Institute of Transport Economics
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ENGLISH **Summary**

Crashworthiness of buses

Analysis of European data and suggestions for improvement

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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 crash-worthiness 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.

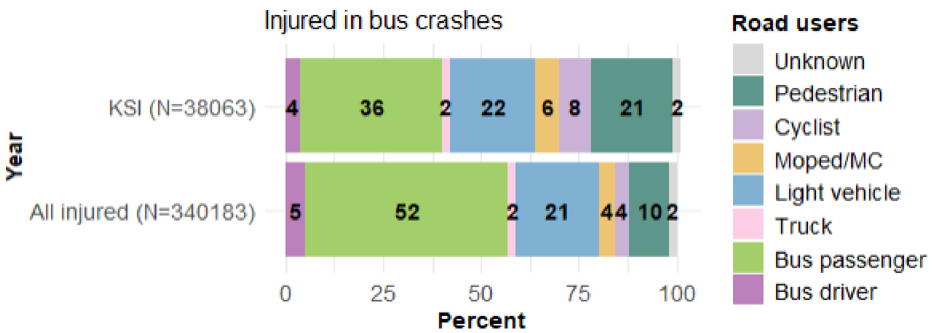

Figure S.1: Distribution of road users injured in crashes involving buses. CARE database 2013-2022.

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.