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THE IMPORTANCE OF BUS PASSENGER TRANSPORT FOR ENHANCING ROAD SAFETY

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Abstract: Bus transport is one of the most common modes of road travel in Europe, according to the European Commission. However, data from recent years indicate that approximately 500 people are killed annually in Europe in road traffic accidents involving buses. Statistics from 2015 indicate approximately 30.000 injuries per year resulting from bus-related accidents in Europe. Certain trends, such as accidents involving passengers falling inside buses, have brought the issue of bus safety into greater focus. This paper provides an overview of the current state of safety in bus transport and potential measures for improving road safety for both drivers and passengers. The aim is to provide decision-makers and other relevant authorities and stakeholders with a basis for establishing effective and appropriate requirements for improving road safety. The paper seeks to identify approaches that could help ensure that as few people as possible are killed or seriously injured in road-based bus transport by improving overall road safety for drivers, passengers, and other road users interacting with buses.
Keywords: passenger transport, bus, accidents, prevention.

1. INTRODUCTION

Most users perceive travel by public transport, whether by bus, train, or tram, as very safe. In recent years, however, buses have been increasingly involved in severe road traffic crashes, and a considerable number of passengers are injured in incidents occurring inside the vehicles themselves. In addition, the growth in urban traffic volumes and the emergence of new modes of transport, such as electric scooters, have led to more frequent conflicts between buses and vulnerable road users in urban areas.

This paper provides an overview of the state of passenger and driver safety in bus transport, together with possible measures for improving it. The aim is to present the current situation and to propose measures that would reduce both the number of crashes and the severity of their consequences. The paper is based on data on road traffic crashes and incidents, as well as on a literature review, in order to consolidate the available knowledge on the effects of measures aimed at improving bus safety.

2. STATE OF ROAD SAFETY

European data show that, between 2010 and 2019, the number of fatalities in crashes involving buses and coaches decreased by 34%. Crashes involving buses are characterized by a high share of vulnerable road users (37%), and pedestrians in particular (29%), which stems from the urban environment in which a large number of buses operate. Bus drivers are exposed to approximately the same risk of injury as car drivers, but to a higher risk than bus passengers.

However, injuries to bus passengers are often recorded incompletely and inadequately. In reports, buses are usually not identified as a separate category but are grouped with heavy goods vehicles. Since a bus carries, on average, considerably more passengers than a goods vehicle, underreporting of injuries is likely to be more pronounced for buses. Moreover, most injuries do not occur in road traffic crashes but in events inside the vehicle or during boarding and alighting; such events account for 80–85% of all passenger injuries in buses. They are most frequently caused by sudden braking and acceleration.

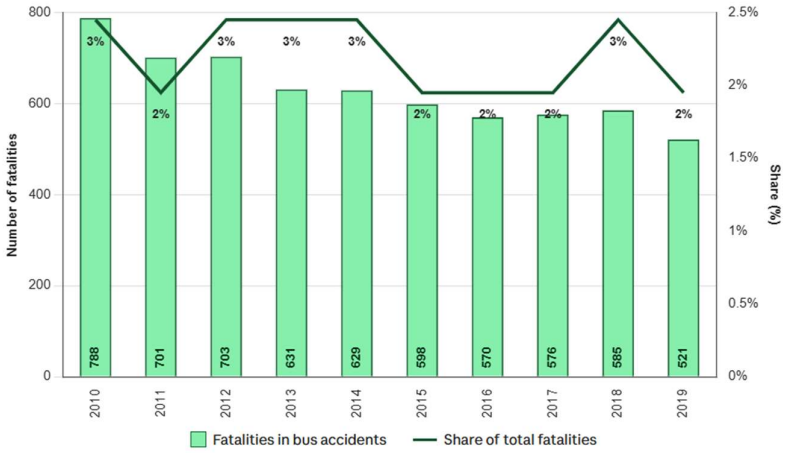


Figure 1. Number of fatalities in road traffic crashes involving buses in Europe and their share of total road fatalities.

According to official statistics, the estimated risk of passenger injury in bus crashes in recent years is approximately 0.007. After correction for underreporting, it is proposed that the actual risk be estimated at 0.05.

A non-collision injury is any injury that does not result from a collision but from other events. These include, for example, injuries inside the bus caused by sudden braking or acceleration, particularly among standing passengers, as well as injuries sustained when boarding or alighting. The average risk of falling in a moving bus is estimated at approximately 0.3–0.5 cases per million passenger-kilometers, while the risk of injury when boarding or alighting is about 0.8–1.7 cases per million passengers. Falls in buses are difficult to prevent, since even a small change in speed or direction is sufficient to cause a standing passenger to fall or lose support. Measures such as grab poles have a dual effect: they help passengers hold on, but if a passenger loses their balance, the poles constitute an obstacle they may strike.

The risk of death or serious injury among bus drivers declined between 1990 and 2022, although a reliable trend line cannot be established. On average, this risk decreased by approximately 5.1% per year.

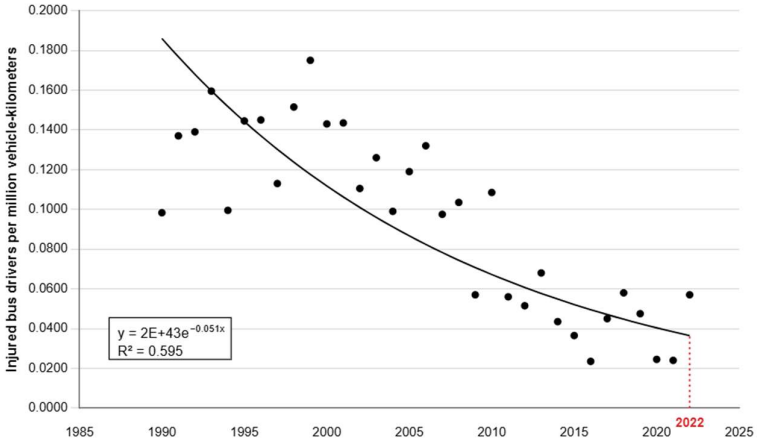


Figure 2. Injury risk for bus drivers, 1990–2022

A declining tendency is also observed among bus passengers, for whom the average annual reduction in injury risk was 7.3%. It should be noted that a slight increase in risk was recorded in 2021 and 2022. The risk of passenger injury can also be reduced and mitigated through gentler acceleration and deceleration of the bus (a change in driving style), floors with a high coefficient of friction (fewer slip-related falls), high-quality handrails, low-floor buses (fewer injuries when boarding and alighting), and the elimination of standing places.

Due to its size, a bus affords its occupants a high level of protection, so most injuries in collisions with buses are sustained by other road users. Nevertheless, there has recently been a growing number of bus drivers injured in severe crashes under circumstances that should not result in such serious consequences. Fatal cases have even been recorded at speeds not exceeding 30 km/h. The key reason for such severe outcomes at low speeds is the absence of legal requirements regarding physical crash protection at the front of buses, as a result of which some buses do not provide drivers with sufficient protection in the event of a crash.

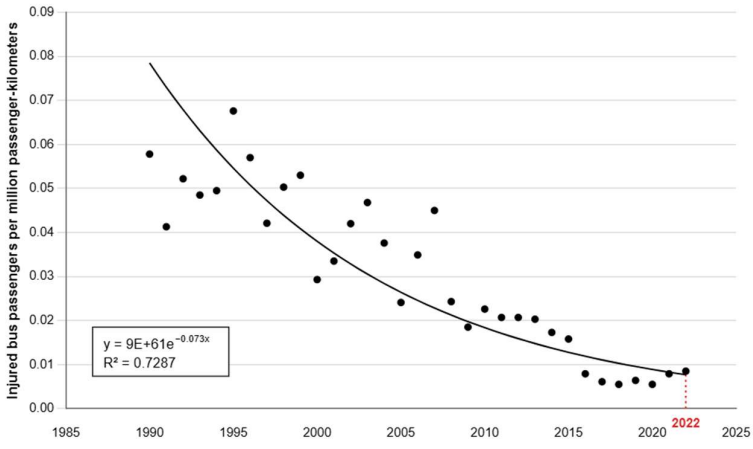


Figure 3. Injury risk for bus passengers, 1990–2022

2.1. Data on bus crashes in europe

Bus crashes account for 2% of all road fatalities in Europe, whereas crashes involving heavy goods vehicles account for 14% of all fatal road crashes in the European Union. In terms of demographic structure, men make up the majority of those killed in bus crashes (64%), and persons over the age of 50 are more strongly represented among the age groups. As regards road user type, 21% of fatalities are passengers and drivers who were inside the bus. This differs from fatal crashes involving passenger cars, in which car occupants account for 60% of fatalities. The cause of this distribution lies partly in the dimensions of the vehicle, which protect the vehicle itself and its occupants, while the consequences are borne by other road users involved in the crash.

Regarding road types, the shares of fatalities in bus crashes on urban and rural roads are similar (49% versus 42% in 2018). On motorways, fatal bus crashes were rare and accounted for 9% in 2018. Most fatalities occurred on particular road sections and corridors rather than at intersections themselves.

3. PASSENGER AND DRIVER SAFETY INSIDE THE VEHICLE

3.1. Seat Belts for Passengers and Drivers as a Measure for Reducing Crash Consequences

Passenger seat belts are not installed in all buses. Urban buses typically have no passenger seat belts, and it is not uncommon for buses on intercity routes to lack them as well.

The example of the Scandinavian countries shows that seat belt regulations differ according to vehicle type. Urban buses (the first vehicle type), which have more standing than seating places, are not required to be equipped with seat belts. For suburban and intercity buses (the second vehicle type), it is required that seated passengers must be able to use a seat belt, whereas standing passengers are not required to do so. Tourist and express coaches (the third vehicle type) have seating places only, and the use of seat belts is mandatory for all passengers. Unfortunately, even where seat belts are installed, a large number of passengers do not use them, which increases the severity of consequences in the event of a bus crash.



Figure 4. Seat belts for bus passengers.

For the first vehicle type, the installation of seat belts is not considered justified, because urban buses stop frequently and dwell times at stops would be prolonged until all alighting

passengers had unfastened their belts. The main reason for this conclusion is the low travel speed in urban conditions. Type 2 buses more often operate on roads with higher speed limits, which entails a greater risk of injury for seated passengers without seat belts, as well as for standing passengers in the event of a fall. Consequently, the measure of introducing and using seat belts in this type of bus is effective for approximately 60% of the passengers on board. Research shows that Type 3 buses, in which seat belt use is mandatory for all passengers, successfully reduce the number of injuries in collisions.

The use of any type of seat belt reduces the overall risk of injury by approximately 20%. The risk of serious injury decreases by approximately 50% with two-point seat belts and by approximately 80% with three-point seat belts. In bus rollovers, no significant differences in mitigating consequences were observed between these two seat belt types. An indirect effect of seat belt use is improved passenger behavior: a belted passenger, by definition, does not stand, leaves their seat less often, and distracts the driver less.

All buses are equipped with seat belts for the driver, but not all drivers use them, although it is known that their use among heavy vehicle drivers has increased considerably in recent years. Measures to increase seat belt use among bus drivers are mainly technical. Seat belt reminders are already installed in most buses, while interlock systems, which prevent the bus from starting if the driver is not wearing a seat belt, could prevent driving without a seat belt. Both types of measures can be bypassed relatively easily if the driver fastens the seat belt behind their back, and this poor habit is common in practice.

3.2. Seat Backs and Handrails: Design and Suitability for Passenger Protection

The shape and materials of seats can influence the risk of passenger injury in buses, both in collisions and in falls unrelated to collisions. Some studies show that high seat backs reduce the risk of injury, both for passengers seated facing the direction of travel and for those seated facing against it. The choice of materials affects the deformability and energy-absorption capacity of the seat, which is directly related to injury severity. Seat back design is important because passengers may strike them in collisions and falls, but excessively flexible seat backs lose their basic function.

To allow standing passengers to hold on during the journey, as well as when moving through the bus, handrails, grab handles, and other elements are necessary. Their installation is particularly important in vehicles in which not all passengers are seated throughout the journey, but handrails may also be needed in vehicles with seating places only, for movement between the seats and the doors.

Handrails and grab handles may be mounted beneath the bus ceiling, but not all passengers are tall enough to reach them. In collisions and falls, injuries often result from striking handrails or grab handles on seat backs. It is difficult to manufacture them from materials with better energy-absorption properties, so it is important to select their shape and position to minimize injury risk. Replacing horizontal handrails with vertical ones prevents certain characteristic injuries.

3.3. Securing Wheelchairs and Strollers

Wheelchairs and strollers are usually placed in the free space next to the bus doors designated for them. Both in a collision and during normal driving, wheelchair users may be exposed to injury from impact with seats or handrails, other passengers, or unsecured luggage, as well as from overturning. The risk of injury can be reduced by securing the wheelchair with seat belts,

by an appropriate restraint system, by the correct positioning of handrails and grab handles, and by reducing the amount of unsecured luggage.

3.4. Crash Protection and Driver Protection as a Measure for Mitigating Crash Consequences

Crash protection and driver protection are particularly significant in frontal collisions, run-off-road crashes, and rollovers. Crash protection refers to the capacity of the structure to protect passengers during an impact and depends on structural integrity and energy absorption. Structural integrity refers to the space that remains for occupants after an impact, the so-called "survival space." Energy absorption is the amount of energy absorbed by structural elements; the greater it is, the less severe the consequences are for occupants of the collision. Both factors may depend on the choice of materials, their properties, and the design of deformation zones.

Buses are generally well protected in the passenger compartment, whereas the area around the driver is less well protected. Since there is no requirement to install protective beams around the driver's seat, as there is for trucks, bus drivers are particularly vulnerable in frontal collisions, especially with other larger vehicles and rigid obstacles such as walls and pillars.



Figure 5. Damage to the front of a bus involved in a crash.

4. PROTECTION OF ROAD USERS IN COLLISIONS WITH BUSES

Measures for protecting vulnerable road users cover all bus measures and features that affect the severity of injuries to vulnerable road users, primarily pedestrians and cyclists struck by a bus. Approximately half of all bus–pedestrian collisions occur on roads with a speed limit of 30 or 40 km/h, that is, mainly in urban areas, where pedestrians are most numerous. Most pedestrians in collisions with buses are struck by the front of the bus, a large number by its side, and a small number by its rear. The highest share of seriously injured or killed pedestrians is recorded when the front of the bus strikes the pedestrian, followed by the side, and the lowest share when struck by the rear.

For cyclists, most impacts involve the side of the bus. Such collisions typically occur when a bus overtakes a cyclist, either between intersections or at intersections, when the bus turns right while the cyclist continues straight ahead.

The severity of consequences is affected by the shape of the bus front, the windscreen, the position of rigid elements, the capacity of the front structure to absorb energy, and other factors. Bus speed affects injury severity, especially when a pedestrian or cyclist is struck by the front of the vehicle.

Some protection measures are still under development and testing, such as run-over protection (devices beneath the bus that activate and prevent contact with a pedestrian who has been thrown under the front axle), pedestrian airbags, and the replacement of side mirrors with cameras (which reduces the number of pedestrians and cyclists struck by a mirror).

Driver assistance systems are also important, such as intelligent speed assistance, obstacle detection when reversing, blind-spot monitoring, warning and braking for potential collisions with pedestrians and cyclists, lane departure warning, and tire pressure monitoring.

An interesting technology still under development is a geofence-based speed limiter. The system adjusts the vehicle's speed when it enters a predefined digital area, so that, for example, speed could be limited to 20 km/h in the zone around bus stops. This would reduce the number of passenger falls inside the vehicle and collisions between passengers. On the other hand, this system increases bus delays and driver stress levels.

Another example of technology, present in some countries, is the alcohol interlock, which prevents the bus from being started until the driver has taken an alcohol test and obtained a negative result. This is an example of good practice that should be pursued.



Figure 6. Example of alcohol testing before starting a bus equipped with an alcohol interlock.

Despite all the advantages of these safety systems, there are also shortcomings and limitations. A lane-keeping system, for example, will not function correctly if road markings are not properly and clearly applied. Another example is the tampering with alcohol interlocks via a switch that allows the engine to be started in the event of a technical fault.

5. MEASURES FOR IMPROVING BUS TRAFFIC SAFETY

Measures can be divided into organizational measures, measures relating to passenger safety inside the bus, vehicle structural safety and driver crash protection, protection of vulnerable road users in collisions, driver assistance systems, and other measures.

Many of these measures, although they may be highly effective in preventing road traffic crashes, are not sufficiently regulated by law. On the other hand, there are also measures that are mandated but insufficiently enforced, an example being the use of seat belts by passengers in Type 2 and Type 3 buses. Some measures are still under development and require further research. These include, among others, geofence-based speed limiters, warning systems for vulnerable road users and automatic emergency braking systems, run-over guards and pedestrian airbags, measures for preventing falls inside buses, and measures for the safe securing of wheelchairs and strollers.

Measures that should be considered and introduced in bus transport include:

1. fleet management systems that enable a calm and safe driving style;
2. measures aimed at improving road safety culture;
3. safety management systems;
4. driver crash protection systems.

6. MEASURES FOR REDUCING CRASH FREQUENCY AND CONSEQUENCES

Safety management systems include measures for the systematic management of road safety: risk identification and analysis, development of corrective measures, definition of roles and responsibilities, regular monitoring of safety conditions and indicators, and the implementation of the measures themselves. All of this constitutes the formal aspect of safety management, whereas the informal aspect is based on actual conditions and people's behavior. Two factors of great importance in this group are management commitment to safety and safety communication. Risk analysis is also important, since insurance claims are lowest for precisely those transport companies that proactively analyze risks. The informal aspect comprises what "people actually do," which is related to safety culture. Driver training in safety and safe behavior also contributes to improving conditions.

Research shows that the road sector in general, including bus transport, pays less attention to safety culture than other transport modes. Nevertheless, the link between safety culture and crash risk cannot be ignored. Simple measures, such as employees proposing and implementing solutions to safety problems together (for example, drivers and traffic planners in bus companies), can be cost-effective and produce good results. The mechanism of peer pressure should also be used, as it can contribute to safer behavior in traffic, while high-quality campaigns can raise awareness of the importance of a high level of safety culture.

Interventions in this area mainly consist of driver self-monitoring supported by technology, supervision, and management support. Driving style parameters (braking, acceleration, engine idling, fuel consumption, etc.) are recorded, and training is individually tailored to drivers based on their results. Management can use a system of rewards and penalties to motivate drivers to change their driving style. The calmer the driving and the less sudden braking and acceleration occur, the lower the likelihood of passenger injury inside the bus due to falls or during boarding and alighting. However, sudden braking caused by the unpredictable behavior of other road users cannot be prevented in this way.

Among the most effective and important measures for reducing crash frequency are warning systems for vehicles or objects in the blind spot and measures for improving visibility. In buses, wide A-pillars worsen the blind-spot problem, which contributes to crashes in which pedestrians are killed or injured.

Among measures for reducing crash consequences, the following stand out: seat belts (in Type 1, 2, and 3 buses), measures to increase seat belt use among bus drivers, and driver crash protection.

The conspicuity of buses can be improved through appropriate measures. Although buses are large vehicles, other road users may nevertheless overlook them. Contour markings and side marker lamps contribute to their conspicuity. Contour markings consist of retroreflective strips applied along the exterior of the body, and side marker lamps serve the same purpose, better conspicuity. Retroreflective strips applied to the rear and sides of buses can reduce the number of crashes in which another motor vehicle strikes a bus from behind or from the side in darkness by 20–40%. For side marker lamps, the reduction in the number of crashes is 7%.

More frequent periodic technical inspections of buses can reduce the number of road traffic crashes by 12% if the number of inspections is increased by 50%. It is particularly important to detect defects in braking systems and tires of these vehicles in a timely manner.

Electric buses must be equipped with an acoustic system that, by emitting a specific sound, warns pedestrians and other road users of the bus's presence on the road. If an electric bus has no such system, this further contributes to crashes with pedestrians and cyclists, who are unaware of the presence of an approaching bus moving behind them.

7. CONCLUSION

This paper shows that the safety of bus transport cannot be viewed solely through the safety of passengers. Owing to its dimensions and construction, a bus protects the passengers inside it well, but the consequences of crashes are often borne by other, more vulnerable road users. Therefore, the main focus of safety improvements should be directed at vulnerable road users, primarily pedestrians and cyclists.

The paper also concludes that the recording of injuries needs to be improved, since road safety cannot be managed without accurate and precise parameters on which it is based. The road safety situation in Europe shows progress: the number of fatalities in bus crashes decreased by 34% between 2010 and 2019, and the risk of death or serious injury declined by approximately 5.1% per year for drivers and 7.3% for passengers. Nevertheless, a reliable trend line cannot be established, and the slight increase in risk for passengers in 2021 and 2022 shows that progress is not guaranteed.

Each of the measures discussed has its advantages and disadvantages. Some have proven particularly significant for improving safety, including fleet management systems for calmer and more consistent driving, seat belts in buses, improvement of safety culture, driver assistance systems, and warning systems for vulnerable road users together with automatic braking in such situations. No measure is universally applicable, since its effect depends on the vehicle type, driving conditions, and other characteristics, so the shortcomings of each measure must be considered. The analysis of measures shows that some are not legally mandated, others are mandated but insufficiently applied in practice, while a third category is still under development and requires further research.

The paper also indicates that technical solutions are often circumvented (e.g., seat belts fastened behind the back, bypassing the alcohol interlock with a switch), which is why participants' behavior must be influenced through organizational measures, primarily by strengthening safety culture.

On the basis of the above, decision-makers and competent institutions are recommended to:

- improve injury recording so that buses are treated as a separate category, including non-collision injuries;
- ensure more consistent application of existing regulations through better enforcement and sanctioning of violators;
- combine multiple measures (e.g., technical and organizational) rather than relying on a single type;
- encourage the evaluation of the effectiveness of measures under development and consider the possibility of their implementation.

Bus traffic safety is improved systematically, and every prevented crash means fewer casualties, both among passengers and among other road users.

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