Institute of Transport Economics
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ENGLISH **Summary**

Technical Study of collision protection for bus drivers

Development of new solution trends for collision protection

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The main objectives of this study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for collision protection. The basis for the technical study is formed by three in-depth reports from the Norwegian Safety Investigation Authority (NSIA), focusing on the 2017 Nafstad, 2021 Tangen and 2022 Fredrikstad bus accidents in Norway. The current report 1) Suggests seven measures to improve crash compatibility, 2) Discusses the position of the driver, 3) Proposes reinforcements in bus structures, 4) Proposes reinforcement of front grill and floor of buses, and 5) Proposes reinforcement of the roof. It is concluded that simulations and testing are needed to refine these solutions and to ensure their effectiveness across a wide range of collision scenarios. Although there are no mandatory EU crashworthiness standards focusing on bus drivers, Norway took a lead in bus driver safety and implemented the UN R29.03 frontal crash test standard for buses as of 01.10.2023. Our estimations indicate that UN R29.03 crash test design requirements are insufficient and that there is a need for an improved bus front structure. Using the three fatal Norwegian low speed (e.g. ca 30 km/h) bus collisions as point of departure, estimates indicate that energy levels in these collisions were 10 times higher than the energy tolerance level required by UN R29.03. The current report 1) Suggests seven measures to improve crash compatibility, 2) Discusses the position of the driver, 3) Proposes reinforcements in bus structures, 4) Proposes reinforcement of front grill and floor of buses, and 5) Proposes reinforcement of the roof. It is concluded that simulations and testing are needed to refine these solutions and to ensure their effectiveness across a wide range of collision scenarios.

Weaknesses in the collision safety of current bus design

In recent years, the Norwegian Safety Investigation Authority (NSIA[1]) issued three reports on accidents with head-on collisions between buses (AIBN 2019; 2022; 2023). These accidents occurred at Nafstad (2017), Tangen (2021) and Fredrikstad (2022), and all resulted in fatalities.

[1] Previously AIBN

All three accidents further raised questions about weaknesses in the collision safety of current bus designs, and insufficiencies in regulatory requirements for the crashworthiness of buses.

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. The driver of one bus was killed instantly, and the driver of the other bus was critically injured.

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.

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 suffered minor injuries.

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), raise particular concerns. This is because the collisions resulted in both fatalities and a lot of 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.

Aims

The main objectives of the current study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for structural improvements in collision protection. The basis for the technical study is formed by the three abovementioned in-depth reports by the NSIA.

The aims of the present study are to:

1) Review the three Norwegian bus accidents studied by the NSIA, and estimate crash energy
2) Review bus and truck regulations for passive safety
3) Propose measures to improve the collision protection of bus drivers

Estimation of impact energy

Despite the introduction of new regulations in Norway requiring frontal impact tests (i.e. UN R29.03), these do not address the structural weaknesses observed in the aforementioned accidents. The impact energy of each of these three accidents was calculated 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 estimated to be 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 compact 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 changes to the bus structure.

Measures to improve collision protection

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 vehicles. What's particularly alarming is the disproportionate severity of both structural damage and personal injuries, especially considering the relatively low impact speeds in these incidents.

A common factor in all three accidents was the small overlap 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 crash compatibility.

1. **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.
2. **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.
3. **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.
4. **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials in bus construction could provide better protection without significantly increasing vehicle weight.
5. **Compatibility Design Standards:** Developing specific standards for vehicle compatibility between buses and smaller vehicles could lead to designs that interact more safely during collisions.
6. **Mandatory Implementation of Regulation UN R93.00**: The United Nations Economic Commission for Europe Regulation No. 93 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 regulation UN 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.

7. **Integration with Towing Hook regulation:** Combining requirements from UN R93.00 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 serviceability.

Implementing these solutions would require a coordinated effort from vehicle manufacturers, regulatory bodies, and safety organizations. By mandating the 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.

The position of the driver

The position of the driver is quite important with respect to the severity of accidents. In urban buses, the height of the driver position is approximately 800mm to 1000mm, 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 position of the driver slightly, but ergonomics would have to be checked in order to be 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 movement restrictions due to the small distance from the seat to the front wheelarch position. In some specific cases it would mean eliminating the capacity of a row of seats, which would make the bus less competitive in the market.

Reinforcements in the structure

In the three studied Norwegian bus accidents, one can see that bus lateral side structures are totally intruding opposite buses, by literally ‘cutting’ the structure, like a knife does. The level of severity for this type of accident is extremely high, so structural design, reinforcements and materials should be focused on avoiding this situation as much as possible to improve crash compatibility. Structural reinforcements should 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 to avoid the collapse of connection hinges to be close to the driver. The strategy could be to use a ‘semi-cage’ open structure, protecting the lower area, as well as providing a better connection with the roof.

In addition, the amount of energy absorption by the structure is important to manage. The reality of these accidents shows that energy levels are much higher than the energy level proposed by the test type-A, required by regulation UN R29.03, which collides a pendulum impactor of 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.

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 that 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, not bus vehicles. In this case, our proposal is to extend this requirement, to combine the requirements of R1005/2010 and UN R93.00, and to develop a frontal structure to effectively increase the crumple zone and energy absorption capabilities of the bus.

This extended structure would serve 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 probably 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.

Reinforcement of the roof

Looking at the three discussed Norwegian bus accidents, upper roof connections were detached from buses' lateral structures. From the accident at Tangen (2021), we could additionally observe that the roof structure was bended down due to the big deformation occurring 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 in the safety results during the crash. Our 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.

Need for future studies

The present study is a desk study, and it is necessary to implement a deeper study based on simulations and/or testing to validate our recommendations and suggestions. It is important to execute a set of simulations considering different overlaps and angles to catch the worst-case scenario, and from this point to define proper tests to be applied. Further research and real-world testing will be crucial in refining our suggested solutions and in 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, including at lower impact speeds, thereby enhancing road safety for all vehicle occupants.