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Crashworthiness of buses: Analysis of European data and suggestions for improvements

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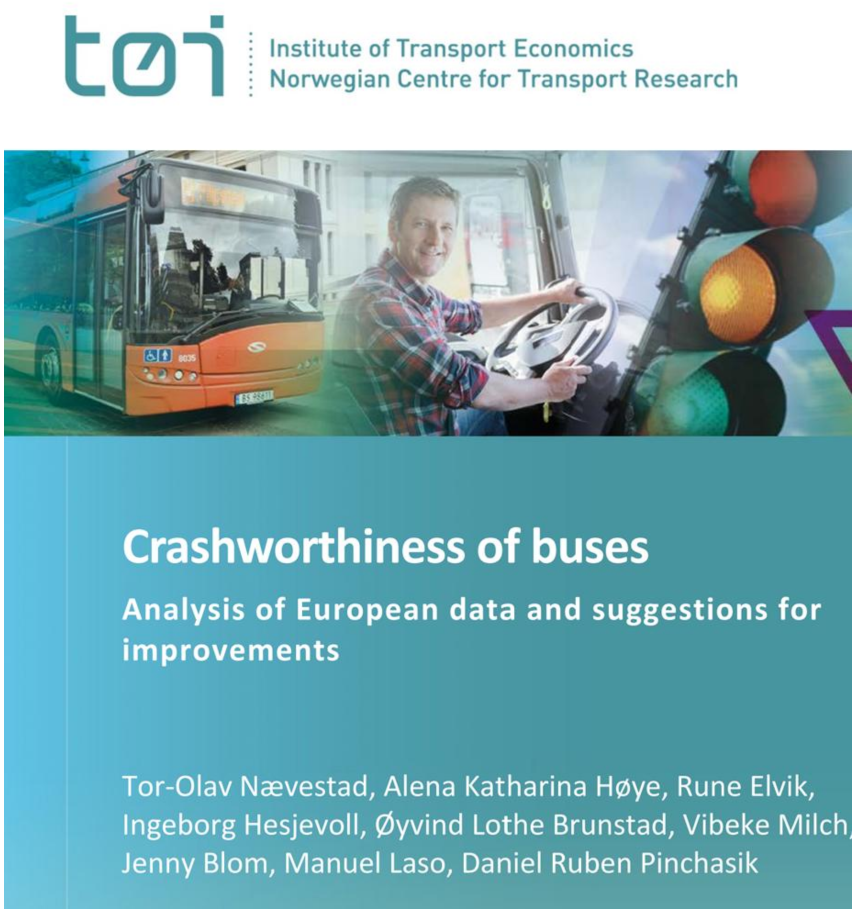
Research in motion

Outline

- What put this on the agenda in Norway
- The scope of the problem
- The nature of the problem
- Suggestions for improvement
- Costs, benefits and safe system
- Ongoing and future work



Research commissioned by Norwegian public road administration

Bus drivers are more vulnerable in collisions than car and truck drivers

Lacking crumple zones in bus fronts

Lack of mandatory EU crashworthiness standards focusing on bus drivers

Low driver seating position in many buses (e.g. city buses).

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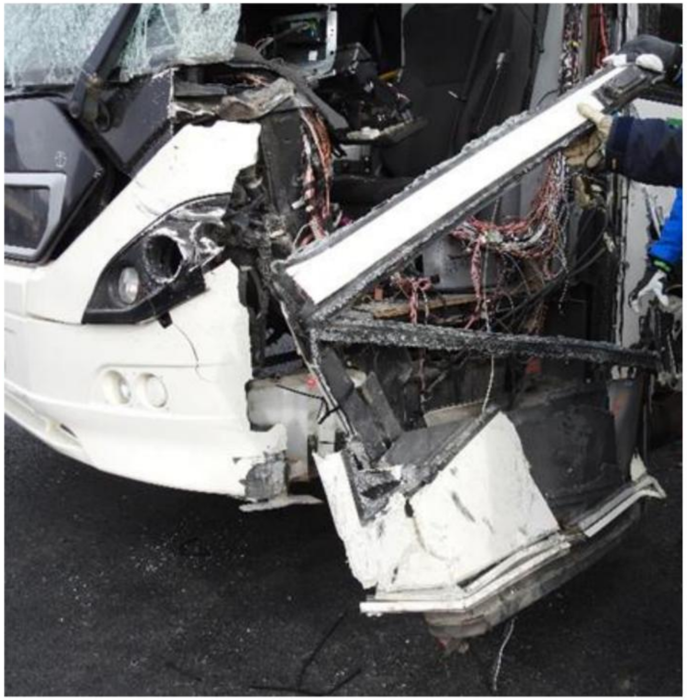
Nafstad 2017: Fatal head on accident with two buses colliding at 34 km/h

Figure 5: Damage to the front of the westbound bus. Photo: AIBN

Figure 6: Cross-beam severed on the left-hand side, seen from the side. Photo: AIBN

Tangen 2021: Fatal head on accident with two buses, around 35- 50 km/h



Photos: AIBN

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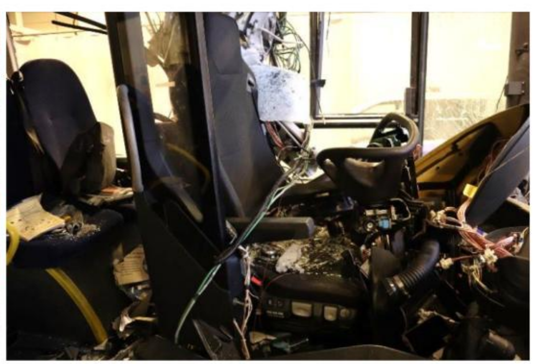
Fredrikstad 2023, fatal head-on accident with two buses, speed 35 km/h

Figur 3: Buss 113 sett forfra. Foto: Politiet

Figur 4: Førerplass i Buss 113. Førerstol er presset bakover som følge av inntrengingen. Foto: SHK

Figur 5: Buss 5 sett fra siden. Foto: Politiet



Figur 6: Førerplass i Buss 5. Førerstol intakt. Foto: SHK

Photos: AIBN, police

Summing up the background

Bus drivers have been killed in low-speed accidents.

Passenger cars crashing at similar speeds would likely not have led to fatalities

The automotive industry has made progress with respect to vehicle safety, due to stricter regulations.

The safety of heavy vehicles, especially buses, has not kept pace.

Thus, bus drivers face a higher injury risk in collisions.

Norway adopted UN R.29.03 for buses in October 2023

This standard applies, however, originally to trucks.

Main objectives:

- 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.

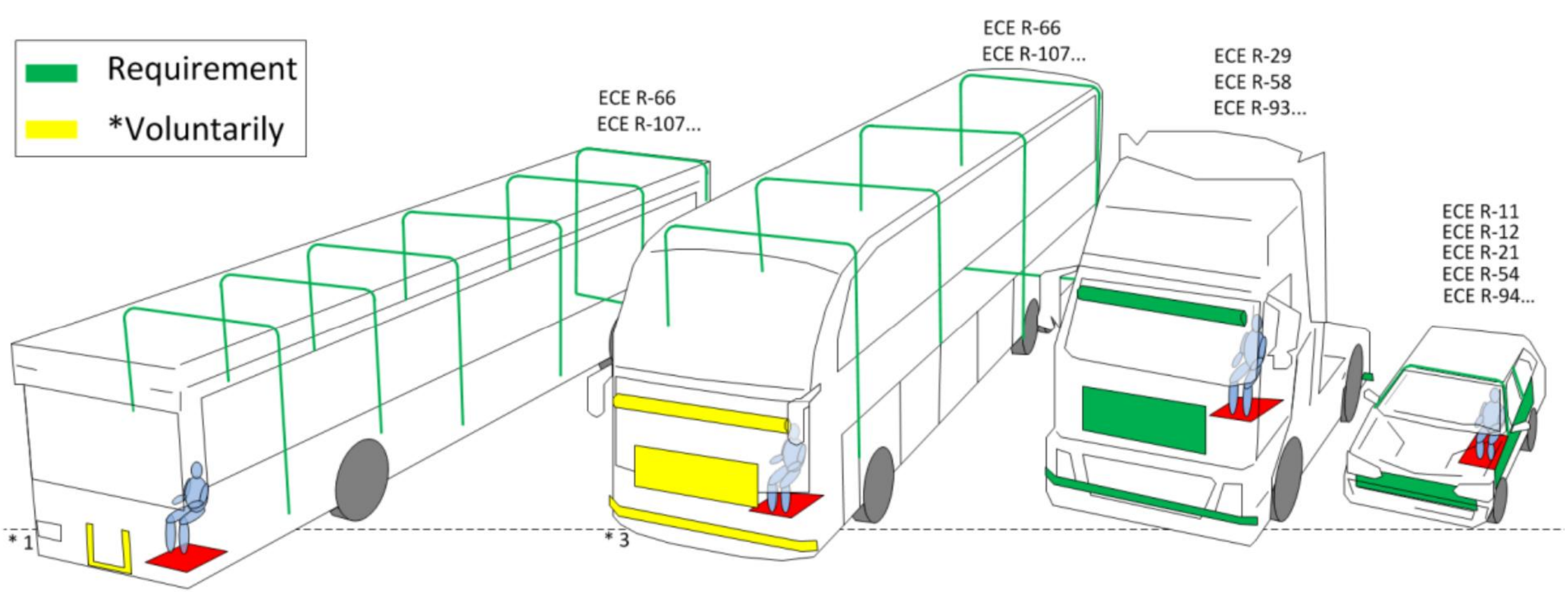


Figure 26: Collision protection requirements for various vehicle groups. Illustration: AIBN

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Overview of bus accidents in Europe, based on the CARE-database 2013-22:

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

Buses/coaches in crashes account for 2% of all road fatalities in the EU.

Bus drivers involved in road accidents in Norway, 2004-2023 (N=2694)

	Total for period			Yearly average			Risk	Severity
Year	All	Injured	KSI	All drivers	Injured	KSI	(pct. Injured)	(pct. KSI)
2004-2008	1051	109	6	263	27	1.5	10.4	5.5
2009-2013	770	102	9	192	26	2.2	13.2	8.8
2014-2018	494	64	7	99	13	1.4	13.0	10.9
2019-2023	379	56	5	76	11	1.0	14.8	8.9

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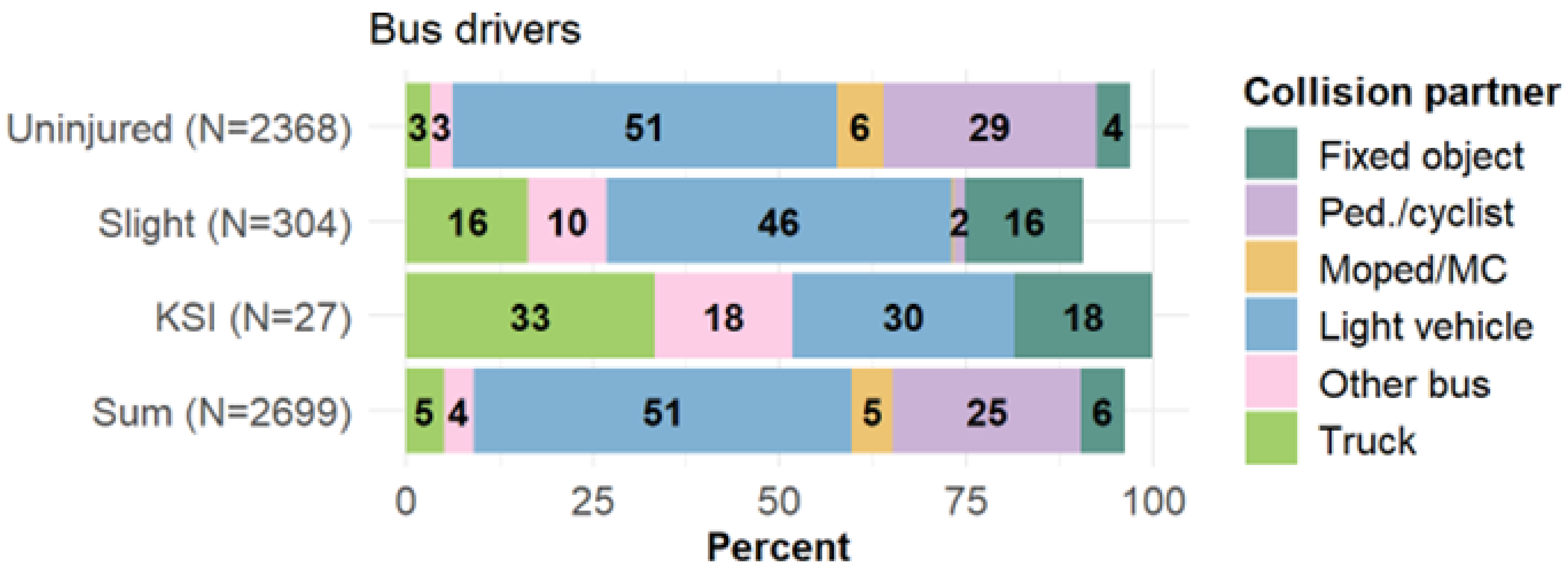
The number of bus drivers in accidents is reduced over time.

But the risk of being injured when you are involved in an accident has not been reduced over time (cf. Risk pct. injured)

Counter parts in accidents with buses involved



How many bus driver KSIs could hypotethically have been avoided, or reduced with improved collision protection?

Our analyses of accidents are based on CARE, but also several national databases with more detailed data, e.g. about impact points in the collisions.

Based on six countries for which the impact point is known: 2/3 of KSI bus drivers were in bus accidents with frontal impact.

In these accident, which account for 963 KSI bus drivers (if the numbers are extrapolated to all countries), severity might have been reduced by better collision protection.

Deficiencies in current bus front designs

AIBN reports from three Norwegian accidents raise concerns about a potential pattern in these accidents.

The scenarios for which buses are designed do not align with the realities of the incidents they face.

Particularly the front corners and A-pillars, are not designed to face frontal collisions with low overlap.

Our result: 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.

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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 is about 10 times higher (approx. 550 kJ) than the energy values prescribed in Regulation UN R29.03 (55 kJ).

Estimations of collisions with passenger cars (1333 kg) indicate that the energy levels absorbed by the bus range from 1124 kj (54 km/h), to 686 (30 km/h) to 148 (20 km/h).

Measures to improve collision safety in buses

Based on

- Estimations of ideal energy absorption capabilities for buses in collision scenarios
- Analyses of the three fatal bus accidents

Goal: 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.

The “bus front improvement model”

1) Improvement of 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:** In the front structure of buses.

c) **Small Overlap Impact Testing:** Similar to tests now common for passenger cars

d) **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials

e) **Compatibility Design Standards**: Between buses and smaller vehicles

f) **Mandatory Implementation of UN R93.00**: Front underrun protection device for trucks. To 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 “bus front improvement model”

2) **The position of the driver.** In the case of urban buses, it would be possible to raise the position of the driver slightly.

3) **Reinforcements in the structure.** Structural reinforcements focused on the driver side. Use a “semi-cage” open structure, protecting the lower area but also providing a better connection with the vehicle’s roof. 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.** 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 towing hook mount point could serve as the starting point to extend the frontal structure reinforcement and the front underrun protection.

5) **Reinforcement of the roof.** The AIBN reports show that in all of them, the upper roof connection was detached from the lateral structure.

Assessment of benefits and costs

Assumptions: 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.

Under these conditions, the present value of the benefits will be EUR 377 per bus, whilst system costs may be assumed to lie between EUR 8 500-12 000 per bus.

Costs therefore seem to outweigh benefits.

Vision Zero and Safe System

Safe System approach: the traffic system must be designed so external forces in accidents do not exceed the human bodies' tolerance for biomechanical impacts.

For bus drivers, there is still a considerable potential when it comes to Safe System implementation.

From a 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.

Vision Zero and Safe System

Our study indicates that the frontal structure of the bus also might endanger other vehicles in crashes.

↓

This is another example of how bus frontal design might conflict with Safe System principles.

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Our suggested model also seeks to mitigate this, and might thus also reduce the injury risk of counterparties in bus accidents.

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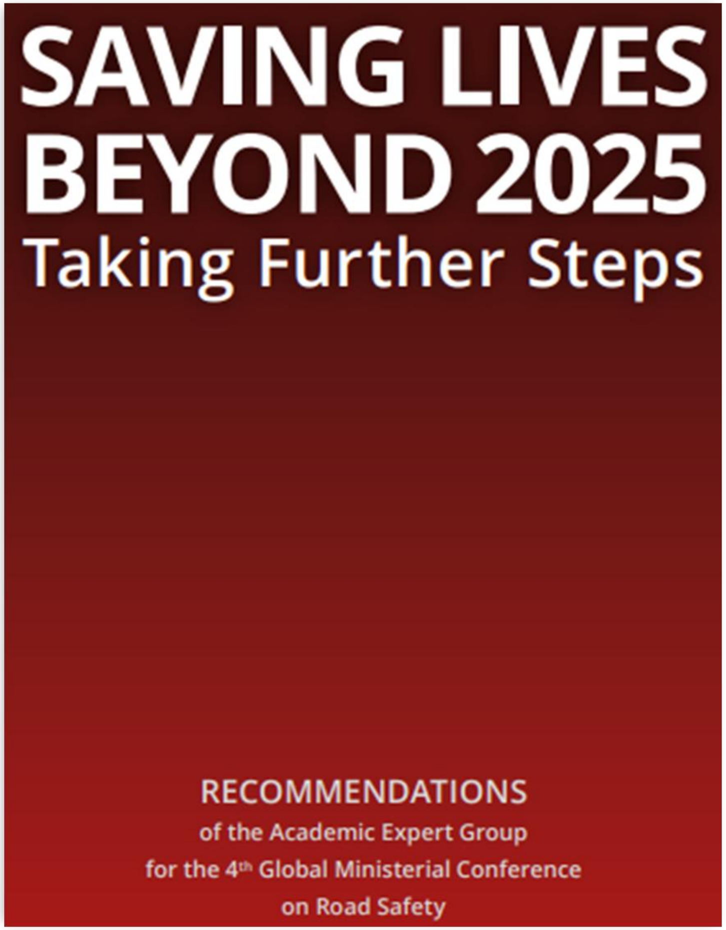
Light vehicle occupants comprise 22% of the killed and severely injured in bus accidents.


SAVING LIVES BEYOND 2025

Taking Further Steps

RECOMMENDATIONS

of the Academic Expert Group

for the 4th Global Ministerial Conference

on Road Safety

Project reports available from toi.no

- Crashworthiness of buses: Analysis of European data and suggestions for improvements. Nævestad,T.-O. A. K. Høye, R. Elvik, I. S. Hesjevoll, Ø. Lothe Brunstad, V. Milch Uhlving, J. Blom, M. Laso, D. R. Pinchasik
- Literature review of active and passive measures to improve bus safety. Nævestad, T.-O., A. K. Høye, R. Elvik, I. Hesjevoll, Ø. L. Brunstad, V. Milch, J. Blom
- Bus accidents in Europe : Factors influencing injury risk and severity. Høye, A.K. I.S. Hesjevoll, T.-O. Nævestad, R. Elvik, Ø. Lothe Brunstad, V. Milch Uhlving, J.Blom.
- Technical Study of collision protection for bus drivers: Development of a new solution trends for collision protection. Laso, M., T.-O. Nævestad
- Expected developments in bus accidents, *TØI Working document.* Elvik, R.

Ongoing: New simulation study

Financed by Ruter

Conducted by IDIADA, administered by TØI

Validated in reference group

Presented at Busworld

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