

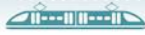
# Literature review of active and passive measures to improve bus safety

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

## Background

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



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

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

## Aims

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

The literature reviews have three aims:

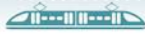
- 1) **Examine what studies of bus accidents** say about severity and mechanisms of injury (e.g. bus design) among drivers, passengers and other road users involved in accidents.
- 2) **Map passive safety measures** that may protect bus drivers (and possibly passengers) from injuries in collisions, especially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

## Bus/Coach is one of the safest mode of transport

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

## Insufficient protection of the bus driver

The literature review shows that there are few studies focusing on the collision protection of bus drivers and on the role that technical aspects of bus design plays for personal injuries of bus drivers. Existing studies indicate that the main focus in bus safety regulation is bus



passenger safety. Bus safety regulations apply for instance to rollover incidents, regulated through ECE regulation 66, or evacuation safety, regulated in ECE regulation 107. There are no mandatory European collision safety regulations for bus drivers.

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

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

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

## New technologies aiming to avoid accidents

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

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

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

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



## Bus drivers' vulnerabilities in a Safe System

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