Institute of Transport Economics
Norwegian Centre for Transport Research

Crashworthiness of buses

Analysis of European data and suggestions for improvements

Tor-Olav Nævestad, Alena Katharina Høye, Rune Elvik,
Ingeborg Hesjevoll, Øyvind Lothe Brunstad, Vibeke Milch,
Jenny Blom, Manuel Laso, Daniel Ruben Pinchasik

2082/2025

Title:	Crashworthiness of buses - Analysis of European data and suggestions for improvement
Tittel:	Kollisjonssikkerhet i buss - Analyse av europeiske data og forslag til forbedringer
Author:	Tor-Olav Nævestad, Alena Katharina Høye, Rune Elvik, Ingeborg Hesjevoll, Øyvind Lothe Brunstad, Vibeke Milch, Jenny Blom, Manuel Laso, Daniel Ruben Pinchasik
Date:	02.2025
TØI Report:	2082/2025
Pages:	57
ISSN Electronic:	2535-5104
ISBN Electronic:	978-82-480-1763-9
Funded by:	Statens vegvesen
Project:	5475 – Collision Safety
Project Manager:	Tor-Olav Nævestad
Quality Manager:	Trine Dale
Research Area:	Safety, Security and Resilience
Keywords:	Buss, kollisjonssikkerhet

Summary

Our study shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that crash design requirements in UN Regulation R29.03 are insufficient, and that there is a need for an improved bus front structure. Our estimates show that the energy level in three recent Norwegian low-speed bus collisions were 10 times higher than the energy tolerance level required by R29.03. We suggest a new model for providing bus drivers with sufficient structural protection in case of collisions with frontal impact. Extrapolations indicate that 963 bus drivers in Europe have been killed or severely injured (KSI) in accidents with frontal impact in the last ten years. Although our cost-benefit analyses indicate that the economic costs of the suggested solution are higher than the expected economic benefits, we argue from a Vision Zero/Safe System perspective and a work environment perspective, that bus drivers should have the same protection in collisions as car and truck drivers. Our solution also aims to provide better protection for light vehicles which are in collisions with buses. These comprise 22% of the KSIs in bus accidents.

Kort sammendrag

Vår studie viser at dagens strukturelle design av bussfronter gir utilstrekkelig kollisjonsbeskyttelse for bussjåfører, at FNs økonomikommisjon for Europa sine krav til kollisjonstestdesign (R29.03) er utilstrekkelige, og at det er behov for forbedret kollisjonsbeskyttelse. Våre estimater viser at energinivået i tre nylige lavhastighetskollisjoner med busser i Norge var 10 ganger høyere enn energitoleransenivået som kreves av R29.03. Vi foreslår en ny modell for kollisjonsbeskyttelse som gir bussførere tilstrekkelig strukturell beskyttelse ved kollisjoner med treffpunkt i front. Ekstrapolasjoner indikerer at 963 bussførere i Europa har blitt drept eller hardt skadet (DHS) i ulykker med treffpunkt i fronten de siste ti årene. Selv om våre kost-nytte-analyser indikerer at de økonomiske kostnadene ved den foreslåtte modellen er høyere enn de forventede økonomiske fordelene, argumenterer vi fra et Nullvisjons/Safe System-perspektiv og et arbeidsmiljøperspektiv, for at bussførere bør ha samme beskyttelse som bil- og lastebilsjåfører ved kollisjoner. Vår løsning tar også sikte på å gi bedre beskyttelse for førere av lette kjøretøy som kolliderer med busser. Disse utgjør 22 % av DHS i bussulykker.

Preface

This is the main report in a project comprised of four reports on bus collision safety. The other reports in the project present the development of a new model for improving collision protection in frontal collisions (Laso and Nævestad 2025), a literature review of bus safety measures (Nævestad et al 2025) and an analysis of bus accidents in Europe (Høye et al 2025). As this is the main report in the project, it presents main findings from the other reports.

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 UN Regulation 29.03 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 R29.03. Particular mention is also made of UN Regulation R93.00 (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 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. We also extend our gratitude to the Norwegian Public Roads Administration and several other European authorities and agencies who provided us with bus and truck accident data, and in particular to Professor George Yannis at the National Technical University of Athens who provided and prepared data from the European accident database CARE.

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, Jenny Blom and Manuel Laso from IDIADA. Høye has prepared data and analysed the accidents. Hesjevoll also analysed data, as well as contributing to the literature review. Elvik contributed with projections of bus accidents and cost benefit analyses, whilst Lothe Brunstad and Milch contributed to the literature review. Milch has also contributed to accident analysis. Blom has organised the collection of statistics of bus accidents. Pinchasik has contributed to problem description, writing and editing. Manuel Laso from the Spanish company IDIADA has written the technical desktop study and developed the suggestion for improved collision safety for bus drivers. Senior researcher Torkel Bjørnskau and Director of research, Trine Dale, have quality assured the report.

Oslo, February 2025
Institute of Transport Economics

Bjørne Grimsrud	Trine Dale
Managing Director	Director of Research

Contents

Summary

Sammendrag

Institute of Transport Economics
Norwegian Centre for Transport Research

ENGLISH **Summary**

Crashworthiness of buses

Analysis of European data and suggestions for improvement

TØI Report 2082/2025 • Authors: Tor-Olav Nævestad, Alena Katharina Høye, Rune Elvik, Ingeborg Hesjevoll, Øyvind Lothe Brunstad, Vibeke Milch, Jenny Blom, Manuel Laso, Daniel Ruben Pinchasik • Oslo 2025 • 57 pages

There are no mandatory EU crashworthiness standards focusing on bus drivers. Norway took, however, a lead in bus driver safety and implemented the R29.03 frontal crash test standard for buses as of 01.10.2023. This standard originally applies to trucks. Our literature review shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that R29.03 crash test design requirements are insufficient and that there is a need for an improved bus front structure. Our desktop study, using three fatal Norwegian low speed (e.g. 30 km/h) bus collisions as point of departure, shows that the energy level in these collisions was 10 times higher than the energy tolerance level required by R29.03. We have developed a new solution to provide bus drivers with sufficient structural protection in case of collisions with frontal impact (the bus front improvement model). Extrapolations indicate that 963 bus drivers in Europe have been killed or severely injured in accidents with frontal impact in the last ten years. The severity of these accidents could potentially have been reduced by a better collision protection solution. Although our cost-benefit analyses indicate that the economic costs of the suggested bus front improvement model are higher than the expected economic benefits, we argue from a Vision Zero/Safe System perspective and a work environment perspective, that bus drivers should have the same protection as car and truck drivers in collisions. The bus front improvement model also aims to provide better protection for light vehicles which are in collisions with buses. These comprise 22% of the killed and seriously injured in bus accidents. We recommend that future studies provide tests or simulations of the bus front improvement model, and that they validate and refine the model. This will make it more likely that it will be adopted by bus manufacturers and contribute to defining new requirements for crash protection for bus drivers.

Background

As a result of 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), bus drivers are more exposed in crashes with frontal impact than e.g. car and truck drivers. This can be seen 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 property 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. The 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 UN Regulation 29.03, 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 UN R.29.03 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

The main objectives of the study are 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 collision, and to assess possible solutions. The report is divided into two main parts, covering four aims.

Part A: Description of the scope of the problem of bus accidents in Europe, including deficiencies in current bus front designs' protection of the bus driver in collisions.

1) **Analysis and comparison of bus accidents** and factors influencing the severity of bus accidents across countries.
2) **Descriptions of deficiencies** in current bus front designs.

Part B: Description of possible solutions to reduce bus accidents, including a new model for bus front design, aiming to increase the collision protection of bus drivers.

3) **Presentation of measures** to improve collision safety in buses.
4) **Assessment of the benefits and costs** of the suggested measures for improving collision safety in buses and the expected developments over time.

In the report, we also present main results from other reports in the project, i.e. our report presenting the bus front improvement model (Laso and Nævestad 2025), our literature review of bus safety measures (Nævestad et al 2025), and our more extensive bus accident analysis, which is reported in Høye et al (2025).

Overview of bus accidents in Europe

Studies of European bus accidents show that buses/coaches in crashes account for 2% of all road fatalities in the EU. For the full period of 2013-2022, the CARE database contains information on 216 bus driver fatalities and 1 243 serious injuries among bus drivers. In addition, 876 bus passengers and 4 775 other road users were killed in these crashes. Table S.1 shows the numbers of injured and killed bus drivers, bus passengers, and other road users involved in bus accidents that are registered in the CARE database. The numbers of seriously injured is under-estimated because some countries do not report injury severity, but there were at least 33 307 in the study period.

Based on six countries for which the impact point is known, we know that about two thirds of the killed or severely injured bus drivers were in bus accidents with frontal impact. In these accidents (which account for 963 killed or severely injured bus drivers, if the numbers are extrapolated to all countries) severity might have been reduced by better collision protection.

Table S.1. Injuries in bus accidents by road user group, severity, and time period in the CARE database.

Road user group	Injury severity*	2013-2014	2015-2016	2017-2018	2019-2020	2021-2022	All years
Bus drivers	All injured	3 911	3 802	3 778	2 688	2 886	17 065
	Seriously injured	266	290	307	192	193	1 248
	Fatal	49	48	41	36	42	216
Bus passengers	All injured	39 570	39 710	40 784	27 997	27 376	175 437
	Seriously injured	2 924	2 822	3 004	2 087	1 935	12 772
	Fatal	214	178	187	134	163	876
Other road users involved in bus accidents	All injured	36 163	34 740	33 222	21 889	20 774	146 788
	Seriously injured	4 628	4 856	4 504	2 841	2 458	19 287
	Fatal	1 152	1 100	1 090	773	660	4 775

*Note: *Counts of "seriously injured" are based only on the countries that report injury severity (Estonia, France, Finland and Italy do not). The real number of seriously injured is therefore higher, and these numbers cannot be used to estimate the share of killed or severely injured.*

Bus passengers make up the largest share of injured road users involved in bus accidents (Figure S.1), followed by light vehicle occupants. Among the severe injuries, light vehicle occupants make up 22 percent, and pedestrians' 21 percent.

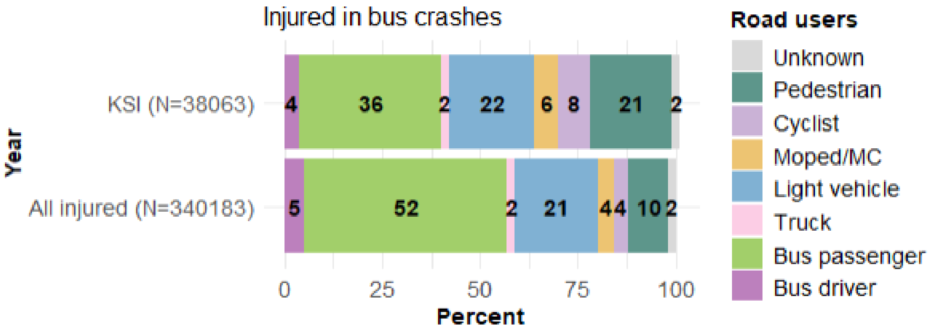


Figure S.1: Distribution of road users injured in crashes involving buses. CARE database 2013-2022.

The bus front improvement model

Our extrapolations indicate that 963 bus drivers in Europe have been killed or severely injured in accidents with frontal impact in the last ten years. The severity of these accidents could potentially have been reduced by a better collision protection solution. We have therefore developed a new model for bus driver collision protection in the project, presented in the following. We refer to is as a model, although it is a description of new solution trends for structural improvements in collision protection, that bus manufacturer can adapt to their own buses.

Although bus accidents do not account for the majority of road fatalities, three serious incidents involving fatalities, which occurred within a short period in Norway, share significant similarities in the nature of the collision, and all resulted in fatal outcomes. These accidents are: Nafstad (2017), Tangen (2021) and Fredrikstad (2022). Data from the Norwegian Safety Investigation Authority (NSIA)'s in-depth accident reports raise concerns about a potential pattern in these accidents, suggesting that overall safety measures on buses may not be functioning as intended, or that the scenarios for which buses are designed do not align with the realities of the incidents they face. These accidents highlight a worrying trend where bus structures, particularly in the front corners and A-pillars, are not designed to face frontal collisions with low overlap. Despite the introduction of new regulations in Norway requiring frontal impact tests (i.e. R29.03), these do not address the structural weaknesses observed in the aforementioned accidents.

The impact energy of each of these three accidents was estimated based on the information given by the reports of the accidentology. The level of energy produced in these three accident scenarios can be considered equivalent, considering the boundary conditions of all buses. The level is about 10 times higher (approx. 550 kJ) than the energy values prescribed in Regulation UN R29.03 (55 kJ).

We have estimated the ideal energy absorption capabilities for transit buses in collision scenarios. These vehicles should be engineered to dissipate kinetic energy across a broad spectrum, ranging from approximately 424 kJ when colliding with light vehicles (mass around 1 333 kg) to as much as 2 000 kJ in impacts involving larger vehicles (mass approximately 12 000 kg). Based on these estimations and the analyses of accidents, we propose five main changes to bus structures. These five improvements and their background are described in a separate report (Laso and Nævestad 2025), and we refer to it as the bus front improvement model.

1. **Improvement of crash compatibility.** To address critical safety concerns, several potential solutions can be considered to improve crash compatibility.
    a) **Enhanced Structural Integrity**: Developing more robust connections between the transverse profile and the side panels of buses is crucial.
    b) **Energy Absorption Zones**: Incorporating dedicated energy absorption zones in the front structure of buses could help manage impact forces more effectively.
    c) **Small Overlap Impact Testing:** Introducing mandatory small overlap impact testing for buses, similar to tests now common for passenger cars, could drive improvements in design to better handle these challenging impact scenarios.
    d) **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials in bus construction could provide better protection without significantly increasing vehicle weight.
    e) **Compatibility Design Standards:** Developing specific standards for vehicle compatibility between buses and smaller vehicles could lead to designs that interact more safely during collisions.
    f) **Mandatory Implementation of UN R93.00**: The United Nations Economic Commission for Europe Regulation No. 93 (UN R93.00) standard requires the installation of a front underrun protection device for trucks. Implementing this in buses could help distribute impact forces more evenly and prevent smaller vehicles from under-riding the bus in a collision.
    g) **Integration with Towing Hook regulation:** Combining the R93.00 requirements with existing towing hook regulation, EU R1005/2010 could ensure that the frontal structure of buses is strengthened without compromising their serviceability.

The goal is to create bus structures that not only protect their occupants but also minimize damage and injury risk to occupants of other vehicles involved in collisions.

2. **The position of the driver.** The position of the driver is quite sensitive with respect to the severity of the accident. In the case of urban buses, it would be possible to raise the position of the driver slightly, but ergonomics would have to be checked in order to be able to carry out passenger control functions.

3. **Reinforcements in the structure.** Structural reinforcements shall be focused on the driver side. The strategy could be to use a “semi-cage” open structure, protecting the lower area but also providing a better connection with the vehicle’s roof. In addition, the amount of energy is also an important point to take into account. Our estimates show that energy levels even in low-speed accidents are much higher than the energy tolerance level required by UN R29.03 (type-A), which applies 55kJ over the whole width of front structure. The definition of a specific test or tests to evaluate bus safety in more realistic conditions would be necessary.

4. **Reinforcement of front grill and floor.** In the realm of bus crash safety, one critical area of concern is the behaviour of the frontal structure during collision events. Current designs often result in the front of the bus transforming into a hazardous "lance" or "battering ram" upon impact. This transformation has lethal consequences, particularly for the drivers involved in such collisions.

One promising approach to addressing this issue involves leveraging the inherent strength of the towing hook mount point, mandatory for buses under regulation EU R1005/2010. This could serve as the starting point to extend the frontal structure reinforcement and to be used as the front underrun protection.

5. **Reinforcement of the roof.** The NSIA’s reports on three different Norwegian accidents show that in all of them, the upper roof connection was detached from the lateral structure. The recommendation is to increase the strength of roof connections with the first arch located in the windscreen, and also the connection with the second safety arch, just behind the driver.

Assessment of the benefits and costs

We make assessments of the benefits and costs of improvements addressed in the bus front improvement model. If the model reduces fatal injury by 30 %, serious injury by 20 % and slight injury by 10 % in crashes with impact points between 10 and 12 o’clock, the present value of the benefits will be EUR 377per bus, whilst system costs may be assumed to lie between EUR 8 500-12 000 per bus. Costs therefore seem to outweigh benefits.

We also discuss other complementary measures to improve collision safety in buses, e.g. an air bag integrated into the seat belt, and seats with reclining or withdrawal function. An air bag integrated into the seat belt is assumed to reduce fatal injury by 30 % and serious injury by 20 %. It will have no effect on slight injury. With these assumptions, the present value of benefits is estimated at EUR 329 per bus, compared to costs of EUR 550per bus. Again, costs seem to outweigh benefits. The effects of a seat reclining or withdrawal function are unknown. If, absent any other information, the same effects are assumed as for the bus front improvement model, the present value of benefits is EUR 377 per bus. If a cost of 200 Euros per bus is assumed, benefits are greater than costs. The combined effects of both the bus front improvement model and an airbag have also been estimated. Total costs are EUR 9 050-12 550 Euros, whilst total benefits have been estimated to EUR 624. Thus, benefits remain smaller than costs even for the combined systems.

Vision Zero and Safe System

Although our cost-benefit analyses indicate that the economic costs of the suggested new model for bus driver collision protection (and other solutions that we analyse) are far higher than the expected economic benefits, we argue (in line with previous studies) that it is necessary to improve the collision protection of bus drivers. 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. One of the key principles of the Safe System approach is that the traffic system must be designed so that the external forces in accidents do not exceed the human bodies' tolerance for biomechanical impacts. 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.

Our study indicates that the frontal structure of the bus also might endanger other vehicles in crashes, as current designs often result in the front of the bus transforming into a hazardous "lance" or "battering ram" upon impact. This is another example of how bus frontal design might be in conflict with Vision Zero/Safe System principles. Our suggested model also seeks to mitigate this, and might thus also reduce the injury risk of counterparties in bus accidents. Light vehicle occupants comprise 22% of the killed and severely injured in bus accidents.

Future research

It is necessary to implement a deeper study based on simulations and/or testing to validate the suggested model for improved bus driver collision safety. Further research and real-world testing will be crucial in refining the suggested solutions and ensuring their effectiveness across a wide range of collision scenarios. By addressing these issues, we can work towards a future where the severity of bus accidents is significantly reduced, even at lower impact speeds, thereby enhancing road safety for all vehicle occupants.

tøi
Transportøkonomisk institutt
Stiftelsen Norsk senter for samferdselsforskning

NORSK **Sammendrag**

Kollisjonssikkerhet i buss

Analyse av europeiske data og forslag til forbedringer

TØI rapport 2082/2025 • Forfattere: Tor-Olav Nævestad, Alena Katharina Høye, Rune Elvik, Ingeborg Hesjevoll, Øyvind Lothe Brunstad, Vibeke Milch, Jenny Blom, Manuel Laso, Daniel Ruben Pinchasik • Oslo, 2025 • 57 sider

Det finnes ikke obligatoriske EU-standarder for kollisjonssikkerhet som fokuserer på bussførere. Norge har imidlertid gått foran og innført R29.03-standarden for frontkollisjonstester for busser fra 01.10.2023. Denne standarden gjelder opprinnelig for lastebiler. Vår litteraturgjennomgang viser at dagens strukturelle design av bussfronter gir utilstrekkelig kollisjonsbeskyttelse for førere, at kravene til R29.03-kollisjonstester er utilstrekkelige, og at det er behov for en forbedret struktur i fronten av busser. Våre beregninger, som tar utgangspunkt i tre kollisjoner (omtrent 30 km/t) med busser i Norge med dødelig utfall, viser at energinivået i disse kollisjonene var 10 ganger så høyt som energitoleransenivået som kreves av R29.03. Vi har utviklet en ny løsning for å gi bussførere tilstrekkelig kollisjonsbeskyttelse i ulykker med treffpunkt i front: «IDIADA modellen for økt kollisjonsbeskyttelse for bussjåfører». Ekstrapoleringer indikerer at 963 bussførere i Europa har blitt drept eller alvorlig skadet i ulykker med treffpunkt i front de siste ti årene. Alvorlighetsgraden i disse ulykkene kunne potensielt ha blitt redusert med en bedre modell for kollisjonsbeskyttelse. Selv om våre kostnytte-analyser viser at de økonomiske kostnadene ved modellen vi foreslår er høyere enn de forventede økonomiske fordelene, argumenterer vi, fra et Nullvisjons-/Safe System-perspektiv og et arbeidsmiljøperspektiv, for at bussførere bør ha samme beskyttelse som bil- og lastebilsjåfører ved kollisjoner. Modellen som vi foreslår for økt kollisjonsbeskyttelse for bussjåfører tar også sikte på å gi bedre beskyttelse for lette kjøretøy som kolliderer med busser. Disse utgjør 22% av de drepte og alvorlige skadede i bussulykker. Vi anbefaler at fremtidige studier utfører tester eller simuleringer av «IDIADA modellen» for økt kollisjonsbeskyttelse for bussjåfører, for å validere og forbedre den, slik at det blir mer sannsynlig at den blir tatt i bruk av bussprodusenter, og for å bidra til å definere nye krav til kollisjonsbeskyttelse for bussjåfører.

Bakgrunn

Bussjåfører er mer utsatt enn 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, sammenleggbar 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 sikkerhetsutstyr i mange av dagens busser. Dette medfører at passasjerer og sjåfører i disse kjøretøyene kan være utsatt for høyere risiko for skader ved kollisjoner.

Førerhytta i lastebiler er underlagt kollisjonssikkerhetsstandarder i henhold til UN R29.03, 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 UN R29.03 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.

Målene med studien

Hovedmålene med studien er å gjennomføre en analyse av kollisjonssikkerhet i busser, med særlig fokus på hvor godt føreren (og andre trafikanter) er beskyttet ved kollisjoner, samt å vurdere mulige løsninger. Rapporten er delt inn i to hoveddeler, som dekker fire mål.

Del A: Beskrivelse av omfanget av bussulykker i Europa, inkludert svakheter ved dagens bussfrontdesigns beskyttelse av føreren ved kollisjoner.

1) Analyse og sammenligning av bussulykker og faktorer som påvirker alvorlighetsgraden av bussulykker på tvers av land.
2) Beskrivelse av svakheter ved dagens bussfrontdesign.

Del B: Beskrivelse av mulige løsninger for å redusere bussulykker, inkludert en ny modell for bussfrontdesign som tar sikte på å øke kollisjonsbeskyttelsen for bussjåfører.

3) Presentasjon av tiltak for å forbedre kollisjonssikkerheten i busser.
4) Vurdering av kostnader og nytte av foreslåtte tiltak for å forbedre kollisjonssikkerheten i busser og de forventede utviklingene over tid.

I rapporten presenterer vi også hovedresultater fra andre rapporter i prosjektet, for eksempel vår rapport som presenterer modellen for forbedret frontdesign for buss (Laso og Nævestad 2025), vår litteraturgjennomgang av sikkerhetstiltak i buss (Nævestad m.fl. 2025), og vår mer detaljerte analyse av bussulykker, som er rapportert i Høye m.fl. (2025).

Oversikt over bussulykker i Europa

Studier av europeiske bussulykker viser at busser står for 2 % av alle trafikkdødsfall i EU. Tabell S.1 viser antall skadde og drepte i bussulykker som er registrert i Care-databasen i 2013-2022, som inneholder ulykkesdata fra 32 land. I perioden 2013–2022 inneholder CARE-databasen informasjon om 216 drepte bussjåfører og 1 243 alvorlig skadde bussjåfører.

I tillegg ble 876 busspassasjerer og 4 775 andre trafikanter drept i bussulykker. Det totale antallet alvorlig skadde i bussulykker er underrapportert i Care fordi enkelte land ikke rapporterer skadegrad, men det er minst 33 307 i perioden.

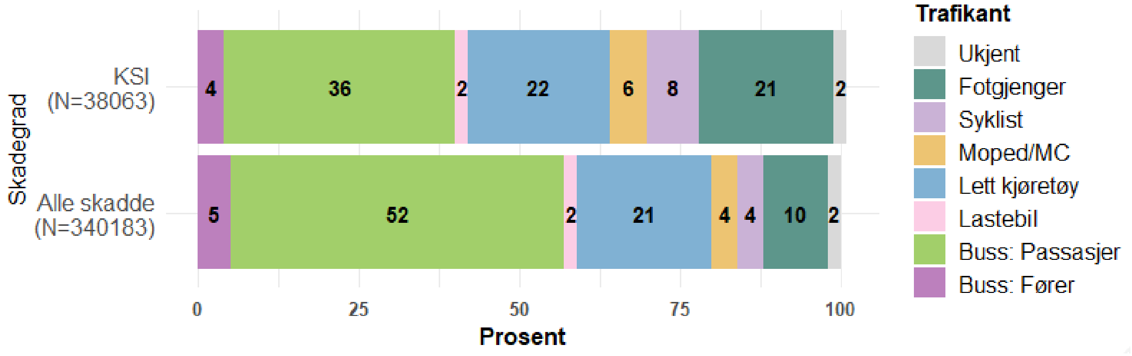
Basert på seks land der treffpunkter for kollisjonene er kjent, vet vi at omtrent 2/3 av de drepte eller alvorlig skadde bussjåførene var i busser med frontkollisjon. Dette er ulykker der alvorlighetsgraden kunne ha blitt redusert med en bedre løsning for kollisjonsbeskyttelse. Dersom tallene ekstrapoleres til alle land, tilsvarer dette 963 drepte eller alvorlig skadde bussjåfører.

*Tabell S.1. Antall skadde og drepte i bussulykker etter trafikantgruppe, skadegrad og tidsperiode i CARE-databasen**

Trafikantgruppe	Skadegrad*	2013-2014	2015-2016	2017-2018	2019-2020	2021-2022	Alle år
Bussjåfører	Alle skadde	3 911	3 802	3 778	2 688	2 886	17 065
	Alvorlig skadde	266	290	307	192	193	1 248
	Døde	49	48	41	36	42	216
Busspassasjerer	Alle skadde	39 570	39 710	40 784	27 997	27 376	175 437
	Alvorlig skadde	2 924	2 822	3 004	2 087	1 935	12 772
	Døde	214	178	187	134	163	876
Andre trafikanter	Alle skadde	36 163	34 740	33 222	21 889	20 774	146 788
	Alvorlig skadde	4 628	4 856	4 504	2 841	2 458	19 287
	Døde	1 152	1 100	1 090	773	660	4 775

***Merk:** Antallet alvorlig skadde er basert på land som rapporterer skadegrad (Estland, Frankrike, Finland og Italia rapporterer ikke). Det reelle antallet alvorlig skadde er derfor høyere, og tallene i tabellen kan ikke brukes for å estimere andelen drepte eller alvorlig skadde.*

Busspassasjerer utgjør den største andelen skadde trafikanter i ulykker som involverer busser (Figur S.1), etterfulgt av førere og passasjerer i lette kjøretøy. Når det gjelder alvorlige skader, utgjør førere og passasjerer i lette kjøretøy 22 %, mens fotgjengere utgjør 21 % av de drepte eller alvorlig skadde.



Figur S.1. Fordeling av trafikanter skadd i ulykker som involverer busser. CARE-databasen 2013-2022.

Modell for økt kollisjonsbeskyttelse

Våre ekstrapoleringer indikerer at 963 bussjåfører i Europa har blitt drept eller alvorlig skadet i ulykker med frontkollisjon de siste ti årene. Alvorlighetsgraden i disse ulykkene kunne potensielt ha blitt redusert med en bedre kollisjonsbeskyttelsesløsning. Vi har derfor utviklet en ny modell for kollisjonsbeskyttelse for bussjåfører i prosjektet, som presenteres i det følgende. Vi omtaler er som en modell, selv om det er en beskrivelse av nye løsningstrender for strukturelle forbedringer innen kollisjonssikring, som bussprodusenten kan tilpasse sine egne busser.

Selv om bussulykker ikke utgjør majoriteten av trafikkdødsfall, har vi hatt tre dødsulykker med bussjåfører i Norge de siste årene, som deler visse kjennetegn. Disse ulykkene er: Nafstad (2017), Tangen (2021) og Fredrikstad (2022). Data fra Statens havarikommisjon og deres dybderapporter fra ulykkene vekker bekymring om et potensielt mønster i disse ulykkene som antyder at de generelle sikkerhetstiltakene for busser kanskje ikke fungerer som planlagt, eller at de scenariene som busser er designet for, ikke samsvarer med virkeligheten i ulykkene de møter.

Disse ulykkene fremhever en bekymringsfull trend der busskonstruksjoner, spesielt i de fremre hjørnene og A-stolpene, ikke er designet for å håndtere frontkollisjoner med liten overlapp. Til tross for innføringen av nye reguleringer i Norge som krever frontkollisjonstester (f.eks. UN R29.03), adresserer ikke disse de strukturelle svakhetene som ble observert i de nevnte ulykkene.

Kollisjonsenergien i hver av disse tre ulykkene er beregnet basert på informasjon fra ulykkesrapportene. Energien som ble generert i disse tre ulykkesscenariene er omtrent ti ganger høyere (ca. 550 kJ) enn energitoleransenivåene som kreves i UN R29.03 (55 kJ).

Vi har estimert de ideelle energiabsorpsjonskapasitetene for kollektivbusser i kollisjonsscenarier. Disse kjøretøyene bør være konstruert for å absorbere kinetisk energi over et bredt spekter, fra omtrent 424 kJ ved kollisjon med lette kjøretøy (masse rundt 1 333 kg) til så mye som 2 000 kJ ved sammenstøt med større kjøretøy (masse ca. 12 000 kg). Basert på disse beregningene og ulykkesanalyser, foreslår vi fem hovedendringer i busskonstruksjonen. Disse fem forbedringene og deres bakgrunn er beskrevet i en egen rapport (Laso og Nævestad 2025), og vi refererer til den som IDIADA modellen for økt kollisjonsbeskyttelse for bussjåfører.

1. **Forbedring av kollisjonskompatibilitet**
   For å adressere kritiske sikkerhetsutfordringer kan flere potensielle løsninger vurderes for å forbedre kollisjonskompatibiliteten:

   a) **Obligatorisk implementering av FN R93.00:** Denne standarden krever installasjon av underkjøringshinder i front på lastebiler. Implementering av dette i busser kan bidra til å fordele kollisjonskreftene jevnere og forhindre at mindre kjøretøy kjører under bussen i en kollisjon.

   b) **Integrasjon med tauekroksregulering:** Kombinasjon av R93.00 med eksisterende regulering for tauekroker (EU R1005/2010) kan sikre at bussens frontkonstruksjon styrkes uten å kompromittere funksjonaliteten.

   c) **Forbedret strukturell integritet:** Utvikling av sterkere forbindelser mellom tverrprofilen og sidepanelene på busser er avgjørende.

   d) **Energidempingssoner:** Dedikerte energidempingssoner i frontstrukturen kan bidra til å håndtere kollisjonskrefter mer effektivt.

   e) **Test for små overlappskollisjoner:** Innføring av obligatoriske tester for små overlappskollisjoner for busser, tilsvarende de som nå er vanlige for personbiler, kan drive frem designforbedringer for bedre håndtering av slike utfordrende kollisjonsscenarier.

   f) **Avanserte materialer:** Utforskning av avanserte, energidempende materialer i busskonstruksjon kan gi bedre beskyttelse uten å øke kjøretøyvekten betydelig.

g) **Designstandarder for kompatibilitet:** Utvikling av spesifikke standarder for kjøretøykompatibilitet mellom busser og mindre kjøretøy kan føre til design som fører til tryggere samhandling under kollisjoner.

Målet er å lage busskonstruksjoner som ikke bare beskytter passasjerene, men som også minimerer skade- og skaderisikoen for andre trafikanter som er involvert i kollisjoner.

2. **Førerens posisjon**
   Førerens posisjon er svært viktig for alvorlighetsgraden av ulykker. I bybusser ville det vært relevant å heve førerposisjonen noe, men ergonomiske hensyn må ivaretas for å kunne utføre passasjerkontrollfunksjoner som billettkontroll.

3. **Forsterkninger i konstruksjonen**
   Den strukturelle forsterkningen bør fokusere på førerens side. Strategien kan være å bruke en "halvburstruktur" som beskytter den nedre delen og samtidig gir bedre tilkobling til taket. I tillegg må energinivået håndteres bedre. Realiteten viser at energinivået selv i lavhastighetsulykker er mye høyere enn energitoleransenivået som kreves av UN R29.03 (type-A), som gjelder 55 kJ over hele frontstrukturen.

4. **Forsterkning av nedre front og gulv**
   Forsterkninger i grill- og gulvområdet kan redusere risikoen for at fronten blir en farlig "lanse" ved kollisjoner.

5. **Forsterkning av taket**
   Ulykkesrapporter viser at takforbindelsen løsner fra sidekonstruksjonen. Styrking av takforbindelsene med de første buene i frontruten og de andre sikkerhetsbuene bak føreren er nødvendig.

Vurdering av nytte og kostnader

Vi har vurdert nytten og kostnadene knyttet til modellen for økt kollisjonsbeskyttelse for bussjåfører. Hvis modellen reduserer dødsulykker med 30 %, alvorlige skader med 20 % og mindre skader med 10 % ved frontkollisjoner, er nåverdien av nytten 377 euro per buss. Kostnadene for modellen kan imidlertid være mellom 8 500 og 12 000 euro per buss, noe som antyder at nytten er lavere enn kostnadene.

Vi diskuterer også andre komplementære tiltak for å forbedre kollisjonssikkerheten i busser, for eksempel en kollisjonspute integrert i setebeltet og funksjon for tilbaketrekking eller tilbakelening av setet.

En kollisjonspute integrert i setebeltet antas å redusere risikoen for dødelige skader med 30 % og alvorlige skader med 20 %. Det antas at dette ikke vil ha noen effekt på mindre skader. Basert på disse forutsetningene estimeres nåverdien av nytten til 329 euro per buss, sammenliknet med en antatt kostnad på 550 euro per buss. Igjen ser vi at nytten er lavere enn kostnadene. Effektene av en funksjon for tilbaketrekking eller tilbakelening av setet er ukjente. Hvis man, i mangel på annen informasjon, antar de samme effektene som for den nye kollisjonsbeskyttelsesmodellen, vil nåverdien av nytten være 377 euro per buss. Hvis en kostnad på 200 euro per buss antas, er nytten større enn kostnadene.

De kombinerte effektene av både kollisjonsbeskyttelsesmodellen og en kollisjonspute er også estimert. Totale kostnader er 9 050–12 550 euro, og total nytte er estimert til 624 euro. Dermed forblir nytten lavere enn kostnadene, selv for de kombinerte systemene.

Nullvisjon og Safe System

Selv om våre kostnytte-analyser viser at de økonomiske kostnadene for den foreslåtte nye modellen for kollisjonsbeskyttelse av bussjåfører (og andre løsninger vi analyserer) er langt høyere enn den forventede økonomiske nytten, argumenterer vi (i tråd med tidligere studier) for at det er nødvendig å forbedre kollisjonsbeskyttelsen for bussjåfører. Fra et Nullvisjons-/Safe System-perspektiv og et arbeidsmiljøperspektiv kan det argumenteres for at bussjåfører bør ha samme beskyttelse som bil- og lastebilsjåfører i kollisjoner.

Et av de viktigste prinsippene i Safe System-tilnærmingen er at trafikksystemet må designes slik at de ytre kreftene i ulykker ikke overstiger menneskekroppens toleranse for biomekaniske påvirkninger. Når det gjelder bussjåfører, ser det ut til at det fremdeles er et betydelig potensial for implementering av Safe System-prinsipper, fordi busser gir utilstrekkelig kollisjonsbeskyttelse for dem.

Studien vår indikerer også at bussens frontstruktur kan utgjøre en fare for andre kjøretøy i kollisjoner, fordi dagens design ofte fører til at bussfronten forvandles til en farlig "lanse" eller "rambukk" i kollisjoner med andre kjøretøy. Dette er et annet eksempel på hvordan designet av bussfronter kan være i konflikt med Nullvisjon-/Safe System-prinsipper. Vår foreslåtte modell søker også å redusere denne risikoen, og dermed kan den også redusere risikoen for skader på motparter i bussulykker. Førere av lette kjøretøy utgjør 22 % av de drepte og alvorlig skadde i bussulykker.

Fremtidig forskning

Det er nødvendig å gjennomføre en grundigere studie basert på simuleringer og/eller testing for å validere den foreslåtte modellen for forbedret kollisjonssikkerhet for bussjåfører. Videre forskning og tester i virkelige situasjoner vil være avgjørende for å forbedre de foreslåtte løsningene og sikre deres effektivitet i et bredt spekter av kollisjonsscenarier. Ved å adressere disse problemene kan vi bevege oss mot en fremtid der alvorlighetsgraden av bussulykker blir betydelig redusert, selv ved lavere kollisjonshastigheter, og dermed forbedre trafikksikkerheten for alle trafikanter.

1 Introduction

1.1 Background

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

This 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.

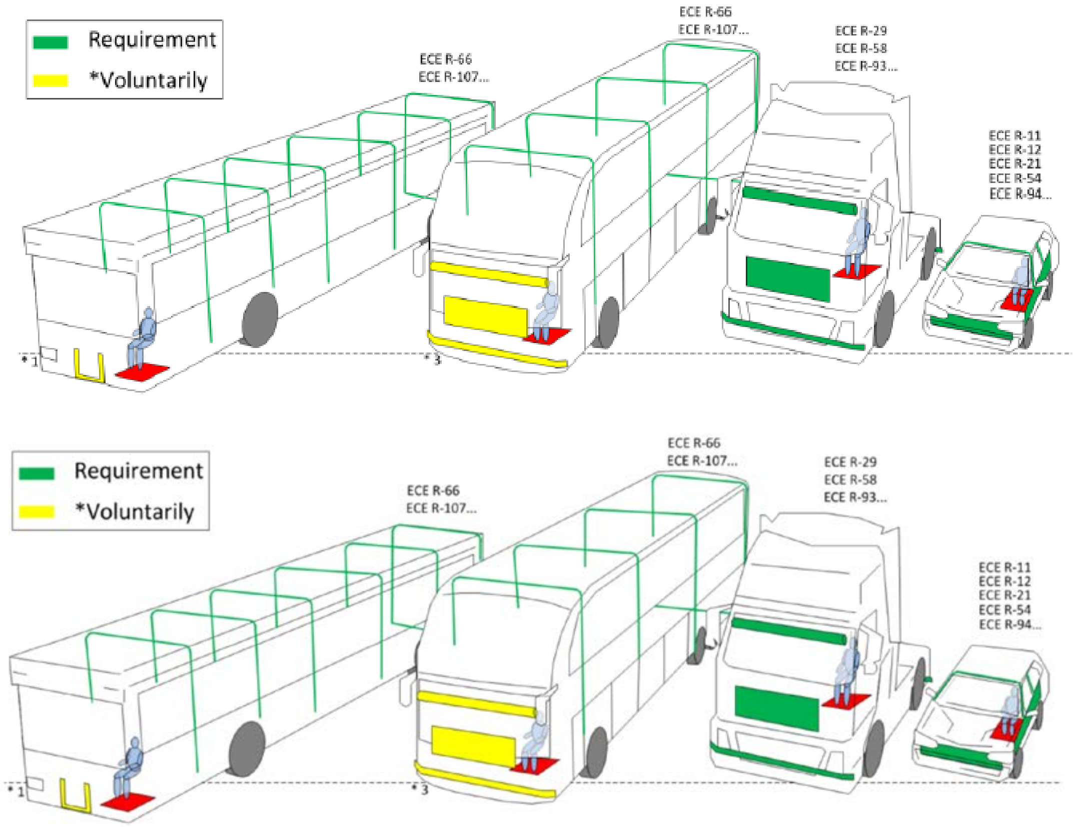


Figure 1.1: Illustration of the most relevant UNECE[1] regulations for collision protection on urban buses (bus categories 1 and 2), express coaches (bus category 3), tractors, and passenger cars. Source: Illustration by AIBN (now: NSIA) report Road 2019-04, figure 26 on p. 20.

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 UN R.29.03, which was made mandatory for buses in Norway as of 01.10.2023 (see section 5.1).

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 cabins are subject to strict crashworthiness standards under UN R29.03, 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 UN R29.03 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

---

[1] United Nations Economic Commission for Europe

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 R66), and passenger evacuation (cf. ECE R107).

1.2 Aims

The main objectives of the study are 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, and to assess possible solutions. The report is divided into two main parts, covering four aims.

Part A: Description of the scope of the problem of bus accidents in Europe, including deficiencies in current bus front designs' protection of the bus driver in collisions.

1) **Analysis and comparison of bus accidents** and factors influencing the severity of bus accidents across countries (Chapter 3).
2) **Descriptions of deficiencies** in current bus front designs (Chapter 4).

Part B: Description of possible solutions to reduce bus accidents, including a new model for bus front design, aiming to increase the collision protection of bus drivers.

3) **Presentation of measures** to improve collision safety in buses (Chapter 5).
4) **Assessment of the benefits and costs** of the suggested measures for improving collision safety in buses and the expected developments over time (Chapter 6).

In the report, we also present main results from other reports in the project, e.g. our report which presents the bus front improvement model (Laso and Nævestad 2025), our literature review of bus safety measures (Nævestad et al 2025), and our more extensive bus accident analysis, which is reported in Høye et al (2025).

1.3 Overview of the project

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 prevent the probability and severity of bus accidents. Reported in Nævestad et al (2025), with main results presented in chapter 4.1 and chapter 5 in this report.
2) **Data collection** and analysis of bus accidents in various countries. Reported in Høye et al (2025), with main results presented in chapter 3 in this report.
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 chapter 3 and section 4.3 in this report.
4) **Technical study** of collision protection for bus drivers, and development of a new model for collision protection. Reported in Laso and Nævestad (2025), with main results presented in section 5.2 in this report. We refer to is as a model, although it is a description of new solution trends for structural improvements in collision protection, that bus manufacturer can adapt to their own buses.
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 chapter 8 in this report.

2 Methods

2.1 Bus accidents in European countries

For bus accidents in European countries, we have several data sources available. The CARE database covers bus crashes in 32 EU-countries, which ensures wide representation, and a sufficient number of cases to enable informative analyses. Information (variables) is adapted such that the same variables and values are used for all countries. We have also data on accidents involving buses from Norway, France and the Netherlands. Results from these data are presented in Høye et al (2024). The advantage with these country-specific data is that it contains more information than the CARE database. Therefore, these data are suited for some of the analyses which cannot be done with the CARE data.

In addition to general descriptive statistics for bus accidents and involved road users, the analyses focus largely on **injury risk**, here defined as the percentage of accident involved road users who are injured, and **injury severity**, here defined as the share of injured road users who are killed or severely injured (KSI).

2.1.1 CARE data and analyses

CARE is a database on road accidents resulting in death or injury in the European Union. It is based on the member countries' own systems for collecting information about traffic accidents and injuries; Data on individual accidents are collected by the member states[2], and the European Commission provides a system for generating comparable data (similar variables and comparable categories) from these national data. The CARE database but it contains no information on crashes that do not lead to injury. The purpose of the database is to quantify road safety problems, and to evaluate road safety measures on EU roads[3][4].

In the current report, we use CARE data on accidents involving buses and/or coaches in the period 2013-2023. For the definition of buses and coaches, se appendix E1.2. Our aim was to include only "large" buses and coaches (more than 16 passenger seats). Hover, due to data limitations, some smaller buses and minibuses may be included. The data have been prepared and provided by George Yannis at the National Technical University of Athens, Greece.

The analyses conducted are for two main purposes. First, to describe the road safety problem of accidents involving buses in the European Union, i.e. the numbers of accidents and injuries, and differences between road user groups, countries and over time. Second, to investigate how crash characteristics are related to injury risk and injury severity among bus drivers and others involved in bus accidents.

As the CARE database is based on 32 countries' statistics over many years, there are some limitations to the possibilities for analyses and comparisons. For instance, if countries differ in how they report injury severity (which is a common problem), a comparison of injury severity between countries will

---

[2] https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/statistics-and-analysis-archive/about-care_en

[3] https://road-safety.transport.ec.europa.eu/document/download/d5161893-a6d2-47f5-8ea1-42bc76f662e3_en?filename=cadas_glossary_v_3_7.pdf

[4] https://road-safety.transport.ec.europa.eu/european-road-safety-observatory/statistics-and-analysis-archive/about-care_en

be influenced by reporting differences in addition to any real differences in injury severity. Furthermore, countries sometimes change their reporting- and registration routines in ways that have implications for national accident statistics. These kinds of shifts can limit the degree to which trends over time are informative, especially when comparing countries. For instance, in describing national time series for buses, coaches and heavy goods vehicles, the European Road Safety Observatory (ERSO) excluded some countries due to "*problems of comparability, missing data or a break in the time series*» (ERSO, 2023, p.8).

The data available for the current report is based on 32 countries, and for most of these we have data for the full period 2013-2023. However, for Cyprus and Malta data start from 2015, Slovenia has data from 2016, and Serbia from 2019. For the UK, there is data from 2013 to 2018. The lack of consistent data over time has consequences for the total number of accidents and injuries in the database, especially since there are many injured bus drivers in the UK.

Although these data make it possible to estimate injury risk or injury severity for all countries for which there is data, it is not meaningful to compare these estimates between countries. We may observe differences due to methodological factors, such as differences between countries with respect to reporting routines or in the definitions of degrees of severity; for example, in countries with large proportions of injured bus drivers, uninjured bus drivers may not be included in the data. Additionally, there may be substantial differences between countries such as general differences in road safety or differences between the buses used in different countries. For example, if we compare injury severity among bus drivers in frontal impacts between countries, the results do not tell us anything about differences in bus safety between countries because of possible differences in reporting routines or other methodological factors. However, if we compare the ratio of injury severity in frontal vs. rear impacts, differences between buses in the different countries are likely to have contributed to the results.

This report includes both analyses of bus accidents in all of Europe, based on the CARE database, and analyses of data from specific countries (Norway, France, Netherlands). While the CARE database includes information from these countries, the three national analyses are based on other datasets. This approach allows each dataset to retain more information than the CARE database and preserves the original variable coding from each country, rather than altering it for cross-country comparability, as is done in CARE.

2.2 Norwegian data on fatal accidents

2.2.1 The crash analysis groups (AAG)

As a part of the systematic road safety work, the National Road Administration's crash analysis group (AAG) has since 2005 carried out in-depth analyses of all fatal road traffic crashes in Norway. The purpose of the AAG work in general is to facilitate preventive road safety work through learning, and thus enable the implementation of measures to reduce the risk of crashes or injuries.

Fatal crashes are also investigated by the police, but there are crucial differences in the purpose and content of these investigations. In the AAG-work, causal relationships and injury mechanisms are mapped, but not legal criminal responsibility (Ringen, 2021).

AAG consists of experts in various fields (roads, vehicles, road users, medicine) who jointly investigate the sequence of events and try to determine conditions that may have contributed crash occurrence and severity.

The analysis of each fatal crash is summarized in a report (AAG-reports), and several characteristics, including the main results from the analyses of possible crash factors and injury factors, are also recorded in a database (the AAG-database). Circumstances that may have contributed to the crash

(crash factors) and to the serious outcome (injury factors) are described with a set of codes that cover road users, roads, vehicles, organizational factors, and rescue conditions.

2.2.2 Crash and injury factors

Crash factors are conditions that, according to AAG's assessments, may have contributed to the occurrence of the crash. Injury factors are conditions that may have contributed to the fatal outcome. In the AAG work, crash and injury are referred to as “possible contributing factors”, as there is often some uncertainty linked to the sequence of events, causal chains and injury mechanisms.

One source of uncertainty is that the available information sometimes is limited or uncertain. For instance, the AAG cannot interview witnesses or involved road users, but rely on information from the police. Another example is that it may be unknown if a fatally injured driver fell asleep or not. For the sake of simplicity, the possible contributing factors are referred to as contributing factors in this report.

Circumstances that were present, regardless of whether or not they may have contributed to the crash or the outcome, , are registered as “fact information”, not as contributing crash factors. For example, it is registered for all drivers whether or not they used a seat belt (as far as information is available). Among unbelted drivers, the lack of seat belt use is registered as a contributing factor only if the AAG’s assessments indicate that the person might have survived with a seat belt. The number of traffic fatalities with people who have not used seat belts is therefore higher than the number attributed to seat belt use as an injury factor.

The contributing factors can refer to the road user (e.g., driver speeding or non-use of seat belt), the vehicle (e.g. technical state of vehicle), or the road or road environment (e.g. slippery road surface, dangerous side terrain).

Based on these in-depth crash data, we have conducted two analyses. First, based on the in-depth reports about selected bus crashes, we conducted a content analysis to gain a deeper understanding and more context about how the buses contributed to fatal and serious injuries. This is described in the next section.

Second, we analyzed contributing factors in all fatal bus accidents, and compared their distribution between bus drivers and other road users.

2.2.3 Injury mechanisms in in-depth reports

To assess how characteristics of the bus may have contributed to fatal or serious injuries among bus drivers, passengers, or other road users, AAG-reports were retrieved for accidents where: i) the driver was killed or seriously injured, and the impact point was at the front, ii) passengers were killed or seriously injured, or iii) crashworthiness /critical point of impact was coded as a contributing factor by the AAG. All reports are about fatal crashes, i.e. if a bus driver was seriously injured, at least one other person was killed in the crash. We included serious injuries among bus drivers and passengers to get a larger sample.

To identify factors related to the bus that contributed to serious injuries or fatalities, we conducted a thematic content analysis. We reviewed all reports to determine whether any characteristics of the bus were identified as contributing to the death or serious injury of the driver, passengers, or other road users. Reports of accidents where bus-related factors were not identified as directly or indirectly contributing to severe injury or death, were excluded (eight reports in total). This left 16 reports in the analysis.

The selected reports were then read and coded. The structure of the reports varied considerably, both in terms of the factors described, terminology, and the level of detail in the analyses. In some reports, factors were listed without further explanation, while others provided detailed descriptions.

A few reports included an assessment of how likely it was that the identified factors contributed to the severity of injuries, but many did not include such evaluations.

2.3 Assessment of the Benefits and Costs

The cost benefit analyses consist of seven steps.

The first step is to estimate injury risk to bus drivers. The benefits in monetary terms of measures improving the crashworthiness of buses depend on the injury risk (likelihood of injury from crash relative to distance driven) of bus drivers. The higher the injury risk, the higher the cost of the injuries given the transport volume carried out. The higher the cost of the injuries, the more can be spent on improving crashworthiness before the costs of improvements become greater than the benefits. To obtain estimates of injury risk that can be regarded as representative for Europe, statistics on the number of killed or injured bus drivers reported in CARE have been combined with estimates of million kilometres driven by buses. For most countries included, the data refer to 2013-2022. The countries included are Belgium, Bulgaria, Croatia, Estonia (fatality risk only), France (fatality risk only), Germany, Italy (fatality risk only), Netherlands, Norway, Poland, Portugal, Sweden, and Switzerland. For the period covered by the data, there were 128 bus driver fatalities, 830 seriously injured bus drivers, and 6 746 slightly injured bus drivers in these countries.

The second step is to estimate monetary valuation of injuries. The Handbook on the external costs of Transport (van Essen et al. 2019) is used to assign monetary values to the injuries. According to the Handbook, the following values were recommended for the EU-28 (the current members plus the United Kingdom) in 2016-prices:

- 1 fatal injury: 3,273,909 €
- 1 serious injury (very serious and serious combined): 498,591 €
- 1 slight injury: 38,514 €
  To update these estimates to 2023-values, the index for real incomes (i.e. incomes in fixed prices) reported by Eurostat has been applied. The updated estimates are:
- 1 fatal injury: 3,921,557 €
- 1 serious injury (very serious and serious combined): 597,223 €
- 1 slight injury: 46,133 €

The third step is to estimate expected costs of injuries per bus. Applying the monetary valuations above and the mean estimates of risk, the total annual societal cost of injuries to bus drivers per bus kilometre can be calculated.

The fourth step is to include the costs of measures improving crashworthiness.

The fifth step is to include effects of measures improving crashworthiness. An important problem in performing a cost-benefit analysis of improved crashworthiness for buses, is that the effects of the measures intended to improve crashworthiness are unknown, as none of the measures have been (widely) implemented. Only their potential effects are known to some extent, for example as results of crash tests.

The sixth step is to assess the impact points influenced by the suggested measures to improve crashworthiness. Based on that, **the share of injuries to bus drivers that these impact points account for, can be assessed.**

The final step is to compare benefits and costs of safety systems based on the information from the preceding steps.

3 Overview of bus accidents in Europe

The focus of this chapter is the first aim of the study, which is to provide an overview of bus accidents in various European countries.

3.1 Overview of bus accidents and injuries over time

For the full period of 2013-2022, the CARE database contains information on 216 bus driver fatalities and 1 243 serious injuries among bus drivers. In addition, 876 bus passengers and 4 775 other road users were killed in these crashes. The total number of seriously injured in accidents involving buses is uncertain due to some countries not reporting injury severity but is at least 39 174 in the studied period.

Table 3.1 displays the number of injured, seriously injured and fatalities in the CARE database over time. The substantial drop in injured and seriously injured after 2018 is, is related to the UK not being included in the database in the two last time periods. Due to the change over time in the countries that are included in the CARE database, the total numbers of injuries included in this table does not give an accurate impression of how the number of injuries or fatalities have changed over time in Europe.

Table 3.1: Numbers of injuries in bus accidents by road user group, severity, and time period in the CARE database.

Road user group	Injury severity*	2013-2014	2015-2016	2017-2018	2019-2020	2021-2022	All years
Bus drivers	All injured	3 911	3 802	3 778	2 688	2 886	17 065
	Seriously injured	266	290	307	192	193	1 248
	Fatal	49	48	41	36	42	216
Bus passengers	All injured	39 570	39 710	40 784	27 997	27 376	175 437
	Seriously injured	2 924	2 822	3 004	2 087	1 935	12 772
	Fatal	214	178	187	134	163	876
Other road users in bus accidents	All injured	36 163	34 740	33 222	21 889	20 774	146 788
	Seriously injured	4 628	4 856	4 504	2 841	2 458	19 287
	Fatal	1 152	1 100	1 090	773	660	4 775

*Note: *Counts of "seriously injured" are based only on the countries that report injury severity (Estonia, France, Finland and Italy do not). The real number of seriously injured is therefore higher, and these numbers cannot be used to estimate the share of killed or severely injured.*

Figure 3.1 displays the number of bus drivers in the CARE database, for all countries. The figure illustrates clearly why the interpretation of trends over time is not straightforward with this material. The drop from 2018 to 2019 is due to the UK only being included up until 2018. The increase from 2020 to later years cannot be explained with additional countries joining the database. However, in some countries, there were quite large increases in the numbers of injured bus drivers in these years (Germany, Italy, Poland, Spain). This may be a real increase related to a drop in accidents (and driving) during the Covid-years, especially in 2020.

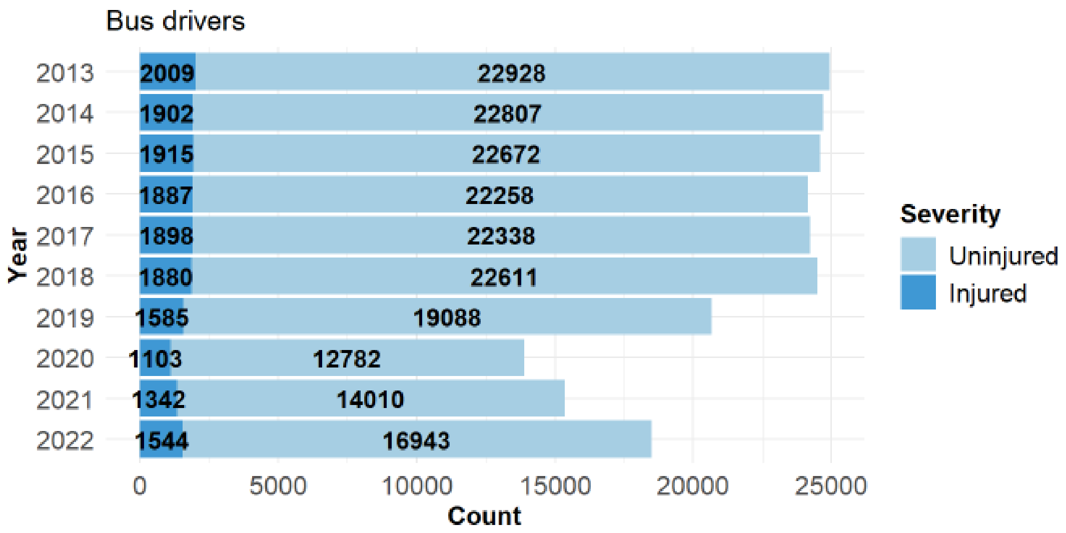


Figure 3.1: Bus drivers registered in the CARE database.

Many groups of road users are injured in crashes involving buses in European countries. Overall, bus passengers make up 52% of those injured in bus crashes, and light vehicle occupants make up 21% (Figure 3.2). We also see that bus passengers make up a smaller share of the killed or severely injured (KSI) than of all injured, while the opposite is true for pedestrians. This indicates that bus passengers' injuries more often are slight, and that pedestrian injuries more often are severe when involved in bus crashes.

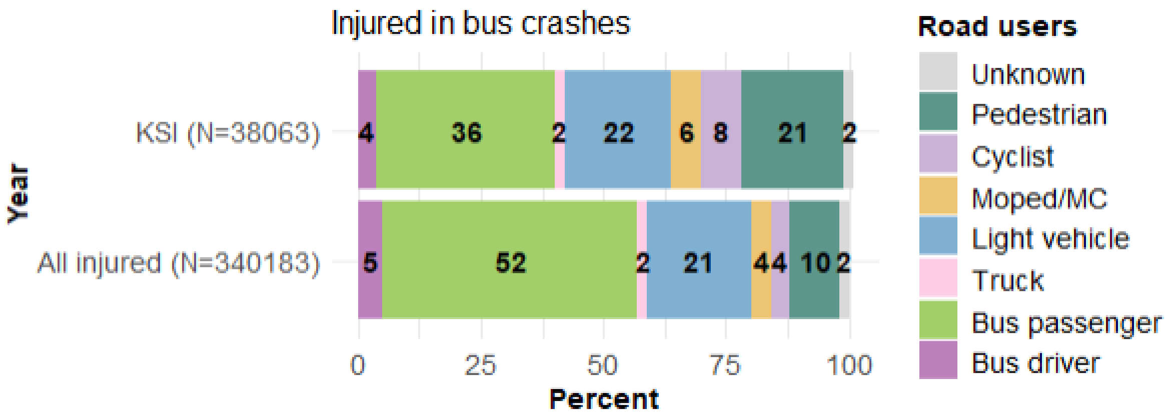


Figure 3.2: Injuries in crashes involving buses, by road user group. Note that not all countries report whether an injury was serious, so the real number of severely injured or killed will be higher than what is shown in the figure.

Based on the countries where a distinction between slight and severe injuries is made, Figure 3.3 displays injury severity for different road user groups involved in bus crashes. We see, as indicated above, that pedestrian injuries are the most severe, while those of bus occupants (drivers, passengers) are less likely to be severe. This comparatively low severity of injuries for bus occupants is related to accident types; bus occupants are rarely injured when a bus is involved in a pedestrian accident, which is a relatively common type of accident.

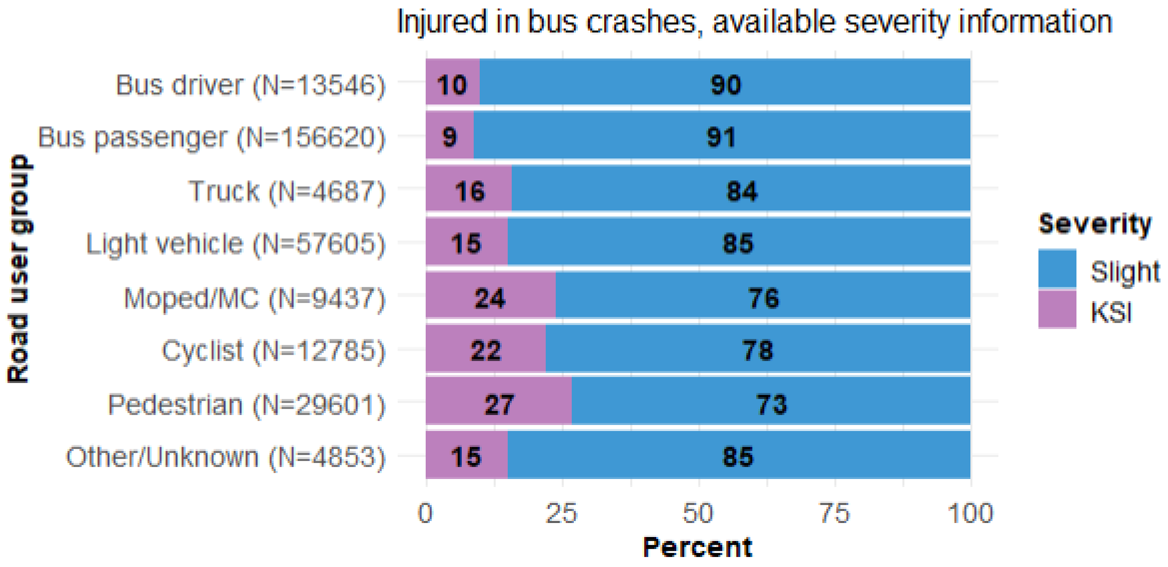


Figure 3.3: Overview of injury severity in CARE database. Based on countries for which injury severity information is available.

3.1.1 Bus drivers' injuries

For bus drivers, injury risk (percent of accident involved drivers who are injured) is between 3 and 21 percent among all bus drivers (average: 8 percent). Thus, in most injury accidents where bus drivers are involved, other road users are injured. Injury severity (percent killed or severely injured when involved in an injury accident) is between 5 and 60 percent KSI among injured bus drivers (average: 10 percent). Possible explanations for the large variation in injury risk and severity between countries are:

- Methodological factors, such as differences between countries with respect to reporting routines or in the definitions of degrees of severity; for example, in countries with large proportions of injured bus drivers, uninjured bus drivers may not systematically be included in the data.
- Substantial differences between countries, such as general differences in road safety or differences between the buses used in different countries.

In either case, an important implication of this is that it is not meaningful to compare bus driver safety between countries; we have no way of separating the effects of different sources of variation.

For example, if we compare injury severity among bus drivers in frontal impacts between countries, the results do not tell us anything about differences in bus safety between countries because of possible differences in reporting routines or other methodological factors. However, if we compare the ratio of injury severity in frontal vs. rear impacts, differences between buses in the different countries are likely to have contributed to the results.

Table 3.2 shows the total numbers of bus drivers, injured bus drivers and KSI bus drivers, as well as the percentages of injured (among all), and KSI (among injured) bus drivers. The numbers refer to all available years for each country. This means that, because not all countries are included for the same number of years, the numbers cannot be directly compared between countries (although the percentages of injured and KSI can). Some countries (marked with "-" in columns for KSI and Pct KSI in Table 3.2) have not reported degrees of severity. For these countries, only information about injury risk is available.

Table 3.2: Number of bus drivers, injured bus drivers and killed and severely injured (KSI) bus drivers by country in the CARE database.

Country	All bus drivers	Injured	Pct injured	KSI	Pct KSI
Austria	7 872	363	5	38	10
Belgium	6 311	706	11	37	5
Bulgaria	2 298	135	6	39	29
Croatia	1 600	141	9	19	13
Cyprus	44	9	20	2	22
Czechia	7 243	325	4	33	10
Denmark	553	32	6	17	53
Estonia	866	124	14	-	-
Finland	929	102	11	-	-
France	8 358	1 000	12	-	-
Germany	55 929	5 048	9	486	10
Greece	2 353	151	6	9	6
Hungary	4 425	264	6	70	27
Iceland	182	23	13	5	22
Ireland	877	154	18	15	10
Italy	22 979	2 293	10	-	-
Latvia	1 663	61	4	10	16
Lithuania	1 539	44	3	5	11
Luxembourg	285	59	21	6	10
Malta	276	36	13	1	3
Netherlands	1 508	72	5	43	60
Norway	928	141	15	16	11
Poland	10 578	547	5	143	26
Portugal	4 265	350	8	19	5
Romania	8 818	417	5	104	25
Serbia	2 541	153	6	16	10
Slovakia	879	83	9	9	11
Slovenia	779	50	6	6	12
Spain	20 403	1 266	6	68	5
Sweden	3 183	441	14	47	11
Switzerland	2 016	141	7	17	12
UK	33 022	2 334	7	129	6
Total	**215 502**	**17 065**	**8**	**1 409**	**10**

3.1.2 Where do the accidents occur?

When we look at all accidents jointly, most occur in urban areas (85 %, Figure 3.4). However, for bus drivers who are injured, or who are killed or severely injured, rural areas make up a far larger share of accident sites. This is likely related to speed at the time of the accidents; the speed is probably higher on rural roads than in urban areas, and accidents at higher speeds are on average more serious.

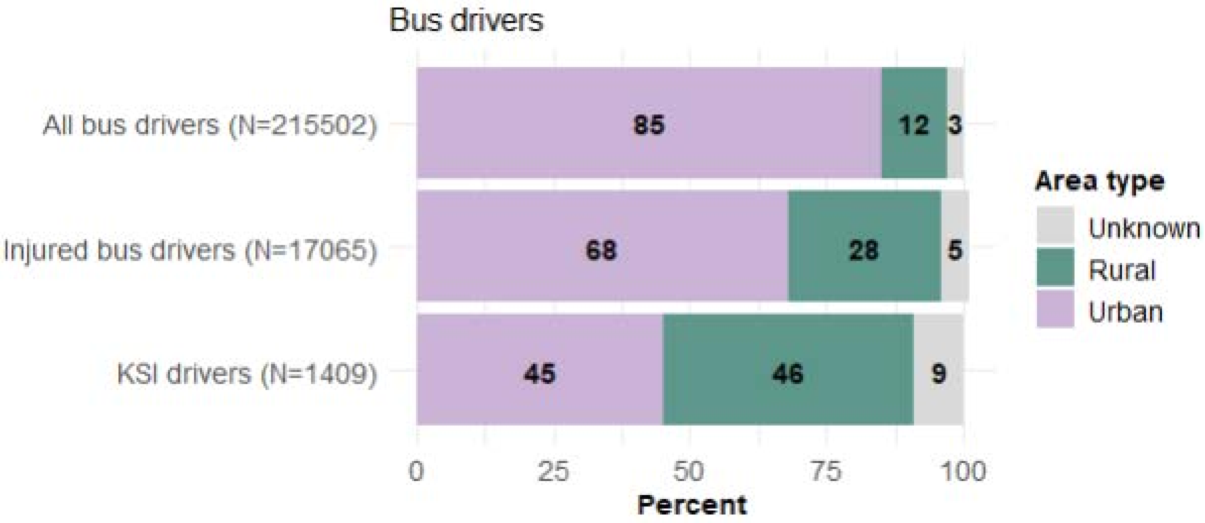


Figure 3.4: Area type of accidents by bus drivers' injury severity. CARE database.

Figure 3.5 shows the different types of intersections in which bus crashes (at intersections) occur. Regardless of the degree of injury, most accidents do not occur at an intersection (but rather at "midblock", Figure 3.5). However, the share of non-intersection accidents is far larger in accidents where the bus driver is severely or fatally injured. This indicates that accidents at junctions are typically less severe for bus drivers, while midblock accidents are more likely to be severe. This could be related to speed or typical collision partners in accidents.

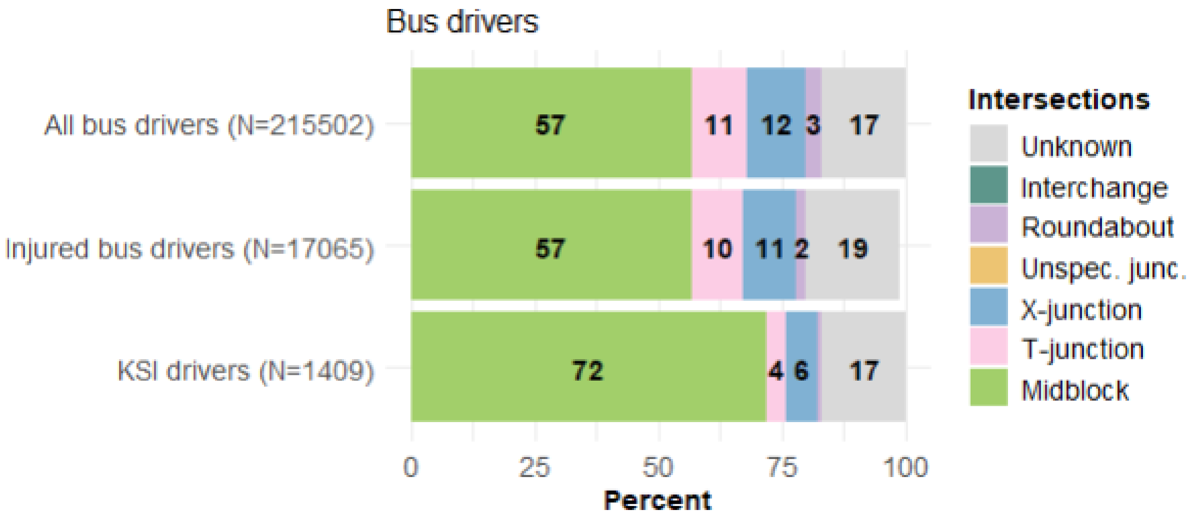


Figure 3.5: Intersection type for accidents by bus drivers' injury severity, CARE database.

3.1.3 Crash types and collision partners

The distribution of different crash types available in the CARE database varies greatly between countries. For instance, the share of intersecting accidents varies from 0 to 86 percent of all crashes, indicating that some of the variation in crash types is likely due to differences in the definition of crash types between countries. We have grouped the available information on accident types into seven crash types, as displayed in Figure 3.6. It should be noted, however, that "Other MV (multi vehicle) crashes" in some countries include head-on and/or intersecting crashes.

Most other road users who are involved in bus accidents are light vehicles. Depending on the accident type, light vehicles make up between 63 and 75 percent of collision partners (Figure 3.6). As our CARE dataset does not link the different parties to the same accident, collision partners were in part inferred based on common crash and crash site characteristics. The method by which this was done is described in more detail in Exhibit 1.

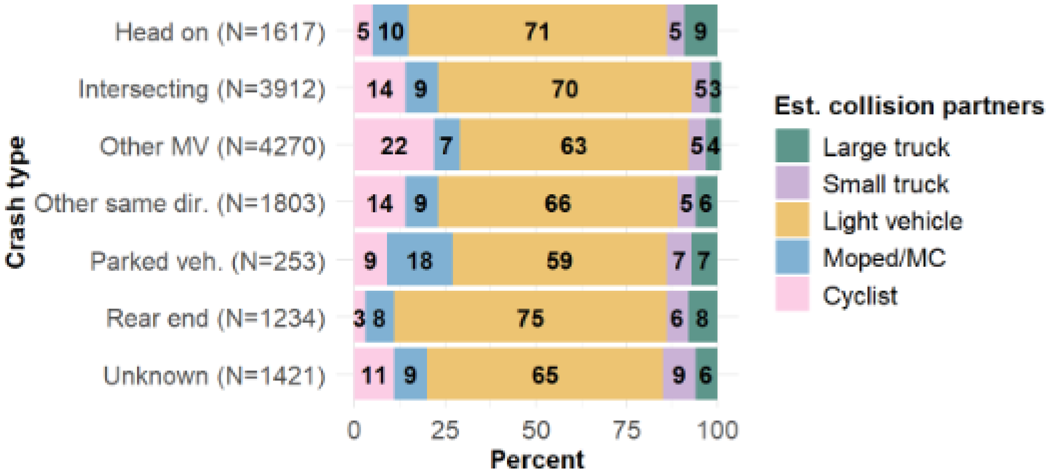


Figure 3.6: Distribution of collision partners in multi-vehicle bus crashes. CARE database 2013-2022.

3.2 Relevance of impact point

For the bus driver, we can generally assume that accidents where the impact point is closer to the bus driver are the most severe ones. In some countries, accident statistics include information on impact points, either in rough categories (e.g. front, rear, side), or more detailed (e.g. front right, front centre, front left etc.). In earlier crash tests with cars, the focus was mainly on "full overlap" impacts, where the entire front of the vehicle collides with an object. However, it was later discovered that a "small overlap" impact on the driver's side are the most critical type of collision, with the highest potential for severe injuries. This is because the point of impact is closer to the driver, and it is more challenging to design a vehicle that can effectively protect the driver in situations where the crash energy is not distributed across the whole front of the bus. As a result, the difference in injury severity between front-centre and front-left impacts can be used as a measure of collision safety.

The relevance of impact point for driver safety is strongly related to collision energy; for bus collisions with pedestrians and cyclists, the impact point on the bus is unlikely to influence bus drivers' risk of injury or high severity. Impact point is most important for driver injury severity in collisions with other heavy vehicles, but to some extent also for collisions with cars and other light vehicles, and possibly collisions with tall objects.

Results for detailed impact points are displayed in Figure 3.7 (bus driver injury risk) and in Figure 3.8 (bus driver injury severity). The figures show that the front left and side left impact points are associated with a higher risk of injury and more serious injuries than other impact points.

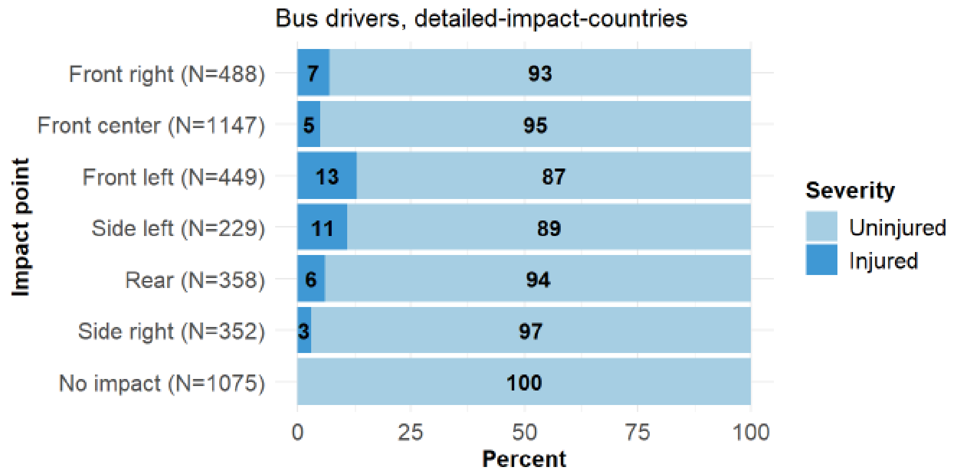


Figure 3.7: Injury risk for bus drivers by impact point in head-on collisions. Results from 3 European countries with detailed impact points, CARE database.

Figure 3.8 illustrates that for injured bus drivers, front centre and front left impact points are associated with more severe injuries.

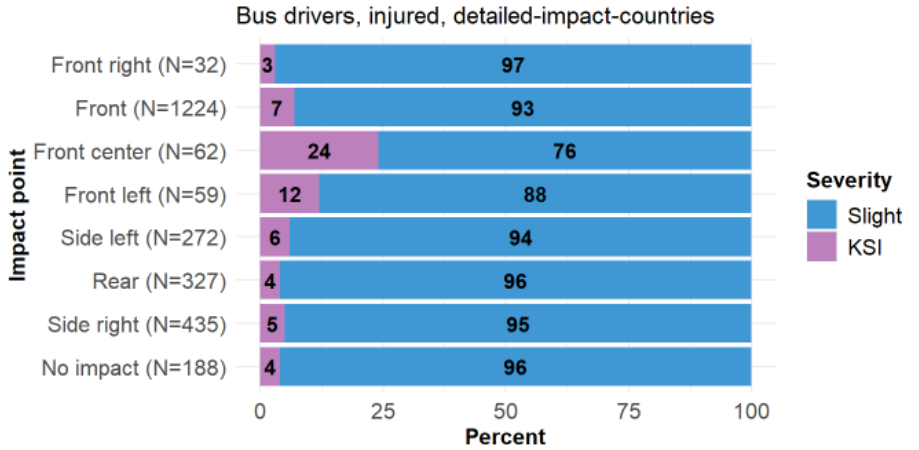


Figure 3.8: Severity risk for bus drivers by impact point in head-on collisions. Results from 3 European countries. CARE database.

In the Norwegian data, the number of injuries is too low to make informative inferences based on multivariate models for this topic. For the French data, however, we can compare impact points when controlling statistically for other potentially confounding crash characteristics.

First, when compared to (any) frontal impact points, rear impact, no impact and side right impacts have lower injury risk, and lower risk of severe outcomes in multivariate models (see Table 3.3). For instance, the odds of injury in rear impact crashes are about half (OR=0.52) of those in frontal impacts. The results displayed in the table are, however, only statistically significant for injury risk. We also see that impact points at the side left do not differ significantly from frontal impact in terms of injury risk.

Table 3.3: Relevance of impact point for injury risk and injury severity for city bus drivers in France. Results from multivariate analyses, controlling for multiple crash characteristics.

	Injury risk			Severity		
Impact point	**β**	**p**	**OR**	**β**	**p**	**OR**
No impact	-1.036	<.001	0.35	-0.967	0.127	0.38
Front (any)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Side left	-0.213	0.150	0.81	-0.004	0.992	1
Rear	-0.65	<.001	0.52	-0.331	0.340	0.72
Side right	-0.753	<.001	0.47	-0.041	0.924	0.96

Second, when comparing more detailed frontal impact points among crashes with frontal impact, we find that front right impacts have lower injury risk, and lower risk of serious injuries, than front centre impacts (Figure 3.9). For front left impacts, the coefficient for injury severity is above 0, indicating that the risk of injuries being severe or fatal is higher in accidents with front left impacts than with front centre impacts, although this result is not statistically significant.

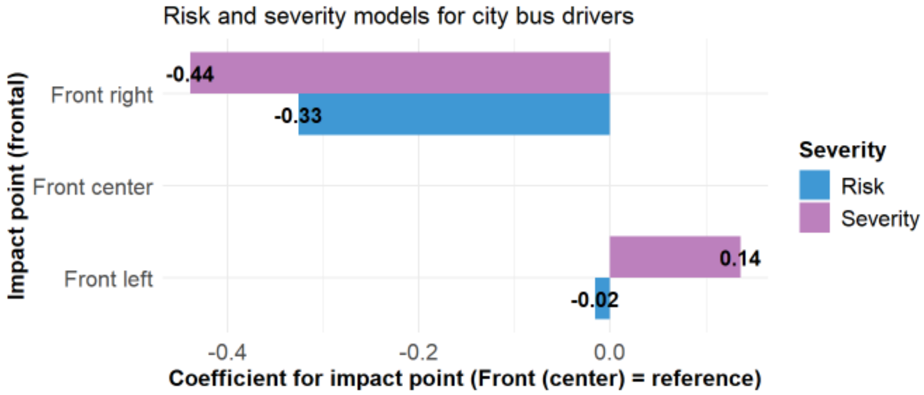


Figure 3.9: Impact point relevance for injury risk and injury severity, based on multivariate models for French city bus drivers involved in accidents.

Overall, in the CARE data, there is information on impact points from 6 countries[5]. Table 3.4 shows how impact points are related to injury severity for bus drivers. In total, based on these countries, 65 % of killed or severely injured bus drivers were in a crash with frontal impact.

Table 3.4: Impact point by injury severity for bus drivers in CARE data, countries with impact information.

Severity	Front	Other	Unknown	Sum	Percent front	Percent other	Percent unknown
Any injury	689	172	38	899	77	19	4
Slight injury	1 264	1 166	6	2 436	52	48	0
KSI	113	56	4	173	65	32	2
All injuries	2 066	1 394	48	3 508	59	40	1

It is not known whether the impact points from the countries that report these are representative of impact points in all EU countries.

---

[5] Denmark, France, Lithuania, Luxemburg, Serbia and the UK.

4 Deficiencies in current bus front designs

The focus of this chapter is the second aim of the study, which is to describe deficiencies in current bus front designs.

4.1 Deficiencies based on peer reviewed studies[6]

When large vehicles crash with smaller vehicles, crashes are generally less severe for the large vehicles, as the height position of 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, large vehicles with greater mass can 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 the 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).

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. For large buses, crashworthiness improved up to the 1980-89 decade. After that, it has deteriorated and was worse for buses of model years 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).

---

[6] These are presented in more detail in Nævestad et al (2025).

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.

4.1.1 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 UN R29.03 is insufficient for protecting the driver in a frontal crash, or that current designs do not fulfil R29.03 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 R29.03 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 the aforementioned UN R29.03 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[7] 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 UN R29.03 regulation is lower than NHTSA's NCAP with 55 kJ and 142 kJ respectively. They find that in the deformation observed from the R29.03 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

---

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

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 R29.03. This indicates that the NCAP test requirements are better for bus driver safety than R29.03.

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 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 29.03, 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 UN R29.03 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. To evaluate this, three clearance distances were defined. Before the impact, c_1 was 176 mm, c_2 was 175 mm and c_3 160 mm.

4.2 Deficiencies based on NSIA reports

In the following, we provide a background to the issue of bus driver collision protection in Norway and Europe, based on investigation reports issued by the NSIA. The content is based on three key reports, cited below, and interviews with key stakeholders in the field of bus transport and bus safety. This provides a general background to the issue of collision safety for bus drivers in Norway and Europe.

In recent years, the Norwegian Safety Investigation Authority (now NSIA, previously AIDN) has issued three reports on accidents with head-on collisions between buses, i.e. in Nafstad 2017, Tangen 2021 and Fredrikstad 2022 (AIBN 2019; 2022; 2023). All three accidents resulted in fatalities, and the accidents all raised questions about weaknesses in the collision safety of current bus designs, and insufficiencies in regulatory requirements for the crashworthiness of buses. As a result, the NSIA issued several safety recommendations and is currently working on a theme report on the topic.

4.2.1 Three fatal accidents

In November 2017, two scheduled buses in opposite directions collided at the exit of the curve at the bottom of the Nafstad slope, on county road 450 (Fv. 450) in Ullensaker municipality. Both buses had a speed of approx. 33–34 km/h at the time of the collision, and the front of both buses penetrated about a meter into each other in the collision. The driver of one bus was killed instantly, and the driver of the other bus was critically injured as a result of the collision[8].

In March 2021, two identical buses in regular service collided in a curve on county road 222 (Fv. 222) near Tangen in Stange municipality. At the entrance of the curve, one of the buses had a speed of approx. 54-57 km/h, whilst the other bus had a speed of approx. 36-37 km/h. Here too, parts of the buses penetrated each other, and one of the drivers died[9].

In December 2022, two identical buses collided head-on on national highway 110 (Rv 110) at the Fredrikstad bridge. Even though the buses collided at low speed (approx. 32 km/h and 35 km/h respectively), the accident resulted in one driver being killed and one driver being critically injured. The two passengers in one bus obtained minor injuries[10].

Although head-on collisions where a bus is one of the involved vehicles, only account for 2-3 % of all road traffic fatalities in Norway, the accidents mentioned above, together with earlier accidents (e.g., at Fardal, in August 2013[11]), raise particular concerns. This is because the collisions resulted both in fatalities and extensive material damage, despite the relatively moderate speeds and the small overlap on the left-hand side of the buses. Additionally, the buses' construction and crashworthiness characteristics were all deemed to have played a role, and the NSIA considers that the lack of a shock-resistant structure on the front left-hand side of the buses represents a general technical challenge across several bus manufacturers – deemed critical for the safety of bus drivers in head-on bus collisions with small overlap.

4.2.2 Crashworthiness concerns and weaknesses in buses' structural design

The accidents mentioned above have increased concerns about the crashworthiness of buses and about the weaknesses in their structural design. The NSIA has repeatedly pointed out that the design, with a lack of impact-absorbing construction on the left front of buses, represents a general technical challenge for several bus manufacturers. NSIA deems this weakness critical for the safety of bus drivers in front collisions with minimal overlap and believes that bus drivers - as employees - should be better protected. In this regard, the NSIA believes that improved crashworthiness for buses could reduce the severity of accidents and has both pointed to a need for enhanced crash protection for drivers of ordinary buses in regular service, and improved crash protection for buses more generally.

Particular concerns have been raised with regard to the construction of the driver's area and the left front part of buses, which the NSIA regards as a combination of unfortunate design elements. These design elements and implications include:

- The lack of shock-absorbent or shock-resistant structures and front underrun protection.
- Limitations in the safety and protection of the driver's cabin (including implications for survival space, and the potential for vehicle parts to penetrate into the driver's cab, such as the A-pillar of one of the buses in the Tangen accident, with pillars being torn off because joints proved too weak to withstand the stresses of relatively low-speed collisions).

---

[8] AIBN (now: NSIA) report Road 2019/04

[9] NSIA report Road 2022/02

[10] NSIA report Road 2023/05

[11] See NSIA report Road 2014/03. This accident involved two buses, driving at 62 and 32 km/h respectively, and colliding with an overlap of 15-20 cm. The accident resulted in the deaths of two passengers and injuries to several others – in addition to major bodywork damage.

- The design of the front left side of buses
    - In its Fredrikstad report, the NSIA points out three design elements of the front left part:
        - the side panel (with a vertical A-pillar and a wall frame of a robust design, with the A-pillar connected to the 'superstructure' of the buses and designs meeting minimum requirements for rollover and impact tests to prevent collapse)
        - the space inside the service hatch, in which there was no shock-absorbent or shock-resistant structure except the outer part of the left front plate (on some buses, this space is designed as a 'service space', while on other buses, it can be designed to house the battery/fuses)
        - the left outer part of the front plate (which collapsed on both buses involved in the Fredrikstad accident, and with the whole left side panel bending outwards, which NSIA believes played a decisive role for the side panel penetration, leading to the death of one driver and penetrating the other bus, but missing the driver)
- Less solid superstructures or chassis than for trucks (as buses are built on smaller and lighter structures, whilst trucks are based on large self-containing structures)
- Construction of drivers' cabs on buses outside of the load-bearing chassis
    - Cabs with a front door for boarding are to be considered a module of the bus, assembled from components including A- and B-pillars, torpedo wall, roof structure and battery box.

It is further pointed out that for buses, it is neither common nor required to have airbags installed. Compared to trucks, NSIA further points to a different position of the driver (i.e. lower), and a differently placed frontal axle (40-50 cm from the front end in trucks and about 200 cm from the front end in buses). Although of little relevance to the outcome of collisions, the NSIA finally observes that storage units (tachographs, video storage units) in buses are often fitted internally on the front left.

4.2.3 Regulation and weaknesses/insufficiencies

Generally, regulations relating to the crashworthiness of buses are part of EU regulations. This means that Norway is obliged to accept buses that are approved based on the common European requirements, pursuant to the EEA agreement.

The NSIA points out that regulations require A-pillars and side walls in buses to be designed to withstand a rollover test, but that there are no regulatory requirements for the construction of the A-pillar and side wall beyond this[12]. I.e. no requirements to withstand frontal impacts to protect the driver (the exception is UN R29.03, which Norway adopted as of 01.10.2023).

Current regulations do not address the crashworthiness of buses in the same way as for passenger cars or heavy goods vehicles. For buses, the NSIA for example points out that there are no requirements for side collision safety, passenger protection in the event of a side collision, the presence of underrun protection at the front, or the strength of the driver's cabin, as is required for various types of trucks. While both passenger cars and trucks are required to have occupant protection in the event of frontal collisions, this safety solution is optional for buses. The NSIA also notes that no structural changes have been made to UNECE regulations that have improved crash protection in buses' drivers' cabs.

As mentioned, new Norwegian requirements for head-on collision protection in new buses came into force on 01.10.2023, through regulations relating to universal design of motor vehicles used for

---

[12] In connection with the Tangen accident, reference is for example made to the busses being subject to regulation no. 918 of October 1994, where Annex 1 lists requirements, which, for busses, refer to a rollover test.

licensed transport etc. Class I, II and III buses that are covered by these regulations and registered for the first time in Norway from October 1st, 2023, shall meet the requirements for frontal protection described in UN R29.03. This regulation requires that the construction passes a test where a metal plate weighing 1 500 kg, attached to a pendular arm, strikes the front of a bus at around 30 km/h (55 kJ).

The NSIA notes, however, that given the observed weaknesses on buses' front left sides, fragilities are not necessarily uncovered in this frontal impact test when this is based on a flat impact against the front of the bus. It is noted that when new buses are registered in Norway pursuant to these new requirements, different manufacturers will take different approaches to comply with the minimum requirements in the test. As such, the NSIA is unaware of whether the technical solutions chosen only satisfy the frontal impact test or whether they can also address the weaknesses their investigations have revealed.

4.2.4 Safety recommendations, potential improvement areas and balancing considerations

Generally, the NSIA issued a number of safety recommendations in the mentioned 2014, 2019, 2022 and 2023 reports, several of which concerned improving the crashworthiness of buses by strengthening tender descriptions, product improvement, and making national and international regulations more stringent. Some of these recommendations have been followed up, whilst others have been closed, amongst others due to insufficient interest in UNECE GRSP after Norway, also in collaboration with other countries, attempted to raise the issues in several rounds (see e.g. the table overview on pp. 42-43 of NSIA's report Road 2022-02). Even though the NSIA considers the work done by the Norwegian Public Roads Administration and Ministry of Transport to be very positive regarding national legislation, it points out that further work on crashworthiness improvements needs to be done internationally. Also, employees' trade unions in several countries have demanded that buses must be made more crashworthy.

Among concrete examples, the NSIA believes that buses need a construction in front which rejects and absorbs impacts – and identifies that the same need for compatibility regarding front and rear underrun protection on heavy vehicles (UN R93.00) should apply for buses. The same applies to requiring R29.03 (front beam) for buses, i.e. the requirement that was introduced for permit-required transport from October 2023, and which currently applies. Both solutions are adapted from trucks, and the NSIA sees no obstacles preventing authorities from introducing underrun protection requirements for buses through universal design regulations—similar to how seat belt requirements were introduced for class II buses. The NSIA has also recommended that the Norwegian Public Roads Administration consider using national regulations to improve the crashworthiness of buses used in permit transport in Norway.

At the same time, the NSIA recognizes that there are several differences between trucks and buses, which affect the extent to which truck requirements applied to buses will provide sufficient protection, and whether there is a need for additional measures. For example, there are differences between trucks and buses with regard to driver cabin safety. For buses, the driver cabin is for example not considered a separate unit, and it is not designed as such.

Further, trucks are based on large self-containing structures, and the superstructure or chassis of trucks is more solid than for buses, which are built on smaller and lighter structures. As such, trucks structures probably provide a more solid base for frontal protection devices such as front beams (R29.03) and underrun protection (R93.00) than can be achieved on buses.

It can also be pointed out that the frontal axle is placed differently on trucks and buses, meaning that buses yield more room (e.g. 200 cm) before one "hits something hard" in a collision, than trucks (e.g. 40-50 cm). This also has implications for safety measures. Further, buses lack a drivers' door on the front left side. In collisions, the front left side therefore works as a “hinge” from the point of the frontal axle, despite this structure being designed to work optimally to prevent collapse in case of rollovers.

Among other relevant issues that can be discussed are: (i) whether drivers should be placed differently inside the bus and (ii) that the transition to electric buses might have positive safety implications since they can be assumed to come with stronger structures.

4.2.5 Non-regulatory developments

Both bus purchasers (including authorities with tenders on public transport services), and bus manufacturers have the opportunity to implement standards and requirements that exceed minimum legal requirements.

The NSIA points out that there are no obstacles for setting more stringent requirements in tenders, and that authorities, as such, are free to set stricter requirements for ensuring collision safety in buses than the minimum requirements that follow from vehicle regulations. The NSIA also points to examples in the different accidents, where collision safety was hardly mentioned in tender requirements, other than minimum regulatory standards.

In their reports, the NSIA also issued recommendations to individual bus manufacturers and notes that even though there are no international crashworthiness requirements, several manufacturers have taken steps to go further than the regulatory requirements.

Starting in 2020, the largest public transport authority in Norway, Ruter (covering Oslo and Akershus county) required that new buses comply with the R29.03 Standard in the new “Oslo South Tenders”:

> *All buses must be equipped with driver collision protection that meets the requirements of UNECE Regulation 29 (UNECE-R29). Operators must document that any alternative collision protection provides equivalent safety to UNECE-R29.*[13]

As of 2020, four bus suppliers were reportedly capable of meeting these standards.[14]

UNECE, the United Nations Economic Commission for Europe, is a standardization body with 56 member states from Europe, North America, and Asia. It was established after World War II to facilitate cooperation and create standards for rebuilding Europe. UN R29.03 is a directive focused on frontal collision safety in trucks, requiring front safety testing through a "pendulum impact test." There is no equivalent requirement for buses.

The Norwegian bus driver union, «Yrkestrafikkforbundet» noted in 2020, that several bus manufacturers already had developed unique solutions for buses, complying with the R29.03 standard. The union also observed that some bus manufacturers had implemented solutions to improve driver safety. MAN Truck & Bus, for instance, has equipped all their new Lion's City buses with extended steel-framed fronts as standard, meeting R29.03’s pendulum impact test requirements. Similarly, Daimler has offered an optional comparable solution since 2012, costing approximately EUR 3 000.

In addition to the mandatory safety requirements, Ruter also expressed a desire for further improvements in bus safety in the 2020 Oslo South tender process. This included structural passive safety systems designed to enhance safety for drivers and passengers, such as compliance with UN R93.00 (front underrun protection) and UN R66 (rollover safety). Additional measures include installing electronic stability control (ESC) or similar features, installing seat belts (e.g. two- or three-point belts), in Class 1 buses, and the implementation of blind-spot warning systems. These measures aim

---

[13] Source: https://ytf.no/nyheter/ruter-styrker-forersikkerheten

[14] Source: https://ytf.no/nyheter/ruter-styrker-forersikkerheten

to go beyond basic safety requirements, providing enhanced protection for drivers and passengers, while enhancing overall vehicle functionality.[15]

In NSIA's report 2019/04, a safety recommendation was that Ruter (as tender owner) should review the traffic safety consequences of requirements set in contracts with bus operators. Ruter followed this up by commissioning a report from the Institute of Transport Economics (TØI), analysing the requirements that Ruter sets in their contracts. Amongst other, Nævestad et al (2020) discussed that Ruter's direct influence on traffic safety particularly applies to cases where Ruter sets requirements that surpass the minimum regulatory standards. Ruter later incorporated this in a public transport tender for the (former) Viken county[16]. The TØI report also examines indirect effects of contract design on traffic safety, such as how punctuality and regularity requirements can create pressure on drivers, or how environmental priorities may lead to selecting high-capacity buses to accommodate more passengers. This, in turn, can make buses a more attractive alternative to cars.

4.3 Deficiencies based on reports from accident analysis groups[17]

The Norwegian in-depth data for fatal accidents provides information on the accident and injury mechanisms, as well as information about which party triggered the accident. The studied in-depth data on fatal accidents (2005-2022) includes in total n=91 fatal accidents with n=95 buses, where n=113 individuals were fatally injured, and n= 43 severely injured.

Nine accidents (5%) are single accidents involving only one bus, whereas the remaining ones include at least two parties (of which at least one is a bus). A total of 17 accidents included 3 or more parties. Table 4.1 below shows the number of fatally injured road users per role. We can see that in the buses, 9 drivers and 19 passengers were killed. Drivers of light vehicles make up the largest share of fatally injured road users in these accidents, with 41 fatalities.

Table 4.1: Fatalities per road user group, in n=91 fatal accidents involving buses.

Road user, role	n	Percent
Bus, driver	9	8%
Bus, passenger	19	17%
Pedestrian	22	20%
Light vehicle, driver	41	36%
Light vehicle, passenger	13	12%
MC, moped etc.	5	4%
Bike	4 or fewer	
Heavy vehicle	4 or fewer	
Total	91	100%

Overall, 44 accidents (49%), including the single accidents, were triggered by the bus, whereas the remaining ones were triggered by the collision partner, most often a car or other light vehicle.

---

[15] Source: https://ytf.no/nyheter/ruter-styrker-forersikkerheten

[16] This county has recently been split up.

[17] These are presented in more detail in Høye et al (2025).

4.3.1 How do the buses contribute to accidents and the severity of injuries?

To gain a deeper understanding of the ways in which the design and technical properties of the buses contributed to the accidents and severity of injuries, we analysed the in-depth reports for bus accidents. A total of 16 accident reports were included in these analyses, but the reports vary in the extent to which they describe, discuss or elaborate on the accident and injury mechanisms. Table 4.2 shows the frequency of different vehicle-related injury factors in these reports.

Table 4.2: Occurrence of vehicle-related injury factors in reports.

	Factor	Description	N accidents
Driver	Inadequate structural safety for driver	Driver's cabin deformed during collision	8
	Seatbelt installed too high	Unfavourable placement of seatbelt contributed to injury severity	1
Passengers	Passenger seats lack seatbelts	Bus not fully equipped with seatbelts for all passenger seats	2
	Inadequate structural safety for passengers	Broken windows or deformed bus sides	2
Other Road Users	Lack of underrun protection	Opposing road user or vehicle gets trapped under the front of the bus, causing severe damage and reduced survival space	3
	Mirror design	Bus mirror structure struck the opposing vehicle, causing severe injury or death	2

Inadequate Structural Safety for the Driver contributed to the severity of injuries in eight accidents, of which seven were head-on collisions and one was a run-off-road accident. In six of the head-on collisions, the opposing vehicle was a large vehicle. In five of these accidents, the opposing vehicle was another bus.

In accidents where inadequate structural safety for the driver contributed to the bus driver being fatally injured, the driver's cabin collapsed inward:

> *"The bus involved in this accident suffered significant damage around the driver's area. In head-on collisions involving buses, such damage is not uncommon. This indicates a lack of sufficient passive safety built into bus bodies."*
>
> *"In the accident, unit B suffered severe collision damage to the driver's area, and the driver was struck by the A-pillar and interior fittings."*

The reports point to a lack of built-in passive safety features in the form of reinforcements in the "cage" surrounding the driver. Two aspects are highlighted: the construction of the bus's front end, and the choice of materials. The reports note that the front is often made of fiberglass-reinforced plastic, glass, and hard plastic, and that the aluminium profiles (A-pillars) lack sufficient reinforcement.

> *"The construction of the bus's front end raises questions. There is little to protect the driver. The front consists of fiberglass-reinforced plastic, aluminium profiles, glass, and hard plastic inside. This choice of materials, without any reinforcements above the chassis rails, is not suitable for absorbing such forces, as demonstrated by this accident."*

Another issue discussed in the reports is the lack of crumple zones. In modern buses, the driver is positioned all the way in the front, where there is limited space and where there are no effective structures to absorb and distribute collision energy. Several reports point out that there was no survival space for the driver.

In all head-on collisions where inadequate structural safety contributed to the driver being fatally or seriously injured (seven accidents), the point of impact was located at the left corner of the bus with minimal overlap. Overlap refers to how much of the surface area of the involved vehicles is in contact during the collision, which plays a significant role in the absorption of collision energy. With minimal overlap, the point of impact is more concentrated, meaning the energy is less distributed, increasing the load on the structure and the risk of structural failure.

In most of these head-on collisions, the opposing vehicle was a heavy vehicle, which is also mentioned in the reports as contributing to the severity of the injuries:

> *"The lack of collision protection for bus drivers is a problem, particularly in collisions with large (tall) vehicles."*

When the opposing vehicle is a heavy vehicle, the point of impact is higher and more directly to the area where the bus driver is seated. This increases the risk of severe injury to the bus driver, as the energy from the collision is concentrated directly on the driver’s cabin.

Incorrectly Mounted Seatbelt. Most bus drivers who were killed or seriously injured wore seat belts. In two reports, the positioning and lack of proper equipment related to the seat belt are discussed as contributing factors to the severity of the injuries: In one case, the seat belt on the driver’s side was most likely installed too high, which caused the seat belt to press against the driver’s neck, contributing to increased injury severity during the collision. In another case with a head-on collision between two buses, it is noted that the buses were not equipped with seat belt pretensioners for the driver’s seat. It is not clear from the reports to what extent this contributed to the injury severity. In a third case, "improper use of the seat belt" is discussed as a factor contributing to fatal injuries:

> *"The bus driver sustained injuries to the liver and spleen. The investigation assumes that this was caused either by impact with the steering wheel or by a seat belt positioned across the abdomen. In any case, this indicates improper use of the seat belt."*

Inadequate Structural Safety for Passengers has contributed to injury severity in several accidents. In one accident, weaknesses in the bus’s construction caused a window frame to collapse and be pushed into the passenger area after being struck by the opposing vehicle's mirror. In two other cases, both rollover accidents, deformed window pillars and shattered windows caused severe or fatal passenger injuries.

Mirror Design. In one accident, the bus's mirror contributed to a fatality in the opposing vehicle. In another case, the mirror caused significant damage to the bus driver's cabin, though it is unclear whether the mirror directly contributed to the severity of the injuries. In both cases, the opposing vehicle was a heavy vehicle. "Donkey ear mirrors" are considered a useful tool for drivers as they are designed to provide good visibility. However, these mirrors are robust, and in collisions involving large vehicles, the mirrors can hook onto each other and then cut into the vehicles, causing significant damage.

> "*The bus mirror's design influences the outcome for the opposing vehicle in accidents, especially those involving two heavy vehicles*."
>
> "*The mirror mount on the frame (A-pillar) protruded slightly to the side and forward on the A-pillar, causing the A-pillars to interlock and shatter the windshield. The frame structure was deformed, and the protruding construction killed the passenger*."

Lack of Underrun Protection[18] contributed to fatalities in an opposing passenger car in four different head-on accidents. In all four accidents, the passenger car ended up under the front chassis beam of the bus, sustaining significant front-end damage. This greatly influenced the severity of the injuries

---

[18] Underrun protection, or underrun barriers, are essentially reinforcement beams installed at the front of a bus to prevent vehicles from sliding under the chassis beam in a collision. Such a beam helps distribute energy more effectively and preserves the structural integrity of both vehicles involved.

for people in the passenger cars. All four drivers of the passenger cars were fatally injured, and there was substantial material damage as well. In one report, the damage to the passenger car is described as follows:

> *"Based on the extent of the damage, the [passenger car] was far under the floor section of the bus, causing the A-pillars to be pushed backward."*

The reports note that there are existing requirements for underrun protection (N3 and N1) for heavy trucks and suggest a similar requirement for buses to potentially reduce the consequences of head-on collisions between buses and passenger cars:

> *"The bus does not have front underrun protection (not required at the time of registration). The damage to the passenger car could have been reduced if such protection had been installed."*
> *"The investigation team believes that several serious bus accidents could have had significantly less severe consequences, with fewer fatalities, if the buses had been equipped with front protection systems."*

Other factors related to bus characteristics are also discussed in the reports. While these are not directly identified as contributing to the severity of injuries, they are still relevant for discussion.

In two head-on collisions, the impact resulted in the destruction of the steering gear in one of the buses, leaving the driver unable to steer. Both reports highlight that the steering mechanism was poorly designed. Other factors noted include:

- Inadequate/insufficient tire equipment (5 accidents)
- Lack of safety barriers related to the opening/closing of the roof hatch (1 accident)
- Steering components in the bus were damaged in the collision (2 accidents)/ Poor design of the steering gear. In two accidents, the collision caused the steering gear to break, rendering the driver unable to control the bus post-collision.

4.4 Deficiencies based on our own analyses[19]

The first of the accidents, in chronological order, took place in Nafstad on November 17, 2017. Two identical low-floor buses, both Volvo 8700 models, were traveling along the FV 450 interurban road when they collided. The collision was caused by a loss of traction due to ice on the road, leading one of the buses, coming from the east, to skid. Notably, the crash occurred on a section of the road with a slight curve and a moderate slope.

Despite the slight curve in the road, this can be considered a fully frontal collision with an overlap of approximately 1 meter, which is 39.21% of the bus's total width of 2.55 meters. The impact speed was around 34 km/h after the braking systems of both buses were activated. Although the buses were traveling at relatively low speeds of 33-34 km/h, the collision caused significant deformation to both vehicles. The eastbound bus driver tragically lost his life on the spot, while the westbound driver suffered severe injuries after being trapped by the structures of the colliding bus.

In the accident reports and the graphical documentation of the vehicle conditions, structural failures that led to the driver’s death and injuries can be observed. The main structural intrusion is due to the penetration of the A-pillar into the impacted bus, causing the structure to collapse and, consequently, reducing the driver’s survival space. In this case, the bus coming from the west intrudes upon the one coming from the east, which is the most affected. The loading line on the A-pillar is notable in the accident, where the upper joint of one pillar penetrates into the bus, while the structure of the

---

[19] These are presented in more detail in Laso and Nævestad (2025).

other pillar pushes outward, creating opposite deformation profiles. This event effectively isolates the impact conditions, as it involves two identical vehicles colliding at the same speed, excluding several variables from the equation.

The second accident occurred on the outskirts of Tangen, on the FV 202 road connecting it with Stange, on March 11, 2021. In this case, similar to the 2017 accident, one of the buses lost control in winter conditions and invaded into the opposite lane, resulting in a head-on collision on the left front sides of both vehicles. Both buses involved were from the same service and were Volvo 8900 models.

The limited visibility in the curve did not help to prevent the accident. As a result, the southbound bus collided at an approximate speed of 27 km/h, while the northbound bus crashed at 42 km/h after both drivers applied the brakes. The impact was primarily frontal, affecting the leftmost edge of both vehicles, with an impacted area estimated between 150-200 mm, which translates to an overlap of about 5% to 8%. The result of the impact conducted the decease of the driver of the southbound bus, whilst the other driver was slightly injured.

The collision primarily involved the left front corners of both buses, causing significant structural damage, particularly in the driver's cabin area. The A-pillar of the northbound bus intruded into the driver's compartment of the other bus, resulting in fatal injuries for the southbound bus driver despite the relatively low speeds. The central section of the vehicles was almost entirely uninvolved in the impact, meaning that all the collision energy was concentrated on the A-pillar of the first arc. As in previous cases, one structure was torn and penetrated, while the other collapsed inward. However, in this instance, the minor overlap allowed the vehicles to keep moving forward.

On December 28, 2022 the third similar accident between line buses took place. The accident occurred on national highway Rv 110 near the Fredrikstad bridge and involved a head-on collision between two identical buses of the MAN Lion's City low entry (2013) model. One of the buses was traveling without passengers, while the other had two passengers on board. Despite the collision occurring at low speed, it resulted in the death of one of the drivers and critical injuries to the other. The passengers only sustained minor injuries.

According to the tachograph records, the bus coming from the south impacted at an approximate speed of 32 km/h, while the one approaching from the northeast collided at a speed of 40 km/h. The exact cause of why one of the drivers veered into the opposite lane, leading to the collision, remains unknown. The report from the Norwegian authorities does not specify the overlap involved in the crash; however, an analysis of the images suggests that the impact was intermediate between the incidents reported in 2017 and 2021, with an overlap estimated to be less than 1 meter on the leftmost side of the vehicle.

The structural analysis of this event suggests conclusions very similar to those of its predecessors. The report indicates a structural collapse of the A-pillar and an opening of the side structures on both buses, causing intrusion and reducing the survival space to zero for the bus that ended up underneath. In this collision, the seat of the deceased driver was completely displaced from its original position, while the other driver's seat remained in place.

These accidents highlight a worrying trend where bus structures, particularly in the front corners and A-pillars, are not designed to face frontal collisions with low overlap. Despite the introduction of new regulations in Norway requiring frontal impact tests, these do not address the structural weaknesses observed in the aforementioned accidents. Current safety standards must be updated to include resistance testing for partial side impacts and to enhance protection in driver cabins.

The impact energy of each of these three accidents was estimated based on the information given by the reports of the accidentology. The level of energy produced in these three accident scenarios can be considered equivalent, considering the boundary conditions of all buses. The level is about 10 times the energy values prescribed in Regulation UN R29.03.

5 Measures to improve bus safety[20]

The focus of this chapter is the third aim of the study, which is to present measures to improve collision safety in buses.

5.1 Measures to reduce accident occurrence

5.1.1 The majority of the studies focus on accident prevention for vulnerable road users

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 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

---

[20] The studies presented here are presented in more detail in Nævestad et al (2025).

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 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 £ 588-1 637, 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.

5.1.2 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.

5.2 Measures to reduce the severity of accidents

5.2.1 Description of R29.03 and R93.00 requirements in trucks

In the following, we discuss the current R29.03 and R93.00 requirements for collision protection tests in trucks. As mentioned already, R29.03 became mandatory for buses in Norway as of 01.10.2023. It has also been suggested to make R93.00 mandatory for buses. This is also discussed in the present report. We therefore present and describe these requirements. This presentation complements the preceding sections, as R29.03 and R93.00 have been suggested as measures to compensate for the lacking collision protection for bus drivers in the front of the buses. Both standards are originally developed for trucks.

R29.03 protection of the occupants of the cab of trucks

Regulation R29.03 defines standards for assessing the structural resistance of cabins in heavy commercial vehicles of type N (e.g., trucks). Its primary objective is to ensure occupant safety in accidents such as rollovers, frontal collisions, or lateral impacts.

The regulation specifies tests to verify that the cabin structure can absorb and distribute forces generated during a crash, avoiding severe collapses. Additionally, it requires sufficient survival space inside the cabin to protect the driver and passengers. For this assessment, a Hybrid III 50th percentile dummy is placed on the driver’s seat to evaluate cabin deformation.

The evaluation consists of three different tests designed to encompass all types of accidents a truck cabin may face:

Test A: Frontal Impact.

A pendulum weighing 1 500 kg strikes 50 mm below the R-point of the driver’s seat. The impactor is a flat plate with a total width of 2 500 mm and a height of 800 mm, covering the entire cabin width. The total energy for the dynamic test is 55 kJ (for vehicles over 7.5 tons).

Test B: A-Pillar Test. Rollover 90°

This test assesses the resistance of the cabin’s A-pillars. The impactor is a cylinder with a total width of 2 500 mm and a diameter of 600 mm, also covering the entire cabin width. The impact occurs directly on the windshield, with an energy of 29.5 kJ.

Test C: Lateral 180° rollover.

This test is analogue to the R66 rollover test for buses and has similar purpose but with a different way to evaluate the cabin's resistance in a side rollover. The test involves a lateral flat impact with an energy of 17.6 kJ at a 20° angle, weakening the structure laterally. A static load of 98 kN is then applied, corresponding to an estimated maximum authorised mass per cabin axle(s).

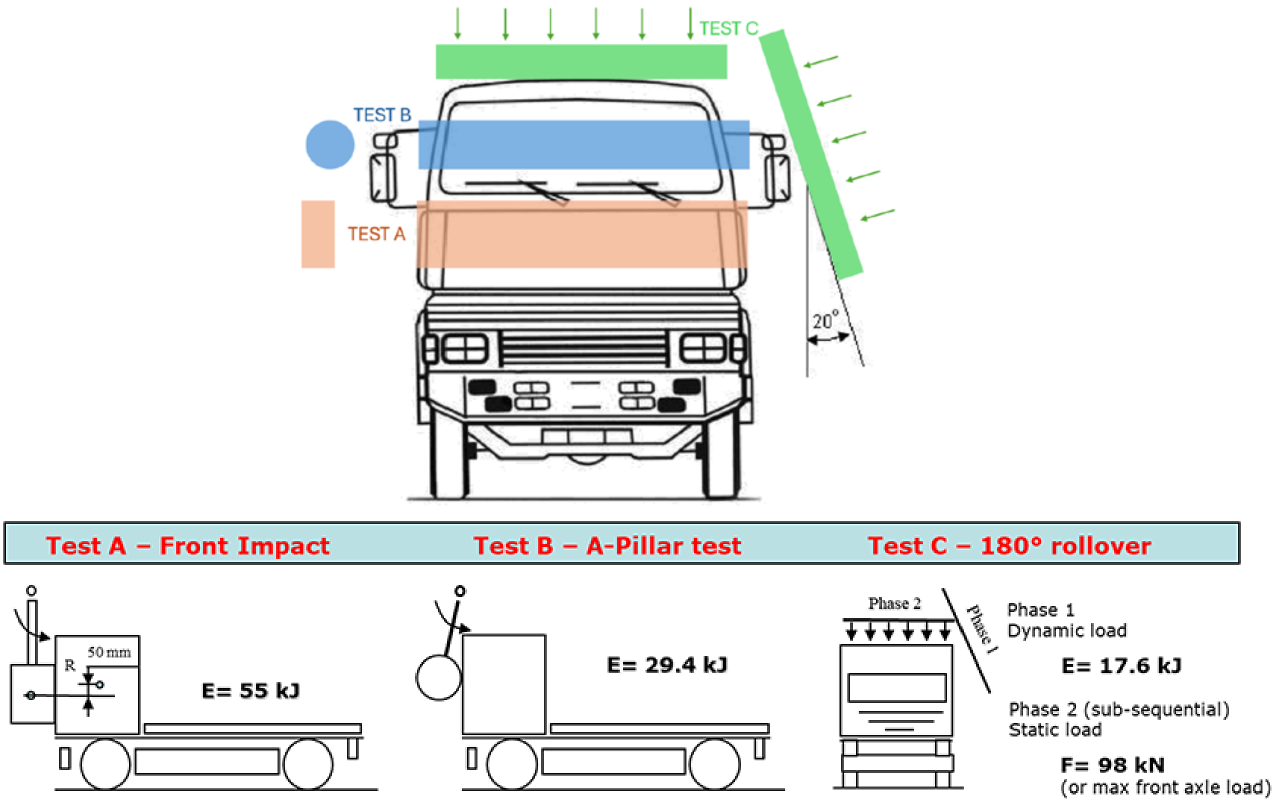


Figure 5.1: Illustration of the UN R29.03 test.

R93.00 Front Underrun Protection Devices

The UN R93.00 regulation sets the technical requirements for front underrun protection devices in heavy commercial vehicles, such as trucks in categories N2 and N3. Its main goal is to prevent smaller vehicles from sliding under the truck in frontal collisions, reducing the risk of severe or fatal injuries to the occupants of these vehicles.

The regulation mandates a beam-like structure strategically positioned to absorb the energy of a passenger car in the event of a frontal crash between a car and a truck. This underrun protection device undergoes tests at various points by applying loads.

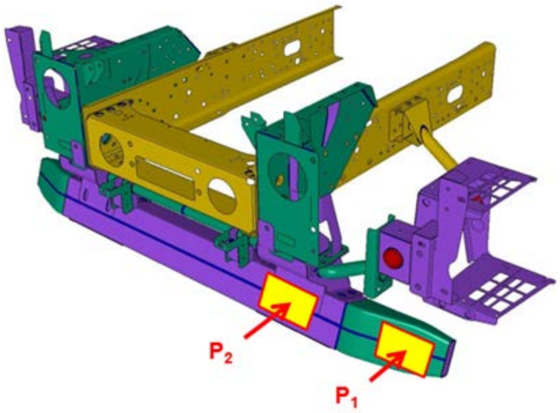


Figure 5.2: Illustration of R93.00. Front Underrun Protection Devices.

At point P1, a load of half the vehicle's mass up to a maximum of 80 kN is applied, while at point P2, the test applies the vehicle's full mass up to a maximum of 160 kN.

This regulation is highly effective for compatibility with light vehicles as it shifts the point of impact and deformation energy to an area where the passive safety mechanisms of light vehicles can function. However, its effectiveness is significantly limited in other types of collisions, and it does not provide compatibility in impacts with larger vehicles, such as another truck or a bus.

5.2.2 The bus front improvement model

The bus front improvement model is presented in more detail in Laso and Nævestad (2025). This model is based on the recognition that current bus front designs provide insufficient collision safety for bus driver, and that this also applies to R29.03 requirements. The level of energy produced in the three studied Norwegian accidents was estimated to be about 10 times higher (approx. 550 kJ) than the energy values prescribed in Regulation UN R29.03 (55 kJ). The peer reviewed studies presented in section 4.1 also indicate that R29.03 requirements provide insufficient protection for bus drivers.

1) Improvement of crash compatibility. The primary problem observed in the three bus accidents is the inadequate energy absorption by vehicle structures during collisions. In the analysed cases, the bus structures tend to deform and open up upon impact, leading to severe intrusions into the colliding vehicle. What's particularly alarming is the disproportionate severity of both structural damage and personal injuries, especially considering the relatively low impact speeds involved in these incidents.

A common factor in all three accidents was the small overlap nature of the impacts. This scenario concentrates the impact energy in a very limited area of the vehicle’s front, magnifying the destructive forces and exacerbating the damage caused. The focused energy transfer in these small overlap collisions poses a significant challenge to current vehicle design paradigms.

One of the most critical issues identified is the behaviour of the bus’s frontal structure during impact. The transversal profile, which serves as the sole structural element connecting the sides at the front of the bus, detaches during the collision. This structural failure leaves the edge of the side panel unrestrained, effectively turning it into a ‘battering ram’. The resistance and rigidity of this now-detached side panel cause it to penetrate the opposing vehicle with devastating consequences, resulting in severe damage and increased risk of injury to occupants.

To address these critical safety concerns, several potential solutions can be considered to improve the crash compatibility.

a) **Mandatory Implementation of UN R93.00**: The United Nations Economic Commission for Europe Regulation No. 93 (UN R93.00) addresses front underrun protection on heavy goods vehicles. While primarily designed for trucks, adapting and mandating this regulation for buses could significantly improve their compatibility with smaller vehicles in frontal collisions. The R93.00 standard requires the installation of a front underrun protection device, which could help distribute impact forces more evenly and prevent smaller vehicles from under-riding the bus in a collision.

b) **Integration with Towing Hook regulation**: Combining the R93.00 requirements with existing towing hook regulation, EU R1005/2010 could provide a dual-purpose solution. By designing a robust front structure that serves both as an underrun protection device and a standardized towing point, we could enhance both safety and utility. This integrated approach would ensure that the frontal structure of buses is strengthened without compromising their serviceability.

c) **Enhanced Structural Integrity**: Developing more robust connections between the transverse profile and the side panels of buses is crucial. This could involve redesigning the frontal structure to maintain its integrity during impacts, preventing the ‘battering ram’ effect observed in the studied accidents.

d) **Energy Absorption Zones**: Incorporating dedicated energy absorption zones in the front structure of buses could help manage impact forces more effectively. These zones should be designed to deform progressively, absorbing energy while maintaining the overall structural integrity of the vehicle.

e) **Small Overlap Impact Testing:** Introducing mandatory small overlap impact testing for buses, similar to tests now common for passenger cars, could drive improvements in design to better handle these challenging impact scenarios.

f) **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials in bus construction could provide better protection without significantly increasing vehicle weight.

g) **Compatibility Design Standards:** Developing specific standards for vehicle compatibility between buses and smaller vehicles could lead to designs that interact more safely during collisions.

Implementing these solutions would require a coordinated effort from vehicle manufacturers, regulatory bodies, and safety organizations. By mandating the UN R93.00 standard for buses, combined with enhanced towing hook regulations and the additional measures suggested, we could significantly improve the safety outcomes in bus-involved collisions.

The goal is to create bus structures that not only protect their occupants but also minimize damage and injury risk to occupants of other vehicles involved in collisions. This holistic approach to vehicle safety design is essential as we strive to reduce the severity of road accidents and improve overall traffic safety. Further research and real-world testing will be crucial in refining these solutions and ensuring their effectiveness across a wide range of collision scenarios.

2) The position of the driver. The position of the driver is quite sensitive with respect to the severity of the accident. In urban buses, the height of the driver position is approximately 800mm to 1000 mm, while in coach buses the driver position is approximately 1400mm-1600mm high.

In the case of urban buses, it would be possible to raise the vehicle slightly, but ergonomics would have to be checked with regard to being able to carry out passenger control functions, such as collecting admission. In any case, this increase in height would be very small. Positioning the driver further back would be even more complicated, since that would mean eliminating the capacity of a row of seats, which would make the bus less competitive in the market.

3) Reinforcements in the structure. In the three studied Norwegian bus accidents, one can observe that bus lateral side structure is totally intruding over the opposite bus by literally “cutting” the structure, like a knife does. The level of severity for this type of accident is extremely high, so the structural design, reinforcements and materials shall be focused on avoiding this situation as much as possible to improve crash compatibility. The structural reinforcement shall be focused on the driver side and avoid mainly two things: One is to prevent the transversal tubes in the front low area to be detached, and the second is to avoid the collapse of the connection hinges 1, 2 and 3 to be close to the driver. The strategy could be to use a “semi-cage” open structure, protecting the lower area but also providing a better connection with the roof (cf. Laso and Nævestad 2025 for illustrations).

In addition, the amount of energy is also an important point to solve. These accidents show that energy levels in reality are much higher than the energy tolerance level proposed by UN R29.03 (type-A), which applies 55 kJ over the whole width of front structure. The definition of a specific test or tests to evaluate bus safety in more realistic conditions would be necessary.

4) Reinforcement of front grill and floor. In the realm of bus crash safety, one critical area of concern is the behaviour of the frontal structure during collision events. Current designs often result in the front of the bus transforming into a hazardous ‘lance’ or ‘battering ram’ upon impact. This transformation has lethal consequences, particularly for the drivers involved in such collisions.

The primary issue lies in the lower frontal structure of buses, which currently lacks adequate connections and reinforcement. During a high-impact crash, this weakness allows the front end to collapse and protrude forward, effectively creating a penetrating force that significantly increases the severity of the collision. This phenomenon not only endangers the bus occupants but poses an extreme threat to the occupants of other vehicles involved in the crash, especially those in smaller passenger cars.

To mitigate this risk, it is imperative that we focus on improving the connections within the lower frontal structure of buses. Enhanced structural integrity in this area would help maintain the bus’s shape during a collision, preventing the formation of the dangerous ‘lance’ effect. This improvement would involve reinforcing key points of the frontal frame and implementing more robust joining techniques to ensure the structure remains cohesive under impact forces.

One promising approach to addressing this issue involves leveraging the inherent strength of the towing hook mount point, mandatory for buses under regulation EU R1005/2010. The towing hook point area, designed to withstand significant forces, could serve as the starting point to extend the frontal structure reinforcement and to be used as the front underrun protection, aiming to reduce the risk of smaller vehicles under riding bus structures in the event of frontal collisions.

Currently, the front underrun protection system is only mandatory for trucks, but not applied for buses. In this case, the proposal is to extend this requirement, to combine the requirements of R1005/2010 and UN R93.00, and develop a frontal structure to, effectively increase the crumple zone and energy absorption capabilities of the bus.

This extended structure would serve in multiple purposes:

1. It would prevent fatalities caused by the intrusion of the lateral panel of the collision partner into the bus driver’s cabin by providing a controlled deformation zone.
2. It would offer better protection to the bus driver and passengers by managing impact forces more effectively.
3. Most importantly, it would significantly enhance the safety of occupants in smaller vehicles involved in collisions with buses.

Implementing such a design would require careful engineering to balance the need for increased frontal protection with considerations of weight, aerodynamics, and overall vehicle performance.

However, the potential benefits in terms of improved safety outcomes make this a worthwhile endeavour.

Summarizing, by focusing on strengthening the lower frontal connections, extending the front structure from the towing hook point (EU R1005/2010), and meeting UN R93.00 requirements, the lethality of bus-involved collisions can be significantly reduced. This approach not only protects bus occupants, but also offers vital protection to other road users, particularly those in smaller vehicles who are most vulnerable in such crash scenarios.

5. Reinforcement of the roof. Looking at the three different bus accident reports, the upper roof connection was detached from the lateral structure. In addition, from the accident in Tangen (March 2021), we could observe that the roof structure was bended down due to the big deformation that occurred during the crash. The stiffness of the roof structure and the quality of the connection with the front pillar is assumed to have a big impact on the safety results during the crash. The recommendation is to increase the strength of the roof connection with the first arch located in the windscreen and also the connection with the second safety arch, just behind the driver. In addition, the use of reinforcement brackets for the tube connection, and the application of a good weld location strategy, would help to keep the big deformations out from welded areas so the risk of detachment of connections could be reduced significantly.

5.2.3 Rounded front design to create deformation zone

The rounded front of a tram is primarily intended as a safety measure for pedestrians. The rounded, backward leaning front will push pedestrians struck by the tram away and prevent them from ending up under the tram. This is likely to reduce injury severity to pedestrians.

It does, however, also provide a deformation zone for the tram driver. It may therefore reduce injury severity to tram drivers in addition to injury severity to pedestrians.

Martin et al. (2020) found that a rounded bus front reduced the number of pedestrians who were run over by buses. In this context, the front of the bus was only slightly rounded and slightly backward leaning. It seems logical that a better protection of the driver can be attained by adopting the more extreme version of front design shown in Figure 5.3.

Figure 5.3. Front design of new trams introduced in Oslo 2022-2024

Making the front of a bus round and backward leading may add a little to the length of the bus compared to a bus with a vertical front. It may also add a little weight. However, so does adding the safety beams required by R29.03 and R93.00. The inside of a rounded and backward leaning bus front need not contain any heavy structures. Indeed, it would probably be advantageous if it did not do so, but simply crumbled upon impact. There should be something similar to the fire wall in a car engine to the rear of the rounded section to prevent it from intruding the driver's compartment or at least reduce the amount of intrusion.

The rounded front should have as low ground clearance as possible. This may, by itself, prevent underrunning and perhaps eliminate the need for a rigid, unforgiving underrun guard rail. The underrun guard rail is unforgiving, since it is designed as rigid barrier that will not yield on impact. It is hardly surprising that front underrun guard rails have not been found to reduce injury severity to car occupants in head-on impacts.

With a rounded front crumbling upon impact, a striking car may be slowed down sufficiently to not run under a bus. Nevertheless, it is probably safest to add an underrun guard rail aligned with the fire wall at the rear end of the rounded section. However, this underrun guard rail may perhaps not need to be as heavy and unyielding as current front underrun guard rails.

Moreover, other challenges with a solution like the rounded front are that:

- Extending the front of the bus would significantly affect the current design
- The length of the cantilever is limited by regulations
- It would add extra mass over the frontal axle (more than the bus front improvement model), which cannot be offset by useful load

Thus, this might be considered a less realistic solution. This is why it was not included in the bus front improvement model. A general proposal should be adaptable to all bus distributions and configurations.

5.2.4 Air bag integrated into seat belt

Olivares (2012) showed how an air bag can be integrated into the seat belt of a bus driver. Once the belt starts to tighten (i.e. once the pressure exerted on it increases as a result of a forward movement of the driver), the air bag is deployed and prevents the driver from striking the steering wheel and possibly also other structures near the steering wheel.

5.2.5 Seat reclining or pulled back on impact

As part of a research program to prevent whiplash injury in rear-end collisions, Volvo and Saab developed new car seats intended to reduce the chance of a whiplash injury (Eriksen et al. 2004). Mercedes Citaro buses have had this solution for several years, and Yutong buses have also developed this solution recently.

The Volvo seat, Whiplash Injury Prevention Seat (WHIPS), had a weakened joint between the seat and the seat back. Upon impact, this joint would break, and, as a result, the seat back would be reclined backward to dampen the impact of the head being thrown backwards as a result of the forward acceleration produced by a rear-end strike.

The Saab seat, Saab Active Head Restraint (SAHR), activates the head restraint upon a rear impact. The force of the driver being pushed backwards into the seat would activate an arm, pulling the head restraint forward to capture the head during its rearward rotation.

Both these systems were found to be effective in reducing whiplash injury. The systems have subsequently been developed and improved. However, the main idea in both systems was strikingly simple and involved only the most elementary mechanics. It should therefore not be impossible to construct a bus driver seat that would be leaned backwards or perhaps even pulled a little backwards in case of a frontal impact.

The dynamics of occupant movement are of course exactly opposite in frontal and rear-end collisions. A rear-end collision is an acceleration. It pushes car occupants backwards and deeper into the seat and ultimately upwards to the region where the headrest is located. A frontal collision is a deceleration. The vehicle slows down rapidly, but the driver is thrust forward in the seat and ultimately downward towards the steering wheel and instrument panel. Hence, the unwanted movements a seat system should prevent are not the same in frontal collisions and rear-end collisions. However, the logic of how to avoid or mitigate injury is the same: pull the driver away from the direction of movement induced by the impact and away from fixed objects in the vehicle that the driver may strike. It ought to be possible to construct a sensor, for example in the bumper, which registers an impact and activates a system leaning the driver’s seat backward and pulling it backwards. Although it is noted that the driver’s seat cannot be pulled very far backwards, even a few centimetres are likely to help.

6 Cost-benefit analysis

The focus of this chapter is on the fourth aim of the study, which is to make an assessment of the benefits and costs of various measures for improving collision safety in buses.

6.1 Injury risk to bus drivers

The benefits in monetary terms of measures improving the crashworthiness of buses depend on the injury risk of bus drivers. The higher the injury risk, the higher the cost of the injuries per bus. The higher the cost of the injuries, the more can be spent on improving crashworthiness before the costs of improvements become greater than the benefits.

To obtain estimates of injury risk that can be regarded as representative for Europe, statistics on the number of killed or injured bus drivers reported in CARE have been combined with estimates of million kilometres driven by buses. For most countries included, the data refer to 2013-2022. The countries included are Belgium, Bulgaria, Croatia, Estonia (fatality risk only), France (fatality risk only), Germany, Italy (fatality risk only), Netherlands, Norway, Poland, Portugal, Sweden, and Switzerland. For the period covered by the data, there were 128 bus driver fatalities, 830 seriously injured bus drivers, and 6 746 slightly injured bus drivers in these countries.

The mean risk of a fatal injury was 0.965 per billion bus kilometres. The mean risk of serious injury was 8.961 per billion bus kilometres. The mean risk of a slight injury was 72.835 per billion bus kilometres. Risk varied considerably between countries. One should, however, remember that both the definition of reportable injuries and the actual reporting of them varies between countries. The most comparable estimates of risk refer to fatal injury. This risk varied from a low of 0.237 per billion bus kilometres to a high of 6.720 per billion bus kilometres. Norway ranked 10 out of 13 countries for which fatality risk could be estimated. The countries that had a higher fatality risk than Norway were Poland, Bulgaria and Estonia.

6.2 Monetary valuation of injuries

The Handbook on the external costs of Transport (van Essen et al. 2019) is used to assign monetary values to the injuries. According to the Handbook, the following values were recommended for the EU-28 (the current members plus the United Kingdom) in 2016-prices:

1 fatal injury	3 273 909 €
1 serious injury (very serious and serious combined)	498 591 €
1 slight injury	38 514 €

To update these estimates to 2023-values, the index for real incomes (i.e. incomes in fixed prices) reported by Eurostat has been applied. The updated estimates are:

1 fatal injury	3 921 557 €
1 serious injury (very serious and serious combined)	597 223 €
1 slight injury	46 133 €

6.3 Expected cost of injuries per bus

Applying the monetary valuations above and the mean estimates of risk, the total annual societal cost of injuries to bus drivers is EUR 0.0125 per bus kilometre. The mean annual driving distance of a bus, estimated for countries that have data both on the number of buses and the total number of kilometres driven, is 27,627 kilometres. Hence the total annual cost per bus is about EUR 345.

If a bus is assumed to operate for 10 years, and an annual discount rate of 3 % is used, the present value of the costs of injury to bus drivers per bus becomes EUR 2 945.

6.4 Costs of measures improving crashworthiness

The main measures intended to improve crashworthiness in this report are:

1. Front underrun guard rail (R93.00)
2. Safety beam just under front windshield (R29.03)
3. The bus front improvement model
4. Airbag integrated into seat belt
5. Seat reclining function on impact

The costs of these systems are not very well known. Cost estimates can be found for some of the systems, but many of these are old and some refer to passenger cars. They may overstate the costs of the systems if they become standard equipment. Thus, the basis for performing a cost-benefit analysis is not as firm as one would want it to be. Nevertheless, the cost estimates that have been found are presented and discussed below.

According to estimates quoted by Høye (2023), a front underrun guard rail costed 100-200 Australian dollars in 2003. This corresponds to about EUR 61-132 at the exchange rate in 2003. Prices have since increased, and for simplicity, a cost of EUR 100-200 is assumed for a front underrun guard rail.

The bus front improvement model costs more than a front underrun guard rail. According to IDIADA, the cost of the suggested model is between EUR 8 500 and 12 000.

Modern trams have a rounded front design intended to push away pedestrians who are struck by the tram and prevent them for being run over by it. The front design also creates a deformation zone which protects the driver in frontal impacts. According to Wijnen (2024), the costs of a rounded tram front are EUR 1400 in additional development and manufacturing cost, and EUR 1000 if the front must be replaced after a crash.

The cost of retrofitting an airbag to a passenger car is stated by Høye (2015) as EUR 500. (2014-prices). A cost estimate of EUR 550 has been applied in this study.

According to Eriksen et al. (2004) the manufacturing cost of the seats developed by Volvo and Saab to prevent whiplash injury was about SEK 1200 (2004). These seats were intended to function in rear-end collisions. However, a similar mechanism might protect drivers in frontal impacts, by reclining the seat or pulling it backwards in case of an impact, thus pulling the driver away from the point of impact and away from the steering wheel or other fixed objects in the bus that the driver may strike when moving forward.

6.5 Effects of measures improving crashworthiness

There is one very big problem in performing a cost-benefit analysis of improved crashworthiness for buses: The effects of the measures intended to improve crashworthiness are unknown. The very simple reason for this is that none of the measures have been (widely) implemented. Only their potential effects are to some extent known, for example as results of crash tests. Apart from that, estimates of potential effect have to be developed by reasoning in terms of analogies or by simply assuming that the effects that have been found for, say, passenger cars, apply to buses as well.

This is clearly not a satisfactory state of affairs. However, despite the difficulties, it is useful to try to develop estimates of the effect of improved crashworthiness, even if these are mainly hypothetical. In this section, the potential effects of improved crashworthiness will therefore be quantified.

6.5.1 Front underrun guard rail (R93.00)

Several of the Norwegian Accident Analysis Groups (AAG) analyses of fatal accidents suggests that a front underrun guard rail (R93.00) could have been effective for reducing severe impacts. The front underrun guard rail is also suggested as part of the model for increased crash protection, especially if it is related to the towing hook area, which seems to provide a strong structural basis.

Available estimates of the effect of front underrun guard rails refer only to the effect on the counterpart in accidents, not to the effect on the driver of the heavy vehicle (bus or truck) equipped with it. Moreover, these estimates refer to front underrun guard rails on trucks, not buses. Truck drivers generally sit higher above the ground than bus drivers. In frontal impacts with a passenger car, the car will strike the truck below the height of the driver and will pass under the truck, unless the truck has a front underrun guard rail.

This is different for buses, at least city buses. Although passenger cars striking a bus will strike it below the height of the bus driver's seat, the front of the bus may nevertheless be deformed more than the front of a truck because of the absence of an underrun guard rail. This is illustrated by a comparison of injury severity to bus drivers and truck drivers depending on impact point.

According to Norwegian accident statistics, the percentage of bus drivers involved in accidents who are killed or seriously injured is highest for the impact point of front-left (11 o'clock), which is where the driver is sitting. This contrasts with truck drivers. If, for both bus drivers and truck drivers, the odds of a fatal or serious injury are set equal to 1.000 for an impact point of front centre (12 o'clock), the odds ratios for other impact points become:

	Odds ratio for fatal or serious injury	
Impact point	Bus drivers	Truck drivers
Front centre (12 o'clock)	1.000	1.000
Front left (driver' s seat) (11 o'clock)	1.665	0.923
Front right (1 o'clock)	0.861	0.502
Front left side (10 o'clock)	1.935	0.887

For truck drivers, the odds of a fatal or serious injury are lower for all other impact points than front centre. For bus drivers, this is not the case. Impact points close to the bus driver's seat increase the odds of fatal or serious injury. This is probably because of the softer front of a bus compared to trucks, combined with the bus driver sitting lower than the truck driver. In frontal impacts, intrusion into the bus driver's survival space is therefore more likely than it is for truck drivers.

There are two approaches to reducing this problem (1) Make the front of a bus stiffer and less yielding upon impact; (2) Create a deformation zone in the front of a bus. These approaches can be combined (as in the bus front improvement model), but it should be remembered that reinforcing the front of the bus will make it more aggressive to other road users, whereas adding a deformation zone need not make the bus more aggressive.

Reinforcing the beams surrounding the bus driver (i.e. the bus front improvement model) may create a cage-like structure that prevents or reduces deformation and thus increases survival space for the bus driver. Such a structure would be effective for impact points between 10 and 12 o'clock from the perspective of the bus driver.

A front underrun guard rail would probably not have an effect in accidents with an impact point of 10 o'clock. It could have an impact in accidents with an impact point of 11 o'clock. If bus drivers were as well protected from fatal or serious injury as truck drivers when the impact point is 11 o'clock, the number of fatal or serious injuries might be reduced by = 0.923/1.665 = 0.554, or about 45 %.

This is probably a maximum estimate, given the current construction of a bus chassis. The bus chassis is not necessarily designed to absorb the force of an impact on an underrun guard rail. The underrun guard rail is a heavier beam than other parts of the bus chassis, and these parts, being lighter and softer, might yield upon an impact, whereas the underrun guard rail remains intact. It simply gets pushed backward upon impact. This is not how it is intended to function. It is intended to stay in place and prevent both deformation of the bus and a striking vehicle from running under the bus or truck. This is why IDIADA, in the technical study, suggests to relate the underrun guard rail to the towing hook area, also strengthening the latter.

AAG analyses argue in favour of underrun guard rails, according to R93.00. More specifically, if it is designed as a bumper with low ground clearance, slightly protruding from the bus (say, by about 10-20 centimetres), and designed to yield upon impact until the distance of the protrusion has been travelled, and it might act both as an energy absorbing device and as a barrier preventing underrunning from occurring. For the moment, the conclusion is that a front underrun guard rail has the potential of preventing fatal and serious injury to bus drivers, but that quantifying the impact is very difficult.

6.5.2 Safety beam under windshield (R29.03)

The potential effects of R29.03, requiring a safety beam in the front of a bus located just under the windshield, have been evaluated by e.g. Jongpradist et al. (2015) and Lopes et al. (2022, 2023). The evaluations employed crash tests under controlled conditions.

The crash tests performed by Jongpradist et al. (2015) represented very low impact speeds. Three different designs of a system intended to comply with R29.03, were compared. One of the systems failed the test. The other two were able to reduce deformation sufficiently to increase the survival space for the bus driver. Deformation was reduced by 20-40 % in the two systems that passed the test. The test criterion was whether deformation could be reduced sufficiently to prevent physical contact between the driver and the steering wheel.

Lopes et al. (2022, 2023) asked whether the current front structure of a bus could pass the R29.03 test criteria. Unsurprisingly, they concluded that this was not the case.

These tests give very limited information about the potential effects of UN R29.03. All they show is that, according to the test criteria specified in the regulation, it may improve the protection of the driver. However, the collision energy in the test is just 55 kJ, which is considerably lower than the energy released in fatal frontal crashes of buses in Norway. Hence, even a system satisfying R29.03 would probably not have had much effect in these crashes. As noted, IDIADA's estimates (Laso and Nævestad 2025) indicate that the energy in the three low speed crashes in Norway was 10 times higher than the energy level that R29.03 is meant to protect against.

The regulation may not improve protection of the driver in accidents involving low vehicles, like passenger cars. Most of these vehicles will strike the bus below the safety beam. It may have an effect in frontal accidents with other heavy vehicles.

6.5.3 Air bag integrated into seat belt

Olivares (2012) showed how an air bag can be integrated into the seat belt for a bus driver. Once the belt starts to tighten (i.e. once the pressure exerted on it increases as a result of a forward movement of the driver), the air bag is deployed and prevents the driver from striking the steering and possibly also other structures near the steering wheel.

The effects of air bags in light vehicles has been extensively studied. Høye (2015) summarises the effects of second-generation air bags for car occupants using seat belts as follows (the numbers parenthesis are confidence intervals):

Type of accident	Change in number of killed (%)	Change in number of seriously injured (%)
Frontal	-34 (-43; -22)	-21 (-42; +7)
Other	-3 (-9; +3)	-56 (-64; -47)
All	-17 (-22; -11)	-19 (no confidence interval)

There are no estimates of effects for buses, but it is not altogether unreasonable to expect the effects to be of the same order of magnitude.

6.5.4 Seat reclining or pulled back on impact

As part of a research program to prevent whiplash injury in rear-end collisions, Volvo and Saab developed new car seats intended to reduce the chance of a whiplash injury (Eriksen et al. 2004). Mercedes Citaro buses have had this solution for several years, and Yutong buses have also developed this solution recently. We discussed this system in section 6.5.

6.5.5 Impact points influenced by the systems

All the systems discussed above will primarily influence crashes with impact points between 10 o'clock and 12 o'clock. For countries that have data about impact points, these impact points account for 60.4 % of all fatal injuries to bus drivers, 66.4 % of all serious injuries to bus drivers and 60.0 % of all slight injuries to bus drivers.

The present value of the cost of these injuries per bus for a service life of 10 years is about EUR 1 850.

6.6 Benefits and costs of safety systems

The most promising of the safety systems discussed above are:

- The bus front improvement model, which among other things creates a semi-cage around the driver
- Air bag integrated into seat belt
- Seat reclining or withdrawal function

If a semi cage designed to protect the driver, this can reduce fatal injury by 30 %, serious injury by 20 % and slight injury by 10 % in crashes with impact points between 10 and 12 o'clock, the present value of the benefits will be EUR 377 per bus. Above, it was assumed that the system would cost EUR 8 500-12 000 per bus. Costs therefore seem to outweigh the benefits.

An air bag integrated into the seat belt is assumed to reduce fatal injury by 30 % and serious injury by 20 %. It will have no effect on slight injury. With these assumptions, the present value of benefits is estimated to be EUR 329 per bus, comparing to a cost of EUR 550 per bus assumed above. Again, benefits are smaller than costs.

The effects of a seat reclining or withdrawal function are unknown. If, absent any other information, the same effects are assumed as for a semi-cage to protect the driver, the present value of benefits is EUR 377 per bus. If a cost of EUR 200 per bus is assumed, benefits are greater than costs.

The combined effects of both a semi cage and an airbag have also been estimated. Total costs are EUR 9 050-12 550 Euros, and total benefits have been estimated to EUR 624. Thus, benefits remain smaller than costs even for the combined systems.

6.7 Improved crashworthiness of buses can benefit other road users

The main focus of this study is on improving the crashworthiness of buses so as to protect bus drivers better from injury. However, the current poor crashworthiness of buses is a hazard not just to bus drivers, but to other road users as well. The collapse of the bus front in head-on collisions may result in tearing loose structural elements that may intrude the compartment of a passenger car and strike occupants, even if the compartment is not compressed and survival space thus remains. Loose pieces of metal moving a high speed can kill or seriously injury car occupants even if the crash had otherwise been survivable or less injurious.

Against this background, an estimate has been developed on the cost per bus of head-on crashes with passenger cars, based on data from eight European countries. The mean cost per bus, stated as present value for a period of 10 years (3 % discount rate), was EUR 7 694. There is, therefore, a large potential for saving injury costs by improving the crashworthiness of a bus. The potential saving in costs of car occupant injuries is much greater than the potential saving in costs of injuries to bus drivers (EUR 2 945 per bus). Adding the potential injury cost savings to bus drivers and car occupants together yields a benefit of 10 639 Euros per bus. This is within the range of the cost estimates for the structural improvements assessed by IDIADA (8 500-12 000 Euros per bus).

It must be added, however, that the effect of improved crashworthiness would need to be close to an elimination of injuries (i.e. a 100 % reduction) for benefits to exceed costs.

7 Discussion

7.1 Bus drivers are insufficiently protected

A 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. Starting in 2020, the largest public transport authority in Norway, Ruter required that new buses comply with the UN R29.03 Standard in the new "Oslo South Tenders". As of 01.10.2023, Norway implemented R.29.03 as a national requirement. UN R29.03 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.

The few studies that have a particular focus on bus driver collision protection conclude that current regulations provide insufficient protection for 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) compared the crashworthiness of buses to the crashworthiness of other heavy vehicles, and found that for large buses, crashworthiness improved until 1989. After that, it has deteriorated and was worse for buses of model years after 2010 than it was for the oldest buses (model years 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).

In line with this, our literature review shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that R29.03 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 driver and passengers' physical integrity are compromised. Lopes et al (2023) also 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.

Thuong and Nguyen (2019) conclude that the energy absorption capacity of bus structures needs to improve by optimizing the frame and chassis. Afripin et al (2019) find that in R29.03 simulations, 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 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.

Although there are no mandatory EU crashworthiness standards focusing on bus drivers, Norway took a lead in bus driver safety and implemented the R29.03 frontal crash test standard for buses as of 01.10.2023. Our desk study, using the three fatal Norwegian low speed (about 30 km/h) bus collisions as point of departure shows, however, that the energy level in these collisions was 10 times higher than the energy tolerance level required by R29.03. Thus, R29.03 does not provide sufficient protection for bus drivers.

7.2 Buses are one of the safest road transport modes

When discussing bus safety, it is important to remember that studies of European bus accidents show that bus crashes account for only 2% of all road fatalities in EU, and that previous studies generally report that bus/coach is the safest mode of transport for vehicle occupants in OECD countries. In OECD countries, the risk of being killed or seriously injured is seven to nine times lower for bus occupants than for car occupants (Albertson, 2005). Moreover, the number of fatalities in accidents with HGVs, buses or coaches decreased by almost 50% from 2004 to 2013 (Evgenikos et al., 2016). Nevertheless, our study indicates that bus drivers are insufficiently protected in accidents with frontal impact, although bus transport is one of the safest road transport modes.

7.3 The frontal structure of the bus also might endanger other vehicles

Another main conclusion of the present study is that the frontal structure of buses might also endanger other vehicles in collisions. The desktop study of the three Norwegian bus accidents shows that current designs often result in the front of the bus transforming into a hazardous ‘lance’ or ‘battering ram’ upon impact. This transformation has lethal consequences, particularly for the drivers involved in such collisions.

The primary issue lies in the lower frontal structure of buses, which currently lacks adequate connections and reinforcement. During a high-impact crash, this weakness allows the front end to collapse and protrude forward, effectively creating a penetrating force that significantly increases the severity of the collision. This phenomenon not only endangers the bus occupants but poses an extreme threat to the occupants of other vehicles involved in the crash, especially those in smaller passenger cars. We have argued that it is important to mitigate this risk through improving the connections within the lower frontal structure of buses. Enhanced structural integrity in this area would help maintain the bus’s shape during a collision and reduce the risk to collision partners.

7.4 Safe System and Vision Zero

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 same applies to the fact that the frontal structure of the bus may also endanger other vehicles in collisions.

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.

7.5 Safe work environment as a sustainable development goal

Bus driver safety is also relevant to sustainable development goals (SDGs). Robust occupational health and safety laws and policies and good business practices, combined with employment injury insurance schemes, contribute to the achievement of several Sustainable Development Goals, including Goal 1 (No Poverty), Goal 3 (Good Health and Well-Being) and Goal 8 (Decent Work and Economic Growth), amongst others.

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".[21]

---

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

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

Although our cost-benefit analyses indicate that the economic costs related to the structural collision safety measure we suggest, and the other solutions that we analyse, are far higher than the expected economic benefits, we argue that it is necessary to improve the collision protection of bus drivers.

In the last ten years, 1 459 bus drivers in Europe have been killed or severely injured in accidents. Based on our 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. 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), bus accidents will still occur in the coming years. Thus, from a Vision Zero, Safe System and Work environment perspective, it is important that the bus driver is sufficiently protected when such accidents happen.

As noted, our study also indicates that the frontal structure of the bus might endanger other vehicles in crashes, as current designs often result in the front of the bus transforming into a hazardous 'lance' or 'battering ram' upon impact. Light vehicle occupants comprise 22% of the killed and severely injured in bus accidents. This is another example of how bus frontal design might be in conflict with Vision Zero/Safe System principles. Our suggested solution also seeks to mitigate this, and it might thus also reduce the injury risk of counterparties in bus accidents.

7.7 Future research

7.7.1 Need for simulations

After the desktop study provided in the present study, it is necessary to implement a deeper study based on simulations and/or testing to validate our recommendations and suggestions. Further research and real-world testing will be crucial in refining the suggested solutions and ensuring their effectiveness across a wide range of collision scenarios. By addressing these compatibility issues, we can work towards a future where the severity of bus-involved accidents is significantly reduced, even at lower impact speeds, thereby enhancing road safety for all vehicle occupants. IDIADA can execute a set of simulations considering different overlaps and angles just to catch the worst-case scenario and from this point to define the proper test to be applied.

7.7.2 How many bus driver KSIs can be avoided?

In the last ten years, 1 459 bus drivers in Europe have been killed or severely injured in accidents. Based on our extrapolated estimates, approximately 2/3 of the bus accidents in Europe have been with frontal impact. This equals approximately 963 killed or severely injured bus drivers in which the severity potentially could have been reduced by a better collision protection solution. With the basis of simulations, we might be able to estimate the number of bus driver KSIs that can be avoided with improved solutions for bus driver collision safety. This can serve as a basis for more precise cost-benefit analyses of the measures we suggest for improved collision protection solutions in the future.

7.7.3 How many KSIs for other road users can be avoided?

Light vehicle occupants comprise 22% of the killed and severely injured in bus accidents. This equals 8 374 killed and severe injuries in Europe in the ten-year period we focus on from the CARE data in the present study. It is important to note that we do not know how important the mentioned ‘lance’ or ‘battering ram’ effect has been as a contributor to injury severity in these accidents. Our suggested solution also seeks to mitigate this and may thereby also reduce the injury risk of counterparties in bus accidents. Given that we do not know how important the ‘lance’ or ‘battering ram’ effect has been for injury severity in accidents with other vehicles, it is important to examine the importance of this in future research. These estimations can also be applied to the implementation of measures like R93.00. This can serve as a basis for more precise cost-benefit analyses of the measures we suggest for improved collision protection solutions in the future.

8 Conclusion

There are no mandatory EU crashworthiness standards focusing on bus drivers. Norway took, however, a lead in bus driver safety and implemented the R29.03 frontal crash test standard for buses as of 01.10.2023. This standard originally applies to trucks. Our literature review shows that current structural designs of bus fronts provide insufficient collision protection for drivers, that R29.03 crash test design requirements are insufficient, and that there is a need for an improved bus front structure. Our desk study, using three fatal Norwegian low speed (about 30 km/h) bus collisions as point of departure, shows that the energy level in these collisions was 10 times higher than the energy tolerance level required by R29.03. We suggest a new solution to provide bus drivers with sufficient structural protection in case of collisions with frontal impact (the bus front improvement model). Extrapolations indicate that 963 bus drivers in Europe have been killed or severely injured in accidents with frontal impact in the last ten years. The severity of these accidents could potentially have been reduced by a better collision protection solution. Although our cost-benefit analyses indicate that the economic costs of the suggested bus front improvement model are higher than the expected economic benefits, we argue from a Vision Zero/Safe System perspective and a work environment perspective, that bus drivers should have the same protection as car and truck drivers in collisions. The bus front improvement model also aims to provide better protection for light vehicles which are in collisions with buses. These comprise 22% of the killed and severe injuries in bus accidents. We recommend that future studies provide tests or simulations of the bus front improvement model, to validate and refine it, to make it more likely that it will be adopted by bus manufacturers, and contribute to defining new requirements for crash protection for bus drivers.

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

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. Safety Science, 48(11), 1397–1405. https://doi.org/10.1016/j.ssci.2010.04.002

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. (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.

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,

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

Hade, 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., 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

Nævestad, T.-O., A. K. Høye, R. Elvik, I. Hesjevoll, Ø. L. Brunstad, V. Milch, J. Blom (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

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

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

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.

Exhibit

Exhibit 1. Details on CARE data

E1.1 Inferring collision partners

Our version of the CARE database contains all accident involved buses, and all other road users involved in or injured in these crashes.[22] However, it is not possible to link bus drivers to specific collision partners (to find out which kind of vehicle the buses crashed with). As the type of collision partner (for example pedestrian, light vehicle, or truck) is strongly related to injury risk and injury severity for bus occupants, we have estimated an approximate average collision partner weight for each bus. These weights represent the relative weight of other (non-bus) road users that crashed on the same types of roads in the same types of crashes.

We have therefore developed a method to estimate the average weight of likely collision partners, using the following steps:

1. Select all drivers of vehicles other than buses; since the data consists only of crashes involving buses, all non-bus drivers can be assumed to be collision partner for a bus.
2. Find the distribution of collision partners for each combination of relevant road and crash characteristics: Road class (principal / secondary arterial / collector / local road), road type (motorway / other dual carriageway / single carriageway), intersection type, area type (urban / rural), speed limit, country, and detailed crash type.
3. Assign the **percentage distribution of collision partners** to each bus driver, based on the relevant road characteristics.
4. Calculate the **estimated average collision partner weight** for each bus driver, based on its percentage distribution of collision partners and weighting factors for the collision partners.

To utilize this method, we estimated **weighting factors** for different vehicle types, by considering the average vehicle weight of each vehicle type on European roads. These weighting factors were calculated by dividing their weight by the average bus weight. The resulting weighting factors (and the approximate average weight in parentheses) are as follows:

- Bus: 1.00 (18.4 ton)
- Truck (mostly heavy trucks): 1.49 (27.5 ton)
- Small truck: 0.15 (2.75 ton)
- Light vehicle: 0.08 (1.5 ton)
- Moped / MC: 0.01 (0.18 ton)
- Bicycle: 0.0004 (0.008 ton)

These estimated collision partner weights are included as a control variable in multivariate analysis. Thus, instead of using the specific collision partner (e.g. “Bus vs. light vehicle”, “Bus vs. truck”, etc.), we use a factor that represents the potential of the “average collision partner” to inflict damage on the bus.

The average weights of collisions partners were based on the following: NEA (2007) measured weight of buses and touring couches on international routes. The study provides measured vehicles weights,

---

[22] The degree to which non-injured road users are included appears to vary between countries and over time

including passenger weight, for different types of buses in the Netherlands, Austria, the UK and Luxemburg. Based on the measured weights we calculated an average bus weight, of about 18.4 tons. However, the weight might depend greatly on the assumptions made in the study and vehicles in the study are not necessarily representative. According to Inovev (2024), the average weight of passenger cars produced in Europe was 1 462 kg in 2022. By simplifying we assume that a European car weighs about 1.5 tons. According to Bikepics (2023), a typical MC weights between 180 and 270 kg, while a scooter typically weighs around 90-180 kg. With this in mind, and if we interpret Moped/MC as a unique group, we assume that Moped/MC weighs about 180 kg. There are many types of different bicycles and each of them has a different weight. However, a typical road bike has an average weight of about 8 kg (Bicycle Warehouse, 2021). In our model, we therefore assume 8 kg as a typical weight of a bicycle. Norwegian trucks below 3.5 tons are registered as vans, while trucks over 3.5 tons are registered as trucks. There is, however, little information about vehicle weight for both vans and trucks/HGVs on European roads. Additionally, the weight also depends greatly on factors like the number of axels, cargo weight, or tractor with trailer or semi-truck configurations. However, we might think that vans normally have a weight between 2.5 and 3 tons. By using this, we assume that vans have a weight of 2.75 tons. We also think that a common vehicle weight for trucks over 3.5 tons, is around 25 to 30 tons. We therefore assume a truck weight of 27.5 tons.

REFERENCES:

Bikepics. (2023). From https://bikepics.com/blog/how-much-does-a-motorcycle-weigh-10-average-figures/

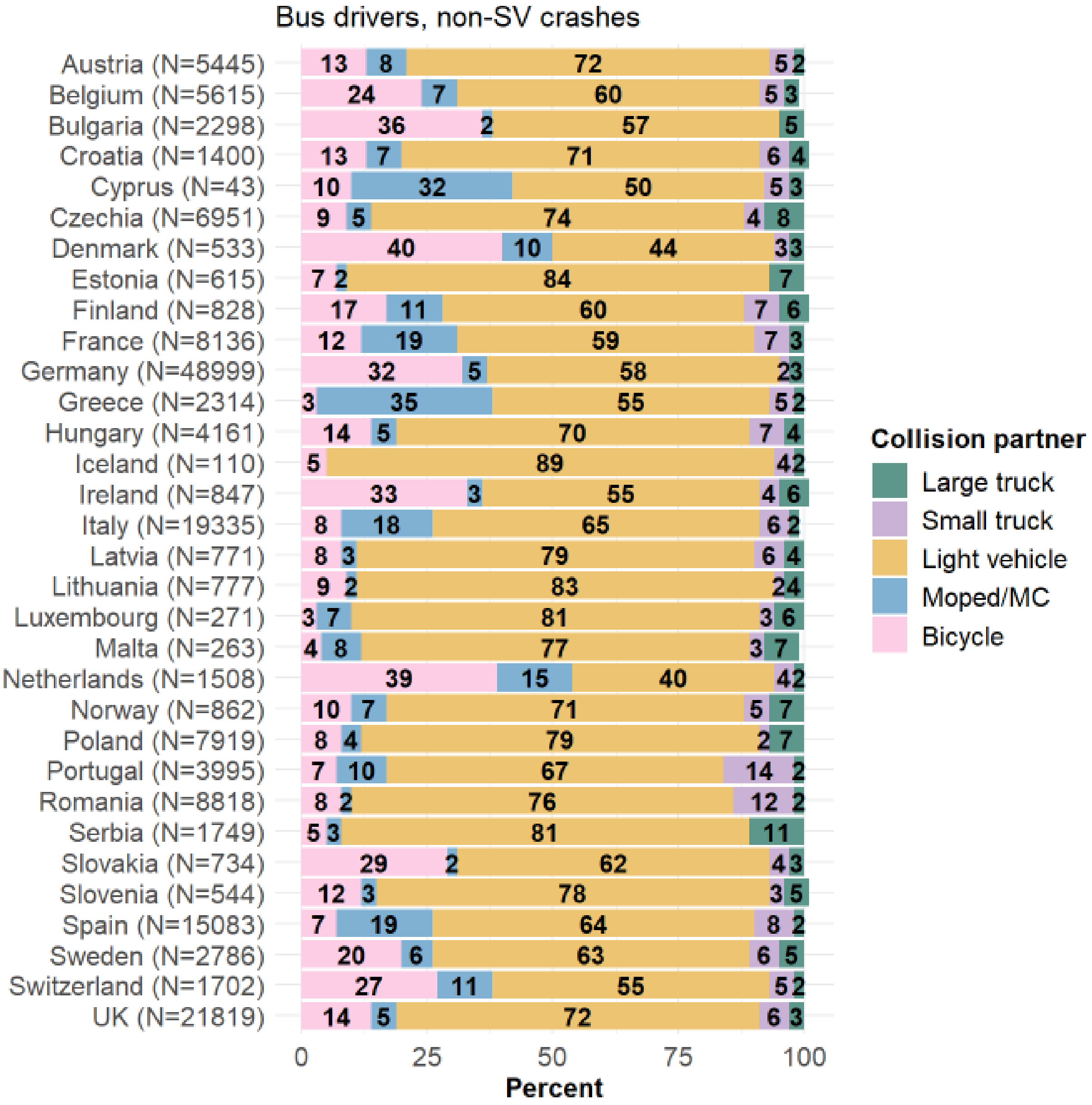
Bicycle Warehouse. (2021). From https://bicyclewarehouse.com/blogs/news/how-much-does-a-bicycle-weigh?srsltid=AfmBOoo41fXhIivR3KOVY2kt_5XzaDxEmlORzH0AKc-HHY98OnlFWQ99

Inovev . (2024). From Automotive Data & Analysis Centre: https://www.inovev.com/index.php/en/market-analyses/category-blog/19969-2023-30-2

NEA. (2007). Research on the Weight of Buses and Touring Coaches. From https://www.iru.org/sites/default/files/2016-01/en-nea-bus-2007.pdf

Distribution of collision partners per country

The following figure shows the distribution of the inferred collision partners for all bus drivers in non-SV crashes for each country. The distributions look reasonable; most potential collision partners are light vehicles, and countries with a lot of bicycle traffic, especially the Netherlands, have many cyclists as potential collision partners.



Vehicle types by crash type for inferred collision partners and actual collision partners.

The following figure shows the distribution of vehicle types other than buses by crash type (non-SV crashes). All these vehicles were involved in bus crashes (we know this because our CARE data include only road users involved in bus crashes), so that this is the ‘real’ distribution of actual collision partners for buses (all countries, all years).

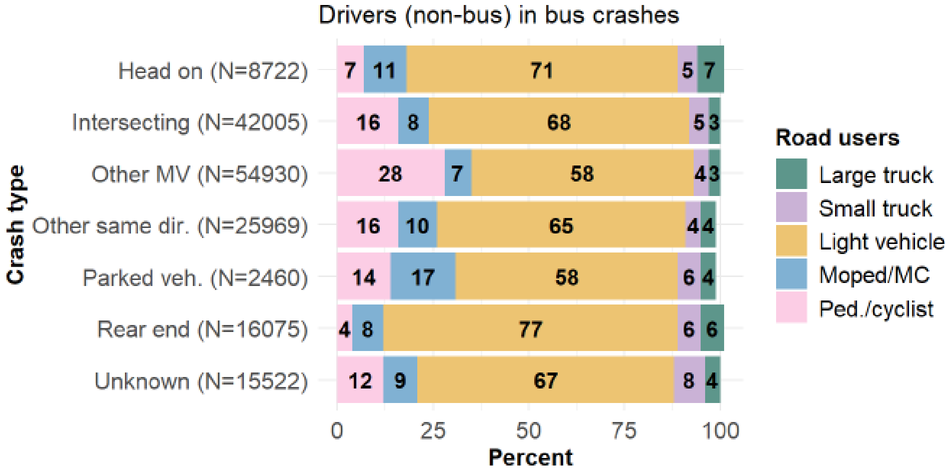


Figure E1 1. Observed collision partners (non-bus occupants) involved in collisions with buses.

The following figure shows **inferred collision partners** for injured bus drivers in non-SV crashes: The percentages refer to bus drivers and which other road users crashed at the same type of sites and in the same type of crash as them, e.g. 70 percent of bus drivers in head-on collisions are assumed to have crashed with a light vehicle. The distributions are very similar to those in the figure above, which indicates that the matching of bus drivers to collision partners is quite reasonable.

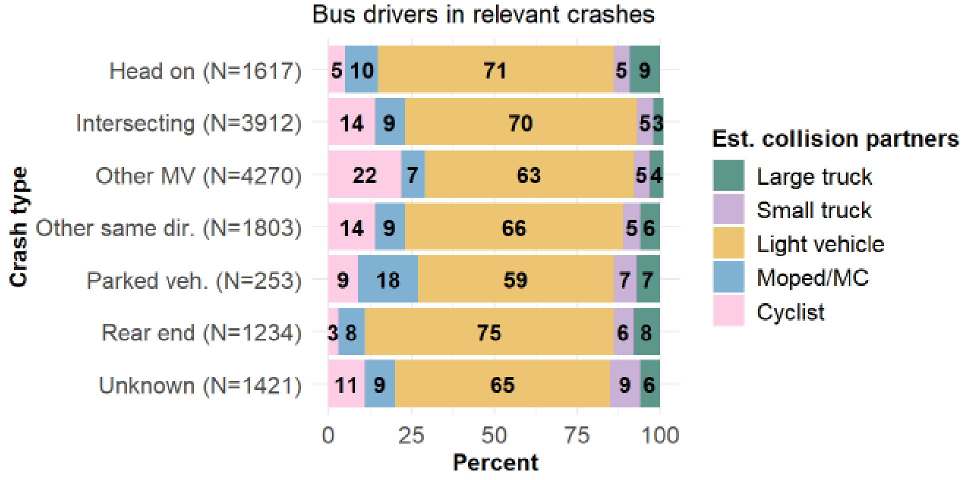


Figure E1 2.Inferred collision partners.

E1.1 Bus types

In the CARE database, there are originally three bus types:

- **Unspecified bus:** “Bus or minibus or coach or trolley” in CARE, defined as “Passenger-carrying vehicle, having more than 9 seats for passengers, most frequently used for public transport.” In countries where all buses are “unspecified”, this category probably includes all kind of buses. In countries with both “unspecified” and “large” buses, we assume that the “unspecified” buses may be minibuses.
- **Large bus:** “Bus” in CARE, defined as “Passenger-carrying vehicle, most commonly used for public transport, having more than 16 seats for passengers.” In countries with no interurban buses, this category probably includes both large city buses and coaches (interurban buses). In countries with both large and interurban buses, we assume that all large buses are large city buses.

- **Interurban bus:** “Coach” in CARE, defined as “Passenger-carrying vehicle, having more than 16 seats for passengers. Most commonly used for interurban movements and touristic trips. To differentiate from other types of bus, a coach has a luggage hold separate from the passenger cabin.”

Since the three original bus categories in CARE probably mean different things in different countries, we have split up the bus types as follows:

- **Unspecified bus**: Unspecified buses in countries with only unspecified buses. These countries are Denmark; Finland; Iceland; Portugal, Serbia, Slovenia, United Kingdom
- **Small bus**: Unspecified buses in countries with both unspecified and large buses. These countries are Denmark, Finland, Iceland, Portugal, Serbia, Slovenia, United Kingdom
- **Large bus, unspecified**: Large buses in countries with large buses and without interurban buses, including countries with unspecified and large buses. These countries are Austria, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Spain, Sweden, Switzerland
- **Large city bus**: Large buses in countries with large and interurban buses. These countries are Belgium, France, Germany, Luxembourg, Malta, Norway, Slovakia
- **Interurban bus**: Interurban buses, whenever available. Countries with interurban buses are the same as those with large city buses.

TØI is an applied research institute that carries out research and study assignments for businesses and public agencies. TØI was established in 1964 and is organized as an independent foundation. TØI develops and disseminates knowledge about transport with scientific quality and practical application. The department has an interdisciplinary environment with 90+ highly specialized researchers.

The department conducts research dissemination through TØI reports, articles in scientific journals, books, seminars, as well as posts and interviews in the media. The TØI reports are available free of charge on the department's website www.toi.no.

TØI covers all means of transport and thematic areas within transport, including traffic safety, public transport, climate and environment, tourism, travel habits and travel demand, urban planning, ITS, public decision-making processes, business transport and general transport economics. The institute participates actively in international research collaboration, with particular emphasis on the EU framework programs.

The Department of Transport Economics requires copyright for its own work and emphasizes acting independently of the clients in all professional analyses and assessments.

Postal Address:
Institute of Transport Economics
Gaustadalléen 21
N-0349 Oslo
Norway

Email: toi@toi.no

Business Address:
Forskningsparken
Gaustadalléen 21

Web address: www.toi.no