3.8/15	20,560	21	36	13/21
5	3.8/12	19,210	16	23	21/24
6	3.2/13.2	13,970	10	17	-/5
7	4.3/14.7	20,910	15	23	-/-
8	3.3/14.5	15,110	21	38	3/-
9	3.3/13.9	14,930	14	38	1/-
10	4.3/14.7	21,480	17	34	-/-
<i>Average</i>	<i>3.8/14</i>	<i>18,360</i>	<i>15</i>	<i>30</i>	<i>Sum: 81/61</i>

*Kerb weight, occupant and luggage weight.

The calculations shown in Table 9 were based upon the actual vehicle and wind speeds and two loading cases of the vehicle, (i) laden, in which the passengers and the goods are evenly distributed in the vehicle and (ii) 10% rear laden bias, in which the passengers and goods are placed in the rear part of the vehicle so that the position of the CM is moved 10% rearwards. The calculation of the necessary coefficient of friction was done with the resulting approach angle of the wind taken into account.

Results

Table 9. Results from calculations with necessary coefficients of friction distributed over different loads.

Crash no.	Wind gusts (m/s)	Speed at the crash (km/h)	Calculations done in the mathematical model		Increase between laden and rear laden cases (%)
			(i) Necessary coefficient of friction with a laden case (μ)	(ii) Necessary coefficient of friction with rear laden 10% case (μ)	
1	16	90 ^b	0.47	0.74	57
2	15	93 ^a	0.31	0.46	48
3	9	60 ^a	0.11	0.16	45
4	21	90 ^b	0.45	0.64	42
5	16	90 ^b	0.32	0.45	41
6	10	75 ^a	0.15	0.20	33
7	15	100 ^a	0.36	0.54	50
8	21	75 ^a	0.56	0.91	63
9	14	65 ^a	0.13	0.16	23
10	17	90 ^a	0.38	0.57	50
					<i>Average 45</i>

^aTachograph ^bDriver interviews

As shown in Table 9, the calculation gave an average increase of 45% for the necessary coefficient of friction in the rear laden cases, compared to the laden cases. In seven laden crash cases (1, 2, 4, 5, 7, 8 and 10) the necessary coefficient of friction (ranging between μ 0.31-0.56) was well above the sufficient friction value (μ 0.25) according to SNRA's best practices (SNRA, 1996). The actual road and weather situation on the crash sites could (see appendix in Paper III), on the contrary, be described as slipperiness or even severe slipperiness ($\mu < 0.25$ - $\mu < 0.15$), with the road surfaces covered with snow and/or ice and the temperature was ranging from + 1° to - 4°. These large differences between actual and calculated necessary coefficient of friction strongly indicate that cross-winds contributed to the crashes. In addition, if the bus would have been 10% rear laden, the calculated necessary coefficient of friction corresponds to high friction on dry roads, according to SNRA's best practices (SNRA, 1996), indicating that the bus may deviate off the road at a given speed also during high friction conditions, i.e. on dry roads, from such cross-winds.

Paper IV

Data comprised 128 occupants in three crashes with more females (63%) than males (37%) and also a higher proportion of occupants in the age groups 10-19 and 20-29 compared to other age groups. The share of injured occupants with an MAIS 2+ injury was 55% for all occupants, 45% for males and 60% for females. Within the age groups, the share of injured occupants with an MAIS 2+ injury was highest in the age groups 50-59 (73%) and 10-19 (66%). The highest share of minor casualties (MAIS 1) was found in the age group 20-29 (57%).

Results

Partial ejection caused most harm to the occupants with 71% of all MAIS 5-6 cases. However, projection i.e. injured inside the coach by hitting other occupants or interior, was the injury mechanism for nearly all occupants (90%) and also the injury mechanism behind 98% of all MAIS 1 cases. The injury mechanisms were examined further concerning those occupants who were able to state plausible mechanisms for their injuries, a task completed by 66 out of the 128 occupants (52%). Those occupants who were not able to state their injury mechanism were mostly either unconscious or did not remember. The results showed that broken glass was the most common reason (32%) leading to lacerations/cuts (some needing surgery), while hitting the seat back and armrest caused the most MAIS 3-4 injuries.

In Table 10 it is shown that position 1 (Figure 7), on the rollover side had the highest proportion of injured occupants (65%) with an MAIS 2+ injury compared with other positions. Position 4, i.e. away from the impacted side had the lowest proportion of injured occupants (39%) with an MAIS 2+ injury.

Table 10. Injury severity for all occupants distributed over lateral positions in the coach.

Injury severity	P 1 (window impacted side)	P 2 (aisle im- pacted side)	P 3 (aisle op- posite im- pact side)	P 4 (window op- posite im- pacted side)	Unknown position	Total
MAIS 1	10 (33%)	11 (37%)	12 (42%)	23 (61%)	1 (50%)	57 (45%)
MAIS 2	11 (37%)	14 (46%)	10 (36%)	8 (21%)	1 (50%)	44 (33%)
MAIS 3	3 (10%)	-	2 (7%)	5 (13%)	-	10 (8%)
MAIS 4	2 (7%)	3 (10%)	3 (11%)	2 (5%)	-	10 (8%)
MAIS 5	-	-	1 (4%)	-	-	1 (0%)
MAIS 6	4 (13%)	2 (7%)	-	-	-	6 (5%)
Total	30 (100%)	30 (100%)	28 (100%)	38 (100%)	2 (100%)	128 (100%)

Table 11 shows the model that was used in the investigation of the potential injury reducing effects of a 2-point and 3-point belt during a rollover crash in 90 degrees to the right.

Results

Table 11. The results of the model used to investigate the potential injury reducing effects in different positions during a rollover crash in 90 degrees to the right.

Position in the coach	P 1 (window im- pacted side)		P 2 (aisle impacted side)		P 3 (aisle opposite impact side)		P 4 (window opposite impacted side)	
Type of seat belt	2- point	3- point	2- point	3- point	2- point	3- point	2-point	3-point
<i>Injury mechanism</i>								
<i>Projection inside the coach</i>								
-hitting side window	—	—	—/+*	++	+	++	+	++
-hitting armrest	**	**	—	++	—	++	—	++
-hitting seatback or handle	+	++	+	++	+	++	+	++
-hit by other occupant	+	++	+	++	+	++	+	++
<i>Ejected</i>	+	++	+	++	+	++	+	++
<i>Partly ejected</i>	—	—	+	++	+	++	+	++
<i>Intrusion on the impact side</i>	—	—	—/+*	++	+	++	+	++

*No prevention against head injuries, but prevention for other injuries.

**Not relevant in this position.

+ A 2-point belt prevent the sustained injury

++ A 3-point belt prevent the sustained injury

— No injury reduction

Table 12 shows that a 2-point belt may provide an injury reduction by 51% of the MAIS 2+ casualties and that a 3-point belt may provide an injury reduction by 80% of MAIS 2+ casualties. However, 13% of all the MAIS 2+ casualties sustained injuries that a neither a 2-point nor a 3-point belt may have prevented their injury.

Table 12. Proportion of MAIS 2+ casualties that may have experienced an injury reduction using 2-point and 3-point belts, respectively.

Injury cases	Number and percentages of occupants estimated to have a reduction of injuries:	
	by use of 2-point belt	by use of 3-point belt
MAIS 2	19/43 (44%)	33/43 (77%)
MAIS 3-4	13/20 (65%)	16/20 (80%)
MAIS 5-6	3/7 (43%)	7/7 (100%)
All MAIS 2+ injury cases	35/70 (51%)	56/70 (80%)
Cases with a possible injury reduction	1/70 (1%)	5/70 (7%)
No injury reduction	34/70 (48%)	9/70 (13%)

All of the occupants with no injury reduction were seated in position 1, next to the impacted side and were exposed to ejection or partial ejection.

Paper V

Summary crash scenario: The crash took place on Friday, January 24th, 2003. Due to technical problems, a train was cancelled in Ludvika, a village in central Sweden. A replacement coach was to transport the passengers 115 km to Västerås, via the

same route. In darkness, at 4.23 p.m. still working hours, the coach went off the road in a left curve. The driver reduced the speed to 49 km/h before the curve, but lost control of the coach, which skidded off the road, down a high road bank and landed on its right side. The coach's structural damage was mainly located to the right side.

Pre-crash phase: The bus operator's policies were detailed regarding vehicle issues but they almost totally neglected traffic safety issues, which instead were based on the present legislation and were non-specific.

Crash phase: The most common and dangerous injury mechanism for occupants seated nearest to the impacted side was ejection and entrapment under the coach. Six of these occupants were fatally injured. The most common injury mechanism over all, was projection 37/49 (77%), a trauma caused by bodily movement inside the coach. A majority of those 37 injured occupants sustained minor injuries. On the opposite side of the coach, injuries from broken glass were most common, followed by injuries from hitting backrests, armrests, or other occupants.

All seats, except the driver's that was broken, were equipped with 2-point belts. Two occupants were belted and sustained minor injuries.

Post-crash phase: SOS Alarm in Västerås directs the emergency forces. How to handle various incidents is specified in the SOS Alarms alert plans. However, a plan for major traffic incidents was missing.

The command and control organisation at the crash site included:

- FIC (Fire Incident Commander).
- MIC, (Medical Incident Commander) initially from the ambulance staff MIC (Amb), later a doctor MIC (Doc).
- PIC (Police Incident Commander).

The nearby road functioned both as a command post for the commanders and as ambulance loading point (ALP) (BMJ, 2000). The nearby crash site facilitated communication and gave the commanders a good overview. After 15 minutes, two ambulances from Fagersta arrived and found people with minor injuries on the road and beside the coach. They had evacuated themselves through the broken front wind screen which was close to a 10,000 volt power-line. The power-line was considered by the rescue personnel to be short circuited, opposing no threat.

One of the ambulance personnel initially took the role as MIC (Amb). A brief triage (McSwain, 1999) was done outside the coach and then the response was concentrated on the remaining injured inside and outside the vehicle. More ambulances arrived after 35 minutes. The post-crash position of the coach complicated working inside. Two ambulance crews worked inside the chaotic coach, amongst luggage

and broken glass, with injured, trapped and deceased occupants. With two doors blocked and no rear window, entrance was possible only through the broken front windscreen and the roof hatch. A normal triage (McSwain, 1999) was difficult; the occupants were instead evacuated with those closest to the exit first.

None of the injured occupants received any analgesics or infusions before being moved to the ambulances. After 15 minutes, the MIC (Amb) asked for a mobile medical team, which arrived from Fagersta one hour after the crash. One doctor was a trained MIC and thus became the MIC (Doc). Many seriously injured occupants had then already been transported to hospitals.

The transport resources were initially not sufficient in relation to the number of injured occupants. In several cases, 2-4 injured with minor or moderate injuries were transported in the same ambulance. The MIC (Amb) requested more ambulances from SOS Alarm and repeated his request later on. However, despite this need of more transports, none of the ambulances returned to the crash site. In all, 37 occupants were transported by ambulances to different local hospitals. Seven injured were transported in a requested bus, also functioning as a Casualty Clearing Station (CCS) (BMJ, 2000). The commanders discussed the need of an ambulance helicopter. The request was later on cancelled because they considered transport by road ambulances faster.

Post-incident evaluation made by the County Council of Västmanland:

- Disaster plans exist at every involved hospital, and were activated in Fagersta and Västerås. Follow-up meetings were conducted in both hospitals for evaluating the medical treatment effort.
- The alert routine from SOS Alarm must be improved, especially during major traffic incidents.
- IS SWEDE was not used due to malfunction.
- Improved communication between the hospital in charge and smaller hospitals is needed. No command unit was established at Fagersta hospital.
- Routines for radio usage (incident channel) need improvement.
- Commanders in charge must inform the dispatch centre when they are ready on-the-spot.
- Emergency pagers must be available.
- A firm control of the crash site is needed, in order to keep spectators and media out.
- Additional computer equipment was needed in the central command unit at Västerås hospital.

Discussion

In general, injury events related to buses and coaches show a contradictory pattern. On the one hand, mass casualty crash situations with several injured occupants are, often exposed in media, and on the other hand non-crash events (for example passengers slipping or stumbling when alighting from the bus or the coach) with generally only one injured occupant render less or no media attention (Albertsson & Falkmer, 2005; Transport Canada, 2002). This thesis is an attempt to describe the range within these two extreme situations and based on the results suggest measures for enhanced bus and coach occupant safety. Bus and coach travellers, bus manufacturers, bus spare part manufacturers and bus and coach companies might be able to benefit from the results in the development of their products. This development may, in turn, contribute to a decrease of incidents, less severe injuries when they do occur and, finally, and making public transport in buses a more attractive mode of transport.

The European Commission has stated that deaths and injuries involving buses and coaches have been “stubbornly stable” over the recent years in the European Union (European Commission, 2002). Although this thesis did not have epidemiology as its scope, it was possible to detect some evidence in Paper I that supports the statement that bus and coach injuries in Sweden, in fact, have been constant or even increasing in numbers. Paper I covered injured occupants over the years 1994-2003 and the increase of 24% over the two investigated five-year periods was most adequate for non-crash events since these events were all individual events e.g. one person falling when alighting the bus. The crash events were, however, difficult to calculate statistically on an individual basis since crashes in many cases affect more than one injured and thus clustered. This increase was confirmed by results from the Swedish part of the ECBOS-project which showed an increase in casualties during the years 1994-98 (ECBOS, 2001). A Swedish study covering the entire country also showed indications of a minor increase of injuries (Nilsson et al., 2002).

The data concerning injuries in this thesis were derived from the medical sector because they offer a more representative view of the impact of bus and coach related incidents compared to the official police-reported data. Only 1/3 of the injured in Paper I was included in the official police-reported traffic injury statistics. All 284 cases included in Paper I, except those injured when the bus or coach were at stand still should have been reported according to the rules concerning official statistics. The explanation for the loss of cases in the police-reported traffic injury statistics is simply that the police is not on the spot and therefore cannot write a report. A reason for their absence can be that for example, another call is given a higher priority or that they are not called upon at all. However, should we expect the police to be on the spot every time an incident in a traffic environment occurs? The answer is

no, according to the present Swedish laws, in which the notion is that they have to be present if there is any suspicion that a legal violation is being committed. The laws concerns, for example, work related incidents or traffic violations. Incidents that do not necessary have to be a violation could be a fall when boarding or alighting a bus. The consequence in the latter case is that no police is present, no report is being written, and the incident is not reported to the official statistics. Other countries, for example the U.K., have other rules that emphasize the need for the police to be present in the cases of traffic incidents and, hence, rendering the police records more reliable concerning injury data (ECBOS, 2001).

Additional findings are further discussed in the following section and structured into non-crash events and crash events followed by a methodological discussion.

Non-crash events

Despite the fact that non-crash events are not as focused on by the media as severe bus or coach crashes with many injured occupants are, non-crash events are nevertheless equally interesting from an injury preventive perspective. In Paper I, it was shown that more than half of the 284 injuries were related to non-crash events, 41% of them being MAIS 2+ injuries. Furthermore, these non-crash related injuries accounted for 57% of the hospital treatment days, clearly showing that preventing crash events are not the sole key to enhancing bus and coach safety. In support for this statement, the ECBOS-project reported that non-crash events constitute an important injury mechanism factor for bus/coach occupants, especially among elderly people travelling in city buses (ECBOS, 2002). The notion that non-crash events are important is also supported by several other studies (Kirk et al., 2001; 2003; Skjoth-Rasmussen & Rasmussen, 1999; SL, 1994).

The most common injury case with a MAIS 2+ injury in Paper I could be described as a woman with a mean age of 57, injured while alighting from an urban bus on a weekday during the winter season at rush hours. The injury mechanism is slipping on wet or icy steps in the vehicle or when stepping down onto an icy pavement. Moreover, the sustained injury is a distortion or a fracture located to one of the lower extremities. Other surveys (ECBOS, 2001; Kirk et al., 2001; 2003) indicate that these findings reflect exposure, i.e. women use public transportation more frequently than men and, logically, they also travel more frequently during rush hours, weekdays and during the winter season. However, it is important to notice that exposure data from the investigated district showed that the age group 16-17 used the bus more than five times as frequently as the age group 65-74 (Umeå municipality, 1999). This, in turn, indicates that the older age groups are exposed to a higher risk of becoming injured when riding the bus compared with younger age cohorts. One explanation may be that even if the bus or coach is modified to facilitate for the elderly, with for example low step entrances, the traffic in general is

not, provoking harsh braking, and stressful situations in connection to boarding and alighting.

Some of the cases in Paper I that were excluded from the material, like for example, instances of “I fell on my way to the bus stop” indicate a bus passenger definition problem. The inclusion criteria in Paper I, i.e. an injury denoted in their medical record as sustained during a bus or a coach journey including boarding and alighting, mean that persons alighting from the bus or coach are coded as bus passengers when slipping on the first step down from the bus stop, but not when slipping in the next step. A similar coding is used for example in the British national road accident data base called “STATS 19” (Department for Transport, 1999). This definition problem raises the question of to what extent bus operators are responsible for their passengers. Does the responsibility start when the bus passenger is entering the bus or when he or she is leaving home aiming for a bus stop, and does it end when leaving the bus or when they are back at home again? One way to penetrate this issue is to apply the “Travel Chain Perspective,” see for example; Carlsson, (2002) and Iwarsson et al., (2000), which means that a bus or coach trip involves all necessary steps from door to door. This, in turn, implies that going to and waiting at the bus stop, as well as boarding and alighting, are natural parts of the journey and should be taken into account when focusing on injury preventive measures. For example, many of the wintertime injuries in Paper I may be prevented by heating coils in the entrance of the vehicle and at the bus stop to enhance surface friction. This safety measure, already implemented in several new buses and bus stops, will especially attract less mobile people such as elderly people with reduced muscle function, coordination and balance, and people with disabilities.

When further exploring possible safety enhancement measures it can be noticed that the outstanding non-crash event injury mechanism in Paper I was alighting, a finding confirmed by other studies, see, for example; Kirk et al. (2001), Kirk et al. (2003), SAMIS, (1995) and Skjoth-Rasmussen & Rasmussen, (1999). Actually, alighting injuries rendered MAIS 2+ injuries in almost half of the cases. Furthermore, slipping due to low friction was claimed to be the reason in more than half of the cases. City-buses with kneeling fronts and sides, in combination with the above described wintertime measures, might prevent this type of injuries. Another example is the Volvo system implemented in Curitiba Brazil and other cities in South America that facilitates boarding and alighting by having the bus floor and the embark area at the same levels (Figure 10).



Figure 10. The Volvo built system in Curitiba Brazil facilitating boarding and alighting.

Another advantage with this system is that the ticket is registered at a ticket barrier on the bus stop, instead of inside the bus which contributes to shorter passenger travelling and waiting time, and perhaps less incidents since the passengers can concentrate on entering the bus instead of handling the ticket.

If public transportation in the future should continue to be an attractive, safe and secure means of transportation for the cohort of older road users, alighting from a bus needs to be further addressed with focus on step height and slippery conditions.

Moreover, once inside the bus, frail and disabled passengers should be offered as safe a journey as possible. Braking and especially harsh braking seemed to be the most frequent reason for passenger injuries in non-crash events when the bus or coach was moving. This was common in urban traffic where, in turn, standing passengers are allowed, and harsh braking may be an inherent part of the journey. Furthermore, the finding in Paper I concerning the fact that passengers, especially standing passengers, actually become injured during a normal bus ride, raises the question of improvement of the interior material as a preventive measure. Two passengers injured when a TV-monitor and a video recorder fell onto their heads, highlights the problem. Safety measures should include improvement of interior passive safety, both by design and by avoiding or reducing the number of standing passengers.

In Paper I it was shown that, in general for non-crash events, the lower extremities, along with neck and the upper extremities were the most frequently injury affected parts of the body. This finding is in line with a similar study from the U.K. (Simpson, 1997). Another finding concerns the length of stay in hospital. About every sixth injured person was treated as an in-patient at the hospital for more than five days, which is approximately the same average treatment time as for all traffic related injuries in the area (Björnstig, Bylund, & Björnstig, 2003). The longest period

of treatment, i.e. six days on average, was given to five injured occupants from non-crash events.

The results from Paper I also indicated an increase (24%) of non-crash casualties in the investigated district over the ten year period, which is in fact also indicated on a national basis in Sweden by other studies (ECBOS, 2001; Nilsson et al., 2002). However, it is important to note that it has not been possible to present the reasons behind this increase, e.g. whether the implemented measures like kneeling buses have resulted in that the share of elderly and people with disabilities have increased, with a more vulnerably bus passenger population as a result although this issue has been discussed in other studies (Kirk et al., 2001; 2003). It is also important to note that a 10-year period, taking into account the relative rareness of bus and coach injury related events, is maybe too short and too sensitive for random changes in the frequency over the years. The latter may be the missing explanation behind the increase of bus or coach casualties.

Crash events

Severe bus and coach crash situations are regularly investigated by national and international studies (Duignan et al., 1991; Hughes & Rodgman, 2000; National Transportation Safety Board, 1999; Rey et al., 2002; SHK, 2001, 2004; SNRA, 2002b). In this thesis, Papers II-V contribute with investigations of several bus and coach crashes. Some results from severe bus and coach crashes were also included in Paper I.

The most common crash case with an MAIS 2+ injury could be described as a woman in the age of 37, seated next to the impacted side and injured in a single coach rollover crash 90° to the right with the coach leaving the road and sliding over the ground. A majority of the side windows are broken while impacting the ground. The injury mechanism is being partially ejected through the side window. Moreover, the sustained injury is a fracture located to the chest or to one of the extremities (Paper I, IV).

Additional results from the papers are further discussed under the following sections: crash mechanisms, injury mechanisms, injury outcome, injury mitigation measures and post-crash experiences.

Crash mechanisms

The influence of cross-winds on buses and coaches have previously been highlighted by The Swedish Accident Investigation Board after a coach crash with 62 occupants where the driver stated that cross-winds contributed to the crash (SHK, 2001). No technical defects, other obvious defects or reasons for the crash were discovered that could explain the course of events. The Swedish Accident Investi-

gation Board (SHK) authorized the Aeronautical Research Institute of Sweden to carry out a wind tunnel testing of a model of the crashed coach (Torlund, 2000). The question of how cross-winds may affect the driving characteristics of a coach was posed in the investigation. One of the outcomes from the investigation was a mathematical model developed from a wind tunnel test (Torlund, 2000). During the investigation done in Paper II, it was found that there were many similarities to the crash investigated by SHK. Thus the mathematical model was used in order to show if the cross-wind contributed to the crash. It was found to be the case, which gave inputs for a further investigation, with additional crashes. Thus, the Paper III study was conducted, in which ten crashes were found and investigated utilising the same mathematical model.

The results in Paper III, in line with the results in the SHK investigation, gave a strong indication that cross-winds contributed to the crashes. It was also shown that a displacement of 10% of the CM away from the front wheels of passenger, goods and/or luggage loading in the bus or coach increased the necessary coefficient of friction with on average 45%. This fact may be devastating for the manoeuvrability of the vehicle. These facts indicate that it may be time to reconsider the free seating of bus passengers, and instead implement numbered seats as in trains and airplanes. Asking the passengers to use the seats in the front part of the vehicle is another suggestion and leaving the rear goods compartment empty when bad weather conditions are prevailing is yet another suggestion.

Another solution that was suggested in the SHK investigation was to assemble a spoiler in the front of the bus or coach. This solution made a considerable reduction of the cross-wind sensitivity to the model (Torlund, 2000). The wind tunnel test also gave inputs for additional tests. Preliminary results from these new tests show that the geometry of the bus or coach is very important for the cross-wind sensitivity. A round shape in the coach body and sharp edges in the front is a favourable design when addressing cross-wind sensitivity (Torlund, 2004).

A spin-off effect of Paper III is that from February 2005 a speed adoption taking wind speed into account is planned for and authored by SNRA and bus operators (SNRA, 2005), which implies that this matter is considered seriously by operators and authorities. The imposed speed adoption is based on a common agreement and the speed adoption levels were calculated with the mathematical model (Torlund, 2000).

Vehicle features of the bodywork, such as height (i.e. single or double-deck), influence the injury outcome in case of a rollover crash. In Sweden, this is especially valid for coaches, since double-decked buses are very uncommon. The height of a

double-deck vehicle may be 60-80 centimetres higher than a corresponding single-deck vehicle (Figure 11).



Figure 11. A double-deck vehicle with rear baggage and goods compartment. This type of coach is used for combined transport of passengers and goods in rural areas in Sweden.

In case of a rollover with a double-deck vehicle, the greater distance from the centre of gravity in the upper compartment the greater increase of the rotation velocity. This, in turn, will increase the impact with greater risk for injuries as a consequence. A study by Botto & Got (1996) supports this statement. The study showed that if the coach had an upper and a lower compartment, more than 80% of the KSI was located in the upper section of the coach. Additional risk factors for these coaches may be hitting low bridges and low positioned road signs (Swedish Television, 1996), and the risk for direction instability due to cross-winds (Juhlin, 2003).

The pattern found in Paper I concerning bus and coach crashes was that crashes were more frequent on urban roads, but with a more serious outcome on rural roads. This pattern was confirmed in a literature review over bus and coach casualties in Europe (Albertsson & Falkmer, 2005). It was also shown in the literature review that the most common crash type on rural roads is a single vehicle crash with the coach leaving the road ending up in a rollover, which in fact was the scenario in many of the studied crash cases in this thesis. Despite the fact that this type of crash does not happen very often, the number of seriously injured occupants can be large (ECBOS, 2002). For example, the risk for fatalities is found to be five times higher in a rollover incident compared to all other crash types (Martínez et al., 2003). Support for these results was shown in the ECBOS-project. By analysis of the in-depth database it was shown that single crashes and overturning were combined in the majority of the cases, causing the highest risk for severe injuries.

Frontal and rollover crashes caused a similar proportion of fatalities but rollover had a greater risk (+ 42%) for MAIS 3+ injuries (ECBOS, 2002)

It was also found in Paper I that whip-lash injuries were a fact in many crashes when the bus was hit from behind by another heavy vehicle. Due to the size and weight, collisions with cars oppose no major problem viewed from a bus or coach occupant perspective. In the ECBOS-project, it was also found that frontal impacts were less serious in terms of injury than rollover incidents but occur more often and therefore make up a large proportion of the casualty populations. It was also found that buses and coaches are generally large and heavy and collisions with other large and heavy vehicles, such as lorries and buses, rendered the most serious injury outcomes (ECBOS, 2002).

Injury mechanisms

In Paper IV, based on three rollover coach crashes, it was shown that partial ejection caused most harm to the occupants with 71% of all MAIS 5-6 cases. This was supported by Botto et al. (1994). This indicates that the single most important crash related preventive measure is to keep the occupants inside the vehicle. Another support for this is that projection was the injury mechanism for nearly all occupants (90%) and also the injury mechanism behind 98% of all MAIS 1 cases.

The result in Paper IV also showed that broken glass was the most common reason for injuries (32%) leading to lacerations/cuts (some needing surgical operation), while hitting the seat back and armrest caused the most AIS 3-4 injuries.

Injury outcome

In Paper IV, it was shown that the most frequently injured region of the body was the head (31%), followed by upper extremities (27%) and the thorax (15%). These results are supported by results in the ECBOS study (2002). Overall, the most common injury type was laceration/cut (35%) followed by superficial contusions (25%) and fractures (17%). The most common injury types for MAIS 2+ cases were concussion and fractures, while crush injuries were the most common injury type for MAIS 6 cases. In Paper I, it was possible to separate crash data into single vehicle crashes and collision with other vehicles. Concerning crash related injury mechanisms; single vehicles crashes rendered a MAIS 2+ injury in half of the cases, while the corresponding figure for multi vehicle crashes was only 5%.

The injury outcome also varies depending on where in the bus or coach the occupants are seated. Based on the results in Paper IV, the safest place in the coach is located in the positions away from the impacted side, despite the risk of being injured while thrown around in the coach during the crash. Hence, it may also be

concluded that it is more risky to be seated near the impacted side, in the event of a rollover crash, due to the possibility for being ejected or partially ejected out of the coach during the crash phase. Moreover, for occupants located near the impacted side, an additional risk factor of being ejected is to be further crushed against the impacted side by fellow occupants, seated in positions away from the impacted side, falling onto them. This fact was also found in the case studies in the ECBOS-project (2002).

Injury mitigation measures

The injury mitigation measures should be based on the results in this thesis and be focused mainly on three areas;

- i, to keep all the occupants belted while seated,
- ii, to prevent the occupants located close to the impacted side from being partially ejected,
- iii, to prevent the occupants from being injured if they are thrown around inside the coach

The single most important preventative measure in crashes, especially in rollover and turnovers, is to keep the occupants inside the vehicle by using a 3-point belt. The relevance of this is shown in Paper IV by the fact that injuries sustained by projection are usually minor injuries and that the injury mechanism ejection and partial ejection causes most harm to the occupants in the case of a rollover crash. A 3-point belt provides, in addition, a better protection in frontal crashes, compared to a 2-point belt (Huijskens et al., 2003; ECBOS, 2002; Rasenack et al., 1996). However, in the case of a rollover, additional measures are needed to provide a full protection against ejection and partial ejection for occupants seated close to the impacted side. Solutions like retentive glazing, pillars or rails are measures that would have reduced many of the AIS 3+ injuries presented in Paper III. These solutions are also suggested by, for example, the two bus and coach studies ECBOS (2002) and Transport Canada (2002).

Despite the regulation regarding mandatory seat belts, a fact in Sweden since 1986 and valid for buses and coaches equipped with seat belts, the usage of seat belts in buses and coaches is very low compared to the usage in cars and thus a real effort has to be made in order to increase the usage of seat belts in buses and coaches.

The interior design of buses and coaches such as seat backs, armrests, luggage racks and hooks intended for clothes might also be improved by padding or other interior design solutions. Some of the sustained injuries noted in Paper I and IV e.g. a subdural haemorrhage, may easily have been avoided with other interior design solutions such as padding.

Post-crash experiences

In Paper V, a severe coach crash was selected and investigated from a disaster medicine perspective i.e. with main focus on the post-crash phase. The post-crash position of the vehicle, a 90° position on the right side next to a high volt power-line, imposed a great challenge for both the ambulance crew, the rescue service, and, at a later stage, the medical team. The 90° position of the coach made the working conditions difficult for the ambulance and rescue services in many ways. For instance, they had access only through the front window and the roof hatches which made the evacuation difficult, and a normal triage (McSwain, 1999) had to be set aside. Instead, passengers had to be evacuated with the one closest to the exit first. This scenario was also found in Paper II. Another example is that the rescue services tried to use their ordinary lifting tools i.e. small airbags in order to lift the coach. The task became difficult because the lifting tools were not designed for lifting a coach body and, in addition, this type of scenario was new for the rescue team.

Another spin-off effect of this thesis is a “heavy rescue” project in co-operation between the Swedish Rescue Services Agency, The Emergency- and Disaster Medicine Centre at Umeå University and The National Board of Health and Welfare. The idea behind the project is to optimize the emergency care of bus and coach crash victims by a close teamwork between the ambulance and rescue organisations with the sustained injuries guiding the rescue work. In the first step, collected experiences from emergency and rescue personnel are discussed in a seminar with work-shop groups. The next step is to develop tactics and techniques based on the gathered experiences and the final step is to develop an especially designed education program for emergency care in bus and coach crashes.

Methodological discussion

Paper I

Paper I focused on injury causation and injury mechanisms among bus and coach occupants, involved in both crash and non-crash injury events, from a well defined geographical area, based on hospital data over a period of ten years. The reason for this choice was that bus and coach incidents are relatively rare events compared to other traffic injury events, and thus data needed to be gathered over a long period of time, in order to allow for sufficient analyses. Another reason was as Nilsson, (1997 p 17) pointed out, “[...] comparisons of fatality rates and injury rates must be done for homogeneous environments and road user groups, as the distribution and comparison of traffic in different environments must be taken into consideration”. In addition, the source from which the data are gathered is of importance. For example, utilising hospital data instead of police data can provide an enhanced coverage of up to 65% concerning non-crash event injured bus/coach passengers (ECBOS, 2001).

The geographical area chosen for the study is an area substantially less densely populated than the rest of Sweden. This means that rural areas are less densely populated than corresponding areas in the rest of the country. Furthermore, the metropolitan areas are somewhat less densely populated. Traffic density could thus also be expected to be lower in these areas than in the rest of Sweden. This, in turn, may endanger the results so that the share of incidents caused by dense traffic is underestimated in the present study and, hence, also the number of crash and non-crash events.

The validity could be described as a high internal validity, since the outcome probably matches the studied population well. The external validity may be more uncertain, since the studied population may be difficult to extrapolate to a national level. General conclusions based on these data should primarily be extrapolated to areas with a similar population and geography.

An investigation of the in-patient register at the hospital was also undertaken for the year 1998, aiming to eliminate any loss of registration of in-patients. The loss of registration data of out-patients at the University hospital was about 2%, mostly minor injuries (Bylund et al., 1999).

The hospital material excludes treatments at health care centres, which means that the number of MAIS 1 cases could be higher than noted in Paper I. It is, however, only on rare occasions that a person with a MAIS 2+ injury would be treated solely at a health care centre. Important to note is that health care centres doctors on duty are stationed at the E.D. at evenings, nights and weekends. The hospital material covers a limited number of cases of high quality both with respect to coverage, as

well as to content. Only the local bus company and the regional bus and coach traffic company were included in the study, but just a few (< 5) injury cases had experienced an injury event in another northern Swedish town, i.e. with another local bus company as service providers. When it comes to reporting bus or coach related injury events by implementation of a travel chain perspective as framework, we do not know the true share of missed cases. Patients on their way to the bus stop or on their way home from the bus stop may not report this as a bus related injury, but rather as a pedestrian injury. A best guess is, nevertheless, that the major finding in Paper I, that non-crash events play a crucial role as bus and coach related injury mechanism, probably might be further supported if these cases could be identified.

Paper II-V

In Paper II-V the Haddon matrix was used to investigate severe coach crashes. The Haddon matrix is a frequently used tool in traffic ever research since it was released in the seventies. In Paper II, a specific coach crash was chosen in order to develop the matrix into a tool for investigating severe bus and coach crashes. However, despite its popularity among researchers criticism against the Haddon matrix has been raised. Evans (2004) argues that it places too much emphasis on the event—the crash—and that the pre-crash phase in the matrix normally implies the few seconds prior to the crash. On the contrary, the really important pre-crash period is the whole decade prior to the crash in which socialization plays an important part. Furthermore, Evans argues that, “The focus need to shift away from the details of the event, and more in the direction of eliminating it. Once occupants wear belts, only modest further improvements in the crash phase features of vehicle design and occupant protection beyond those already in place are likely to occur” (Evans, 2004, p. 355). This might be the fact for car crashes, but there are still improvements needed for buses and coaches with respect to passive and active safety in the crash phase. One major difference is the recently implemented Directive 2001/85/EEC (2002), which prescribes mandatory seatbelts in all new buses or coaches for seated passengers exclusively, while as a comparison, seat belts in cars have been mandatory for decades. Another major difference is the seat belt usage in cars and buses/coaches. While the seat belt usage in cars in Sweden has been stable around 90% the recent years (Cedersund, 2003), the usage in buses and coaches is still very low, reaching only 6-8% (Gustafsson & Thulin, 2002). Another example is that new buses and coaches are still leaving the factories equipped with only 2-point belts. Furthermore, the interior design is different; in buses and coaches, unnecessary harm is caused to occupants due to improper design details from a passive safety perspective. For example, in Paper IV it was shown that one person struck a hook intended for clothes with his head, causing a subdural haemorrhage. Similar design solutions are probably very difficult to find in modern cars. For these reasons, the Haddon matrix is still useful when investigating bus and coach crashes.

There are other research frameworks used for investigating bus and coach incidents. The Jovanis et al. (1991) framework “Transit service characteristics and agency policies” was developed in order to be able to structure, and thereby to compare bus and coach crash statistics. The main disadvantage with this framework is that it does not take the passengers into consideration. Since this thesis has injury causation and injury mechanisms among bus and coach occupants i.e. driver and passengers as its scope, the Jovanis framework was not useful.

In this thesis Paper II-V have investigated a number of severe bus and coach crashes. Although some of the crashes are included in several papers, the scope of the papers is different. By studying a crash case, a matrix suitable for investigating severe bus and coach crashes was elaborated and further developed (Paper II). In Paper III, ten crashes were selected with the aim to identify cross-winds as a pre-crash factor behind coach crashes. The same crash as in Paper II and two other severe coach crashes were used in Paper IV with the purpose to identify the injury causations and based on this knowledge, investigate the possible injury reducing effect of seat belts. In Paper V, a third coach crash from Paper IV was used in yet another framework; focusing on the emergency, rescue and hospital response.

One limitation in Paper III was that in some of the investigated crashes the vehicles were not equipped with a tachograph and, hence, the speeds were self reported by the drivers themselves. A driver reporting him/herself as speeding is likely to be convicted. This fact may, in turn, give somewhat biased speed figures in the reported crashes; they are probably lower than the actual speed. Another limitation was that cross-wind speeds at the actual crash sites were not recorded. Instead these figures were collected from the closest wind station, i.e. 5-20 km from the crash sites. However, according to SMHI these figures provide a fair value of the crash site wind speed. The actual wind speed may in some cases actually be higher than the meteorological wind speed. For example in a case where the road is elevated compared to the surroundings, the wind speed increases when it enters the elevation of the road. Yet another limitation was that the actual local coefficients of friction were not recorded. Instead the SNRA's best practice values for coefficients of friction in different road conditions were used. The reason for using the SNRA's best practice values is that an exact measure of the coefficient of friction is difficult to achieve, since the instruments measuring friction values are given mean values during the measured retardation distance of the vehicle used during the measurement.

The main motive for investigating the injury reducing effect on seat belts in a theoretical way is simply that there is no real world data on seat belt usage in bus or coach crashes. This notion can be supported by results from the ECBOS work, where an in-depth analysis of 36 severe bus and coach crashes was conducted. As

some of the vehicles were older and not equipped with seat belts, the overall wearing rate was generally low anyway, but in one case two full coaches, both equipped with 2-point lap belts, impacted each other with no one at all wearing their restraint (ECBOS, 2002). Hence, the theoretical study conducted in Paper IV represents a first legitimate approach while “waiting” for real world crash data in which belted and unbelted occupants would be compared.

A limitation in Paper IV is that it describes a best case scenario of possible injury reduction with all occupants using their seat belts and the seat belts working to their full effect. It is also presumed that there are no ‘side effects’ from the use of seat belts. As the belt system has to physically restrain the occupant, there is the possibility of injury from the seat belt itself, presumably contusions. It is unlikely that an AIS 3-4 injury can be completely reduced to an AIS 0 or AIS 1 injury. Usage of the seat belt also presumes that seat belts are correctly worn, which may be a problem for children who may see it as fashionable or not unsafe to wear the seat belt incorrectly, for instance the diagonal section under the arm, close to the armpit.

The main motive for performing the analysis in Paper IV for both 2-point and 3-point belts was that the 3-point belt reduces movement of the thorax from the back rest of the seat, which is an highly relevant aspect in positions 1 and 2, shown in Figure 8. If an occupant uses a 2-point belt in a rollover crash to the right, it can lead to a high risk for head impact (HIC-values $>1,000$, i.e. risk for a life threatening injury) (Gadd, 1966; NHTSA, 1972; Henn, 1998) to the right hand side of the coach or into an occupant sitting in position 1 (ECBOS, 2002). The 2-point and 3-point belt analyses are particularly applicable on position 1 and 2. However, such analyses may also be applied on position 3 and 4, positions in which a 3-point belt may prevent thorax movement.

Another limitation in Paper IV is that it was not possible to identify the injury causations in all cases due to lack of data in some cases and that the occupants in some cases were not able to state what caused their injury. Instead, result from simulations (ECBOS, 2002) had to be used in these cases and thus causations were set on a more general basis. The simulations conducted in the ECBOS-project also showed that the occupant’s thorax did not slide out laterally from a 3-point belt in a rollover situation. In reality this may be the case for occupants located in positions 3 and 4 if belted with a 3-point belt with the upper anchorage point mounted towards the side window. This problem has been studied in far-side car crashes where a side support is suggested as a countermeasure against the thorax lateral movement (Fildes et al., 2003).

In Paper IV, results from simulations done with MADYMO (version 5.4.1) performed in the ECBOS project were used. In MADYMO, finite elements techniques (simulation of structural behaviour) and multi-body techniques (simulation of the bodies connected by joints or the gross motion of systems) are combined in one program. The simulations can be performed with only multi-bodies or only finite elements models or combination of both. MADYMO allow both 2-D and 3-D modelling. MADYMO can simulate the dynamic behaviour of physical systems, with a focus on the analysis of 4-wheeled vehicle collisions and the sustained occupant injuries. Also in motorcycle and bicycle crashes, MADYMO could be used to reconstruct the crash. In addition, the performance of restraint systems, such as seat belts and airbags is yet another area for MADYMO. It has been developed by TNO Automotive in the Netherlands in the early nineteen eighties and has been continuously up-dated since then.

A general limitation for simulation programs is that the reconstruction of real-world crashes may be less detailed on various parameters, which will result in a less accurate reproduction of the crash. However, simulations based on dummy movement are continuously validated (Scholpp et al., 2004) and hence a good correlation is achieved.

In Paper V, a major traffic incident was investigated with its scope on the emergency and hospital response. In order to complete a comprehensive report covering all the phases in the incident, two frameworks were used. The Haddon matrix and the prospective standardized Protocol for Major Incidents. This approach proved to be a fruitful combination since the two frameworks overlapping each other; the Haddon matrix emphasising on the pre-crash and crash phase and the Protocol for Major Incidents emphasises more on the post-crash phase. Finally, since this incident was analysed from a Disaster Medicine perspective, the matrix still served as a useful tool because of its ability to provide structure to all the factors generated from the complex situation characterised as a major incident.

Conclusions

Bus and coach fatalities represents only 0.3-0.5% of all traffic fatalities, it is in fact comparatively safe to travel by bus. In recent years the bus and coach related casualties in Europe have been stable, and in Sweden an increase in injuries is indicated.

The key findings in this thesis are as follows:

In general:

- Data from the medical sector are in Sweden more reliable compared to data from the police i.e. official statistics

In non-crash events:

- Non-crash events make up a majority of all bus and coach casualties
- There is a high proportion of elderly female occupants among the MAIS 2+ injury cases
- Boarding and, especially, alighting is a major factor for injuries causing many injuries to the lower extremities. Step heights and slippery conditions need to be addressed with respect to this matter
- Harsh braking is a major cause for injuries in a moving bus or the coach

In the pre-crash phase:

- Cross-winds do affect the safety of buses and coaches and requires more attention taking aero dynamical factors and exterior design of buses and coaches into consideration
- Bus and coach operators have to introduce or improve their traffic safety policy, especially taking driving conditions like type of road, road surface, weather and wind conditions into consideration when planning trips or regular traffic
- The usage of seat belts among bus and coach occupants has to be increased. In the long term, at least to the same level as in cars i.e. around 90%

In the crash phase:

- Rollover and ejection are the major causes behind serious and fatal injuries to bus and coach occupants, consequently should more attention be given preventative measures like retentive glazing, pillars or rails that prevents occupants from being ejected
- An upgrade from 2-point seat belts to 3-point seat belts yields an increase in the estimated injury reduction from approximately 50% up to 80% for the MAIS 2+ casualties.

In the post-crash phase:

- Proper equipment for lifting a coach body originated from experience and development is essential in a rescue operation of a crashed bus or coach
- Proper methods for the emergency response inside crashed coaches originated from experience need to be developed

Euro NBAP, a European New Bus and Coach Assessment Programme

Based on the results and conclusions generated in this thesis, a European New Bus and Coach Assessment Programme is suggested which would provide bus and coach occupants with a programme similar to the Euro NCAP (European New Car Assessment Programme, 2004) that “provides motoring consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe.” A Euro NBAP could like the Euro NCAP “become a catalyst for encouraging significant safety improvements” in new bus and coach design. In addition, it would also simplify for travel agencies and bus operators in their choice of which buses and coaches to hire. A similar assessment program has previously been suggested by the ECBOS-project (ECBOS, 2002).

Full scale crash tests similar to Euro NCAP might not be feasible for buses and coaches because of practical reasons and the costs of such tests, but reliable and accurate comparative information may be obtained in other ways. This could be achieved if certain demands, like for example 3-point belts on all seats, were provided or a low entrance solution like “kneeling buses” was provided in a city bus. Credits in form of a star rating similar to the Euro NCAP, could be one suggestion to reward a proper design that would fulfil the needs in a Euro NBAP.

One way to realize a Euro NBAP might be to introduce a new legislation valid inside the EU. This is however, a solution that probably would be time-consuming and perhaps difficult to realize at all. Another suggestion might be to have a common agreement between the authorities and the different bus manufactures (in Sweden, SNRA, BR, Volvo, Scania etc). This method has proven to be a much more effective way of making rapid progress in achieving agreements compared to legislation that might be a way of working on longer terms. In addition, such an agreement may also be a way for the authorities and manufactures to fulfil their moral and ethical responsibility for improved safety for bus and coach occupants.

The Euro NBAP might give credits in the following areas.

Suggestions based on results from this thesis:

- Injury mitigation measures that would facilitate boarding and alighting:
 - Low entrances preventing slips and trips during boarding and alighting the bus or coach. Separate solutions for buses and coaches
 - Heating coils in the entrance and stairs preventing slips and trips during boarding and alighting
- Step highs inside the bus or coach preventing slips and trips during transportations inside the coach
- Measures that protects belted occupants located next to a side and unbelted occupants from being ejected, e.g. pillars, rails and/or retentive glazing

- A 3-point belt on all seats that protects the occupants from being ejected and in addition gives protection in case of a frontal and rear impact
- A seat belt reminder on all seats
- Injury mitigation solutions for protruding interior details inside buses and coaches in the following categories:
 - Seat backs
 - Grab rails
 - Armrests
 - Luggage racks
 - Side walls
- Emergency exits specially designed for evacuating occupants in case of a rollover or turnover i.e. when ordinary exits are blocked
- An Advanced Driver Assistive Systems (ADAS) combining the three factors; loading, road friction and cross-winds providing recommended speed (a passive system) or limiting it (an active system)
- A proper vehicle design, taking aero dynamical and stability factors into consideration

Additional suggestions based on industry and expert experiences:

- Automatic fire-extinguisher in the engine compartment
- Automatic fire extinguishing system in the passenger compartment
- Smoke warning system
- Fire warning system (engine)
- Non-inflammable interior i.e. seats, roof and side-walls
- Fuel shut-off function
- Fire extinguisher
- Anti-lock brakes
- ESP - Electronic Stability Program
- Collision avoidance system
- All-round mirrors
- Reverse camera
- Surveillance camera at exit door
- Light at exit door
- Anti jamming doors
- Ignition Interlock
- Hands-free mobile phone
- Seat belt cushions for children
- Safety information card
- Safety information film
- Crash data recorder (“Black box”)

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