Institute of Transport Economics
Norwegian Centre for Transport Research

Literature review of active and passive measures to improve bus safety

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Summary

A main conclusion of our literature review is that bus/coach is the safest mode of transport for the occupants of road vehicles in OECD countries. The risk of being killed or seriously injured is seven to nine times lower for bus and coach occupants as compared to the risk of car occupants. Another main conclusion of the present study is that bus drivers are insufficiently protected in accidents with frontal impact. This is largely related to the fact that there are no mandatory European collision safety regulations for bus drivers. We discuss this paradox; that the bus driver is insufficiently protected in bus transport, which is the safest mode of road transport. We also conclude that bus drivers' vulnerability in collisions with frontal impact, even at low speeds, is in contrast with the principles of current road safety policies, as described in Vision Zero and Safe System.

Kort sammendrag

En hovedkonklusjon fra vår litteraturgjennomgang er at buss/turbuss er den sikreste vegbaserte transportformen i OECD-land. Risikoen for å bli drept eller alvorlig skadet er sju til ni ganger lavere for passasjerer i buss sammenlignet med risikoen for bilpassasjerer. En annen hovedkonklusjon i denne studien er at bussjåfører er utilstrekkelig beskyttet i ulykker med frontkollisjon. Dette er i stor grad knyttet til det faktum at det ikke finnes obligatoriske europeiske kollisjonssikkerhets-reguleringer for bussjåfører. Vi diskuterer dette paradokset; at bussjåføren er utilstrekkelig beskyttet i busstransport, som er den sikreste formen for vegtransport. Vi konkluderer også med at bussjåførers sårbarhet i frontkollisjoner, selv ved lave hastigheter, står i kontrast til prinsippene i dagens trafikksikkerhetspolitikk, slik de er beskrevet i Nullvisjonen og Safe System.

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Preface

This is one of four reports in a project focusing on bus collision safety. Nævestad et al (2024) present the main results of the project. The other reports in the project present the IDIADA bus front improvement model (Laso et al 2025), and an analysis of bus accidents in Europe (Høye et al 2025).

The Ministry of Transport has tasked the Norwegian Public Roads Administration (NPRA) with evaluating proposals for national requirements on bus collision safety, aiming to enhance driver protection during collisions, while considering potential effects on passengers and other road users. There are no mandatory EU crashworthiness standards targeting the collision safety of bus drivers. Taking a lead in bus driver safety, Norway adopted UNECE Regulation 29 for buses as of 01.10.2023. This standard, however, originally applies to trucks, and may not fully address the unique design and operational characteristics of buses. Thus, there is a need to evaluate the suitability of R29. Particular mention is also made of ECE Regulation 93 (front underrun protection), which currently applies only to heavy goods vehicles, as a measure to be assessed. The Ministry states that the evaluation should also serve as a basis for a potential Norwegian initiative to develop a voluntary international standard.

The NPRA has approached the Institute of Transport Economics (TØI) to conduct an analysis of bus collision safety, focusing on how well the driver (and other road users) are protected. The NPRA's contact for this analysis was Thea Berg-Halsen. We are very grateful for good cooperation and interesting discussions during the project. We also thank the many individuals and organizations in the Norwegian public transport environment for insightful discussions and valuable feedback. This applies e.g. to Public Transport Norway, Ruter, bus driver unions like YTF and Fellesforbundet, Fagforbundet, employer organisations like NHO transport, the Norwegian Safety Investigation Authority, Bussmagasinet, and many more.

Project manager at TØI has been Tor-Olav Nævestad. He has had the main responsibility for writing the report together with Ingeborg Hesjevoll, Rune Elvik, Alena Høye, Vibeke Milch, Øyvind Lothe Brunstad and Jenny Blom. Senior researcher Daniel Ruben Pinchasik and director of research, Trine Dale have quality assured the report.

Oslo, May 2025
Institute of Transport Economics

Bjørne Grimsrud Managing Director	Trine Dale Chief Research Officer

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ENGLISH **Summary**

Literature review of active and passive measures to improve bus safety

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The present study provides a systematic literature review to examine results from studies of bus accidents, passive safety measures that may protect bus drivers (and possibly passengers) from injuries in collisions, and active safety measures that may reduce the probability of bus accidents. A main conclusion of our review is that bus/coach is the safest mode of transport for the occupants of road vehicles in OECD countries. The risk of being killed or seriously injured is seven to nine times lower for bus and coach occupants as compared to the risk of car occupants. Another main conclusion of the present study is that bus drivers are insufficiently protected in accidents with frontal impact. This is largely related to the fact that there are no mandatory European collision safety regulations for bus drivers. Our literature review discusses this paradox; that the bus driver is insufficiently protected in bus transport, which is the safest mode of road transport. We also conclude that bus drivers' vulnerability in collisions with frontal impact, even at low speeds, is in contrast with the principles of current road safety policies, as described in Vision Zero and Safe System. We also discuss bus drivers' vulnerability in light of the Academic Expert Group (AEG) recommendations related to the 4th Global Ministerial Conference on Road Safety in Marrakech, 2025.

Background

Bus drivers are more exposed in crashes with frontal impact than e.g. car and truck drivers. The reasons for this are: lacking crumple zones in bus fronts, lack of mandatory EU crash-worthiness standards focusing on bus drivers, and a low driver seating position in many buses (e.g. city buses). The vulnerable situation of bus drivers in collisions with frontal impacts has been indicated in bus accidents in Norway in the last ten years. In some of these crashes, bus drivers have been killed or seriously injured despite relatively low speeds of impact. In one of these crashes (Accident investigation board 2019), one driver was killed and the other critically injured in a head-on crash, even though the speed of the buses at the time of impact was just a little over 30 km/h. If two passenger cars with state-of-the-art crashworthiness had crashed head-on at a similar speed, it is unlikely that the crash would have been fatal. If all protective systems (crumple zone, collapsible steering wheel column, seat belts, air bags) had worked properly, it might very well have resulted in material damage only.

In recent decades, the automotive industry has made significant strides in vehicle safety due to stricter regulations. However, despite these advancements, the progress in the safety of heavy vehicles, especially buses, has not kept pace. Regulations governing safety in this sector have remained relatively unchanged, resulting in a lack of advanced safety equipment in many buses currently on the road. Consequently, passengers and drivers of these vehicles may face a higher risk of injuries in the event of a collision.

Truck cabs are subject to crashworthiness standards under UNECE Regulation 29, which mandates tests for structural integrity and occupant safety in head-on and rollover crashes. Passenger cars must meet crash-test standards that ensure survival space for drivers and passengers during collisions. There are, however, no mandatory EU crashworthiness standards targeting the situation of bus drivers. As an exception to this situation, Norway adopted UNECE Regulation 29 for buses on 01.10.2023. This standard, however, originally applies to trucks, and it may not fully address the unique design and operational characteristics of buses compared to trucks. Thus, there is a need to study the crash protection of bus drivers, and to develop targeted solutions which can provide bus drivers with sufficient protection in case of accidents with frontal impacts.

Aims

To better understand the factors influencing bus safety and to identify measures to enhance it, we have conducted a series of comprehensive literature reviews. These reviews focused on critical aspects of bus safety, encompassing both passive and active safety measures, as well as the design features of buses that impact driver, passenger, and road user safety.

The literature reviews have three aims:

1) **Examine what studies of bus accidents** say about severity and mechanisms of injury (e.g. bus design) among drivers, passengers and other road users involved in accidents.
2) **Map passive safety measures** that may protect bus drivers (and possibly passengers) from injuries in collisions, especially head-on collisions, and assess whether they are effective.
3) **Map active safety measures** that may reduce the probability of accidents for buses, and assess whether they are effective.

Bus/Coach is one of the safest mode of transport

When discussing bus safety, it is important to remember that studies of European bus accidents show that buses/coaches in crashes account for 2% of all road fatalities in EU. Meanwhile, the number of fatalities in bus/coach crashes per million inhabitants, ranges between about 0.3 fatalities (Sweden) and 4.9 fatalities (Croatia). Existing studies generally report that bus/coach is the safest mode of transport for the occupants of road vehicles in OECD countries. In OECD countries, the risk of being killed or seriously injured is found to be seven to nine times lower for bus and coach occupants as compared to that of car occupants. Studies also find a decrease in bus accidents in Europe over time. Studies of passenger injuries find that the majority of injuries are not related to accidents, but incidents on the bus, e.g. people falling onboard the bus or while going on/off.

Insufficient protection of the bus driver

The literature review shows that there are few studies focusing on the collision protection of bus drivers and on the role that technical aspects of bus design plays for personal injuries of bus drivers. Existing studies indicate that the main focus in bus safety regulation is bus passenger safety. Bus safety regulations apply for instance to rollover incidents, regulated through ECE regulation 66, or evacuation safety, regulated in ECE regulation 107. There are no mandatory European collision safety regulations for bus drivers.

As of 2020, Norway's largest transit authority Ruter mandated that buses in their transport service contracts must include physical collision protection for drivers that comply with the UNECE-R29 standard. This requirement was first implemented in the Bus Services Oslo South contract awarded in 2021. Norway implemented R29 as a national rule from October 1. 2023, as the first country in Europe. ECE regulation 29 is originally for trucks. Thus, while passenger cars and trucks benefit from decades of advancements in crash testing, with extensive use of materials and designs aimed at driver survival, buses are more regulated for passenger safety and rollover protection. This indicates a gap in regulatory focus on bus driver safety.

Our literature review of studies of bus accidents and simulations of bus crashes (testing relevant bus crash test standards and bus collision protections) shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that R29 crash test design requirements are insufficient, and that there is a need for an improved bus front structure.

A Hungarian study, which uses data from 560 frontal bus collisions from all over the world, finds that drivers were 2-15 times more exposed to serious injuries and fatalities than passengers in frontal collisions. The Hungarian study concludes that drivers are strongly endangered in frontal collisions and that their protection is an essential obligation in future legislative work.

New technologies aiming to avoid accidents

The search yielded few studies that investigate effects of active safety measures in buses. In total eight studies were identified, four of which are peer-reviewed studies, and the remaining four are scientific reports. The measures evaluated span several ADAS technologies:

- Pedestrian/cyclist collision warnings
- Blind spot monitoring
- In-vehicle data recorders (IVDR)
- Intelligent Speed Adaptation (ISA)
- Retarder systems simulating advanced driver assistance features.

Five of the eight studies focus on VRU accident prevention. Thus, this is the most important issue in the identified studies. Technologies like blind spot monitoring and turn warning systems aim to reduce collisions with VRUs.

The second key topic in the identified studies is improving driver behaviour through ADAS (ISA, IVDR). Several studies indicate that ADAS can positively influence driver behaviour. However, a consistent challenge lies in driver acceptance. Many drivers reported issues such as false alarms, late warnings, or distracting system interfaces. A recurring concern related to systems aiming to avoid bus collisions is the balance between implementing such safety measures and ensuring passenger stability, particularly for standing passengers. ISA systems, designed to prevent speeding, have been shown to improve compliance with speed limits in urban environments. Finally, few of the studies investigated effects of such systems on the number of crashes or near-misses, and little is known about long term effects. This is a significant limitation indicating an important issue for future research.

Bus drivers' vulnerabilities in a Safe System

We conclude that bus drivers' vulnerability in collisions with frontal impact, even at low speeds, is in contrast with the principles of current road safety policies, as described in Vision Zero and Safe System. The Academic Expert Group (AEG) recommendations related to the 4th Global Ministerial Conference on Road Safety in Marrakech, 2025, suggests a strategy of "Saving Lives Beyond 2025", through integrating road safety into occupational health and safety management. It seems that reducing bus drivers' vulnerability in collisions with frontal impact is in line with this strategy.

Transportøkonomisk institutt
Stiftelsen Norsk senter for samferdselsforskning

NORSK **Sammendrag**

Litteraturgjennomgang av aktive og passive tiltak for økt sikkerhet i busstransport

TØI rapport 2094/2025 • Forfattere: T.O. Nævestad, I. S. Hesjevoll, Ø. L. Brunstad, V. M. Uhlving, J. Blom, A. K. Høye, R. Elvik • Oslo 2025 • 39 sider

Den foreliggende studien gir en systematisk litteraturgjennomgang for å undersøke resultater fra studier av bussulykker, passive sikkerhetstiltak som kan beskytte bussjåfører (og muligens passasjerer) mot skader ved kollisjoner, samt aktive sikkerhetstiltak som kan redusere sannsynligheten for bussulykker. En hovedkonklusjon fra vår litteraturgjennomgang er at buss/turbuss er den sikreste vegbaserte transportformen i OECD-land. Risikoen for å bli drept eller alvorlig skadet er sju til ni ganger lavere for passasjerer i buss sammenlignet med risikoen for bilpassasjerer. En annen hovedkonklusjon i denne studien er at bussjåfører er utilstrekkelig beskyttet i ulykker med frontkollisjon. Dette er i stor grad knyttet til det faktum at det ikke finnes obligatoriske europeiske kollisjonssikkerhets-reguleringer for bussjåfører. Vår litteraturgjennomgang diskuterer dette paradokset; at bussjåføren er utilstrekkelig beskyttet i busstransport, som er den sikreste formen for vegtransport. Vi konkluderer også med at bussjåførers sårbarhet i frontkollisjoner, selv ved lave hastigheter, står i kontrast til prinsippene i dagens trafikksikkerhetspolitikk, slik de er beskrevet i Nullvisjonen og Safe System. Vi diskuterer også bussjåførers sårbarhet i kollisjoner, i lys av anbefalingene fra Academic Expert Group (AEG) knyttet til den fjerde globale ministerkonferansen om trafikksikkerhet i Marrakech, 2025.

Bakgrunn

Bussjåfører er mer utsatt enn for eksempel bil- og lastebilsjåfører ved frontkollisjoner. Dette skyldes manglende deformasjonssoner i fronten av busser, mangelen på obligatoriske EU-standarder for kollisjonssikkerhet som fokuserer på bussjåfører, og lav førerposisjon i mange busser (for eksempel bybusser). Dette har blitt påpekt i analyser av bussulykker i Norge de siste ti årene. I noen av disse ulykkene har bussjåfører blitt drept eller alvorlig skadet, selv om kollisjonshastigheten har vært relativt lav. I én av disse ulykkene (Statens havarikommisjon, 2019) ble én sjåfør drept og den andre kritisk skadet i en frontkollisjon, selv om bussene hadde en hastighet på litt over 30 km/t ved sammenstøtet. Hadde to personbiler med moderne kollisjonssikkerhet kollidert front mot front ved en tilsvarende hastighet, er det lite sannsynlig at ulykken ville vært dødelig. Hvis alle sikkerhetssystemer (deformasjonssoner, sammenlegg-bar rattstamme, setebelter og kollisjonsputer) hadde fungert som de skulle, ville det trolig bare ha resultert i materielle skader.

I løpet av de siste tiårene har bilindustrien gjort betydelige fremskritt innen kjøretøysikkerhet som følge av strengere regelverk. Til tross for denne utviklingen har sikkerhetsnivået for tunge kjøretøy, spesielt busser, ikke holdt samme tempo. Regelverket som gjelder for sikkerhet i denne sektoren har vært relativt uendret, noe som har resultert i mangel på avansert sikker-hetsutstyr i mange av dagens busser. Dette medfører at passasjerer og sjåfører i disse kjøre-tøyene kan være utsatt for høyere risiko for skader ved kollisjoner.

Førerhytta i lastebiler er underlagt kollisjonssikkerhetsstandarder i henhold til UNECE R29, som krever tester for strukturell integritet og sikkerhet for føreren ved frontkollisjoner og velt. Personbiler må oppfylle kollisjonsteststandarder som sikrer overlevelsesrom for fører og passasjerer under kollisjoner. Det finnes imidlertid ingen obligatoriske EU-standarder for kollisjonssikkerhet som spesifikt adresserer situasjonen for bussjåfører. Som et unntak fra denne situasjonen vedtok Norge UNECE R29 for busser fra 01.10.2023. Denne standarden gjelder imidlertid opprinnelig for lastebiler og tar kanskje ikke fullt ut hensyn til de unike design- og driftskarakteristikkene for busser sammenlignet med lastebiler. Det er derfor nødvendig å studere bussjåførenes kollisjonsbeskyttelse og utvikle målrettede løsninger som kan gi tilstrekkelig beskyttelse ved frontkollisjoner.

Mål

For å bedre forstå faktorene som påvirker sikkerheten i busser og identifisere tiltak for å forbedre den, har vi gjennomført en serie litteraturgjennomganger.

Litteraturgjennomgangene har tre mål:

1) Undersøke hva studier av bussulykker sier om skadegrad og skademekanismer (f.eks. bussdesign) blant førere, passasjerer og andre trafikanter involvert i ulykker.
2) Kartlegge passive sikkerhetstiltak som kan beskytte bussjåfører (og muligens passasjerer) mot skader i kollisjoner, særlig frontkollisjoner, og vurdere om de er effektive.
3) Kartlegge aktive sikkerhetstiltak som kan redusere sannsynligheten for bussulykker, og vurdere om de er effektive.

Buss er en av de sikreste transportformene

Når man diskuterer bussikkerhet, er det viktig å huske at studier av europeiske bussulykker viser at busser/turbusser i ulykker utgjør 2 % av alle vegtrafikkdødsfall i EU. Sammenlignet med antall dødsfall per million innbyggere i buss-/turbussulykker, varierer andelen mellom omtrent

4,9 dødsfall i Kroatia og 0,3 dødsfall i Sverige. Studiene rapporterer generelt at buss/turbuss er den sikreste transportformen for passasjerer i vegtrafikk i OECD-land. I OECD-land er risikoen for å bli drept eller alvorlig skadet funnet å være sju til ni ganger lavere for passasjerer i buss og turbuss sammenlignet med bilpassasjerer.

Utilstrekkelig beskyttelse av bussjåføren

Litteraturgjennomgangen viser at det er få studier som fokuserer på kollisjonsbeskyttelse for bussjåfører og rollen tekniske aspekter ved bussdesign spiller for personskader blant bussjåfører. Studiene indikerer at hovedfokuset i bussikkerhetsreguleringer er passasjersikkerhet. For eksempel gjelder bussikkerhetsreguleringer veltehendelser, som er regulert gjennom ECE-regulering 66, eller evakueringssikkerhet, som er regulert i ECE-regulering 107.

Det finnes ingen obligatoriske europeiske kollisjonssikkerhetsstandarder som spesifikt fokuserer på bussjåfører. Enkelte transportmyndigheter og Norge har implementert ECE-R29, som opprinnelig er laget for lastebiler. Dette betyr at mens personbiler og lastebiler nyter godt av flere tiår med utvikling innen kollisjonssikkerhet, med omfattende bruk av materialer og design for å sikre førernes overlevelse, er busser i større grad regulert med tanke på passasjersikkerhet og veltebeskyttelse. Dette indikerer en mangel i reguleringsfokuset på bussjåførenes sikkerhet.

Vår litteraturgjennomgang av studier av bussulykker og simuleringer av kollisjoner (som tester relevante busskollisjonsteststandarder og bussenes kollisjonsbeskyttelse) viser at dagens strukturelle design av bussfronter gir utilstrekkelig kollisjonsbeskyttelse for sjåfører, at R29-standardens krav til kollisjonstester er utilstrekkelige, og at det er behov for en forbedret bussfront-struktur.

En ungarsk studie, som bruker data fra 560 frontkollisjoner med busser fra hele verden, finner at i frontkollisjoner er sjåfører 2–15 ganger mer utsatt for alvorlige skader og dødsfall enn passasjerer. Den ungarske studien konkluderer med at sjåførene er sterkt utsatt i frontkollisjoner, og at deres beskyttelse bør være fokus i fremtidig lovgivningsarbeid.

Ny teknologi for å unngå ulykker

Litteraturgjennomgangen identifiserte få studier som undersøker effekten av aktive sikkerhetstiltak i busser. Totalt åtte studier ble identifisert, hvorav fire er fagfellevurderte studier, og de resterende fire er vitenskapelige rapporter. De evaluerte tiltakene omfatter flere avanserte førerstøttesystemer (ADAS):

- Varslingssystemer for kollisjon med fotgjengere/syklister
- Blindsonemonitorering
- Kjøretøybaserte dataloggere (IVDR)
- Intelligente fartsgrenser (ISA)
- Retardersystemer som simulerer avanserte førerstøttefunksjoner

Fem av de åtte studiene fokuserer på å forhindre ulykker med myke trafikanter. Dette er derfor det viktigste temaet i de identifiserte studiene. Studiene fokuserer for eksempel på teknologier som blindsonemonitorering og systemer som varsler om myke trafikanter.

Det andre hovedtemaet i de identifiserte studiene er forbedring av føreradferd gjennom ADAS (ISA, IVDR). Flere studier indikerer at ADAS kan påvirke føreradferd positivt. En tilbakevendende utfordring er imidlertid førerens aksept av teknologien. Mange førere rapporterte problemer som falske alarmer, forsinkede varsler eller distraherende brukergrensesnitt.

En utfordring knyttet til systemer som skal unngå busskollisjoner, er balansen mellom implementering av slike sikkerhetstiltak og å sikre passasjerenes stabilitet, særlig for stående passasjerer. ISA-systemer, som er designet for å forhindre fartsoverskridelser, har vist seg å forbedre overholdelsen av fartsgrenser i urbane miljøer. Likevel undersøkte få av studiene effekten av slike systemer på antall ulykker eller nestenulykker, og lite er kjent om langtidsvirkninger. Dette er en betydelig begrensning som indikerer et viktig område for fremtidig forskning.

Bussjåførers sårbarhet i et «Safe System»

Vi konkluderer med at bussjåførers sårbarhet ved frontkollisjoner, selv i lave hastigheter, står i kontrast til prinsippene i dagens trafikksikkerhetspolitikk, slik de er beskrevet i Nullvisjonen og Safe System. Anbefalingene fra Academic Expert Group (AEG) knyttet til den fjerde globale ministerkonferansen om trafikksikkerhet i Marrakech, 2025, foreslår en strategi for å "SAving lives beyond 2025", gjennom å integrere trafikksikkerhet i HMS-arbeidet (helse, miljø og sikkerhet). Det ser ut til at det å redusere bussjåførers sårbarhet ved frontkollisjoner er i tråd med denne strategien.

1 Introduction

1.1 Background

Bus drivers are more exposed in crashes with frontal impact than e.g. car and truck drivers. The reasons for this are: lacking crumple zones in bus fronts, lack of mandatory EU crashworthiness standards focusing on bus drivers, and a low driver seating position in many buses (e.g. city buses). (Afripin et al., 2019; Holenko et al., 2024).

The vulnerable situation of bus drivers in collisions with frontal impacts has been indicated in bus accidents in Norway in the last ten years. In some of these crashes, bus drivers have been killed or seriously injured despite the fact that impact speeds were quite low.

In one of these crashes (Norwegian Safety Investigation Authority (NSIA), 2019), one driver was killed and the other critically injured in a head-on crash, even though the speed of the buses was just over 30 km/h at the time of impact. The buses struck each other with an overlap of about 40-50%. This means that the first point of impact for both buses was the driver's compartment. In both buses, this compartment was crushed completely, leaving little or no space for survival.

If two passenger cars with state-of-the-art crashworthiness had crashed head-on at a similar speed, the crash would probably not have been fatal. If all protective systems (crumple zone, collapsible steering wheel column, seat belts, air bags) had worked properly, such a crash might very well have resulted in property damage only.

The NSIA compared buses to other motor vehicles with respect to crashworthiness standards. This comparison is shown in Figure 1.1.

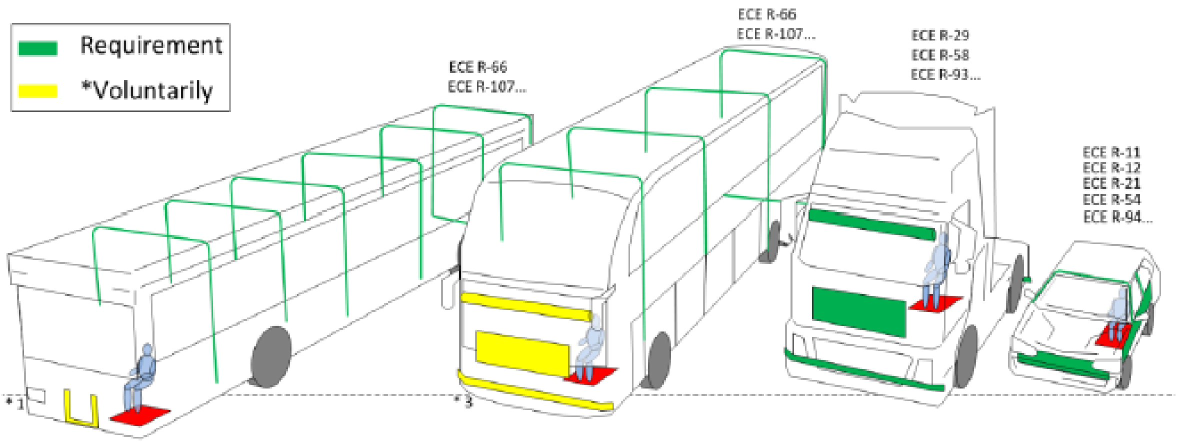

Figure 1.1: Crashworthiness regulations for buses and other vehicles. Source: Accident Investigation Board (2019).

For coaches used in long distance traffic, safety bars can be installed but are not mandatory (shown in yellow on the second bus from the left in Figure 1.1). For trucks, safety bars are mandatory (shown in green). The buses that crashed in the head-on collision mentioned above were of the type shown to the left in Figure 1.1. In these buses, the seat belt is the only protection of the driver. There are no safety bars, no extra bumper functioning as a buffer, no air bag, and no system for retracting and/or reclining the seat in case of an impact. There are, in other words, many measures that can improve crashworthiness, but that are not required by current safety standards for city buses or buses operating regional routes. The exception is ECE R-29. As of 2020, Norway's largest transit authority

Ruter mandated that buses in their transport service contracts must include physical collision protection for drivers that comply with the UNECE-R29 standard. This requirement was first implemented in the Bus Services Oslo South contract awarded in 2021.

Since the above-mentioned crash is not the only one of this kind in Norway in recent years, the Norwegian government has taken an initiative in order to improve bus crashworthiness, in particular to improve bus driver protection in head-on crashes.

Truck cabs are subject to strict crashworthiness standards under UNECE Regulation 29, which mandates tests for structural integrity and occupant safety in head-on and rollover crashes. Passenger cars must meet crash-test standards that ensure survival space for drivers and passengers during collisions. There are, however, no mandatory crashworthiness standards targeting the situation of bus drivers. The exception is Norway, which in 01.10.2023 adopted UNECE Regulation 29 for buses. This standard applies, however, to trucks, and it may not fully address the unique design and operational characteristics of buses compared to trucks. Thus, there is a need to study the crash protection of bus drivers and to develop targeted solutions which can provide bus drivers with sufficient protection in case of accidents with frontal impacts. As indicated by Figure 1.1., the main crashworthiness issue in buses has been the protection of the passengers in case of rollover accidents (cf. ECE R-66) and bus passenger evacuation (cf. ECE R-107).

1.2 Aims

To better understand the factors influencing bus safety and to identify measures to enhance it, we conducted a series of comprehensive literature reviews. These reviews focused on critical aspects of bus safety, encompassing both passive and active safety measures, as well as the design features of buses that impact driver, passenger, and road user safety.

The literature reviews have three aims:

1) **Examine what studies of bus accidents** say about severity and mechanisms of injury (e.g. bus design) among drivers, passengers and other road users involved in accidents.
2) **Map passive safety measures** that may protect bus drivers (and possibly passengers) from injuries in collisions, especially head-on collisions, and assess whether they are effective.
3) **Map active safety measures** that may reduce the probability of accidents for buses, and assess whether they are effective.

1.3 Overview of the project

This is one of four reports in a project focusing on bus collision safety. Nævestad et al (2025) present the main results of the project. The other reports in the project present the IDIADA bus front improvement model (Laso et al 2025), and an analysis of bus accidents in Europe (Høye et al 2025).

The main objective of the project is to conduct an analysis of collision safety in buses, particularly focusing on how well the driver (and other road users) are protected, in case of collisions. The project seeks to fulfil six aims:

1) **Literature review** of bus accidents and collision safety in buses, including a review of measures aiming to reduce the probability and severity of bus accidents. Presented in the present report.

2) **Data collection** and analysis of bus accidents in various countries. Reported in Høye et al (2025) and in the main report from the project (Nævestad et al 2025).

3) **Analysis and comparison of factors influencing the severity of bus accidents across countries.** Reported in Høye et al (2025), with main results presented in the main report (Nævestad et al 2025).
4) **Technical study** of collision protection for bus drivers, and development of a new model for collision protection. Reported in Laso et al (2025), with main results presented in Nævestad et al (2025).
5) **Estimate expected developments** in traffic safety. Reported in Elvik et al (2025).
6) **Assessment of the benefits and costs** of various measures for improving collision safety in buses and the expected developments over time. Reported in Nævestad et al (2025).

2 Method

2.1 Literature review

To better understand the factors influencing bus safety and to identify measures to enhance it, we conducted a series of comprehensive literature reviews. These reviews focused on critical aspects of bus safety, encompassing both passive and active safety measures, as well as the design features of buses that impact driver, passenger, and road user safety.

I) Based on studies of bus accidents, we conducted a review guided by the following research questions (RQ):

1. What are the severity and mechanisms of injury among bus drivers involved in accidents (RQ1)?
2. How does bus design affect damage/ injuries to other vehicles and road users involved in collisions with buses (RQ2)?
3. Which technical aspects of bus design have what expected impact on personal injuries for bus drivers and passengers and other road users (RQ3)?

II) Based on studies of (passive) road safety measures aiming to reduce the severity of accidents, we conducted a review of the following:

4. What measures exist to protect bus drivers (and possibly passengers) from injuries in collisions, especially head-on collisions, and are they effective (RQ4)?

III) Based on studies of (active) road safety measures aiming to reduce the probability of accidents, we conducted a review of the following:

5. What measures exist to reduce the probability of accidents for buses, and are they effective (RQ5)?

Regarding passive road safety measures, we focus particularly on those in accordance with ECE regulations 93 and 29. Other relevant measures could include factors related to bus front design or external airbags for pedestrian protection. We also discuss trade-offs between the advantages and disadvantages of reinforcements, as these can have opposite effects on drivers (or passengers) in the bus and on other road users. The main focus is on head-on collisions and on accidents with frontal impact.

Research questions 1-5 were investigated based on three main types of literature:

a) Empirical studies presenting results of analyses of bus accidents (**RQ 1, 2, 3**)

b) Studies presenting results of analyses of passive safety measures for bus drivers (e.g. R-29, R-93, airbags, seat belt) **(RQ 2, 3, 4**). This includes measures aimed at reducing injury severity for bus drivers specifically.

c) Studies presenting results of analyses of active safety measures for bus drivers (e.g. different types of ADAS; collision avoidance system, lane keeping system, ESC) **(RQ 5).** These groups of studies include measures aimed at accident prevention for buses, aimed at either buses or collision partners, but limited to measures focused on bus accidents, not measures that are for all road users generally, such as speed humps.

2.2 Search strategy and search terms

Due to the likely overlap in search hits for the different research questions, several of them were conducted jointly. We used the following groups of search terms (all used in combination with "bus"):

- **Bus accidents and injuries**: Bus AND (injury OR accident OR crash OR accident OR in-depth OR frontal impact)
- **Bus crashworthiness and passive measures**: Crashworthiness OR structural integrity OR crash protection OR collision safety OR impact resistance OR impact protection OR occupant protection OR crash energy management OR injury prevention OR safety performance OR occupant protection OR collision safety OR Impact absorption OR Collision impact OR safety design
- Driver compartment OR Driver safety cell OR Driver cabin OR Driver space
- **Specific passive safety measures**: R-29, R-93, airbag, seat belt, beams, bumpers
- **Active safety measures:** "ISA", "intelligent speed assist" "blind spot detection", "pedestrian detection", "pedestrian warning" "warning" "feedback" "direct vision" "indirect vision" "speed limiter" "lane departure warning" "ADAS", in combination with "bus driver", "bus" "buses" "transit".

Searches were conducted in the ScienceDirect and Web of Science databases in November 2024. We searched titles, abstracts and author keywords, limited to publications in the English language.

2.3 Criteria for comparing the studies in each review

2.3.1 Studies of bus accidents

We use the following five points as a checklist in our presentations of empirical studies presenting results of analyses of bus accidents:

I) Study, country, year. Aims.
II) Sample method. Method of analysis. How many accidents? When, where? What kind of buses? Types of accidents among the studied accidents (percentages head on accidents, single, with vulnerable road users).
III) Main results from the study.
IV) Overview of injuries in the studied accidents; for drivers, passengers and other road users, including:
  a) Does the study say anything about the factors influencing the injury among bus drivers, passengers and others involved in accidents?
  b) Does the study say anything about the role of technical aspects of the bus design for injuries to the bus drivers, passengers and other road users?
V) Weaknesses and strengths of the study. Does the study have any recommendations regarding measures to protect drivers, passengers or other road users in accidents?

2.3.2 Studies of passive safety measures

We use the following four points as a checklist in our presentations of empirical studies presenting analyses of passive safety measures for bus drivers:

I) Study, country, year.
II) Study design: simulation, crash test etc.
III) Main results: What are the effects of the measure for the target group of the measure (e.g the driver, passengers, other road users)?
IV) Weaknesses and strengths of the study. Does the study have any recommendations regarding measures to protect drivers, passengers or other road users in accidents?

2.3.3 Studies of active safety measures

We use the following five points as a checklist in our presentations of empirical studies presenting analyses of active safety measures for bus drivers:

I) Study, country, year.
II) Study design
III) What are the effects of the measure for the target group of the measure (i.e. the driver)?
IV) What are the effects of the measure for other involved groups (e.g passengers, other road users)?
V) Does the study have any recommendations regarding measures to protect drivers, passengers or other road users in accidents?
VI) Weaknesses and strengths of the study.

3 Results

The following section presents results from a series of literature reviews, including studies on bus accidents, collision safety in buses, and measures designed to reduce the probability and severity of bus accidents.

3.1 Studies of bus accidents

We present the empirical studies with results of analyses of bus accidents, in Table 3.1, in accordance with the five-point checklist presented above:

Table 3.1: Overview of studies of bus accidents.

Study, country, year. Aim of the study.	Method, data design	Main results	Overview of injuries, injury factors, technical aspects	Strengths and weaknesses. Recommendations?
Björnstig at al (2005), Sweden «The aim of the present study was to provide an overview of the injury epidemiology in both crash and non-crash injury incidents among bus and coach occupants.»	Studies 284 injured bus and coach occupants in Sweden, considering both non-crashes and crashes. Ten year complete data set from the health sector, comprising 284 injured bus and coach occupants	The annual injury incidence was 2 per 10,000 inhabitants, 3/4 were women. In non-crash incidents, 54% were injured; 2/3 while alighting from a bus or coach. In crashes, 46% were injured; 2/3 in collisions with other vehicles and 1/3 in single vehicle crashes. Most injuries in the winter: During October-March, 3/4 were injured.	Of those injured in collisions with other vehicles, 78% were injured in collisions with other heavy vehicles. Slippery conditions contributed to half of the alighting injuries. The proportion of moderate or more serious injuries (MAIS 2+) was highest in single vehicle crashes (48%) and in alighting and boarding (43%) incidents, and was lowest (5%) in collisions.	Injury reducing measures against alighting injuries, addressing especially step height and slippery conditions, may have a great potential to reduce these injuries. Rear-end collisions by other heavy vehicles in urban areas, causing a high number of "whip-lash" injuries, also need to be further addressed. The newly introduced law on compulsory seat belt use in long distance coaches may have a potential to reduce single vehicle crash and some collision injuries.
Evgenikos et al (2016) Studies road safety in Europe related to buses/ coaches and HGVs, by using data from the EU CARE database and other resources.	Time-series data on road accidents involving HGVs and buses/coaches for 27 EU countries over a period of 10 years are correlated with basic safety parameters, such as area type, season of the year, casualty age and gender, as well as the day of the week. Additional insight into accident causation is offered through analysis of a set of in-depth accident data from the EU SafetyNet project.	The results of the analysis allow for an overall assessment of the HGV and buses/coaches safety level in Europe in comparison to other modes of transport, thus providing useful support to decision makers working for the improvement of safety in the European road network.	Dominant causes for injuries involving accidents with HGVs and buses/coaches are typically "faulty diagnosis" and "observation missed".	Provides both a general 10-year overview and more specific information based on in-depth analysis.
Berg (2015) The paper gives an overview of the recent (mostly 2012) figures of killed bus/coach occupants (drivers and passengers) in 27 Member States of the European Union as reported by CARE.	Considering different types of buses/coaches, the paper analyzes long-term evaluations for fatalities, slight and serious injuries, using data from EU CARE.	Figures of killed occupants and of casualties related to person-kilometres are calculated and displayed for the shorter period 1995 to 2012. The authors conclude that buses/coaches are the safest mode of road transport, considering the drivers and passengers. However, this is especially the case for the passengers.	In 2012, 92 occupants of buses/coaches were killed. This represents a proportion of 0.3% of road fatalities in Europe. The fatalities include 20 drivers and 72 passengers.	Points out that vehicle safety could potentially be improved by increasing seat belt use among the occupants.
Albertsson (2005) Describes the pattern of injuries and fatalities in buses/coaches and improvements of safety.	The aim of this literature analysis was to identify and describe a pattern in bus- and coach-related incidents leading to injuries and fatalities in Europe, with special attention to injury causation and injury mechanisms, and to suggest some possible future measures for the improvement of bus and coach safety, especially with respect to passive safety	Boarding and alighting caused about one-third of all injury cases. Buses and coaches most frequently collided with cars, but unprotected road users were hit in about one-third of all cases of a collision, the point of impact on the bus or the coach being typically frontal or side.	Of all traffic fatalities in Europe, bus and coach fatalities represented 0.3–0.5%. In OECD countries, the risk of being killed or seriously injured was found to be seven to nine times lower for bus and coach occupants as compared to those of car occupants. Even though fatalities were more frequent on rural roads, a vast majority of all bus and coach casualties occurred on urban roads.	Although the study is 20 years old, and based on data which is 25-30 years old, the higher risk of other modes is supported in more recent studies (Morency et al 2018; Savage 2013; Elvik 2009). These studies find risk levels between four and 66 times higher for car than bus.

Study, country, year. Aim of the study.	Method, data design	Main results	Overview of injuries, injury factors, technical aspects	Strengths and weaknesses. Recommendations?
			Rollovers occurred in almost all cases of severe coach crashes.	
European Commission (2020) Provides recent statistics related to HGVs and buses in Europe.	A report, presenting facts and figures, mostly based on the EU CARE database and statistics from Eurostat. In this Facts and Figures report, two types of heavy vehicles are discussed, on the one hand buses/coaches and on the other hand heavy goods vehicles.	In crashes, HGVs account for 14.5% of all road fatalities in the EU. The respective value for buses/coaches is 2.5%. Between 2010-2018, this has remained quite stable. Most bus/coach fatalities occur in urban areas. Bus/coach occupants accounts for 19% of fatalities in bus/coach crashes.	Considering crashes involving HGVs, the occupants of the HGV itself only account for 13% of the fatalities. In crashes involving buses/coaches, the respective value is 19% of the occupants, whereas car crashes have a value of 60%. The report mentions that, due to the mass of buses/coaches, collisions are often more serious.	Provides an overview based on a long period of data.
Matolcsy (2017) Study of frontal bus collisions, using mathematical statistics and showing strong evidences for future international regulatory work.	Collects media reports on accidents in Hungary, Europe and in the world, for 12 years. 560 frontal collisions of buses were collected. The study documents categories of frontal collisions and differentiates between passengers and drivers.	For 12 years, 560 bus frontal collisions were collected in a data set, which provides the possibility to build up reliable, representative statistical samples.	Bus drivers were 2-15 times more exposed to serious injuries and fatalities than passengers. It is obviously proved by the results that the driver is strongly endangered in frontal collisions and his protection is an essential obligation in the future legislative work.	The dataset is not considered representative due to its inhomogeneity. However, all the collected accident statistics cover frontal collisions. This study shows a practical, usable way to collect a large dataset with accident information based on media coverage.
af Wåhlberg, A. E. (2002). The main goal of the study is to capture common features of bus accidents.	Low-speed accidents with buses in public transport in the city of Uppsala during the years 1986–2000 are coded in 17 variables concerning mainly physical properties of the accident. The taxonomy uses classifications from existing schemes, but some are altered and some new are added to capture common features of reports of bus accidents in this population.	It is found that side contacts and singles are the most common accidents, and that more than a quarter of all accident involvements occurs at bus stops.	Accidents with pedestrians involved were very rare, while those where people are hurt outside of buses are somewhat more common. To hit an object (which includes running off the road) is rather common, and almost all of those instances (88.5%) are singles.	The data sample is old: 1986-2000. Inter-rater reliability calculations for the categories show that all except one have reliabilities above 80%. The level of internal validity, calculated as agreement of frequencies between time periods, is acceptable, despite many possible sources of change and bias Drivers should be instructed not to aim for stopping a few decimetres behind another bus. The many side contacts would seem to imply that there is a lack of space for buses when they are moving into stops
Albertsson, et al. (2006). Aim of this study was to go beyond the ECBOS study by using a selection of three rollover coach crashes with similar crash circumstances, where the occupants have been interviewed about their injury outcome, injury mechanism and seating position.	128 injuries in rollover cases were analysed regarding the injury outcome, mechanisms, and the possible injury reduction for occupants when using a safety belt. The study describes injury mechanisms and estimates the possible injury reducing effect of 2-point or 3-point seat belts, if all of the occupants in these crashes had used them.	The analysis of the 128 injured showed a considerable increase in safety for belted occupants through limiting interior contacts, minimising passenger interaction and reducing the possibility of ejection.	The present study also shows that the most common injury mechanisms for the occupants involved occupant movement inside the coach, hitting armrests, side windows and seat backs. The most dangerous injury mechanism that occupants could be exposed to is, however, the risk of being partially ejected.	The study pointed out that use of safety belts increased the safety among the occupants.

Study, country, year. Aim of the study.	Method, data design	Main results	Overview of injuries, injury factors, technical aspects	Strengths and weaknesses. Recommendations?
Björnstig, U., et al. (2008). The aim of this study was to analyse characteristics and differences in epidemiology and injuries in fatal passenger car collisions with respect to collisions with (i) other passenger cars and (ii) different types of heavy vehicles, and to answer the question of whether the death rate in collisions with other cars, and with heavy vehicles, has increased or decreased during recent decades.		In head-on car–truck/bus collisions, at least 73 (79%) of the 92 colliding with oncoming vehicles were killed in crashes with first impact in the opposite lane, a higher percentage than in car–car collisions.	Head and chest injuries accounted for most of the fatal injuries. Multiple fatal injuries and critical and deadly head injuries characterized the deaths in collisions with heavy vehicles. Per kilometre driven, 5 times as many car occupants were killed when colliding with buses or trucks, compared to collisions with cars.	Frontal collision risks might be reduced by a mid-barrier, by building less injurious fronts on trucks and buses, by efficient skid prevention, and by use of flexible speed limits varying with road and light conditions. Measures such as flexible speed limits depending on road condition, more effective winter road maintenance, safer intersection design, and ESP may also contribute to a reduction of the fatal collisions.
Edwards, M., et al. (2019). Although bus travel is one of the safest modes of transport, a substantial number of bus passengers in London are still injured in collision and harsh manoeuvre incidents, in particular emergency braking. The objective was to better understand the injury mechanisms and develop countermeasures.	This study focuses on understanding injury mechanisms and how to mitigate these injuries by developing countermeasures. The study uses data from the UK.	The study showed that, in 75% of all injuries, there was no physical impact with another object or vehicle.	The analysis indicated that a proportion of passengers were injured transitioning to and from their seats, while the bus was moving. A higher proportion of injuries occurred at "wheelchair areas" and among "passengers seated in the area close to the middle doors", which means that vulnerable passengers are more exposed to injuries.	Measures to help address this cohort could include driver training to not move off until all passengers are seated and announcements to ask passengers to remain seated until the bus stops. The authors mentioned some disadvantageous design parts of the bus: "poorly positioned handrails, lack of compartmentalization (restraint), and objects with sharp edges and corners".
Páez, J., et al. (2014). The aim of the study is to identify the main injury mechanisms in buses and coaches' frontal collisions that have occurred in Spain over the last years.	The buses and coaches are the safest means of transportation. Nevertheless, several severe accidents occur creating a high public concern. During the last years, the international community has developed a spectacular activity related to the definition of new regulations for improving the passive safety in buses and coaches. The effectiveness of these regulations will be based on their influence in real accidents, and especially on the reduction of injuries.	It can be demonstrated that the implementation of R66 has reduced significantly the severity of rollover accidents of buses and coaches in Spain. Nevertheless, and instead of all above mentioned, there is still not any regulation about frontal collision safety on these vehicles. The study is based on an in-depth analysis using a buses and coaches accident database including highly detailed information, retrospective investigation, reconstruction, police reports and medical records with injury description and mechanisms.	.Real-world accidents were considered, in depth-analyzed by the Accident Research Unit of INSIA and investigated in collaboration with the Police Forces, Paramedics and Hospitals. Finally, conclusions are proposed about the protection provided by the current regulations in the accidents considered (frontal collisions); and recommendations for improving these regulations according to the reduction of injuries in this type of accidents.	The severity of injuries is reduced, and fatalities are less likely, when buses are equipped with seat restraint systems and laminated glass. Besides, a side airbag especially developed for rollover movement could prevent the ejection of occupants. Special protection devices should be designed to enhance driver safety in the front section of the coach, as current regulations do not adequately address this aspect
Atasayar et al (2024)	Comparison of truck and bus accidents in 2022, based on CARE data.	There were 413 fatalities related to buses and coaches in EU27 in 2022. Comparing fatalities per million inhabitants killed in	No specific discussion of injury factors. 32% of the fatalities involved car occupants, 25% were pedestrians, 19% of the fatalities involved bus occupants,	Provides a broad overview of all bus accidents in Europe.

Study, country, year. Aim of the study.	Method, data design	Main results	Overview of injuries, injury factors, technical aspects	Strengths and weaknesses. Recommendations?
		bus/coach crashes, the share ranges between about 0.3 fatalities in Sweden and 4.9 fatalities in Croatia .	9% were cyclists, 9% were riders of powered two-wheelers, 3% were occupants of light goods vehicles, while 3% were defined as “other”	

3.1.1 Main results for European bus accidents

Studies of European bus accidents show that buses/coaches in crashes account for 2% of all road fatalities in EU. There were 413 fatalities related to buses and coaches in EU27 in 2022 (Atasayar et al., 2024). Meanwhile, the number of fatalities in bus/coach crashes per million inhabitants, ranges between about 0.3 fatalities (Sweden) and 4.9 fatalities (Croatia).

The studies also find a decrease in accidents over time, e.g. that the number of fatalities involving accidents with HGVs, buses or coaches decreased by almost 50% in the period 2004-2013 (Evgenikos et al., 2016).

In the bus accidents in EU27 in 2022, 32% of the fatalities involved car occupants, 25% were pedestrians, 19% were bus occupants, 9% were cyclists, 9% were riders of powered two-wheelers, 3% were occupants of light goods vehicles, and 3% were defined at "other" (Atasayar et al., 2024). As shown in Figure 3.1, the share of pedestrians involved in bus accidents is higher than for other crashes in general.

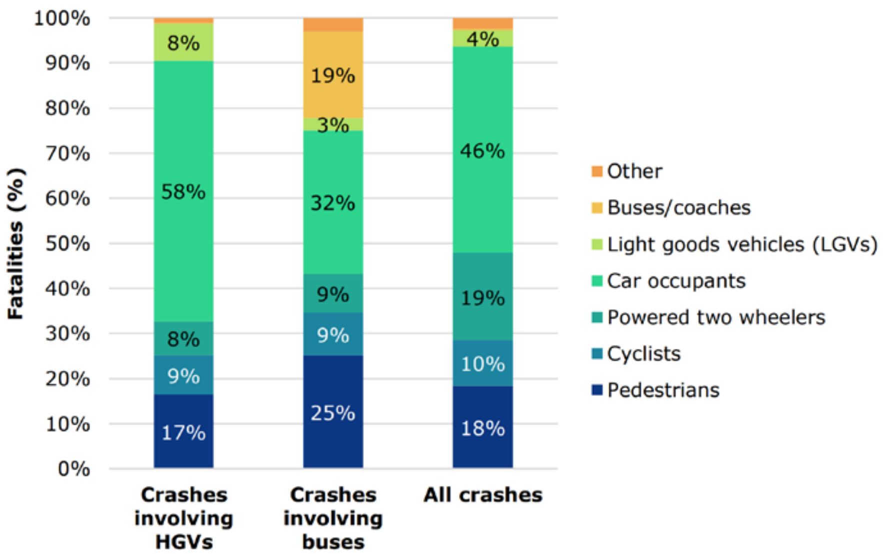

Figure 3.1: Distribution of fatalities by transport mode in crashes involving HGVs, buses/coaches and all road users. Source CARE data: (Atasayar et al 2024). https://road-safety.transport.ec.europa.eu/document/download/d8610fe4-cb96-48bf-99b3-544a384c6f93_en?filename=ff_buses_hgv_20240326.pdf

The share of fatalities in crashes involving buses/coaches also differs in the distribution by road type compared to all crashes in EU27 in 2022, with a considerable higher share of fatalities on urban roads (50%) (Atasayar et al., 2024).

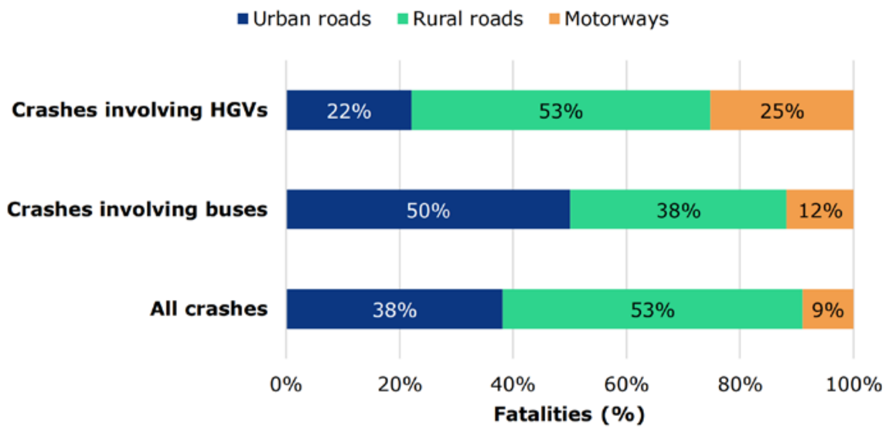

Figure 3.2: Distribution of fatalities by road type in crashes involving HGVs, buses/coaches and all crashes in the EU27 (2022). Source CARE data (Atasayar et al 2024).: https://road-safety.transport.ec.europa.eu/document/download/d8610fe4-cb96-48bf-99b3-544a384c6f93_en?filename=ff_buses_hgv_20240326.pdf

CARE data from 2022 also shows that the share of fatalities in crashes involving buses/coaches at junctions is 24%, compared to 16% for fatalities in crashes involving HGVs and 18% for fatalities in all road crashes (Atasayar et al., 2024).

Comparing characteristics and causes of HGV and bus accidents in Europe based on CARE data, Evgenikos et al., (2016) find that HGVs accounted for 5 times more fatalities compared to buses/ coaches per year.

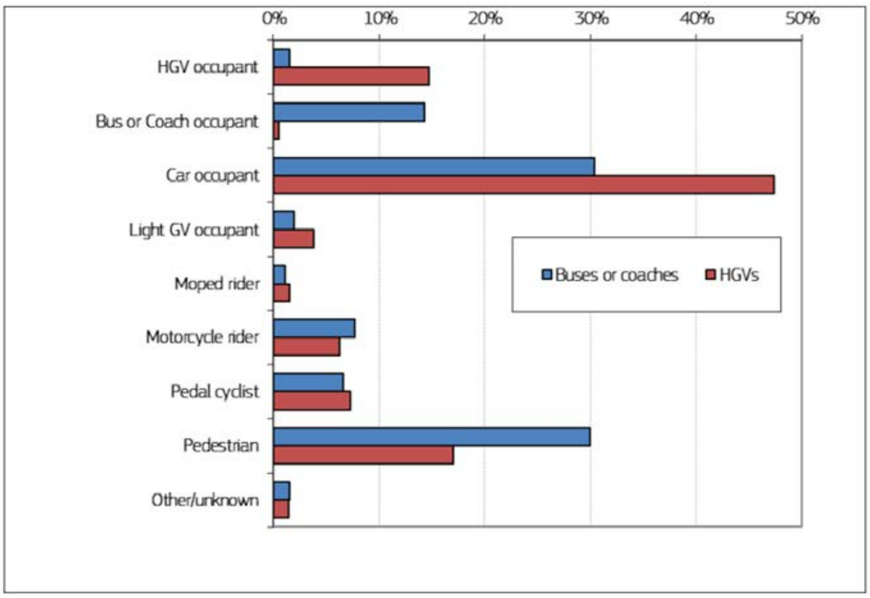

Figure 3.3: Distributions of fatalities in accidents involving heavy goods vehicles and buses, according to road user type in EU 2013, based on the CARE database. Source: Evgenikos et al., (2016).

The studies generally report that bus/coach is the safest mode of transport for the occupants of road vehicles in OECD countries (e.g. Albertson 2005; Berg 2015; Edwards et al 2019). Albertson (2005) reports that in the OECD countries, the risk of being killed or seriously injured was found to be seven to nine times lower for bus and coach occupants as compared to the risk of car occupants.

Table 3.2. Killed or severely injured (KSI) rate per 100 million during 1994-1998, based on Swedish data from SIKA and SNRA Source: (Albertson 2005; ECBOS 2001).

Mode of travel	Passenger		
	Kilometres	Journeys	Hours
Car	3.1	51.5	155.5
Foot	21.5	20.9	80.9
Bus or coach	0.4	7.6	17.5
Motorcycle/moped	19.2	44.7	224.5

It must, however, be noted that Alberston's (2005) study is 20 years old, and based on data which is 25-30 years old. Nevertheless, this result is also supported in more recent studies. A Canadian study (Morency et al 2018) report that city bus is a safer mode than car, for vehicle occupants but also for cyclists and pedestrians traveling along these bus routes. For ten studied routes, the rates of injuries per million passenger kilometer was 3.7 times higher for cars than bus, 4.1 times higher for pedestrian and 5.3 times higher for cyclist. A US study found the fatality rate to be as high as 66 times greater for car occupants than those for bus occupants per passenger-mile traveled (Savage 2013). Elvik (2009) found that car occupants have ten times greater rate of death compared to bus occupants and 20 times greater rate of death compared to train occupants, per kilometer traveled.

3.1.2 Injury mechanisms for passengers

Bus and coach safety research often examines injury patterns among occupants. For instance, Björnstig et al., (2005) analysed injuries among 284 bus and coach occupants in Sweden over a decade, distinguishing between non-crash incidents (54%) and crashes (46%). Non-crash injuries frequently occurred during boarding or alighting, often exacerbated by slippery conditions. In crashes, single-vehicle incidents resulted in a higher proportion of serious injuries (MAIS 2+). These findings underscore the importance of addressing specific scenarios such as high winds and slippery conditions to enhance safety.

In Europe, Albertsson et al., (2006) highlighted rollover crashes as significant injury contributors. These events often involved ejection or intrusion injuries, which could be mitigated by proper seat belt use. Similarly, Páez et al., (2014) identified ejection and collisions among occupants as severe injury mechanisms in Spanish frontal bus accidents. Both studies recommend enhanced seat restraint systems and safety devices to reduce risks.

Vehicle mass and structural integrity also play pivotal roles. Albertsson (2005) observed that buses' heavy structure generally offers better occupant protection compared to lighter vehicles, especially in collisions. However, roof intrusions in rollover crashes remain a concern, emphasizing the need for stronger roof designs and three-point seat belts.

Examining accident characteristics, Albertsson (2005) found that fatalities in bus accidents were most common on rural roads, that cars were the most common collision partner, and that in severe coach crashes, rollovers almost always occurred. The main injury mechanisms were "total ejection, partial ejection, intrusion and smoke inhalation". Wåhlberg (2002) found that urban areas with a speed limit below 50 km/h were frequently associated with bus/coach crashes. It was confirmed that the injury rate increased in areas with more people and more dense traffic. In crashes, frontal impacts constituted the most common crash type, but many injuries were also caused by non-collision incidents, especially in some countries.

Passenger injury risks also vary with seating and design elements. Edwards et al. (2019) noted that injuries often occur during transitions to and from seats or in poorly designed areas like wheelchair zones. These injuries are influenced by abrupt manoeuvres and inadequate protection of occupants in incidents. Recommendations include driver training to minimise harsh braking and design improvements to mitigate impact risks. Björnstig et al., (2005) also find a high level of underreporting of bus accident injuries after finding that police reports covered only 38% of the injuries among bus occupants. They therefore recommend using data from the medical sector.

3.1.3 Recommendations for increased passenger safety

While buses and coaches are among the safest road transport modes, these studies reveal areas for improvement. The reviewed studies mention several areas of improvement for increased passenger safety:

- Improved seat restraint systems, including three-point belts and laminated glass (Albertsson et al., 2006; Páez et al., 2014).
- Stronger roof structures to prevent intrusions in rollovers (Albertsson et al., 2006).
- Better compartmentalization[1] and elimination of sharp-edged objects inside buses (Edwards et al., 2019).

3.1.4 The role of technical aspects of bus design for injuries to bus drivers

There are no mandatory European collision safety regulations for bus drivers. As noted, Norways largest transit authority Ruter made it mandatory in the Oslo Sough contract in 2020 and Norway made it mandatory in 20203. ECE regulation 29, originally is for trucks. Thus, while passenger cars and trucks benefit from decades of advancements in crash testing, with extensive use of materials and designs aimed at driver survival, buses are more regulated for passenger safety and rollover protection (e.g. ECE R 107 and ECE R66). This indicates a gap in regulatory focus on bus driver safety.

The high safety level of bus transport primarily applies to passengers, while drivers may not benefit to the same extent, particularly in terms of passive safety. Berg (2015) reports that in 2012, 92 occupants of buses/coaches were killed in Europe. This represents a proportion of 0.3% of all road fatalities in Europe. The fatalities include 20 drivers and 72 passengers. Thus, bus drivers comprise 28% of the fatalities among bus occupants. The few existing studies that have a particular focus on bus driver collision protection conclude that current regulations provide insufficient protection of bus drivers in collisions with frontal impact. Compared to cars, buses are safer for the occupants when they collide with a lighter vehicle, due to the dimension of the bus.

The studies that have a particular focus on bus driver collision protection conclude that current regulations provide insufficient protection of bus drivers in collisions with frontal impact. A Hungarian study based on data from 560 bus frontal collisions from all over the world over a 12-year period, finds that drivers were 2-15 times more exposed to serious injuries and fatalities than passengers in frontal collisions (Matolcsy & Mátyás, 2016) (cf. Table 3.3). The authors differentiated between types of frontal collisions. Collision with small partners, heavy vehicles/stable objects, city buses, small buses, and combined frontal impacts were explored, as well as bus driver safety. The authors noted that frontal collisions are the most frequent accident type among buses. The data only contains casualties/fatalities involving large buses (LB) and small buses (SB).

[1]Inadequate compartmentalization means that the bus provides inadequate protection of occupants in incidents. This inadequacy can result from factors such as insufficient seat strength, improper seat spacing, or lack of energy-absorbing materials.

Table 3.3: Injury risk of the driver in different types of bus accidents (Matolcsy & Mátyás 2016)

Type of accident	Number of events	Number of fatalities and serious injuries		Injury risk		
		Driver	Passenger	Driver	Passenger	D/P
SB (small bus)	142	80	690	0,56	0,30	1,9
LB with small partner	126	39	123	0,31	0,02	15,5
LB with heavy object	239	132	2199	0,55	0,18	3,0

3.1.5 Recommendations for increased driver safety

Matolcsy & Mátyás (2016) conclude that the bus driver is strongly endangered in frontal collisions and that bus driver protection is essential in the future legislative work. The dataset is, however, not considered representative, as it is based on media reports in Hungary, Europe and around the world. The study shows, however, that media coverage is a possible way to collect data on bus frontal collisions.

Large buses that crash with small objects have a low energy level and are not considered dangerous for the bus passengers (Matolcsy & Mátyás 2016). The most dangerous accident type is frontal collisions with other heavy vehicles.

When it comes to implications for the industry, the authors note that in future legislative work, the protection of the driver should be an essential obligation. There are currently no international regulations directly addressing the issue of casualties in bus frontal collisions, which is the most frequent type of fatal bus accidents. This is due to the complexity of frontal collisions. UNECE regulation R.80 indirectly relates to frontal collisions of buses, by regulating/testing the anchorage and strength of passenger seats. Matolcsy and Mátyás (2016) pose two important questions:

1) "(…) what shall be regulated, what kind of regulations are really needed? Before answering on this question, the next one shall be answered:(…)"

2) "(…) who and what shall be protected in bus frontal collisions? (…)" the authors mention different groups: "The bus driver", "the crew and the second driver (if any)", "the passengers", "children and students", "persons in the colliding partners", "Bus systems of vital importance"

Paez et al., (2014) address similar questions and conclude that special protection devices should be designed to enhance driver safety in the front section of the coach, as current regulations do not adequately address this aspect.

3.2 Studies of passive safety measures

We now present studies of passive safety measures, using the four points presented above as a checklist.

Table 3.4: Overview of studies of passive safety measures in buses.

Study, country, year.	Method, data, design	Main results: effects and technical aspects	Strengths and weaknesses. Recommendations?
Jongpradist et al. (2022) Presents an in-depth analysis of the impact behaviour of a lightweight monocoque sandwich composite microbus body under full-frontal crash conditions.	Studies the frontal impact safety by modifying a "lightweight monocoque sandwich composite microbus body".	Under front collision, the front panel, A-pillars, and front sidewalls of the original bus were found to be extensively damaged in the compressive fibre mode. The frontal parts of the original structure were seriously deformed, resulting in intrusion into the survival space of the passengers and high injury risk to the occupants.	The study proposes a modified version, by increasing foam core thickness of front bottom, sidewalls, front floor, as well as four 5mm thick stiffeners. The modified version of the vehicle enhances the crashworthiness, and the structural weight is only increased by 35.6 kg. Increased foam core thickness can reduce intrusion of front panel and A-pillars. Increased core thickness can reduce intrusion of door sidewalls and intrusion into driver.
Holenko et al. (2024) The main goal is to develop an applicable methodology for a frontal impact simulation on a city bus, considering UNECE R29 requirements for the passenger's safety and distinctive features of the low-entry body layout.	Considering UNECE R29, a low-entry city bus was simulated in frontal collision. Euro NCAP was also simulated.	R29 deforms the front part well, but without affecting the rest of the bus sections (passengers do not feel the acceleration impact enough), and Euro NCAP is more focused on assessing accelerations at control points, as in the case of R80 (passengers feel the impact enough on the seats), but the front parts are far from deformations seen with R29.	The goal is to develop a methodology for simulation, not to test collision protection.
Lopes et al. (2023) Aims to develop new solutions for passive safety used in coaches, focusing on "full frontal impact test" in ECE R29, considering a M3 class III coach.	Feasibility study involving experimental and numerical techniques conducted to assess the improvement of driver safety in case of a frontal impact. Frontal crash test, whereby the ECE Regulation R29 was considered as the baseline, ECE R29 was used and adapted to the studied model. A 2500kg pendulum supported by two steel bars was used. Monitoring techniques were employed to track the structure.	According to the ECE R29 standard guidelines, the bus structure has no potential to meet the essential safety requirements. The driver and passengers' physical integrity is compromised. A real testing system showed that structural points were prone to structural collapse, resulting in intrusion, material failure, and reduced structural stiffness. The requirements of R29 are not satisfied.	Fills a literature gap by developing a realistic testing system and incorporating advanced monitoring techniques for evaluating frontal collisions in vehicles. The authors note that to guarantee survival of the driver, a reinforced driver zone would provide protection. The authors state that manufacturers would be able to reformulate their models, considering the results in this study.
Thuong & Nguyen (2019) Analysis of the bus structural performance in the event of a full frontal impact (FFI), based on a computer-based crash simulation model.	Under frontal impact, the structural performance of the bus was analysed according to EURO NCAP (New Car Assessment Programme).	The most serious deformation occurred to the frontal frame of the bus structure. The bus chassis was bending in crashworthiness simulation. The energy absorption capacity of bus structures needs to improve by optimising the frame and chassis.	The authors describe a need for improving the frame and chassis of the vehicle.
Afripin et al. (2019) Full frontal impact simulation.	A finite element simulation was used, considering the bus superstructure under frontal impact. The	The collision energy impact required by the R29 regulation is lower than NHTSA's NCAP with 55 kJ and 142 kJ	R29 exposes the bus to less energy, compared to NCAP. Considering the R29 regulation, the front structure of the bus is severely deformed,

Study, country, year.	Method, data, design	Main results: effects and technical aspects	Strengths and weaknesses. Recommendations?
Two regulations for frontal impact: R-29 and New Car Assessment Program (NCAP) are used to determine whether the structures have enough strength to withstand the load produced by the impact.	study applies both R29 and NCAP regulation tests and compares the results.	respectively. However, R29 simulation shows that front structures are severely deformed. The structures in the NCAP simulation are still intact and the steering wheel structures are still not in contact with any body parts of the driver.	and the impact is absorbed by the superstructure. Considering NCAP, the structures are still intact.
Jamroziak et al. (2020) Analyses the results of dynamic loads during a frontal impact exerted on coach passengers travelling with and without (two- and three-point) safety belts.	Experimentally studies the aftermath of coach frontal impacts, with and without safety belts. Experimental studies and modelling with focus on the process of dynamic load transfer on the human body during a traffic accident. Parallel on an adult and a child dummy.	Both for the two-point safety system and the lack of safety belts, there were high values of acceleration recorded in the centre of gravity of the head. Only a three-point safety belt system ensures the satisfaction of all injury criteria within admissible standards (R 80 and R94).	The study notes that a three-point safety belt satisfies UNECE 80 and 94 with respect to injury criteria.
Budd, Newstead and Watson (2021) Aims to quantify the safety performance of various heavy vehicle types in Australia by analyzing crashworthiness (the protection a vehicle offers its own occupants) and aggressivity (the potential harm a vehicle poses to other road users in a collision).	Utilizing police-reported crash data from 2006 to 2017, the research seeks to inform future road safety policies by identifying specific heavy vehicle types that contribute significantly to road trauma, thereby highlighting areas where targeted safety interventions could be most effective. A crashworthiness rating (CWR) was defined as follows: CWR = R · S R is the probability that a driver of a heavy vehicle involved in a crash is injured. S is the probability that the injured driver is hospitalised. CWR is used to measures the share of drivers of heavy vehicles involved in crashes who are hospitalised.	Crashworthiness has improved over time in three of four classes of trucks. For large buses, crashworthiness improved up until the 1980-89 decade. After that it has deteriorated, and was worse for buses of model year after 2010 than for the oldest buses (model year before 1980). There has been no improvement in the crashworthiness of buses after 1980.	Comprehensive analysis of heavy vehicle safety performance in Australia, utilizing extensive police-reported crash data to assess crashworthiness and aggressivity metrics.
Vincze-Pap and Csiszar (2005)	Tested the crashworthiness of a Hungarian-built Ikarus 411 bus The bus was crashed into a rigid wall at speeds of 3.6, 6.98 and 29.76 km/h. Impact speed was 29.76 km/h.	The force of the impact was distributed across the entire front area of the bus, not just the part where the driver was sitting.	If crash forces can be absorbed by a larger area, there may be less deformation than if crash forces are absorbed by a small area. A safety bar mounted across the whole front of the bus could reduce deformation even in crashes with only 40-50 % overlap.
Olivares (2012)	Discusses measures to increase bus driver safety, e.g. safety bumper in front and airbags.	The safety bumper might function well in frontal impacts with cars or other buses but could be a hazard to pedestrians and cyclists. If, however, the bumper can detect whether it has been impacted by a pedestrian or a car, it could be fitted with air bags that would inflate in case of a pedestrian impact and catch the pedestrian before an impact with the front of the bus occurred.	The effects are hypothesized.

3.2.1 Bus driver collision protection

When large vehicles crash with smaller vehicles, crashes are generally less severe for the large vehicles, as the driver compartment in the larger/heavier vehicle is usually located well above the impact area in any accident involving a passenger vehicle (Afripin et al 2019; Holenko et al 2024). Moreover, due to their greater mass, the large vehicles can also absorb more impact energy. The higher position of the driver is the reason that most manufacturers of buses do not include crumple zones in their designs of vehicle fronts, in contrast to what car manufacturers do (Afripin et al 2019; Holenko et al 2024).

In an international study of bus crashworthiness, Holenko et al (2024) state that in recent years, much attention has been paid to the frontal crash testing of city buses, especially after a series of accidents resulting in deaths and injuries. City buses with low-entry designs show greater vulnerability to frontal impacts due to their lightweight front structures and shorter energy absorption times during collisions (Holenko et al., 2024). In city buses, the driver compartment is typically located lower than in e.g., trucks. As a result of lacking crumple zones in buses, lacking mandatory EU crashworthiness standards targeting the situation of bus drivers, and a lower seating position in class 1 and class 2 buses, bus drivers seem more exposed than other road users in crashes with frontal impact.

This is especially evident when buses crash with other heavy vehicles. In the case of frontal collisions between two buses, or with a rigid wall or other fixed objects, the possibility of energy absorption of the bus structure is very low, and the remaining energy will be transferred directly to the driver and occupants (Afripin et al., 2019).

3.2.2 Crashworthiness of buses compared to other heavy vehicles

Budd, Newstead and Watson (2021) compared the crashworthiness of buses to the crashworthiness of other heavy vehicles. A crashworthiness rating (CWR) was defined as follows:

$CWR = R \cdot S$

R is the probability that a driver of a heavy vehicle involved in crash is injured. S is the probability that the injured driver is hospitalised. CWR was used to measure the share of drivers of heavy vehicles involved in crashes who are hospitalized. CWR values for trucks varied between 4.51 and 7.53. For buses, the CWR values varied between 2.05 and 6.14. The lower value referred to "ME buses", which are defined as a heavy omnibus with more than 9 seats and a gross weight of more than 5 tonnes. "MD buses" are smaller and would be referred to as minibuses in Norwegian terminology. These buses have a gross vehicle weight between 3.5 and 5 tonnes.

The results from this study are nuanced. First, crashworthiness has improved over time in three of four classes of trucks (cf. Figure 3.4). For large buses, crashworthiness improved up to the 1980-89 decade. After that, it has deteriorated and was worse for buses of model year after 2010 than for the oldest buses (model year before 1980). There has been no improvement in the crashworthiness of buses after 1980. This contrasts sharply with cars, which have become considerably more crashworthy after 1980 (see, for example, Høye 2019).

Second, the mean crashworthiness rating includes all crashes. The counterpart in most crashes involving buses is a vehicle or an unprotected road user with less mass than the bus. Although the data set included several thousand crashes, there were too few crashes between buses or between a bus and a truck to model crashworthiness in those crashes.

Third, the (logistic) models of crashworthiness that were developed, although including many variables, were too imprecise to assess the crashworthiness of buses. The most comprehensive models included sex, age, speed zone, number of vehicles involved, state and year. Speed zone refers to speed limit, not impact speed. Point of impact (by clock direction) was not included. Use of seat belts was not included. The mass of the other vehicle(s) involved was not included. These are all variables that influence the probability and severity of injury to a bus driver.

One should therefore not conclude that this study shows that bus drivers are better protected from injury than drivers of other heavy vehicles in all types of crashes, nor that the crashworthiness of buses cannot be improved.

3.2.3 The current structural protection of bus drivers is insufficient

Most of the studies focus on possible regulations related to the collision safety of bus drivers and passengers in case of frontal crashes. The studies conclude that the collision protection provided by ECE regulation R29 is insufficient for protecting the driver in a frontal crash, or that current designs do not fulfil R29 requirements. We will sum up the main results of these studies below.

Lopes et al (2023) conclude that "According to the standard guidelines, the present structure has no potential to meet the essential safety requirements.", and that the test shows that "The driver and passengers' physical integrity are compromised." Lopes et al (2023) also conclude that a real testing system showed that structural points were prone to structural collapse, resulting in intrusion, material failure, and reduced structural stiffness. The requirements of R29 are not satisfied.

The authors note that there is a need for structural improvement in the frontal structure of the bus, and that to guarantee survival of the driver, a reinforced driver zone would provide protection. Lopes et al (2023) further conclude that manufacturers would be able to reformulate their models, considering the results in their study.

Thuong and Nguyen (2019) present an analysis of bus structural performance in the event of a full-frontal impact (FFI), based on a computer-based crash simulation model. The structural performance of the bus was analysed according to EURO NCAP. The crash analysis using finite element models showed that the most serious deformation occurred to the frontal frame of the bus structure. The bus chassis was bending in the crashworthiness simulation. The frontal frame of the bus was exposed to the most significant deformation. The authors conclude that the energy absorbed by the bus structures needs to improve by optimising the frame and chassis.

Afripin et al (2019) use two prominent regulations for frontal impact, namely United Nation Economic Commission of Europe (UNECE) Regulation no. 29 and New Car Assessment Program (NCAP) to determine whether the bus structures have enough strength to withstand the load produced by the impact. A finite element simulation[2] was used, considering the bus superstructure under frontal impact. The results for both simulations are compared in terms of energy produced, structure deformations, maximum stress, and the corresponding plastic strains. Afripin et al (2019) find that the energy from the ECE R29 regulation is lower than NHTSA's NCAP with 55 kJ and 142 kJ respectively. They find that in the deformation observed from the R29 simulation, the front structures are severely deformed, while the structures in the NCAP simulation are still intact, and the steering wheel structures are still not in contact with any body parts of the driver. Thus, they conclude that the NCAP regulation requirements provided a better structural integrity and collision protection for the bus drivers than R29. This indicates that the NCAP test requirements are better for bus driver safety than R29.

Elhussieny et al. (2021) provide a study of an optimization of crash dynamics for bus cabin structure during a frontal collision. They state that simulation results conclude that both deceleration and deformation deviated from the acceptable limits of occupant safety exceeding the first zone. They

[2] A Finite Element Simulation (FES) is a computational technique used to predict how objects or systems behave under various physical conditions.

also find that the structure deformation behaviour tends to be bending in most of the structural members, which is undesirable behaviour from an energy absorption perspective. The authors conclude that it is recommended to increase the front zone length.

Morocho et al. (2022) present an analysis of frontal impact and lateral overturn collisions of a double-decker bus, carried out in accordance with UN Regulations 66 and 29, and the Ecuadorian Standardization Service Institute (INEN) with its regulation 1323:2009. The study concludes that in general, the frontal part of the bus structures does not have any protection system to safeguard the life of the cabin occupants during a frontal impact. These elements of the bodywork structure are not capable of totally dissipating the kinetic energy, which should be considered in the design of these elements.

Jongpradist et al. (2015) evaluated a strengthened frontal structure of a bus. The objective of their study was to determine whether an implementation of ECE Regulation 29 would provide better protection for bus drivers. This regulation is, as mentioned, mandatory for trucks, but not for buses. A frontal impact with an energy of 55 kJ was simulated using a pendulum test. A pendulum is raised and dropped towards the front of a stationary bus to simulate the impact. The simulated impact was a low-speed impact of about 3-4 km/h. In a standard bus, there was nevertheless significant intrusion into the driver’s compartment. The objective of the tested system was to better protect the driver.

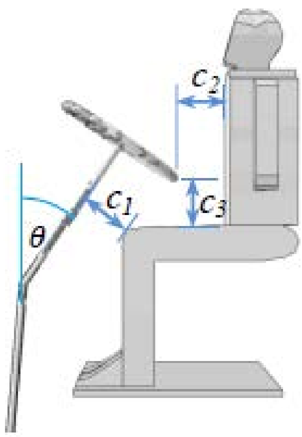

Figure 3.4: Clearance distances between bus driver and steering wheel system. (Jongpradist et al. 2015)

3.2.4 Relevant measures

All the studies suggest structural enhancements to improve the collision safety of bus drivers. Jongpradist et al. (2022) recommend increasing foam core thickness in critical areas (front panel, sidewalls, and floor) to reduce intrusion and enhance crashworthiness with minimal weight increase. They also recommend adding stiffeners to strengthen the structure. Holenko et al. (2024) recommend developing and refining simulation methodologies for better prediction of crash impacts on low-entry buses, focusing on UNECE R29 and Euro NCAP requirements. Lopes et al. (2023) suggest reinforcing the driver zone to ensure survival in frontal impacts and that manufacturers should reformulate bus models based on realistic crash test systems to improve safety standards. Thuong & Nguyen (2019) recommend optimising the bus frame and chassis for better energy absorption and reduced deformation during frontal impacts. Afripin et al. (2019) recommend adopting NCAP-like standards, which provide better structural integrity and energy absorption compared to R29, and to design bus structures to withstand higher energy impacts while maintaining driver and passenger safety. Olivares (2012) suggests mounting a safety buffer outside and in front of the bus. This solution might, however, endanger vulnerable road users. The other solution discussed by Olivares (2012) was how an air bag integrated into the seat belt might protect bus drivers. The air bag is activated when a sensor detects that an impact has occurred. As shown in Figure 3.5, the air bag will prevent the driver from impacting the steering wheel with the head and from impacting the dashboard with the knees.

Figure 3.5: Air bag protecting bus driver. (Olivares 2012)

R29 requires the installation of three safety bars in the front of a truck. In the study by Jongpradist et al. (2015) a simpler system adding as little weight to the bus as possible was tested, see Figure 3.6.

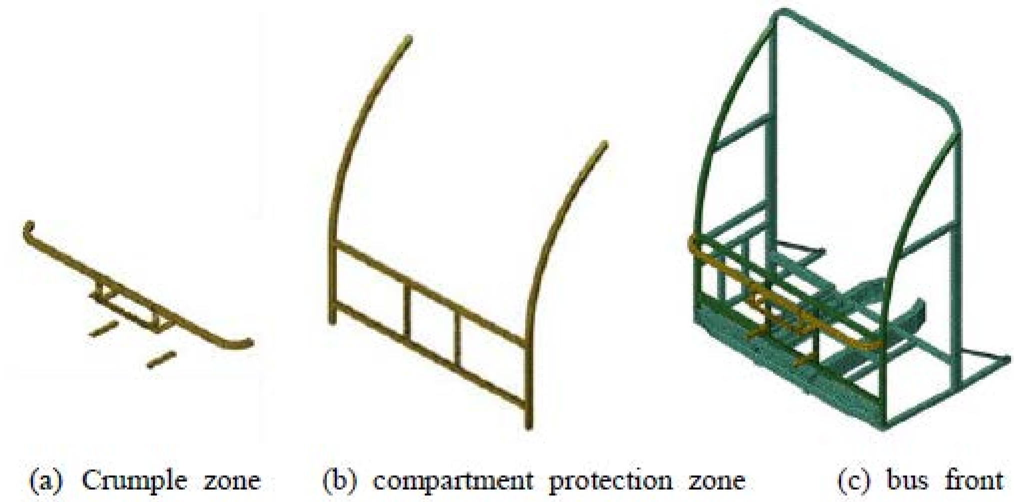

Figure 3.6: Reinforcement of bus front. Jongpradist et al. 2015

Three versions of the system were tested. All three systems prevented the driver from impacting the steering wheel system, whereas without the reinforcement, the bus driver did impact the steering wheel system.

Acar et al. (2020) and Güler et al. (2020) replicated these findings by testing a new energy absorbing bumper on a bus. The bumper was found to improve crashworthiness.

In addition to the systems mentioned above, one can imagine a system analogous to car seat designs intended to reduce the risk of whiplash injury in rear-end crashes. An analogous system for frontal impacts with a bus would be a system that automatically pulls the driver’s seat rearward upon impact and reclines the seat back. For such a system to work, there must be some space behind the seat into which it can be pulled. The system would pull the seat and driver away from the point of impact.

3.2.5 Seat belts

Some studies also focus on other passive road safety measures, like seat belts. Jamroziak et al (2020) analyse the results of dynamic loads during a frontal impact exerted on coach passengers travelling with and without (two- and three-point) seat belts. They conclude that only a three-point seat belt system satisfactorily ensures all injury criteria within admissible standards with regard to UNECE rules 80 and 94. They also conclude that the three-point seat belt system should be obligatory in all intercity buses.

Sun et al. (2024) provide a literature review of occupant safety and injuries in coach frontal collision. They conclude that three-point seat belts are advantageous and can protect occupants' heads and necks, both adults and children. The authors conclude that future studies should evaluate the less-covered areas of occupant safety, such as the safety of driver and co-driver.

3.2.6 Protecting pedestrians struck by buses

Buses are hazardous to pedestrians, having an almost vertical front and being substantially higher than a pedestrian. Therefore, a pedestrian struck by a bus will usually be knocked over and may subsequently be run over by the bus. Martin et al. (2020) studied how the geometry of bus fronts can be modified to better protect pedestrians in impacts. The aspects of geometry that were studied are shown in Figure 3.7.

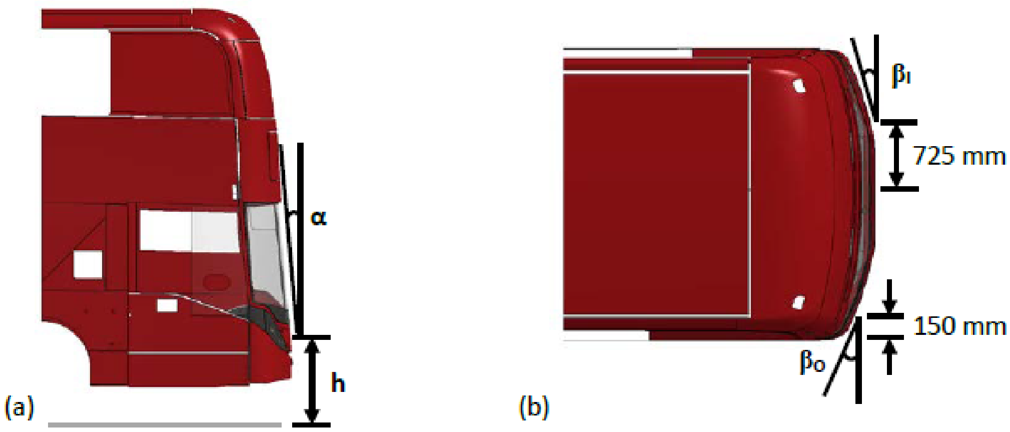

Figure 3.7: Angles defining the geometry of bus front design. Martin et al. 2020

It should be noted that the bus that was studied is a double decker, designed for left hand driving. However, the various angles describing front geometry should not be influenced by this. The basic principle is to make the bus rounder, i.e., increase angle α (making the front lean more backwards) and the angles β_1 and β_2. This increases the chances that a pedestrian is pushed away from the bus and avoids getting run over by it. The probability of serious head injury and serious thorax injury was estimated for a male crash test dummy for three front designs, in which B3 was the most rounded. The results are shown in Figure 3.8.

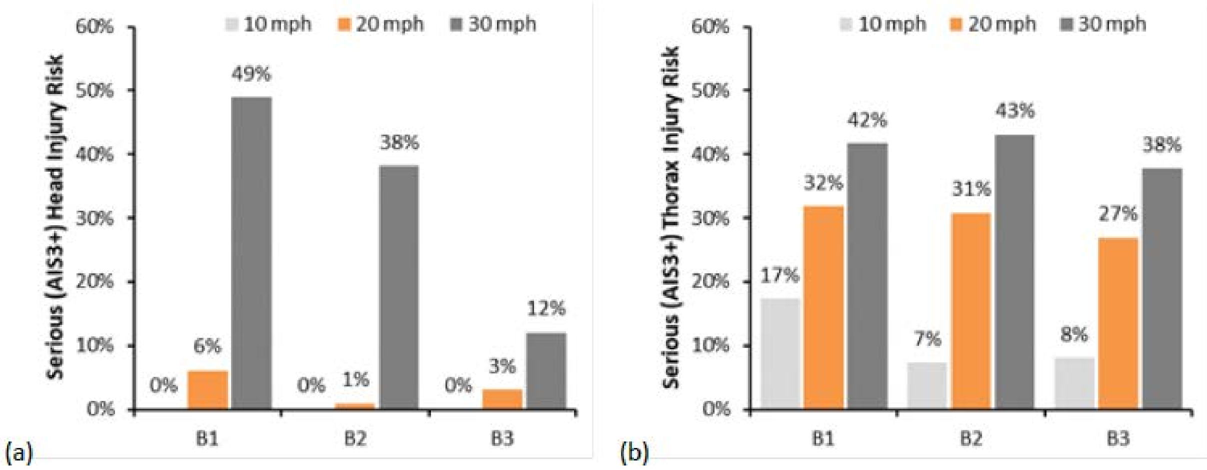

Figure 3.8: Risk of serious head injury and thorax injury associated with different front designs of buses. Martin et al. (2020).

The test results show that the risk of serious injury increases quickly as impact speed increases from 10 to 30 miles per hour. However, the risk of serious injury decreases when the front of the bus becomes more rounded in shape and more backward-leaning (B3).

The bus driver is sitting in one of the corners of the front. Still, if a more rounded shape of the front is accomplished by increasing the distance between the straight middle section of the front and the compartment, changing front geometry could provide some additional protection to drivers as well.

The concept discussed has been most clearly implemented in the front design of modern trams. Figure 3.9 shows the front design of new trams that have been introduced in the city of Oslo during 2022-2024.

Figure 3.9: Front design of new trams introduced in Oslo 2022-2024

The driver is sitting at the centre of the vehicle in a separate compartment and does not interact with travellers. We are unaware of the possibilities for adopting such designs in buses.

In Oslo, both tram stops and bus stops have been designed according to principles of universal access. Both buses and trams stop at platforms that have the same height as the floor of the bus or tram. Wheelchair users and those pushing prams can therefore enter or leave the bus or tram without assistance from others.

3.3 Studies of active safety measures

We use six points as a checklist in our presentations of empirical studies ofanalyses of active safety measures for bus drivers (cf. Table 3.5).

Table 3.5: Overview of studies of active safety measures in bus.

Study, country, year.	Method, data design	Main result	Effects for target groups	Effects for others	Recommendations?	Strengths and weaknesses
Blades et al., (2020) (Northern Ireland)	A review of the on-road ADAS bus trials shows that passive forward collision warning (FCW) and intelligent speed assistance (ISA) systems have been successful in reducing the number of imminent pedestrian/vehicle collision events and improving speed limit compliance, respectively.	Bus accident statistics for Great Britain have shown that pedestrians account for 82% of all fatalities, with three quarters occurring with frontal bus impacts. These statistics suggest that the bus forward collision warning system is a priority for inclusion in future vehicles to enhance the driver's direct vision, and to increase reaction time for earlier brake application. Almost 80% of bus occupant casualties occurred in non-impact situations, mainly during acceleration/deceleration events. Therefore, care must be taken in implementing autonomous braking in buses, to ensure that it does not cause an increased number of deceleration events beyond the safe stability limits for passengers.	Unknown. Expected that an unexpected AEB-event would result in significant injury both for standing and seated passengers	Effects apply mainly for passengers	The study recommends that care must be taken in implementing autonomous breaking in buses, to ensure that it does not cause an increased number of deceleration events beyond the safe stability limits of passengers.	Small sample. Despite being an on-road study, ADAS functionality is simulated.
Anund et al., (2010)	Pilot study exploring safety gains from driver support systems in the bus, and intelligent bus stops for school buses. Two buses where equipped ISA, extra internal and external mirrors, enhanced lighting at the rear doors, and external loud speakers Pre-/post-design, questionnaire, focus group.	Drivers experienced that the systems contributed to increased routines and hazard perception, however inaccurate GPS-data led to frustration and negative attitudes towards using the system.	Unknown	Study reports a slight speed reduction at one bus stop, but this effect is attributed to the bus stop design with running lights, not any features in the bus.	Recommends further research	Small sample size, no control group. Difficult to discern effects between various types of measures, as they are integrated in one package.
Hadi et al., (2021) (USA)	Naturalistic driving study.10 transit buses were fitted with camera-based ADAS (Headway warning, forward collision warning, pedestrian and cyclist warning). Post-implementation test with control group. Data collected included telematics, video data, survey data and interview data.	The main effects observed in this study were that the ADAS: (1) improved bus driver reaction time to both rear-end and pedestrian conflicts, (2) increased the frequency with which drivers yielded to pedestrians, (3) did not affect the frequency of pedestrian and bicycle conflict alerts, (4) led to more conservative driving in terms of time headways and hard braking frequency when the system was activated.	For bus drivers: improved reaction times to potential rear-end and pedestrian collisions, more conservative driving behaviour and increased yielding to pedestrians.	None	Although the ADAS had a positive impact on driver behaviour and reaction times, driver acceptance of the system was low. Only about 20% of drivers reported consistently positive perceptions of the ADAS. Common complaints about the system included that the alarms were sometimes issued too late, the location of the visual displays was not optimal, and more training on the system was needed.	Very limited sample. Only post-implementation measure. Study included only one bus route.

Study, country, year.	Method, data design	Main result	Effects for target groups	Effects for others	Recommendations?	Strengths and weaknesses
Tomasch & Smit (2023) (Austria)	Naturalistic driving study. 15 HGVs and 5 busses where retro-fitted with a blind spot monitoring system (+ pedestrian collision warning) Data collected over a period of 2 years, using a telemetry system. Baseline period where the system was in silent mode, collecting data. After this period, the system was switched to active mode, where drivers were provided with warnings and feedback.	The study found that activating the system resulted in a significant decrease in both pedestrian danger zone (PDZ) and pedestrian collision warnings (PCW) for both HGVs and buses. HGVs saw a 41% reduction in PDZ warnings and a 33% reduction in PCW, while buses experienced an 18% reduction in PDZ warnings and a 10% reduction in PCW.	For bus drivers, there was a 10 % reduction in pedestrian collision warning events.	None	Need for a system that differentiates between pedestrians and cyclists. Need for more comprehensive data on driver experiences and acceptance. Some drivers disabled the systems due to the high frequency of warnings.	Small sample size (5 buses), Warning frequency is used as a surrogate measure for accidents. Study did not explore long-term effects.
Pecheux et al., (2015) (USA)	Field demonstration to test three commercially available turn warning systems for transit buses (system that warns VRUs that the bus is about to turn). 45 buses were equipped with turn warning systems (15 in each group). Exploring bus drivers' perceptions and acceptance of the technology, as well as pedestrians and cyclist perceptions and acceptance. Survey + focus group interviews.	Bus drivers perceived the systems as more successful at alerting pedestrians than at reducing close calls, but their opinions differed regarding which system worked best. Surveyed pedestrians were more optimistic. The study highlights the challenges of setting appropriate warning volumes. Finding a balance between effective warnings and minimizing annoyance for both bus drivers and VRUs remain a challenge.	Unknown. Perceived to be effective for alerting pedestrians by 62% of surveyed pedestrians. Effects not measured. Effects on close calls not measured.	Primarily a measure that targets VRUs.	Refine the sensitivity settings of steering-wheel-activated systems to reduce false alarms. Explore alternative activation methods, such as linking warnings to turn signals	Adequate sample. No pre-measurement or control group. No measuring of effects on target group.
Goodall & Ohlms (2022) (USA)	Evaluates the effectiveness of a transit bus collision avoidance warning system (CAWS) in Virginia. Naturalistic driving study. 51 busses equipped with collision avoidance warning system. Pre-post design. Pre period (2	Mixed findings regarding the system's effectiveness in a transit operating environment. Driving performance of bus operators improved after the systems were activated, as measured by a statistically significant decrease in the number of events in most categories. However, in operator surveys, 75% of respondents noticed false alarms	Uncertain. Although most empirical measures showed improvement as evidenced by fewer alerts and warnings after the live mode was initiated, survey	Primarily a measure that targets VRUs.	Transit and roadway agencies should exercise caution when using CAWS data for decision-making	Adequate sample, pre-post design. No control group. Did not look into long-term effects.

Study, country, year.	Method, data design	Main result	Effects for target groups	Effects for others	Recommendations?	Strengths and weaknesses
	months) where vehicles were equipped with system, operating in "stealth mode", following a 6-month period where the system was in "live mode".	and 76% of respondents found the system distracting.	results indicated excessive false alarms and unnecessary alerts in areas with high volumes of pedestrians.			
Martin et al., (2022) (England)	Study of the effects of indirect vision safety measure in London city buses.	Investigated the performance of a specific mirror model, the Ashtree Vision & Safety Ltd. CycleSafe combined Class II/IV blind spot mirror model. The study found that this mirror, which utilizes curved reflective surfaces, significantly improves the driver's field of vision compared to standard Class II mirrors.	Unknown effect on collision events.	Unknown. Measure is expected to benefit VRUs and other road users.	Although blind spot mirrors can improve the driver's ability to see potential hazards, their effectiveness still relies on the driver actively using them. The report stresses that even with good vision, drivers must be "looking in the right direction at the right time". This highlights the importance of driver training and awareness campaigns that emphasize the importance of regularly checking mirrors	The research relies on analyses of collision data and human factors studies to estimate the effectiveness of mirrors in reducing casualty rates. There is a lack of direct experimental evidence that definitively correlates mirror size and quality with driver observation, detection, and collision avoidance behaviour.
Greenshields et al. (2016). (England)	Study designed to evaluate the effectiveness of Intelligent Speed Assistance technology (ISA) (intervening type) on London buses. Before- and after-observational approach, comparing various metrics related to bus operations and traffic behaviour before and after the activation of the ISA system. Telemetric data + interviews with drivers and passengers.	The ISA system does appear to ensure effective speed limit compliance except temporarily on some downhill sections and at the initial transition boundaries to lower speed limits. This has comparably greater impact in (increasingly common) 20mph speed limits as bus performance and street geography generally enable buses to reach and exceed 20mph with relative ease (far more easily than a 30mph limit or greater).	Unknown.	There was a slight increase in the proportion of overtaking manoeuvres that involved entering the opposing lane after the introduction of ISA. This suggests a potential, but not conclusive, link between ISA and a marginal increase in risky overtaking behaviour	Provide thorough training to drivers on the functionality and operation of ISA, emphasizing its role in enhancing safety and the importance of adhering to its speed restrictions	Limited sample size and scope. Do not assess the effectiveness of ISA on collision rates or near misses.

3.3.1 The majority of the studies focus on VRU accident prevention

Our literature search yielded few studies that investigate effects of active safety measures in buses. In total eight studies were identified, four of which are peer-reviewed studies, and the remaining four are scientific reports. The measures evaluated span several technologies:

- Pedestrian/cyclist collision warnings
- Blind spot monitoring
- In-vehicle data recorders
- Intelligent Speed Adaptation
- Retarder systems simulating advanced driver assistance features.

Five of the eight studies focus on VRU accident prevention. Thus, this is the most important issue in the identified studies. Technologies like blind spot monitoring and turn warning systems aim to reduce collisions with VRUs. Tomasch & Smit (2023) found that retrofitting buses with blind spot monitoring systems led to an 18% reduction in pedestrian danger zone warnings and a 10% reduction in pedestrian collision warnings. Similarly, turn warning systems studied by Kennedy et al. (2015) were perceived as effective by pedestrians, although their impact on close calls was unclear.

Martin et al. (2020) used human body models to simulate the effects of a rounded and backward leaning bus front compared to current front design. A rounded and backward leaning front was found to reduce the probability of serious head injury at an impact speed of 30 miles per hour (48 km/h) from 38-49% with current bus front design to 12% with the rounded backward leaning design. The probability of serious thorax injury at an impact speed of 30 miles per hour was reduced from 42-43% with current front design to 38% with the rounded backward leaning design. At lower impact speeds, the differences in the probability of serious head or thorax injury were smaller.

Martin et al. (2022) evaluated a package of new safety systems for Transport for London. Sensors enabling forward detection of pedestrians, cyclists or motorised two-wheelers and activating emergency braking if needed (system 2 on the list above) were judged, on the basis of a literature survey, to reduce the risk of fatal injury by 38-46% and the risk of serious injury by 26-34%. A similar system for detecting vulnerable road users (pedestrians, cyclists, motorised two-wheelers) on the nearside of the bus (often in the blind zone) (system 3 on the list above) was judged to have a similar effect. Various systems for blind spot monitoring and warning (system 4) were judged to reduce fatal or serious injuries to vulnerable road users by 42-69 %.

It should be added that emergency braking systems are a dilemma in buses. Such systems may prevent, or make less serious, impacts with vulnerable road users. On the other hand, hard braking increases the risk that passengers may fall or hit fixed objects or other passengers in the bus. This could increase the number of passenger injuries. Nevertheless, if one takes the estimates developed by Martin et al. (2020, 2022) at face value, they show that there is a great potential for reducing injuries to vulnerable road users caused by buses. Although we are unaware of the actual prevalence of the four systems listed above, we might assume that although some buses might have these systems, there is a potential for a much wider use. Moreover, system 2-4 are relatively new technologies, and we have not identified studies examining their effects on accidents. There are some studies from heavy goods vehicles, which estimate the potential for accident avoidance.

Tomasch and Smit (2023) describe a naturalistic driving study in Austria in which 15 heavy goods vehicles and 5 buses had the Mobileye blind zone monitoring and warning system retrofitted. This system gives good coverage of forward blind zones, but do not cover the blind zone towards the rear of the vehicle. The system gives two warnings: (1) danger zone warning: there is a vulnerable road user close to the vehicle but no imminent danger of a collision; (2) collision warning: a vulnerable road user is very close to the vehicle and there is imminent danger of a collision. The driver is warned by a visual display and a warning sound.

The trial found that the warnings were activated very often. In buses, there were 2.06 warnings per kilometre. However, only 4.9 % of these were of type 2, i.e. indicating a high risk of collision. There were no collisions during the study. The system was run both in silent mode and with the sound turned on. Warnings of type 2 (critical risk) were reduced by 10 % for buses when the sound was turned on. Tomasch and Smit (2023) interpret this as an estimate of the accident reducing potential of the system. This effect, 10 %, is much smaller than assumed in the study made for Transport for London (38-46 % for fatal injury; 26-34 % for serious injury).

Martin et al. (2022) included a cost-benefit analysis of the safety systems. The results were highly uncertain, but nevertheless quite unequivocal. Only one of the systems included, class V blind spot mirrors, was found to give benefits greater than costs. For many systems, the benefit-cost ratio had a lower value below 1 and an upper value above 1, meaning that it could not be ruled out that benefits were greater than costs. However, the opposite could also not be ruled out.

Estimates of cost were highly uncertain. As an example, the cost of a blind spot camera monitoring system was stated as £ 588-1637, a range of 2.78. Nevertheless, the report is very useful in presenting cost estimates and unless other sources of data on costs can be found, these estimates will be applied in this study. Not all the estimates are relevant, however, since the main focus of this study is on improving the crashworthiness of buses, not on improving their active safety.

3.3.2 Improving driver behaviour through ADAS

The second key topic in the identified studies is improving driver behaviour through ADAS. Several studies indicate that ADAS can positively influence driver behaviour. Hadi et al. (2021) showed that camera-based ADAS, including systems for headway and pedestrian warnings, improved drivers' reaction times and encouraged more conservative driving. Similarly, Goodall & Ohlms (2022) found that collision avoidance warning systems (CAWS) reduced unsafe driving behaviours in buses. These systems helped drivers maintain safer time headways and reduced instances of hard braking.

However, a consistent challenge lies in driver acceptance. Many drivers reported issues such as false alarms, late warnings, or distracting system interfaces. For example, in Goodall & Ohlms (2022), 76% of surveyed drivers found CAWS distracting due to excessive false alarms, especially in high-pedestrian-density areas. This highlights the importance of refining systems for better usability and providing comprehensive driver training. ADAS shows potential to improve safety outcomes by enhancing driver behaviour, but its success depends on system accuracy, user-friendliness, and driver acceptance.

A recurring concern related to systems aiming to avoid bus collisions is the balance between implementing such safety measures and ensuring passenger stability, particularly for standing passengers. For instance, Blades et al. (2020) simulated autonomous emergency braking (AEB) on a city bus, finding that deceleration events often exceeded the stability limits for passengers. Emergency stops posed significant risks of injury to both standing and seated passengers, emphasizing the need for tailored implementations in buses, where passenger dynamics differ from private cars.

Moreover, introducing new systems that demand new ways of interacting or provide different types of warnings also introduces changes to the driver environment, which can add new types of hazards. For example, excessive false alarms can result in heightened workload and lead to distractions (Salmon, Young & Reagan, 2011). There is a need for studies that address how combined ADAS technology impacts driving performance and the total workload.

ISA systems, designed to prevent speeding, have been shown to improve compliance with speed limits in urban environments. A study by Transport for London (2016) on buses equipped with ISA found that the system effectively reduced instances of speeding, particularly in 20 mph zones.

However, the study also noted a potential increase in risky overtaking behaviour (i.e. cars overtaking buses), highlighting the need to consider indirect behavioural effects when implementing ISA.

Finally, few of the studies investigated effects of such systems on the number of crashes or near-misses, and little is known about long term effects. This is a significant limitation indicating an important issue for future research.

4 Concluding discussion

4.1 Why is the bus driver insufficiently protected in the safest mode of road transport?

Our literature review indicates a paradox: The bus driver is insufficiently protected in bus transport, which is the safest mode of road transport.

A main conclusion of our review is that that bus/coach is the safest mode of transport for the occupants of road vehicles in OECD countries. Albertson (2005) report that in the OECD countries, the risk of being killed or seriously injured was found to be seven to nine times lower for bus and coach occupants as compared to the risk of car occupants.

Another main conclusion of the present study is that bus drivers are insufficiently protected in accidents with frontal impact. This is largely related to the fact that there are no mandatory European collision safety regulations for bus drivers. This indicates a gap in regulatory focus on bus driver safety. The studies that have a particular focus on bus driver collision protection conclude that current regulations provide insufficient protection of bus drivers in collisions with frontal impact. Matolcsy and Mátyás (2016) use data from 560 bus frontal collisions from all over the world over a 12-year period and find that drivers are 2-15 times more exposed to serious injuries and fatalities than passengers in frontal collisions. Budd, Newstead and Watson (2021) find that there has been no improvement in the crashworthiness of buses after 1980. This contrasts sharply with cars, which have become considerably more crashworthy after 1980 (see, for example, Høye 2019).

In line with this, our literature review shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that R29 crash test design requirements are insufficient, and that there is a need for an improved bus front structure. Lopes et al (2023) conclude that the present bus structure has no potential to meet the essential safety requirements, and that the drivers' and passengers' physical integrity is compromised. Thuong and Nguyen (2019) conclude that energy absorption capacity of bus structures needs to improve by optimising the frame and chassis. Afripin et al (2019) find that in the deformation observed from R29 simulation, the front structures are severely deformed. Elhussieny, et al. (2021) state that simulation results conclude that both deceleration and deformation deviated from the acceptable limits of occupant safety. Morocho, et al. (2022) conclude that in general, the frontal part of the bus structures does not have any protection system to safeguard the life of the cabin occupants during a frontal impact.

4.1.1 Low risk

An answer to the paradox: why the bus driver is insufficiently protected in bus transport, whilst this is the safest mode of road transport, might be the low risk in itself. This means that as there are few bus accidents compared to other traffic accidents, and even fewer which involve bus driver injuries, the topic of bus driver collision safety comes lower on the agenda than other road safety topics. This might also influence cost-benefit analyses.

4.1.2 There is a high focus on passenger safety

Another possible and related answer is that there is a high focus on passenger safety. In total numbers, there are more injured bus passengers than bus drivers. Thus, we might assume that this leads to a higher societal focus on the prevention of injuries among bus passengers. In addition, a high perceived level of bus safety is important to make bus transport an even more popular alternative, in order to reduce car driving, and congestion in urban areas, including emissions.

4.2 What is the solution?

4.2.1 Vision Zero and Safe System

The situation for bus drivers' vulnerability in collisions with frontal impact, even at low speeds, is in contrast with the principles of current road safety policies, as described in vision Zero and Safe System.

The Safe System approach emerged in the 1990s in Sweden and the Netherlands as a response to a slow-down in reductions of traffic fatalities and injuries and the realisation that 'doing more of the same' will not bring the ultimate solution to the road safety problem (Green et al 2022). By now, Safe System has become the state-of-the-art in road safety management, and it is recommended to countries worldwide (WHO & UN 2021, ITF 2022).

The novelty of the Safe System approach is the ethical standpoint that road fatalities cannot be accepted, i.e. there is no 'optimisation problem' to solve, and we must improve road safety until no one is killed or severely injured. Hence Vision Zero, which is another name for Safe System adopted in Norway and Sweden (referring to the systematic management approach to fulfil Vision Zero). The goal of Vision Zero may look unrealistic at first sight, yet Safe System makes it achievable by clearly limiting the scope of the problem. While minor accidents are likely to continue to happen, all efforts and resources must be focused on prevention of the most severe ones with people injured and killed.

In practical terms, Safe System has its grounds in four fundamental principles (ITF, 2016; Green et al 2022):

1) It is human to make mistakes; the traffic system must be designed to tolerate (unintended) errors made by the road users
2) The traffic system must be designed so that the external forces in accidents do not exceed the human bodies' tolerance for biomechanical impacts
3) The responsibility for road safety must be shared by those who design, build, manage, and use roads and vehicles, as well as the providers of the post-crash care and emergency response
4) All system components must be strengthened to multiply the protection effect; if one component fails, road users should still be protected.

The Safe System approach involves a cultural change ("paradigm shift") in the sense that the "blame the victim" culture is superseded by "blaming the traffic system", which throws the spotlight on authorities' accountability (Green 2022). The Safe System approach is generally summed up in six pillars, describing how road safety work should be organised (WHO & UN, 2021; ITF 2022):

i. ***Road safety management:*** Multi-sectoral partnerships and lead agencies to develop and lead national road safety strategies, plans and targets; research-based monitoring of implementation and effectiveness.
ii. ***Safe infrastructure:*** Inherently safe and protective road networks, especially for the most vulnerable (e.g. pedestrians, bicyclists and motorcyclists) road users.
iii. ***Safe vehicles:*** Standards, consumer information and incentives to accelerate the uptake of active and passive vehicle safety technologies.
iv. ***Safe speed:*** Speeds within the boundaries of biomechanical tolerance.
v. ***Safe road users:*** Enforcement and supplementary measures (e.g. public awareness/education) targeting high-risk behaviours.
vi. ***Post-crash response:*** Appropriate emergency response, treatment, and rehabilitation for crash victims.

4.2.2 Bus driver safety in light of Safe System and Vision Zero

Nævestad et al (2025) report that, in the last ten years, 1 459 bus drivers in Europe have been killed or severely injured in accidents. Based on extrapolated estimates, approximately 2/3 of the bus accidents in Europe have been with frontal impact. These are accidents (approximately 963 killed or severely injured bus drivers) in which the severity potentially could have been reduced by a better collision protection solution (Nævestad et al 2025). From a Vision Zero/Safe System perspective and a work environment perspective, it can be argued that bus drivers should have the same protection as car and truck drivers in collisions.

As noted above, some of the key principles of the Safe System approach are that it is human to make mistakes. Thus, the traffic system must be designed to tolerate (unintended) errors made by the road users, and that the traffic system must be designed so that the external forces in accidents do not exceed the human bodies' tolerance for biomechanical impacts. This can be achieved by a combination of safe vehicles (active and passive vehicle safety technologies) and safe roads. It seems that in the case of bus drivers, there is still a considerable potential when it comes to Safe System implementation, as buses provide insufficient collision protection for them. Although our study has highlighted several active safety measures that might reduce the probability that accidents will occur (e.g. Hadi et al. 2021; Goodall & Ohlms 2022), it is important that the bus driver is sufficiently protected when such accidents happen.

We conclude that bus drivers' vulnerability in collisions with frontal impact, even at low speeds, is in contrast with the principles of current road safety policies, as described in Vision Zero and Safe System. The Academic Expert Group (AEG) recommendations related to the 4th Global Ministerial Conference on Road Safety in Marrakech, 2025, suggests a strategy of "Saving Lives Beyond 2025", through integrating road safety into occupational health and safety management (STA 2025). Thus, current global road safety policies, has a strong focus on occupational road safety. It seems that reducing bus drivers' vulnerability in collisions with frontal impact is in line with this strategy.

4.2.3 Safe work environment as a sustainable development goal

Public bus transport plays a pivotal role in advancing several Sustainable Development Goals (SDGs) set by the United Nations. Buses contribute to economic, environmental, and social dimensions of sustainable development. For instance, bus systems are essential for achieving SDG 11 (Sustainable Cities and Communities) by providing affordable, accessible, and safe transportation. Well-designed bus networks may reduce dependence on private vehicles, mitigating urban congestion and promoting inclusive access to jobs, education, and healthcare (Target 11.2). Additionally, buses contribute to improving air quality and reducing urban pollution (Target 11.6), especially when fleets are modernized to low-emission or electric models. In terms of health, bus transport supports SDG 3 (Good Health and Well-Being) by reducing traffic accidents (through professional driving and safer infrastructure) and lowering air pollution levels, both major determinants of public health outcomes. Increased use of buses in the transport system can decrease the incidence of respiratory and cardiovascular diseases linked to vehicular emissions (Target 3.9). Environmental sustainability is further reinforced through contributions to SDG 13 (Climate Action). Buses, particularly when powered by clean energy sources, offer significant reductions in greenhouse gas emissions per passenger-kilometer compared to private cars. Shifting travel demand from private cars to buses is thus a key strategy for climate mitigation efforts.

The Stockholm Declaration following the third ministerial conference on road safety in Stockholm 2020 (STA 2019) and UN Resolution 74/299, implies an "expanded understanding of the role of road safety" as part of the concept of sustainability, with a focus on how road safety can contribute to achieving other sustainability goals (e.g. increased active mobility, health). The Stockholm Declaration emphasizes the importance of building synergies between road safety (SDG 3.6) and other sustainability goals. This understanding of road safety is referred to as an integrated approach to the SDGs. Such an integrated approach to the SDGs involves seeing road safety as a natural part of and as a prerequisite for other sustainability goals. This way of understanding road safety, as a prerequisite for other sustainability goals, is the official global strategy we have for achieving the goal in UN Resolution 74/299, to halve the number of road deaths in the world by 2030 (STA, 2019).

Our study supports the ideas in the integrated goal approach; bus transport is one of the safest modes of road transport, while at the same time it contributes to the fulfilment of several other SDGs. Focusing on the vulnerable position of bus drivers in collisions, there seems however to be a potential for improvement, when it comes to fulfilment of SDGs related to road safety and occupational safety, e.g. Goal 3 (Good Health and Well-Being) and Goal 8 (Decent Work and Economic Growth).

Sustainable development goal number 8 is to:" Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. Target 8.8 of Goal 8 has made occupational safety and health a sustainable development priority. It calls for concerted action: "protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment".[3]

Thus, it seems that there is an imbalance when it comes to SDG fulfilment in bus transport; as bus transport contributes to the fulfilment of several crucial SDGs, while there is still potential for improvement related to SDGs focusing on bus driver safety and working environment.

[3] https://unglobalcompact.org/take-action/safety-andhealth#:~:text=Target%208.8%20of%20Goal%208,and%20those%20in%20precarious%20employment%E2%80%9D.

References

Acar, E., Yilmaz, B., Güler, M. A., & Altin, M. (2020). Multi-fidelity crashworthiness optimization of a bus bumper system under frontal impact. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 42, 493. https://doi.org/10.1007/s40430-020-02608-3

Afripin, M. A. A., Zainudin, A. Z., Sahar, M. A. H. F. M., & Yusof, M. (2019, November). Frontal impact on bus superstructure as per UNECE R29 and NCAP. In IOP Conference Series: Materials Science and Engineering (Vol. 670, No. 1, p. 012014). IOP Publishing. https://doi.org/10.1088/1757-899X/670/1/012014

Accident Investigation Board Norway (2019). Report on collision between two buses on fv. 450 by Nafstad, Ullensaker November 17th 2017. (Report Road 2019/04). Accident Investigation Board Norway

Afripin, M. A. A., Zainudin, A., Z., Sahar, M., Yusof, M. (2019). Frontal impact on bus superstructure as per UNECE R 29 and NCAP. ACADME 2019 012014.

Albertsson, P. (2005). Occupant casualties in bus and coach traffic: Injury and crash mechanisms (Doctoral dissertation, Umeå University).

Albertsson, P., Falkmer, T., Kirk, A., Mayrhofer, E., & Björnstig, U. (2006). Case study: 128 injured in rollover coach crashes in Sweden—injury outcome, mechanisms, and possible effects of seat belts. Safety Science, 44(2), 87–109. https://doi.org/10.1016/j.ssci.2005.10.004

Anund, A., Dukic, T., Börsbo, B., & Falkmer, T. (2010). Piloting smart safe school bus: Exploration of security gains from implementation of a driver support system, additional technical equipment, and intelligent bus stops. European Transport Research Review, 2, 157-163.

Atasayar, H., Fleischer, M., Donabauer, M., Soteropoulos, A. (2024). Facts and Figures. Buses and Heavy Goods Vehicles. European Road safety Observatory.

Berg, A. (2015). Evolution of the figures of casualties for bus/coach occupants with corresponding risk indicators compared to those for occupants of cars and goods vehicles.

Björnstig, U., Bylund, P. O., Albertsson, P., Falkmer, T., Björnstig, J., & Petzäll, J. (2005). Injury events among bus and coach occupants: Non-crash injuries as important as crash injuries. IATSS Research, 29(1), 79–87. https://doi.org/10.1016/S0386-1112(14)60118-1

Björnstig, U., Björnstig, J., & Eriksson, A. (2008). Passenger car collision fatalities–with special emphasis on collisions with heavy vehicles. Accident Analysis & Prevention, 40(1), 158–166. https://doi.org/10.1016/j.aap.2007.04.001

Blades, L., Douglas, R., Early, J., Lo, C. Y., & Best, R. (2020). Advanced driver-assistance systems for city bus applications. SAE Technical Papers, Article 2020-01-1208. https://doi.org/10.4271/2020-01-1208

Budd, L., Newstead, S., & Watson, L. (2021). VSRG research program: An analysis of heavy vehicle safety performance in Australia (Report No. 354). Melbourne, Australia: Monash University Accident Research Centre.

Chirwa, E. C., Li, H., & Qian, P. (2015). Modelling a 32-seat bus and virtual testing for R66 compliance. International Journal of Crashworthiness, 20(2), 200–209. https://doi.org/10.1080/13588265.2014.1003311

Edwards, M., Edwards, A., Appleby, J., & Beaumont, D. (2019). Banging heads onboard buses: Assessment scheme to improve injury mitigation for bus passengers. Traffic Injury Prevention, 20(sup1), S71–S77. https://doi.org/10.1080/15389588.2019.1604347

Elvik R. The non-linearity of risk and the promotion of environmentally sustainable transport. Accid Anal Prev. 2009;41(4):849–855

Elvik R. (2025) Expected developments in bus accidents, TØI Working document. Institute of Transport Economics.

ERSO, 2023. Facts and figures - Buses / coaches / heavy goods vehicles - 2023. Retrieved from https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/statistics-and-analysis-archive/basic-facts_en

European Commission. (2020). Facts and figures: Pedestrians. European Road Safety Observatory. Brussels, Belgium: Directorate-General for Transport.

Evgenikos, P., Yannis, G., Folla, K., Bauer, R., Machata, K., & Brandstaetter, C. (2016). Characteristics and causes of heavy goods vehicles and buses accidents in Europe. Transportation Research Procedia, 14, 2158–2167. https://doi.org/10.1016/j.trpro.2016.05.233

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

Goodall, N. J., Ohlms, P. B. (2018). Evaluation of a transit bus collision avoidance warning system in Virginia. Report FHWA/VTRC-22-R18. Virginia Transportation Research Council.

Green, M. C. Muir, J. Oxley, A. Sobhani (2022) Safe System in road safety public policy: A case study from Victoria, Australia, IATSS Res., 46 (2022), pp. 171-180

Green, M. C. Muir, J. Oxley (2024) What is the purpose? Practitioners' perspectives of the Safe System approach to road safety in Australia, IATSS Research, Volume 48, Issue 1, pp. 84-99,

Greenshields, S., Ball, S., Barlow, T. (2016). Intelligent speed assistance on London buses. TRL Report.

Güler, M. A., Cerit, M. E., Mert, S. K., & Acar, E. (2020). Experimental and numerical study on the crashworthiness evaluation of an intercity coach under frontal impact conditions. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 234(11), 3026–3041. https://doi.org/10.1177/0954407019901078

Hadi, M., Islam, M. A., Afreen, S., & Wang, T. (2021). Evaluation of an advanced driver-assistance system to reduce pedestrian and rear-end crashes of transit vehicles. Transportation Research Record, 2675(11), 1301–1309. https://doi.org/10.1177/03611981211026302

Holenko, K., Dykha, O., Koda, E., Kernytskyy, I., Royko, Y., Horbay, O., & Wierzbicki, T. (2024). Validation of frontal crashworthiness simulation for low-entry type bus body according to UNECE R29 requirements. Applied Sciences, 14(13), 5595.

Høye, A.K., I. Hesjevoll, T.-O. Nævestad, R. Elvik, Ø. L. Brunstad, V. Milch, J. Blom (2025) Analysis of bus accidents in Europe, TØI report. Institute of Transport Economics.

ITF. (2016). Zero road deaths and serious injuries: Leading a paradigm shift to a safe system. OECD Publishing.

ITF. (2022). The Safe System Approach in Action, https://www.itf-oecd.org/safe-system-approach-action-experience-based-guide-enhanced-road-safety

Jamroziak, K., Joszko, K., Wolanski, W., Gzik, M., Burkacki, M., Suchon, S., & Zielonka, K. (2020). Experimental and modelling research on coach passengers' safety in frontal impacts. Archives of Civil and Mechanical Engineering, 20, 1–13. https://doi.org/10.1007/s43452-020-00056-1

Jongpradist, P., Saingam, N., Tangthamsathit, P., Chanpaibool, P., Sirichantra, J., & Aimmanee, S. (2022). Crashworthiness analysis and design of a sandwich composite electric bus structure under full frontal impact. Heliyon, 8(12), e12089. https://doi.org/10.1016/j.heliyon.2022.e12089

Kongwat, S., Jongpradist, P., & Hasegawa, H. (2020). Lightweight bus body design and optimization for rollover crashworthiness. International Journal of Automotive Technology, 21, 981–991. https://doi.org/10.1007/s12239-020-0095-7

Laso,M. J. L. Cardini, T.-O. Nævestad (2025) Technical Study of collision protection for bus drivers: Development of a new model for collision protection, TØI report. Institute of Transport Economics.

Lopes, R., Ramos, N. V., Cunha, R., Maia, R., Rodrigues, R., Parente, M. P. L., & Moreira, P. M. (2023). Coach crashworthiness and failure analysis during a frontal impact. Engineering Failure Analysis, 151, 107369. https://doi.org/10.1016/j.engfailanal.2023.107369

Luu, N. P. T., & Anh, L. H. (2021). A study on optimal design of longitudinal shape for improving small-overlap performance. In Proceedings of the 8th International Conference on Fracture, Fatigue and Wear: FFW 2020, August 26–27 2020 (pp. 109–128). Springer Singapore. https://doi.org/10.1007/978-981-15-7743-1_10

Matolszy, M. (2017). Analysis of bus frontal collisions – statistical approach. Securitas Vialis, 8, 15-30.

Morency P, Strauss J, Pépin F, Tessier F, Grondines J. Traveling by Bus Instead of Car on Urban Major Roads: Safety Benefits for Vehicle Occupants, Pedestrians, and Cyclists. J Urban Health. 2018 Apr;95(2):196-207. doi: 10.1007/s11524-017-0222-6. PMID: 29500736; PMCID: PMC5906382.

Nævestad, T.-O., I. Hesjevoll, Ø. L. Brunstad, V. Milch, J. Blom; A. K. Høye, R. Elvik (2025) Literature review of active and passive measures to improve bus safety, TØI report. Institute of Transport Economics.

Olivares, G. (2012). Crashworthiness evaluation of mass transit buses (FTA Report No. 0021). Washington, DC: U.S. Department of Transportation, Federal Transit Administration.

Páez, J., Furones, A., Aparicio, F., & Alcalá, E. (2014). Spanish frontal accidents of buses & coaches: Injury mechanism analysis. Procedia-Social and Behavioral Sciences, 160, 314–322. https://doi.org/10.1016/j.sbspro.2014.12.144

Pecheux, K., Strathman, J., Kennedy, J. (2015). Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists. FTA report 0084. Washington D. C. U. S. Departement of Transportation, Federal Transit Administration.

Richards, D. C. (2010). Relationship between speed and risk of fatal injury: Pedestrians and car occupants. Road Safety Web Publication, No. 16. London, England: Department for Transport.

Rosen, E., & Sander, U. (2009). Pedestrian fatality risk as a function of car impact speed. Accident Analysis & Prevention, 41, 536–542. https://doi.org/10.1016/j.aap.2009.02.002

Savage I. Comparing the fatality risks in United States transportation across modes and over time. Res Transp Econ. 2013;43(1):9–22

Schmitt, K.-U., Niederer, P. F., Cronin, D. S., Muser, M. H., & Walz, F. (2014). Trauma biomechanics: An introduction to injury biomechanics (4th ed.). Berlin, Germany: Springer. https://doi.org/10.1007/978-3-642-53910-4

Swedish Transport Administration (2019). Saving lives beyond 2020: The next steps. Recommendations of the Academic Expert Group for the 3rd Global Ministerial Conference on Road Safety. Trafikverket Publikation 2019:209. Swedish Transport Administration, Borlänge, Sweden

Swedish Transport Administration (2025). Saving lives beyond 2025: Taking further steps. Recommendations of the Academic Expert Group for the 4th Global Ministerial Conference on Road Safety. Trafikverket Publikation 2025:007. Swedish Transport Administration, Borlänge, Sweden

Tefft, B. C. (2013). Impact speed and a pedestrian's risk of severe injury or death. Accident Analysis & Prevention, 50, 871–878. https://doi.org/10.1016/j.aap.2012.07.022

Tingting, S., Xin, X., Zhuan, Z., Xiaolong, S., & Jianwei, F. (2022). The effect of crash pulse on occupant injury in frontal coach collisions. Journal of Mechanical Science and Technology, 36(11), 5437–5444. https://doi.org/10.1007/s12206-022-1127-4

Tomasch, E., & Smit, S. (2023). Naturalistic driving study on the impact of an aftermarket blind spot monitoring system on drivers' behaviour of heavy goods vehicles and buses in reducing conflicts with pedestrians and cyclists. Accident Analysis & Prevention, 192, 107242. https://doi.org/10.1016/j.aap.2022.107242

Transport for London. (2016). Intelligent speed assistance: TfL bus trial. TRL Limited.

Vincze-Pap, S., & Csiszar, A. (2005). Real and simulated crashworthiness tests on buses. Proceedings of IRCOBI Conference, Paper 05-0233.

Walber, M., Meira Jr., A. D. D., Goedel, F., Fazio, E. A., Izquierdo, F. A., & Iturrioz, I. (2014). Evaluation of the seat fastening in the frame of a road bus submitted to frontal impact. Latin American Journal of Solids and Structures, 11, 1463–1489. https://doi.org/10.1590/S1679-78252014000800008

WHO & United Nations Regional Commissions. (2021). Global plan for the decade of action for road safety 2021-2030. World Health Organization. https://cdn.who.int/media/docs/default-source/documents/health-topics/road-traffic-injuries/global-plan-for-road-safety.pdf?sfvrsn=65cf34c8_35&download=true

Wåhlberg, A. E. (2002). Characteristics of low speed accidents with buses in public transport. Accident Analysis & Prevention, 34(5), 637–647. https://doi.org/10.1016/S0001-4575(01)00063-1

Wijnen, W. (2024). Road safety and welfare (PhD dissertation, TRAIL Thesis Series No. T2024/4). Delft, Netherlands: Technical University of Delft.

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