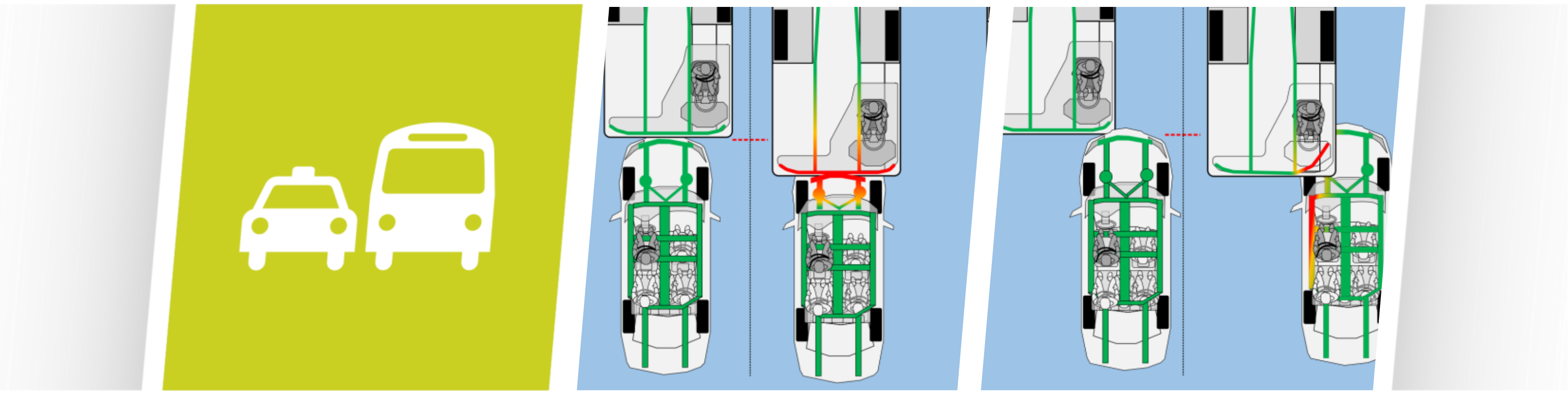
Norwegian Safety
Investigation Authority



Issued June 2026

REPORT ROAD 2026/02

Thematic investigation of frontal collisions involving buses: active and passive safety

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report for reference.

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The Norwegian Safety Investigation Authority (NSIA) has produced this report exclusively for the purpose of improving road safety.

The object of the NSIA's investigations is to clarify the sequence of events and causal factors, elucidate matters deemed to be important to the prevention of accidents and serious incidents, and to issue safety recommendations if relevant. It is not the NSIA's task to apportion blame or liability under criminal or civil law.

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Illustration: NSIA

Legal authority for the NSIA's activities is found in Section 44 of the Act of 18 June 1965 No 4 relating to road traffic (the Road Traffic Act); cf. Section 2 of the Regulations of 30 June 2005 No 793 on Public Investigation and Notification of Traffic Accidents etc Section 2.

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Summary

In this thematic investigation, the NSIA has investigated 55 frontal collisions involving buses during the period 2012–2025. Among these accidents, there were 30 fatalities and 25 accidents.

Previous safety investigations have shown that the lack of an impact-deflecting design at the front of buses may increase the risk to bus drivers. The primary question in this thematic investigation is whether this may also contribute to greater damage and more severe consequences for other oncoming vehicles. Of the 55 accidents included in the thematic investigation, a large proportion of fatalities were drivers of light vehicles (23). During the course of the investigation, it also became clear that the NSIA needed to investigate the significance of the vehicles' active driver assistance systems in preventing such frontal collisions from occurring in the first place.

The analysis shows that the extent of injuries was largely dependent on the energy range and the point of impact between vehicles. Corner-to-corner collisions often resulted in fatalities, whereas accidents involving serious injuries at a corresponding energy level were to a greater extent full-frontal collisions. The fatal accidents showed a clear tendency for the bus's corner structure to give way, resulting in significant intrusion into the driver's seat of the lighter vehicle. The NSIA believes the findings support the conclusion that a lack of an impact-deflecting design at the front of buses contributes to a greater degree of damage and more severe consequences for oncoming vehicles in frontal collisions with small overlap.

The investigation identifies limitations in active lane departure warning systems (LDWS/LKA) related to both activation speed and road conditions. The systems have a regulated activation speed of at least 60–65 km/h, which is higher than the vehicles' individual speed in many of the accidents. Manufacturers are also free to programme their driver assistance systems with lower activation speeds. The NSIA believes that the variations in activation speed between different vehicle models are significant, and that consumers should be aware of this information. In this context, the NSIA encourages vehicle manufacturers to consider activating and maintaining lane assistance systems at lower speeds than the regulations dictate, based on more factors than speed alone.

The investigation shows that current frontal protection for buses is inadequate in collisions with small overlap. The Norwegian requirements for frontal protection in new buses, which came into force in October 2023, constitute a clear signal that bus drivers are entitled to better protection of their driving compartment, but these measures alone are not sufficient. The corner structure on buses lacks deflecting surfaces, and any underrun protection device can fail in the outer zones. The NSIA therefore assesses that there is a need for solutions that combine energy-absorption and impact-deflection. Changes to the layout of the driver compartment – such as a centrally positioned driver's seat or moving the front passenger entrance behind the front axle – could increase driver protection while allowing more space for an improved front structure. A curved front could provide improved impact angles and deflection of oncoming vehicles without compromising visibility, universal design or technical requirements.

The NSIA believes that a new regulation for the frontal protection of buses is an appropriate measure, and that the Norwegian Public Roads Administration should pursue this work internationally. There is also scope within current regulations to develop improved front crash protection that is both energy-absorbing and impact-deflecting. Euro NCAP has established the ‘Safer Trucks’ programme for heavy vehicles, and the NSIA believes it is appropriate to introduce crash simulations and component tests for buses within this programme.

Based on this investigation, the NSIA issues two safety recommendations.

1. About the thematic investigation

1. About the thematic investigation

1.1 Background and purpose

The Norwegian Safety Investigation Authority (NSIA) has previously investigated several serious frontal collisions between buses. Investigations into the accidents at Nafstad in 2017, Tangen in 2021 and Fredrikstad in 2022 showed that the buses sustained extensive damage in the driving compartment and became fatal accidents despite low collision speeds.

The NSIA revealed that crashworthiness requirements for buses were lower than for other vehicle categories. The accidents and subsequent NSIA's reports and safety recommendations resulted in an increased focus on bus crashworthiness among organisations such as Public Transport Norway, Ruter, and the Norwegian Public Roads Administration. Initially, technical requirements were introduced in new tenders for bus transport. Based on the NSIA's safety recommendation ROAD No. 2019/10T from the Nafstad report, new Norwegian requirements for frontal protection in new buses were introduced from October 2023. The requirement includes a pendulum test in which a 1,500 kg plate on a pendulum impacts the front of a bus at approximately 30 km/h.

However, the investigation into the Fredrikstad accident revealed that the front left corner of buses has significant weaknesses in small-overlap frontal collisions – weaknesses that are not necessarily captured by a pendulum test with a flat impact across the front of a vehicle. The design, which lacks an impact-deflecting structure on the front left-land side, represents a general technical challenge for multiple bus manufacturers. Following the Fredrikstad accident, the NSIA therefore called for better protection for bus drivers as employees. The NSIA also considered there was a need for greater knowledge regarding the overall challenge surrounding bus crashworthiness, including the significance that weaknesses in the front structure may have on the severity of damage to other oncoming vehicles in frontal collisions.

Accident statistics show that frontal collisions involving buses account for approximately 2–3% of all traffic fatalities. The main question in the thematic study is whether the lack of impact-deflecting design at the front of buses not only increases the risk for bus drivers, but also contributes to a greater degree of damage and more severe consequences for vehicles involved in a frontal collision.

During the course of the investigation, it also became clear that the NSIA needed to investigate and assess the significance of the vehicles' active driver assistance systems in preventing such frontal collisions. The investigation therefore addresses both passive and active safety.

The thematic investigation assesses injury mechanisms and survival aspects in frontal collisions between buses and other vehicle categories, combining this with the NSIA's previous investigation findings from bus accidents. It then evaluates how active driver assistance systems function in preventing such situations. The purpose is to identify what can contribute to increasing safety and reducing the severity of injuries in frontal collisions involving buses.

1.2 Delimitation of the thematic study

The NSIA chose to limit the investigation to frontal collisions between buses and other vehicles. For each accident, the investigation includes an overall assessment of the accident's energy level immediately prior to the collision, followed by an analysis and assessment of vehicle damage and personal injuries resulting from the impact. The sequence of events and causal factors that led to the accidents are only addressed to a limited extent. The investigation also excludes assessments of road conditions that may have affected the severity of the accidents, as well as assessments of the rescue operations following the accidents.

1.3 Selection and method

1.3.1 INTRODUCTION

The investigation process followed the steps described in the sections below.

1.3.2 STEP 1: SELECTION OF ACCIDENTS

The selection of accidents included in the thematic investigation was made by searching the NSIA's internal operational logs and archives for accidents reported to the NSIA during the period 2012–2025, supported by searches in the Norwegian Public Roads Administration's traffic accident registry (TRULS). Based on a broad search for serious frontal collisions involving a bus, the NSIA requested and obtained police documents relating to these accidents.

To be included for further investigation, the accidents had to meet specific criteria:

- Frontal collision between vehicles travelling in opposite or intersecting directions of travel.
- Vehicle type of the oncoming vehicle: bus over 3,500 kg, heavy goods vehicle, articulated lorry, passenger car/light commercial vehicle.
- Severity: fatal accident or accident involving serious injury[1].

Accidents initially categorised as involving serious injury, but where closer investigation revealed a lower degree of injury, were excluded from further investigation.

Based on the criteria described above, 55 frontal collisions from the period 2012–2025 were included in the thematic investigation. The accidents were distributed as follows:

- 30 fatal accidents, of which:
  - 4 accidents involved a bus in collision with another bus
  - 3 accidents involved a bus in collision with a heavy vehicle
  - 23 accidents involved a bus in collision with a lighter vehicle

- 25 accidents involving serious injury, all involving a bus in collision with a lighter vehicle.

Across the 55 accidents, there were 250 registered individuals involved, with the following distribution of injury severity:

- 166 persons with minor injuries
- 48 persons seriously injured
  - 4 persons very seriously injured
  - 44 persons seriously injured
- 36 fatalities
  - 31 driver fatalities
    - 7 bus driver fatalities
    - 1 lorry driver fatality
    - 23 driver fatalities in other light vehicles (cars, light commercial vehicles)
  - 5 passenger fatalities, either in a bus or other light vehicle

The documentation obtained by the NSIA from the police regarding the fatal accidents included reports from the Norwegian Public Roads Administration, postmortem reports, forensic reports,

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[1] *An accident with serious injury or "severe injury" is a collective term for accidents where persons are classified with the injury severity levels; very seriously injured + seriously injured.*

technical and investigative evidence, as well as interviews with witnesses and those directly involved. The police documentation from accidents involving serious injury contained less information and fewer sources. Figure 1 shows the annual distribution and severity level of the accidents.

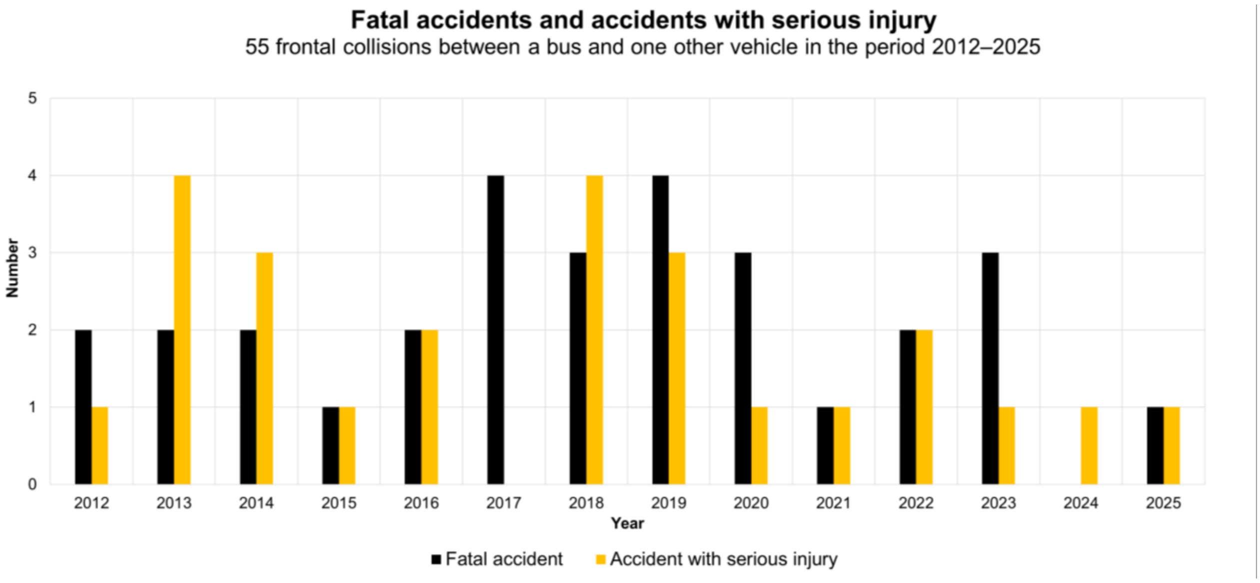


Figure 1: 55 frontal collisions between buses and other vehicles, broken down by fatalities and serious injury, in the period 2012–2025. Source: NSIA

1.3.3 STEP 2: ASSESSMENT OF ENERGY LEVEL IMMEDIATELY PRIOR TO COLLISION

Based on available data, the NSIA conducted an assessment of the vehicles' estimated speeds immediately prior to the frontal collision in each of the 55 accidents. In several of the accidents, no stored data from the vehicles was available, and speeds were only reported by the individuals involved. In some of the accidents, data resolved to the nearest second was available from one or two of the vehicles, while a few accidents had high-resolution speed data from a single vehicle.

Based on an assessment of the vehicle's speed (v) and registered kerb weight with driver (m) in the vehicle registration, NSIA has calculated the vehicle's kinetic energy ($E = ½ mv^2$) prior to the collision. The kinetic energy from both vehicles in the frontal collision was then combined. Together, this sum constituted the total energy level in each accident immediately prior to the collision.

In frontal collisions between a bus and a lighter vehicle, the total weight of the bus will have a major impact on the combined energy level if the vehicles are travelling at approximately the same speed. Tachographs are required to record speed to an accuracy within +/- 6 km/h. For a 14-tonne bus travelling at a speed of 50 km/h, +/- 6 km/h represents a difference in kinetic energy of around 300 kJ. With this in mind, the NSIA established a margin of uncertainty of +/- 300 kJ when calculating the total energy level of each accident.

1.3.4 STEP 3: CATEGORISATION OF ENERGY RANGE AND MAPPING OF VEHICLE DAMAGE

1.3.4.1 Introduction

Based on the energy levels of the accidents, each of the 55 accidents was divided into an energy range, and the vehicle damage was mapped and grouped. The different energy ranges and the methods used to map the vehicle damage are described below.

1.3.4.2 Categorisation of the frontal collision energy range

The NSIA chose to categorise the frontal collisions into three distinct energy ranges:

- **High energy:**

  Frontal collisions involving the highest energy levels among the accidents in the sample. The accidents in this range consist largely of fatal accidents.

- **Breaking zone:**

  Frontal collisions in the middle tier of energy among the accidents in the sample. The breaking zone is defined as having an equal number of fatal accidents as accidents involving serious injury.

- **Low energy:**

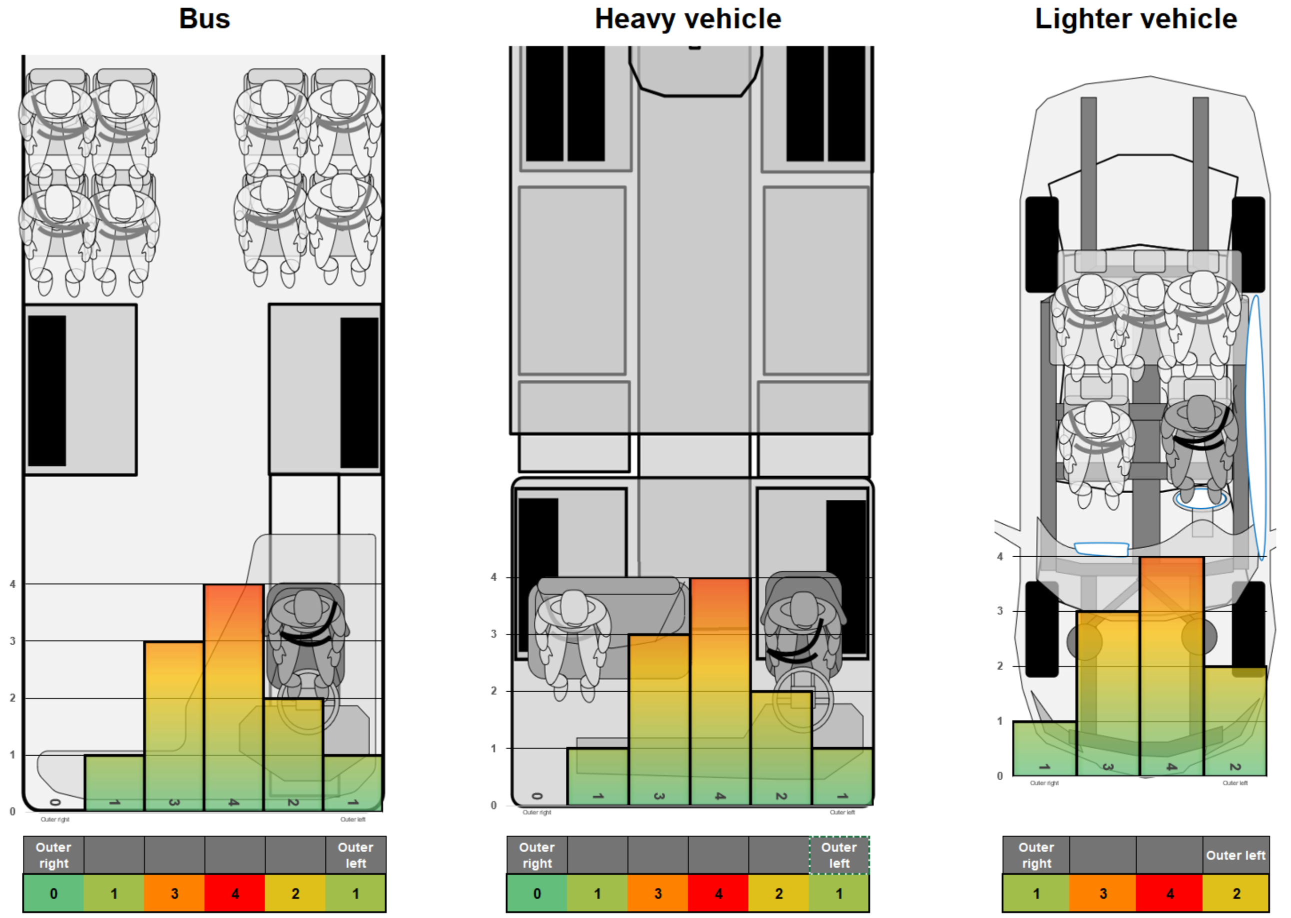
  Frontal collisions involving the lowest energy levels among the accidents in the sample. The accidents in this range consist largely of accidents involving serious injury.

1.3.4.3 Mapping of vehicle damage within each energy range

NSIA mapped the vehicle damage for each of the 55 accidents. The damage recording included damage across the width of the vehicles' front, and the subsequent depth of deformation inwards into the vehicle's body. This formed a damage profile for each vehicle.

The front of buses and heavy vehicles was divided into six zones, from the outer right corner to the outer left corner. Light vehicles were categorised in the same manner, but into four zones. The depth of vehicle damage within each zone of the vehicle's front was mapped on a scale with five gradations of depth, from 0 to 4.

Within each of the three energy ranges, the vehicle damage is presented via an illustration that shows the average damage profile following frontal collisions with different opposing vehicles – either another bus, a heavy vehicle or a lighter vehicle. A table of these damage profiles is also shown in Appendix A.



Outer right					Outer left
0	1	3	4	2	1

Outer right					Outer left
0	1	3	4	2	1

Outer right			Outer left
1	3	4	2

Figure 2: Recording of vehicle damage across the vehicle's width and depth, where grade 4 (red) is assigned to the zone where the bodywork damage is deepest. The illustration shows a damage profile increasing in depth towards the centre of different vehicles – a bus, a heavy vehicle and a lighter vehicle. Illustration: NSIA

1.3.5 STEP 4: MAPPING OF FRONTAL COLLISIONS IN THE BREAKING ZONE

The severity of damage in accidents within the breaking zone – in which there are an equal number of fatal accidents as accidents involving serious injury – cannot be explained solely by the calculated energy level just prior to collision. The NSIA has therefore carried out a more detailed study of these accidents to help explain the extent of the damage. The fatal accidents and the accidents involving serious injury were compared with regard to energy level, the buses' speed range, relative speed between the vehicles, vehicle damage and the occurrence of personal injuries to the drivers of the lighter vehicle.

1.3.6 STEP 5: INVESTIGATION OF THREE FRONTAL COLLISIONS IN THE BREAKING ZONE

Based on the mapping in Step 4, the NSIA selected three accidents for closer investigation. The accidents were chosen based on energy levels and the type of frontal collision indicated by the mapped vehicle damage. The three accidents comprised one full-frontal collision and two corner-to-corner collisions. For these accidents, the NSIA conducted more detailed investigations into the sequence of events, vehicle damage and personal injuries. Relevant information about the vehicles' driver assistance systems and crash characteristics was also investigated.

2. Mapping of frontal collisions involving buses

2. Mapping of frontal collisions involving buses

2.1 Energy level immediately prior to frontal collision and vehicle damage

2.1.1 INTRODUCTION

The NSIA assessed the energy level immediately prior to the frontal collisions in the 55 accidents. The result of this assessment is shown in Figure 3, where the accidents are sorted by descending energy level. Each accident represents a frontal collision between a bus and an opposing vehicle. The opposing vehicles were either another bus, a heavy vehicle or a lighter vehicle. Fatal accidents are marked with a black square. Accidents involving serious injury are marked with a yellow square.

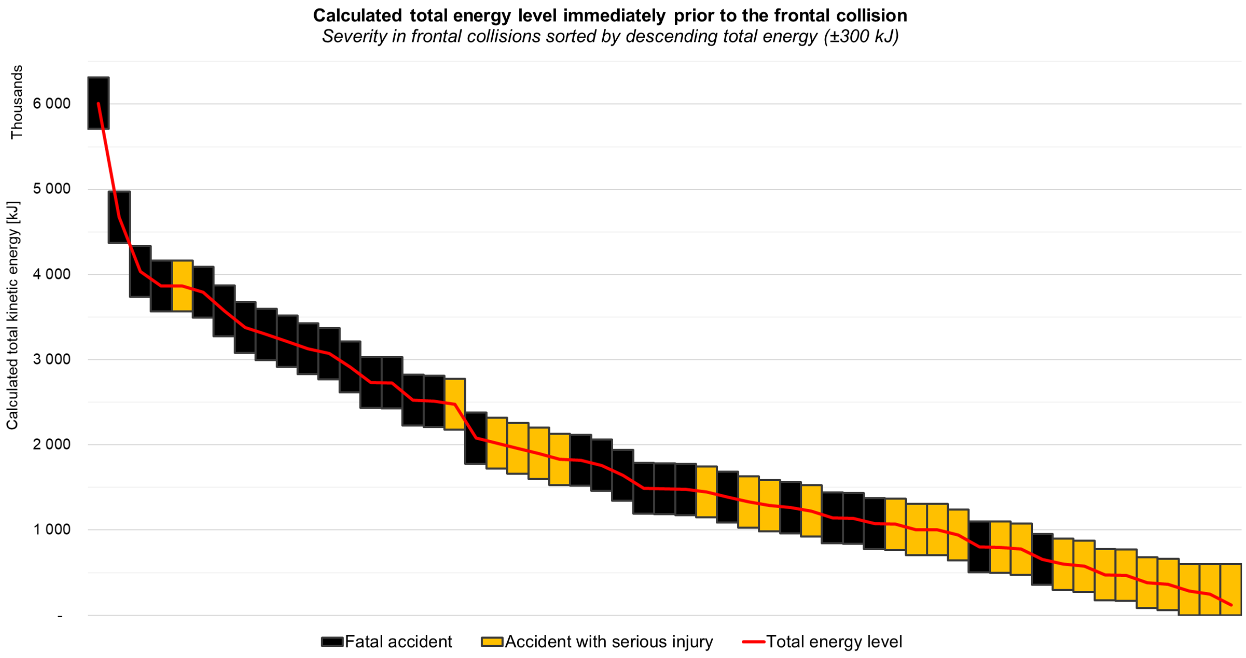


Figure 3: Calculated total energy level immediately prior to the frontal collision between the bus and the opposing vehicle, as well as the severity of the accident. The accidents are sorted by descending energy level. Source: NSIA

The NSIA's division of the 55 frontal collisions into the high-energy, breaking zone and low-energy ranges is shown in Figure 4. Figure 5 shows the average damage profile for each vehicle category within each energy range.

- The high-energy range included 17 accidents, of which one involved serious injury and the remainder were fatal accidents. Each accident had a total energy level exceeding 2,500 kJ. See section 2.1.2.
- The breaking zone included 26 accidents, with an equal number of fatal accidents and accidents involving serious injury. Each accident had a total energy level in the range of 800–2,500 kJ. See section 2.1.3.
- The high-energy range included 12 accidents, of which one was a fatal accident and the remainder involved serious injury. Each accident had a total energy level of up to 800 kJ. See section 2.1.4.

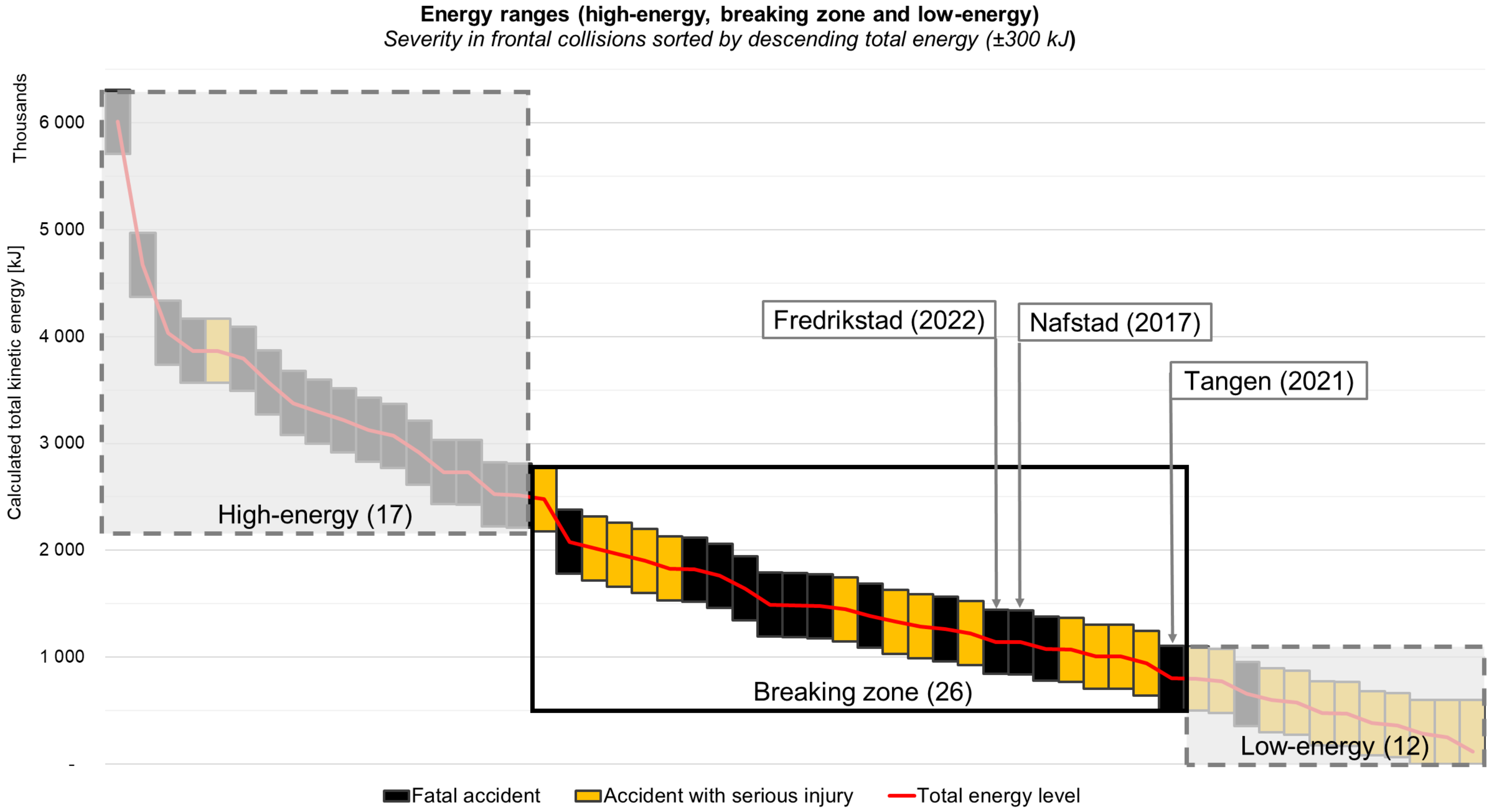


Figure 4: Accidents in the different energy ranges: High-energy (17), breaking zone (26) and Low-energy (12). In the breaking zone, which contained 13 fatal accidents and 13 accidents involving serious injury, three bus accidents have been previously investigated by the NSIA. Source: NSIA

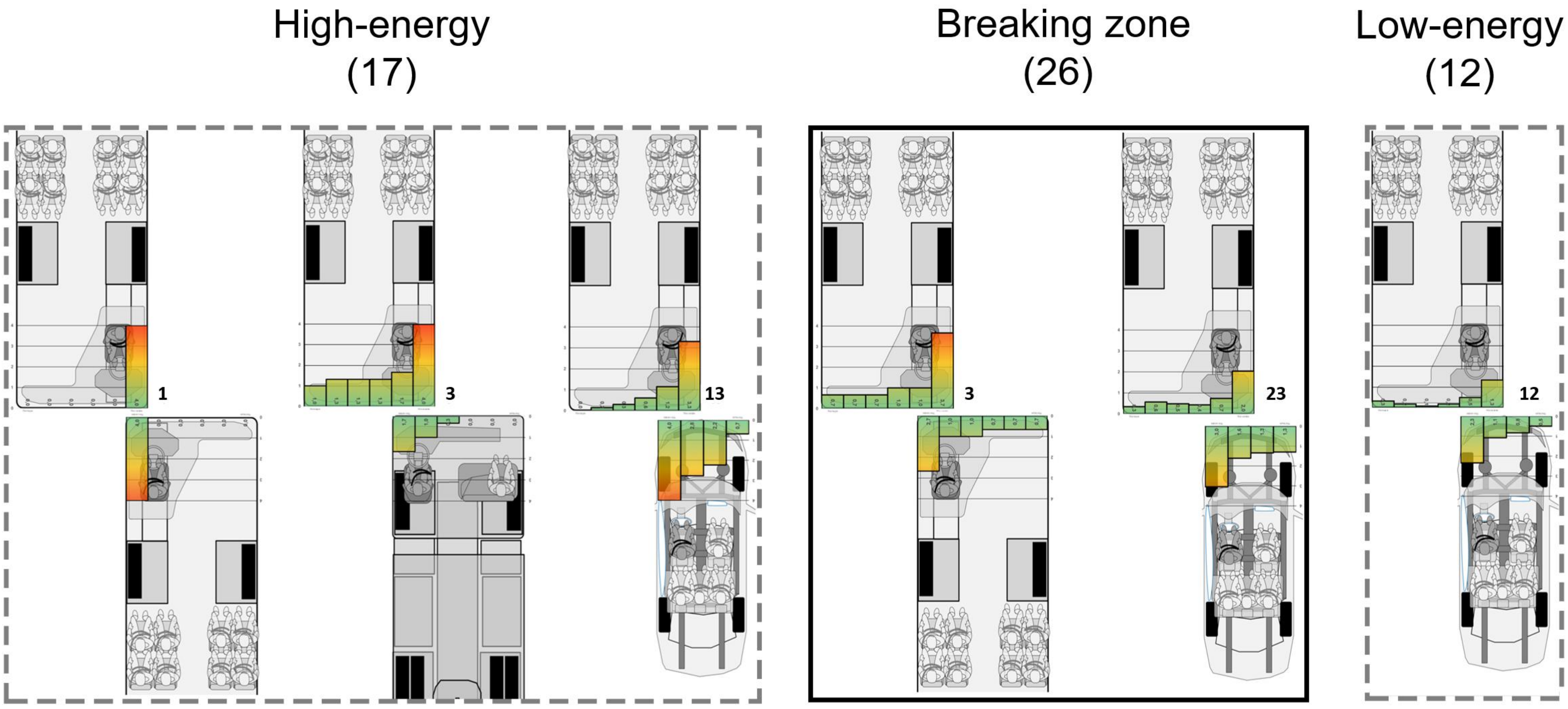


Figure 5: Mapped vehicle damage and average damage profile for the various vehicles across the different energy ranges: high-energy, breaking zone and low-energy. The figures show the number of accidents by vehicle type within each energy range. Illustration: NSIA

2.1.2 HIGH ENERGY

There were 17 frontal collisions in the high-energy range. In one of the accidents, the opposing vehicle was another bus. In three accidents, the opposing vehicle was a heavy vehicle, and in 13 accidents, the opposing vehicle was a lighter vehicle.

In the high-energy range, 16 of the 17 accidents were fatal. The single non-fatal accident was a corner-to-corner collision where the opposing vehicle was a lighter vehicle. In that accident, the driver of the lighter vehicle was recorded as seriously injured, and the driver of the bus was recorded as uninjured.

Based on available information from the 17 accidents in the high-energy range, the speed immediately prior to the collision was over 60 km/h for the buses in all but two of the accidents. The average damage profile for the vehicles shows that the vast majority of vehicles sustained deep damage to the front left corner, as shown in Figure 5.

2.1.3 THE BREAKING ZONE

There were 26 frontal collisions in the breaking zone. In three of the accidents, the opposing vehicle was another bus. In 23 of the accidents, the opposing vehicle was a light vehicle.

The 23 accidents comprised fatal accidents and accidents involving serious injury. The vehicles in these accidents had an average damage profile that was somewhat more distributed across the front of both vehicles compared to the vehicles in the high-energy range accidents. The 23 accidents are further analysed in section 2.2

The three bus-to-bus accidents in the breaking zone were fatal accidents previously investigated by the NSIA, see Figure 6. The average damage profile for the buses is shown in Figure 5.

Figure 6: Frontal collisions between buses investigated by the NSIA. The accidents from left to right after descending energy: Fredrikstad 2022, Nafstad 2017 and Tangen 2021. Photo: The police, Norwegian Public Roads Administration (from the reports).

2.1.4 LOW ENERGY

There were 12 frontal collisions in the low-energy range. The opposing vehicle in all of these accidents was a lighter vehicle.

In the low-energy range, there was one fatal accident, which was a full-frontal collision in which the driver of the lighter vehicle lost their life.

Based on available information about the 12 accidents in the low-energy range, the highest speed of the buses immediately prior to collision was 35 km/h. The average damage profile of the vehicles shows less deep damage distributed across the front compared to the average damage profile of the other energy ranges, as shown in Figure 5.

2.2 Frontal collisions in the breaking zone

2.2.1 ENERGY LEVEL

The 23 frontal collisions between buses and lighter vehicles in the breaking zone consisted of 10 fatal accidents and 13 accidents involving serious injury, see Figure 7. The NSIA has mapped and compared the damage profile and personal injuries in the fatal accidents against the damage profile and personal injuries in the accidents involving serious injury.

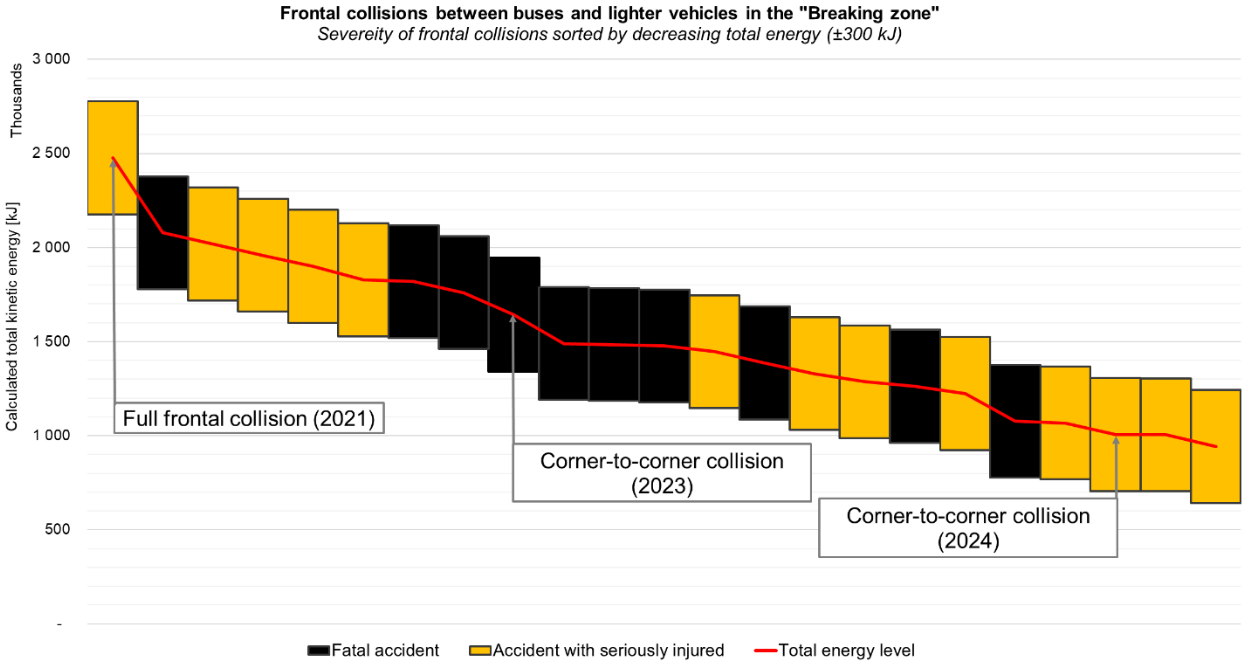


Figure 7: The 23 frontal collisions in the breaking zone consisted of 10 fatal accidents and 13 accidents resulting in serious injury. Three accidents are investigated in more detail by the NSIA in section 3. Source: NSIA

Based on available information, the speed of the buses prior to the 23 frontal collisions was in the range of 30–60 km/h. In the fatal accidents, the closing speed of the vehicles was in the range of 100–140 km/h. In the accidents involving serious injury, the closing speed of the vehicles was somewhat lower, in the range of 70–118 km/h.

2.2.2 VEHICLE DAMAGE

The damage profile of the vehicles is markedly different in the fatal accidents compared to the accidents involving serious injury. In the fatal accidents, the buses and the lighter vehicles show prominent damage to the front left corner. In the accidents involving serious injury, the depth of damage to the buses is shallower and also more evenly distributed across the entire front of the vehicle. The same is true for the lighter vehicles in the accidents involving serious injury, although it is the depth of damage to the front left corner that is most reduced.

The average vehicle damage and damage profile in the fatal accidents and the accidents involving serious injury within the breaking zone are shown in Figure 8.

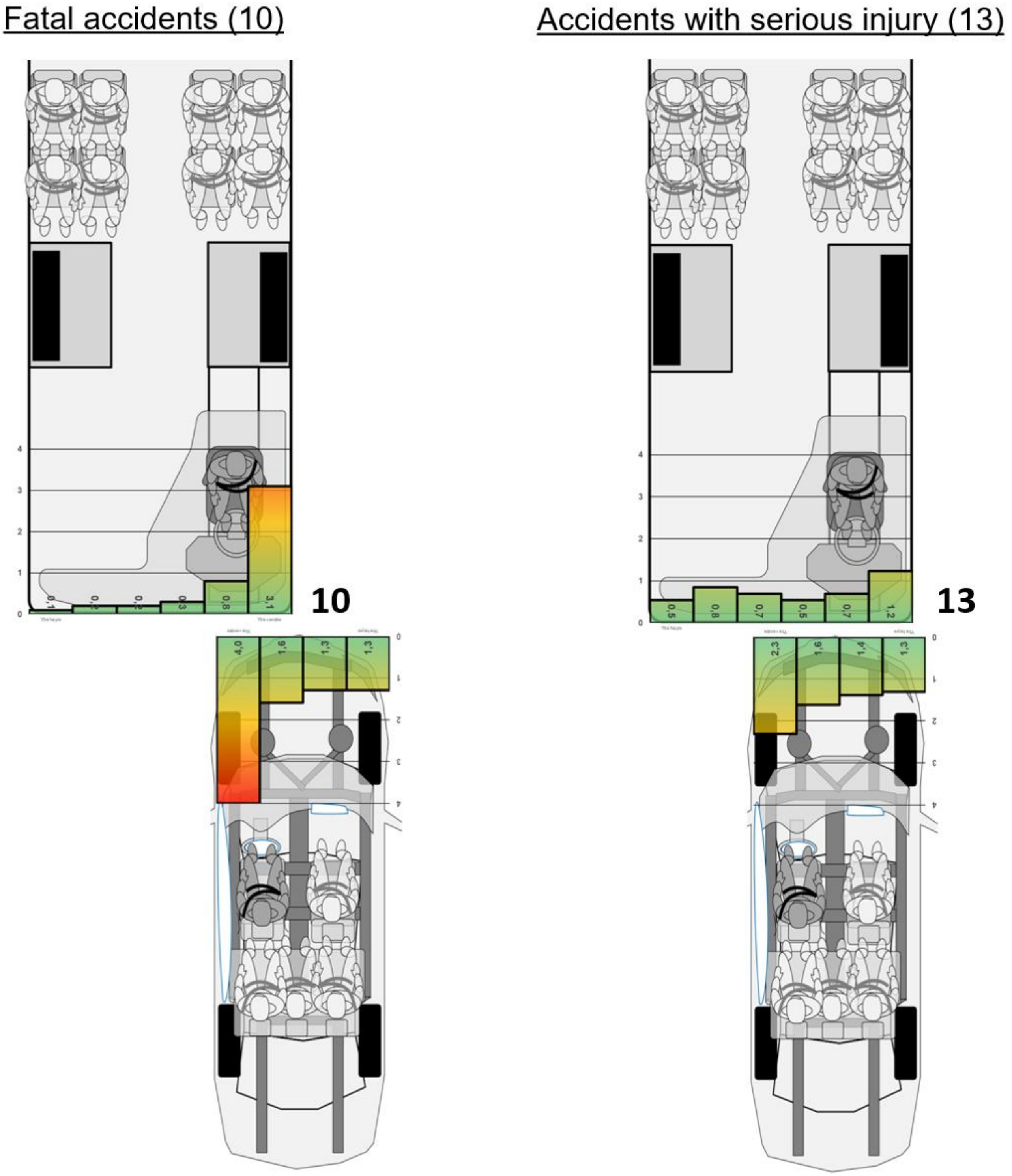


Figure 8: Mapped vehicle damage and average damage profile in 23 frontal collisions between buses and lighter vehicles in the breaking zone (10 fatal accidents and 13 accidents involving serious injury). Source: NSIA

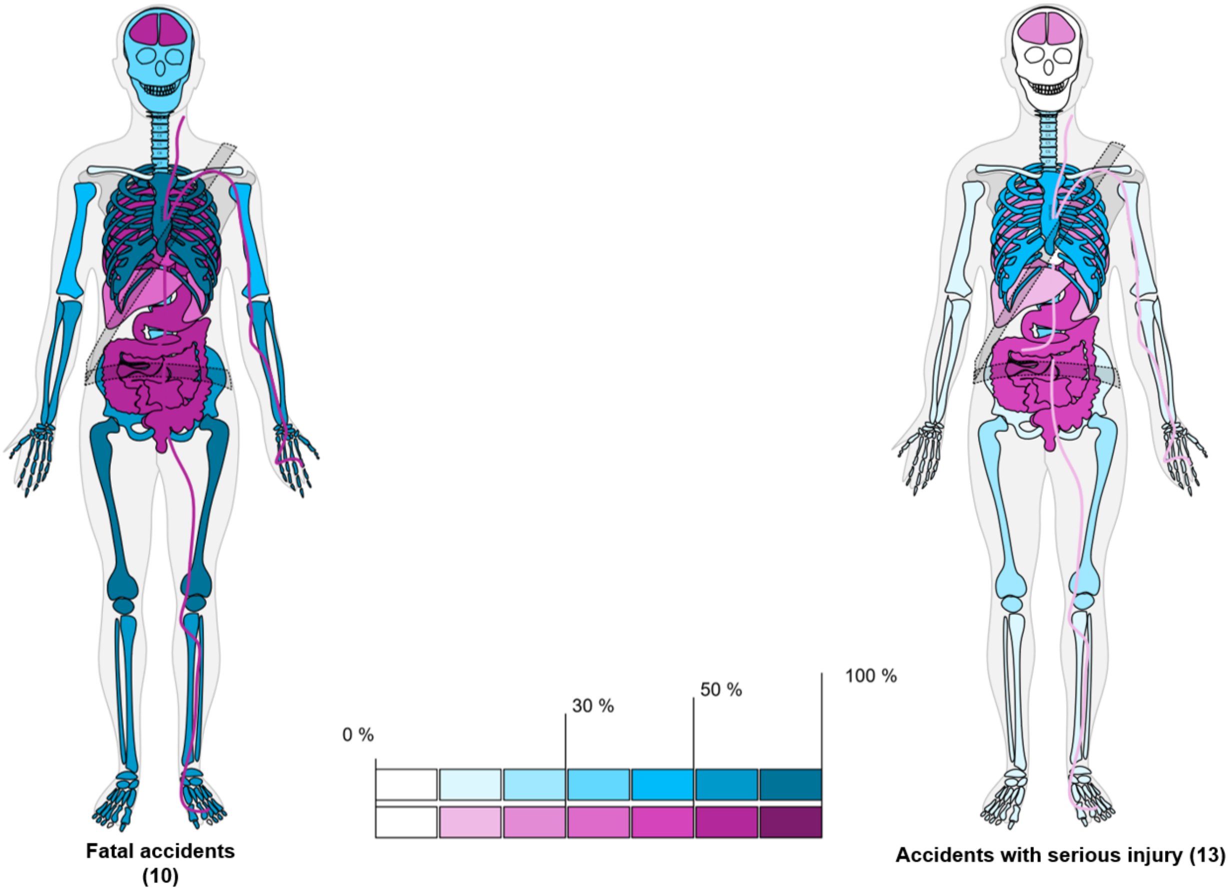
2.2.3 PERSONAL INJURIES

In the 10 fatal accidents, there were a total of 12 fatalities. The driver of the lighter vehicle lost their life in all of the accidents. In one of the accidents, a passenger in the lighter vehicle was also killed. In another of the accidents, a bus driver also lost their life. In the remaining accidents, the bus driver was recorded as either slightly injured or uninjured.

The review of personal injuries showed a high incidence of chest and abdominal injuries among the drivers of the lighter vehicles across all 23 accidents, see Figure 9.

Based on available information, there was a significantly higher incidence of skull, pelvic, femoral, lower-leg and forearm fractures in the fatal accidents, as well as a higher incidence of injuries to the heart, liver, spleen and aorta, compared to the accidents involving serious injury.

All of the lighter vehicles were equipped with SRS-system which features airbags designed to work in conjunction with the seatbelt during a collision. All the vehicles the driver's front airbag was deployed during the collisions. In one of the accidents, seatbelt use could not be verified, but in that specific accident, there was no survival space left in the driver's position.



Fracture injury	Skull fracture	Neck fracture	Spine fracture	Clavicle fracture	Rib fracture	Pelvic fracture	Femur fracture	Lower leg fracture	Upper arm fracture	Forearm fracture
Fatal accidents (10)	30 %	30 %	30 %	10 %	70 %	50 %	60 %	50 %	40 %	50 %
Accidents with serious injury (13)	0 %	23 %	31 %	15 %	38 %	15 %	23 %	15 %	15 %	8 %

Organ damage	Brain	Heart	Lungs	Abdomen / intestines	Liver	Spleen	Pulmonary artery
Fatal accidents (10)	50 %	40 %	60 %	50 %	30 %	30 %	40 %
Accidents with serious injury (13)	23 %	0 %	23 %	38 %	8 %	8 %	8 %

Figure 9: Percentage incidence of fractures and organ injuries to the driver of the lighter vehicle in 23 frontal collisions with buses (10 fatal accidents and 13 accidents involving serious injury). Illustration: NSIA

3. Three frontal collisions in the breaking zone

3. Three frontal collisions in the breaking zone

3.1 Introduction

From the accidents in the breaking zone, the NSIA selected three frontal collisions between a bus and a passenger car for more detailed investigation: one full-frontal collision and two corner-to-corner collisions.

For these accidents, the NSIA conducted closer investigations into the sequence of events, vehicle damage, personal injuries, the vehicles' driver assistance systems and their crash characteristics.

In all three collisions, all persons in the passenger cars were wearing a seatbelt and the airbags deployed in all of the cars. In the lighter vehicles, the seatbelt pretensioners activated, and the front, window, knee and side airbags deployed, depending on what each specific vehicle was equipped with and programmed to do.

In all three accidents, it is probable that the passenger car crossed the centreline and entered the oncoming lane shortly before impact. There were no clear skid marks before the collision sites, and the absence of such marks may indicate a lack of driver activity shortly before impact. Furthermore, there were no indications of intoxication, phone use or active steering inputs that could help explain why the accidents occurred. A lack of alertness in regard to the vehicle’s trajectory and position on the carriageway, falling asleep, loss of consciousness, or low blood pressure may partly explain why the passenger car crossed the centreline in some of the accidents, but there is no definitive evidence to confirm this.

3.2 Full frontal collision on Fredrikstad Bridge (2021)

3.2.1 SEQUENCE OF EVENTS AND PERSONAL INJURIES

In 2021, a full-frontal collision occurred on the Fredrikstad Bridge between a coach and a passenger car. The collision occurred in the centre lane of the three-lane road. The NSIA was not notified about the accident. Available information indicates that the coach was travelling at the speed limit, around 60 km/h, when the accident occurred. The passenger car's speedometer was stuck at around 40 km/t after the collision. The passenger car was thrown backwards with rotation, struck the safety barrier, and came to a stop after approximately 38 m. The coach stopped after approximately 55–60 m, as shown in Figure 10.

The driver of the passenger car survived with fractures to the arm, ribs, upper femur and nose, as well as a brain haemorrhage and injury to the abdominal muscles. The bus driver sustained minor injuries from the accident.

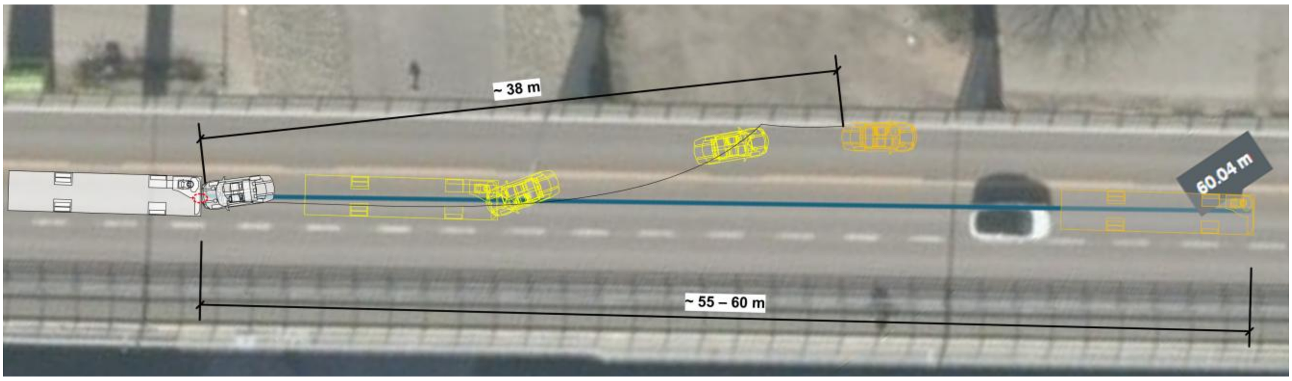


Figure 10: Diagram of the collision site, estimated point of impact and distance to the vehicles' final positions. Map: vegkart.no Illustration: NSIA

3.2.2 VEHICLE DAMAGE

The coach (Class III) was fitted with a front underrun protection device. The damage to the coach was concentrated around the centre of the front of the vehicle, and the underrun protection device was pushed backwards, see Figure 11. There were vertical scrape marks on the right of the vehicle's front left headlight, as well as paint damage in a curved formation across the front. These scrape marks were made by the passenger car's bonnet and right-hand-side A-pillar, as shown in Figure 12. The damage to the passenger car indicates that the front of the coach overrode the car's bonnet to some extent during the impact, while the crumple zone on the passenger car's bumper was fully utilised.

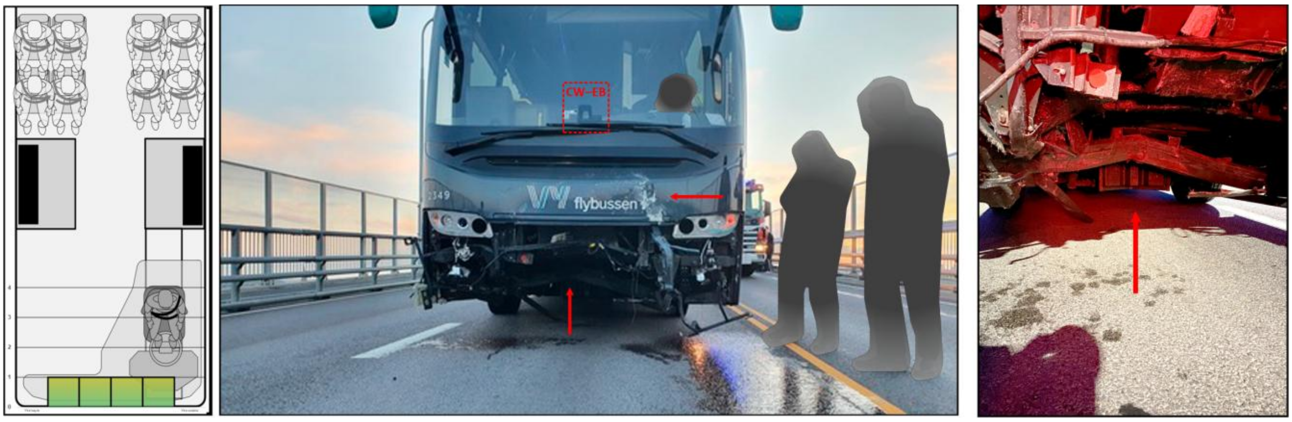


Figure 11: Vehicle damage illustrated on the left. Camera and radar marked on the windscreen. Arrows indicate the point of contact with the car and the deformed underrun protection device. Photo: The police and the Norwegian Public Roads Administration. Markings and illustration: NSIA

Figure 12: Vehicle damage and activated safety equipment illustrated on the left. Arrows indicate point of contact with bus. Photo: The police and the Norwegian Public Roads Administration. Markings and illustration: NSIA

3.2.3 ACTIVE DRIVER ASSISTANCE SYSTEMS

The coach was a 2020-model Volvo 9700. It featured a camera and radar in the windscreen that is used by the driver assistance system's forward collision warning with emergency brake (AEBS, or CW-EB). This system *'takes into account stationary vehicles and vehicles moving ahead in the same direction and same lane. It does not take into account oncoming or crossing vehicles'*. The NSIA has no information indicating that this system issued a warning or managed to activate prior to the collision.

The passenger car was a 2008-model Toyota Avensis. It was not equipped with active driver assistance systems. In frontal crash tests, the vehicle achieved good results in Euro NCAP(2003), and NCAP USA (2004) with the Scion TC, a car model built on a similar chassis.

3.3 Corner-to-corner collision in Figgjo (2023)

3.3.1 SEQUENCE OF EVENTS AND PERSONAL INJURIES

In 2023, a corner-to-corner collision occurred at Figgjo in Sandnes municipality, involving a bus and a passenger car with three occupants. The collision took place in the bus's lane, on a two-lane road with a double solid line. The NSIA was notified but did not deploy to the scene. Stored data from the vehicles indicates that the bus was travelling at a steady speed of approximately 61 km/h, braked during the final second before the collision, and impacted at a speed of approximately 52 km/h. The bus struck the nearside safety barrier and continued for approximately 200 m after the collision. The car was travelling at a steady speed of approximately 55–56 km/h before the collision. Immediately following the collision, the car's speed was reduced to approximately 3–4 km/h, and it stopped approximately 2 metres past the point of impact, as shown in Figure 13[2].

The car driver was killed in the accident, likely as a result of head injuries. The passenger in the rear left seat sustained fractures to the arm, and the centre rear passenger sustained minor injuries. The bus driver sustained minor injuries from the accident.

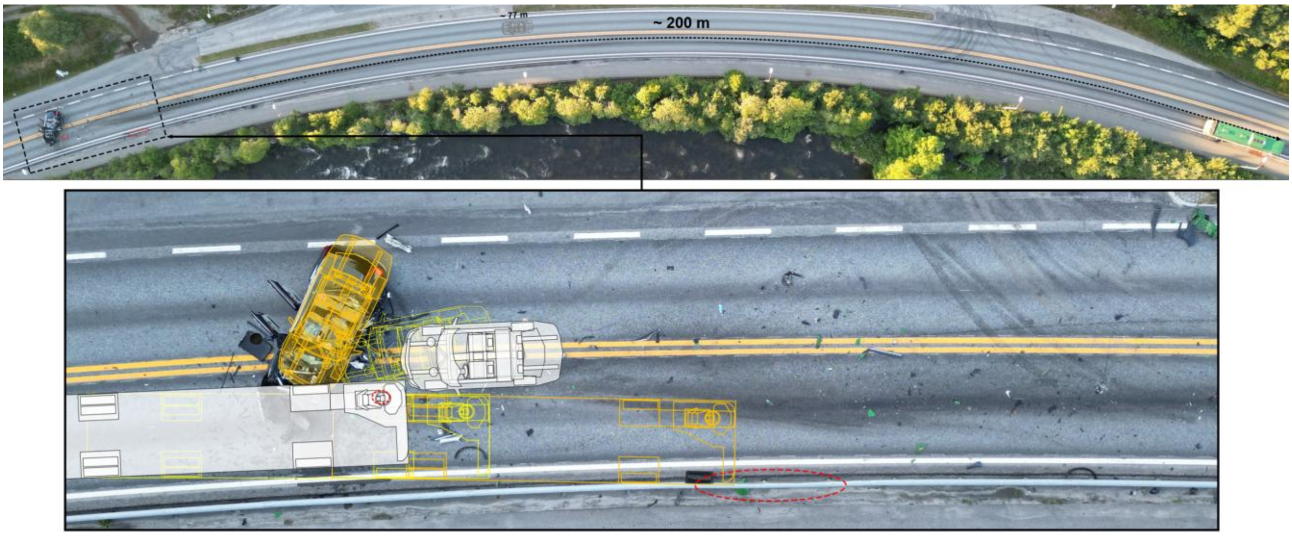


Figure 13: Overview of the accident site, estimated point of impact, and vehicle movement immediately following the collision. Photo: Norwegian Public Roads Administration. Illustration: NSIA

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[2] *Several tyre marks on the road at the exits were established prior to the accident.*

3.3.2 VEHICLE DAMAGE

The bus, a regional bus (Class II), sustained damage to its front left corner. The left side of the bus's front crossmember was torn off. The damage to the front of the bus was located approximately 35 cm from the bus's front left corner, towards the centre, at a height of 80 cm, see Figure 14. The car's left-hand-side roof rail penetrated the bus's windscreen at a height of approximately 1.5 metres. During the collision, the bus's brake pedal was jammed upwards by the front panel, making it impossible to use. The bus's steering column was fractured but remained functional. The bus driver slowed the bus by steering into the safety barrier.

‘The passenger car's chassis rails and bumper were relatively intact after the collision. The car's front left wheel was torn off, and the A-pillar was severely deformed, see Figure 15.

Figure 14: Vehicle damage illustrated on the left. Images of the jammed brake pedal, the area around the bus's front left crossmember, and scrape marks extending rearwards along the left-hand-side of the bus. Photo: Norwegian Public Roads Administration. Markings and illustration: NSIA

Figure 15: Vehicle damage and deployed safety equipment illustrated on the left. The passenger car's front left wheel was torn off, but there was little damage to the left chassis rail. Photo: Norwegian Public Roads Administration and the police. Markings and illustration: NSIA

3.3.3 ACTIVE DRIVER ASSISTANCE SYSTEMS

The bus was a 2016-model Volvo 8900. It was not equipped with active driver assistance systems.

The passenger car was a 2021 model Volvo XC90. It was equipped with several active driver assistance systems.

The passenger car featured a Lane Departure Warning System (LDWS) via steering wheel vibration, and Lane Keeping Aid (LKA), which warns and applies subtle torque to the steering wheel if the vehicle approaches a lane boundary line. It was possible to activate one or both of these two driver assistance systems via the settings. For both of the systems to be active, the vehicle's speed must be *‘within the speed range of 65–200 km/h on roads with clearly visible lane markings’*.

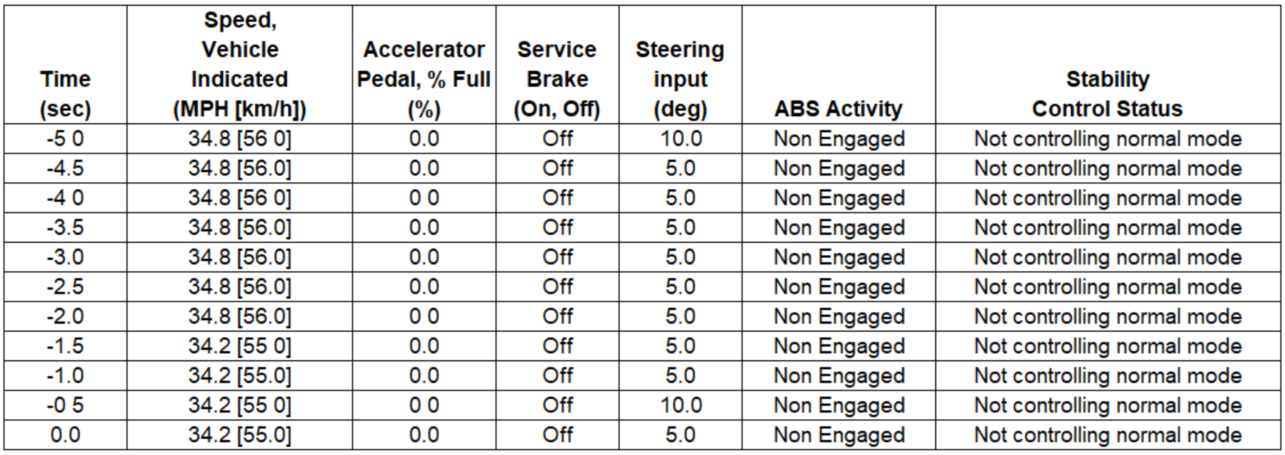
The car was also equipped with an Emergency Lane Keeping System (ELKS), which is designed to prevent the vehicle from crossing the centreline into an oncoming lane if another vehicle is approaching. ELKS *‘is active within the speed range of 60–140 km/h on roads with clearly visible lane markings*’.

The car also featured various forms of Autonomous Emergency Braking (AEBS) through the City Safety system, which can brake in response to preceding vehicles in the same lane. The system is active at lower speeds and can perform effective braking interventions ‘*as long as the relative speed is below 50 km/h. For stationary or slow-moving vehicles, warnings and brake interventions are effective at vehicle speeds up to 70 km/h*’.

Additionally, the car was equipped with various types of cruise control. The most advanced, Pilot Assist, provides steering assistance by centring the vehicle between the lane markings and can remain active at speeds as low as 15 km/h. This is a form of lane centring (LC), see section 4.4.6.

3.3.4 COLLISION DATA FROM THE PASSENGER CAR

Collision data was stored within the passenger car's airbag control module. The airbag module also recorded data[3] for the final five seconds prior to the impact. This showed a steady speed of 55–56 km/h, corresponding to data extending roughly 77 metres before the collision, marked in grey in Figure 13. No acceleration or braking was registered, while a steady leftward steering input (5–10°) was maintained on the steering wheel, as shown in Figure 16.



Time (sec)	Speed, Vehicle Indicated (MPH [km/h])	Accelerator Pedal, % Full (%)	Service Brake (On, Off)	Steering input (deg)	ABS Activity	Stability Control Status
-5 0	34.8 [56 0]	0.0	Off	10.0	Non Engaged	Not controlling normal mode
-4.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-4 0	34.8 [56 0]	0 0	Off	5.0	Non Engaged	Not controlling normal mode
-3.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-3.0	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-2.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-2.0	34.8 [56.0]	0 0	Off	5.0	Non Engaged	Not controlling normal mode
-1.5	34.2 [55 0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-1.0	34.2 [55.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode
-0 5	34.2 [55 0]	0 0	Off	10.0	Non Engaged	Not controlling normal mode
0.0	34.2 [55.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode

Figure 16: Data stored in the airbag module 5 seconds prior to the collision. Speed in mph [km/h], percentage accelerator pedal application, steering wheel angle, ABS activity and stability control status. Source: Bosch CDR, Norwegian Public Roads Administration, NSIA

Data from the final five seconds indicates that the car was driving with some form of cruise control active. The NSIA has received information indicating that the car was highly likely operating with Adaptive Cruise Control (ACC) engaged, whereby the car maintains a selected speed and a chosen time interval against potentially slower vehicles ahead of the car.

The collision occurred in a 60 km/h zone, located between two 70 km/h zones, as shown in Figure 17.

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[3] *The original table is shown in Appendix A.*

Figure 17: Overview of speed limits adjacent to and at the accident site. Source: Vegkart

3.3.5 CRASH TESTING OF THE PASSENGER CAR

The crash safety performance of the passenger car model in a small-overlap test qualified it for a '*Top Safety Pick+*' rating by the Insurance Institute for Highway Safety (IIHS) in 2016.

Figure 18 shows the test of a 2016 Volvo XC90 impacting an immoveable barrier with a 25% overlap. In the test, the car was deflected and pushed to the side, and continued past the safety barrier without stopping. The driver dummy registered a peak acceleration of approximately 23–24 g. A comparison between data from the crash test and the actual collision is shown in Appendix A.

Figure 18: Test of a 2016 Volvo XC90 (CEN1543) Small Overlap Front Test, sequences 1–4, and damage post-test. Source: IIHS

3.4 Corner-to-corner collision in Eidsvoll (2024)

3.4.1 SEQUENCE OF EVENTS AND PERSONAL INJURIES

In 2024, a corner-to-corner collision occurred north of Sagmoen in Eidsvoll municipality, involving a bus and a passenger car with a sole occupant. The collision took place on a two-lane road in the bus's lane. The NSIA was notified and deployed to the accident site. Logged data from the bus indicates that it had a speed of approximately 38 km/h at the point of impact. The speedometer of the passenger car remained stuck at approximately 55 km/h after the collision. The bus continued for approximately 90 metres following the collision, while the passenger car was thrown backwards approximately 9 metres with rotation following the impact, as shown in Figure 19.

The passenger car driver, who was pregnant at the time of the collision, sustained fractures to the neck, lower spine, and left lower leg, but no internal injuries were detected in either the driver or the foetus. The bus driver sustained minor injuries from the accident.

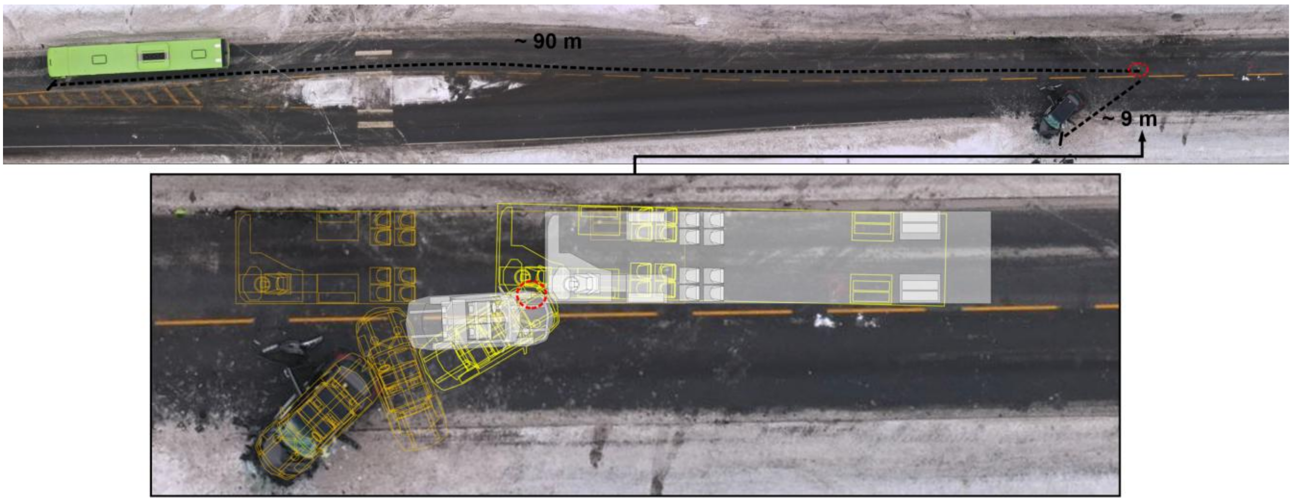

Figure 19: Overview of the collision site and the estimated point of impact with damage the roadway. Photo, markings and illustration: NSIA

3.4.2 VEHICLE DAMAGE

The bus, a regional bus (Class II), sustained damage to its front left corner. The left section of the bus's front crossmember was bent backwards in the collision, and the lower portion of the bus's left-hand-side sidewall was twisted outwards, see Figure 20.

The passenger car's chassis rails and bumper remained relatively intact following the collision, with the front left wheel forced backwards. Traces of green paint matching the bus's paint colour were found on the inside of the passenger car's A-pillar. The driver's door, which was removed during the extrication, was only slightly deformed, see Figure 21.

Figure 20: Vehicle damage illustrated on the left. The bent front crossmember and outward twisting of the left sidewall are marked. Photo, markings and illustration: NSIA

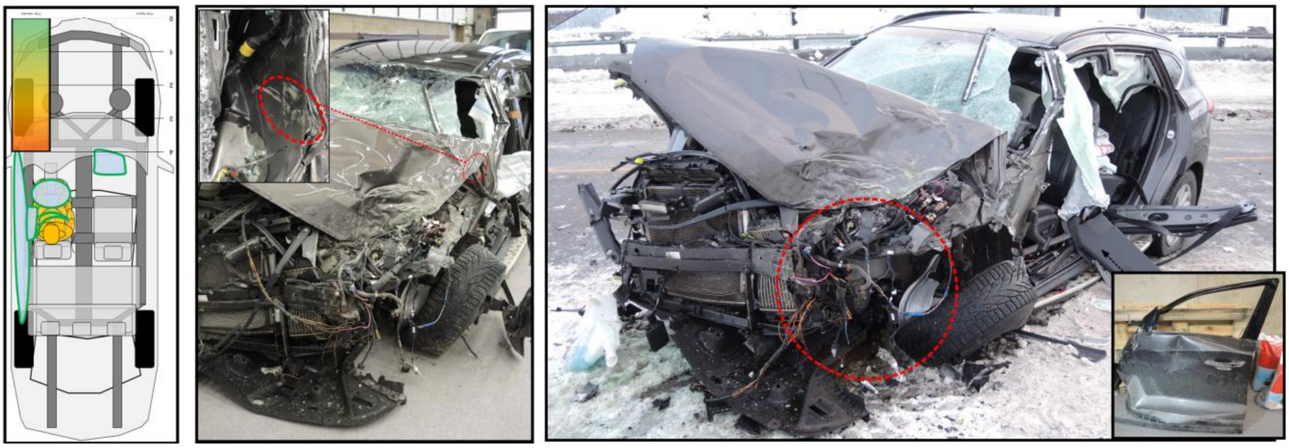

Figure 21: Vehicle damage and activated safety equipment illustrated on the left. Traces of green paint on the inside of the A-pillar, and minor damage to the left chassis rail. Photo, markings and illustration: NSIA

3.4.3 ACTIVE DRIVER ASSISTANCE SYSTEMS

The bus was a 2015-model Volvo 8900 and was not equipped with active driver assistance systems.

The passenger car was a 2017-model Hyundai Tucson ix35, and was equipped with several active driver assistance systems.

The car featured a Lane Keeping Assist (LKA) system which warns and applies subtle torque to the steering wheel if the vehicle approaches a lane boundary line. The vehicle speed *'must be at least approximately 60 km/h to activate the LKA system'.* The car's AEBS or Forward Collision-Avoidance Assist (FCA system) is active within a speed range of 8–80 km/h and brakes for preceding vehicles, but this system does not detect vehicles in the oncoming lane or approaching cross-traffic.

3.4.4 CRASH TESTING OF THE PASSENGER CAR

The crash safety performance of the car model in a small-overlap test qualified it for a '*Top Safety Pick+*' rating by the Insurance Institute for Highway Safety (IIHS) in 2016.

Figure 22 shows the test of a 2016 Hyundai Tucson impacting an immoveable barrier with a 25% overlap. In the test, the front of the car stopped against the barrier and the vehicle rotated approximately 90 degrees outwards alongside the barrier. In the test, as in the actual accident, the side airbag to the left of the driver deployed. The driver dummy registered a peak acceleration of approximately 64–65 g.

Although data from the actual collision was unavailable, the crash test is comparable to the accident since the vehicle, in both cases, came to a complete stop and rotated laterally. Data from the test is shown in Appendix A.

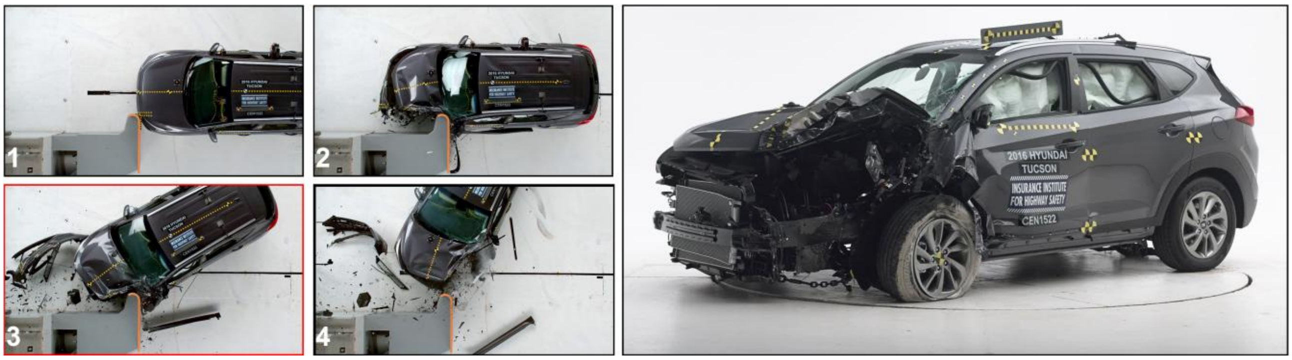

Figure 22: Test of a 2016 Hyundai Tucson (CEN1522) Small Overlap Frontal Test, sequences 1–4, and damage post-test. Source: IIHS

4. Framework conditions and other information

4. Framework conditions and other information

4.1 The Vehicle Regulations' minimum requirements for active and passive safety

The minimum requirements for active and passive vehicle safety are described in the Vehicle Regulations[4]. Some relevant requirements are outlined in Table 1.

Table 1: Appendix 1 of the Vehicle Regulations – Technical requirements for individual approval of new vehicles. Source: Lovdata.no

Topic (classification in the vehicle regulations)	***Applies to [5]:***	***Technical legal doc (requirements)***	***Mandatory for new vehicles***
A11 – Front underrun protection	*N2 and N3.*	*UN-reg. 93.00*	*01.11.2016*
A24 – Cab strength	*N with separate cab.*	*UN-reg. 29.03*	*30.01.2021*
C1 – Steering system	*M, N and O.*	*UN-reg. 79.01*	*01.11.2016*
C2 – Lane departure warning system (LDWS)	*M2, M3, N2 and N3.*	*(EU) no. 351/2012*	*01.11.2016*
		UN-reg. 130.00	*01.10.2022*
C3 – Emergency Lane Keeping Assist (ELKS)	*M1 and N1.*	*(EU) 2021/646*	*01.02.2025*
C8 – Advanced emergency braking system in heavy vehicles (AEBS)	*M2, M3, N2 and N3.*	*(EU) no. 347/2012*	*01.11.2016*
		UN-reg. 131.01	*01.10.2012*
C9 – Advanced emergency braking system in light vehicles	*M1 and N1*	*UN-reg. 152.00*	*01.02.2025*

4.2 Requirements for frontal protection in buses

4.2.1 NATIONAL REGULATIONS

On the basis of NSIA safety recommendation ROAD No. 2019/10T, the Norwegian Public Roads Administration introduced new Norwegian requirements for frontal crash protection in new buses from 1 October 2023, through Section 4 of the Regulations on Universal Design of Motor Vehicles used for Licensed Transport etc. in Norway. The requirements are identical to those applicable to heavy goods vehicles with a separate cab:

> *Section 4. Requirements that apply to buses*
>
> *Class I, II and III buses that are covered by these Regulations and that are registered for the first time in Norway from and including 1 October 2023, shall meet the requirements for frontal protection described in Section 5 of UN Regulation No 29 point 5 when the crash test*

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[4] Regulation of 28 June 2022 No 1233 on the approval of road vehicles and road vehicle trailers (The Vehicle Regulations).

*[5] **M1**: Passenger car (Max 9 seats), **M2:** Bus (max. 5,000 kg, at least 10 seats), **M3:** Bus (over 5,000 kg, at least 10 seats), **N2:** Heavy goods vehicle (over 3,500 kg, but max 12,000 kg), **N3**: Heavy goods vehicle (over 12,000 kg).*

has been carried out in accordance with Annex 3 Test A where the impact value of the impactor shall be in accordance with point 5.5.2. The conditions in section 5.1.6 can be used as an alternative to mechanical testing.

4.2.2 INTERNATIONAL REGULATIONS

In May 2023, the Norwegian Public Roads Administration presented a proposal to the Working Party on Passive Safety (GRSP) at UNECE[6] to *'amend the scope of ECE Regulation 29 and perhaps add a new section for testing the front of buses. Alternatively, establish a new regulation for the frontal protection of buses. This includes introducing this as a common requirement within the EU'*.

Within UNECE, under the GRSP, a task force has been established titled 'Frontal protection of buses'[7] Information regarding the regulatory development for enhanced frontal protection of buses is available on the task force's website:

> *'Norway further intends to propose a Taskforce at the upcoming GRSP meet in May/June 2026, with the aim of developing safety regulations related to improved crashworthiness for buses. Norway invites all interested parties to support this initiative.'*

4.3 Requirements for underrun protection on heavy goods vehicles (FUPD[8])

There are no requirements for underrun protection devices on buses. For heavy goods vehicles (N2 and N3), requirements for underrun protection were first introduced through UN ECE Regulation No. 93, which came into force in 1994. The directive introducing these requirements in the EU was adopted on 26 June 2000, and the provisions were subsequently implemented in the Norwegian Vehicle Regulations in 2001.

Figure 23 on the left shows the design requirements for the width and shape of the underrun protection device, and the maximum deformation post-test (400 mm). On the right are design examples of underrun protection devices.

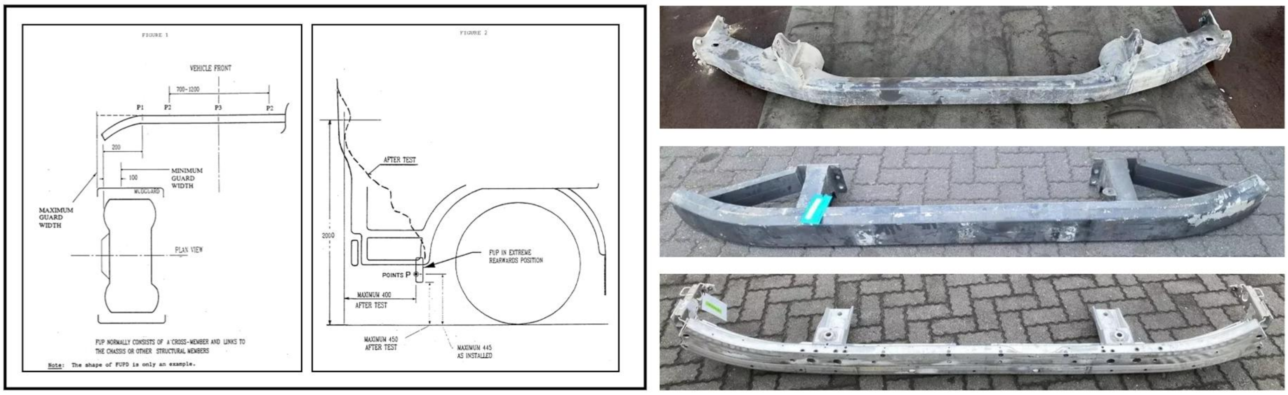

Figure 23: Design requirements for underrun protection devices as described in UN ECE R 93, with examples of different designs on the right. Source: UN ECE

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[6] *Informative document presented at the United Nations Economic Commission for Europe (UNECE).*

[7] *https://wiki.unece.org/spaces/trans/pages/352124994/Frontal+protection+of+buses*

[8] *FUPD is an abbreviation of Front Underrun Protection Device*

4.4 Requirements for advanced driver assistance systems

4.4.1 INTRODUCTION

Advanced Driver Assistance Systems (ADAS) is a collective term for several systems that are intended to contribute to safe and comfortable driving. Figure 24 provides an overview of some of the driver assistance systems described in this section. The systems primarily utilise radar, Lidar and forward-facing cameras as sensors.

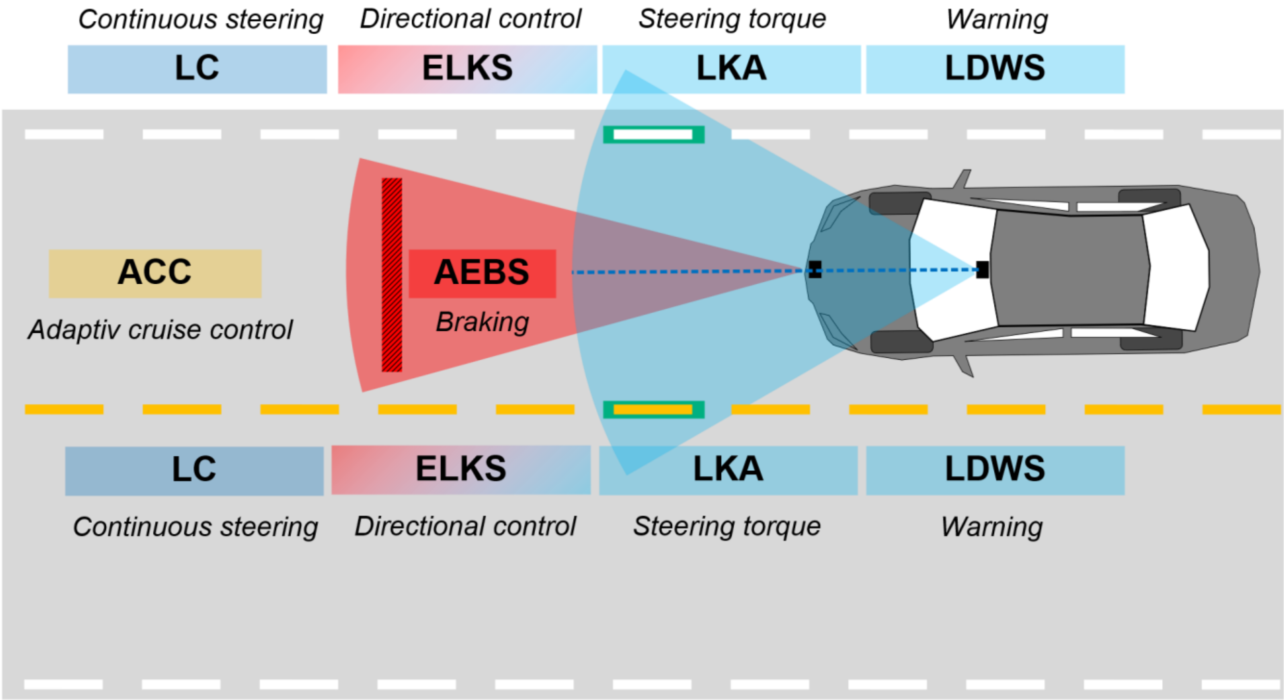

Figure 24: Illustration of four systems for lane support (LDWS, LKA, ELKS and LC) and two systems for speed regulation (AEBS and ACC). Illustration: NSIA

These driver assistance systems can have a preventative effect by detecting, warning and intervening in the driving process, thereby reducing the likelihood of collisions. To varying degrees, the systems can be modified or disconnected by the driver while driving. The systems and the manner in which they operate to prevent collisions[9] from occurring are described below.

The collective term 'lane support' encompasses one or more of the systems LDWS, LKA, ELKS, and LC.

4.4.2 LANE CHANGE WARNING SYSTEM (LDWS)

Lane Departure Warning System (LDWS) monitors the vehicle's position as long as the ignition is on. It monitors the vehicle within its own lane using cameras that interpret the lane markings ahead. If the vehicle is about to leave its lane above a given speed, the driver is alerted either visually, acoustically or via steering wheel vibrations. LDWS depends on clear lane markings to function optimally and is a reactive system.

UN ECE R 130 specifies that the LDWS system for buses and heavy goods vehicles must be active at a speed of at least 60 km/h or higher. Testing of the system must be performed at 65 km/h.

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[9] *Rethinking Advanced Driver Assistance System taxonomies: A framework and inventory of real-world safety performance*

For passenger cars undergoing type approving , the requirement for the LDWS system is that it must at a minimum be active within the speed range of 65–130 km/h. The system must be tested at a speed of 70 km/h.

4.4.3 LANE KEEPING ASSIST (LKA)

Lane Keeping Assist (LKA) is a system that helps the driver remain within the lane by providing steering corrections, or steering torque, when the vehicle is about to cross lane markings without the indicator being activated. It can be seen as a more corrective system based on LDWS. The system uses cameras to detect lane markings and is a reactive system.

4.4.4 EMERGENCY LANE KEEPING ASSIST (ELKS)

Emergency Lane Keeping System (ELKS) is a further development of the LKA system for passenger cars. This is a driver assistance system designed to warn the driver and steer the vehicle to prevent collisions by *'correcting the vehicle's path, but only when the driver leaves the lane unintentionally'.* This system must co-operate with several other systems and is a reactive system.

The Corrective Directional Control Function (CDCF) must be active at least within the speed range of 70–130 km/h, and additionally remain active down to 65 km/h if the vehicle reduces speed from above 70 km/h. The system must automatically engage every time the master switch is turned on, and it must not be possible to deactivate it with fewer than two deliberate actions.

4.4.5 ADVANCED EMERGENCY BRAKING SYSTEM (AEBS)

The Advanced Emergency Braking System (AEBS) monitors the vehicle's position as long as the ignition is on. It is a system designed to automatically detect a risk of collision and activate the vehicle's braking system. The purpose of the system is to avoid a collision within the vehicle's own lane, or to reduce the vehicle's speed before a collision occurs. AEBS monitors continuously but is a reactive system.

The AEBS system is regulated for both passenger cars in UN ECE R 152 and for heavy vehicles[10] in UN ECE R 131. For passenger cars, this system must be active at least within the speed range of 10–60 km/h, and for buses and heavy goods vehicles from 10 km/h up to the vehicle's maximum permitted speed. The braking must be capable of achieving a deceleration of 5 m/s^2 for passenger cars and 4 m/s^2 for heavy vehicles under normal friction conditions. The scenario for automatic emergency braking must be unambiguous. A scenario is unambiguous if:

(i) The preceding vehicle is unobstructed, clearly separated from other objects in the driving lane and constantly travelling or stationary.

(ii) The vehicle longitudinal centre planes are displaced by not more than 0.2 m[11]*.*

(iii) The direction of travel is straight with no curve, and the vehicle is not turning at an intersection and following its lane.

4.4.6 LANE CENTRING (LC)

Lane Centring (LC) is a system that keeps the vehicle centred in the lane by continuously providing steering corrections. This system is regulated through UN ECE 79, which deals with steering

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[10] *UN ECE R 131 applies to vehicle categories M2, M3, N2 and N3.*

[11] *Corresponding requirements apply to passenger cars and light commercial vehicles, M1 and N1, in UN ECE R 152, section 5.2.1.4*

systems, where lane centring is classified as an Automatically Commanded Steering Function (ACSF) graded under Category B1, B2. This system must be activated by the driver, and once engaged, it operates as a continuous, proactive system.

4.4.7 ADAPTIVE CRUISE CONTROL (ACC)

Adaptive Cruise Control is a system that performs speed regulation, utilising radar, LiDAR and cameras, or a combination thereof, to automatically regulate the vehicle's speed independently. The driver sets a target speed and the vehicle adjusts its distance relative to any preceding vehicle. ACC does not have a separate type-approval requirement, but in the new UN ECE R 171 Driver Control Assistance Systems (DCAS), requirements are placed on systems that perform speed regulation. This is a continuous, proactive system.

4.4.8 INTERACTION BETWEEN DRIVER ASSISTANCE SYSTEMS (ADAS)

The performance and interaction of driver assistance systems in modern vehicles are both tested and regulated, alongside rapid and significant technological development in the field. In October 2025, Euro NCAP established a test protocol for lane departure with an extended speed range (50–100 km/h) to assess Emergency Lane Keeping Systems (ELKS). In November 2024, requirements were introduced for vehicles with ‘systems to assist the driver in executing dynamic control’ through DCAS in UN ECE R 171. This regulation imposes stricter requirements for clear warnings regarding system status, including whether the system is ‘off’, ‘on’, or ‘on and active’.

4.5 Buses with central driving position and entrance behind the front axle

This section shows examples of different front concepts on buses, though the examples are not exhaustive of what has been manufactured.

A common feature of these front designs is that the front passenger entrance is located behind the front axle, and the area in front of the front axle is designed more or less as a cab for the bus driver, where the driving position is nearly or completely centrally aligned.

In 1994–1995, Volvo developed an Environmental Concept Bus (ECB) as a future concept for how buses might look in the future, see Figure 25.

Figure 25: Volvo ECB 1995, a bus with 30 seats and a central driving position. Photo wiki.gearknob.org

In 2016 in Malmö, a concept bus was developed with Volvo Buses, see Figure 26. In several Norwegian cities, the Van Hool ExquiCity, a Class I metro-bus, is in service, see Figure 27.

Figure 26: Volvo concept bus 2016. Central driving position and forward passenger entrance behind the front axle. Photo: Volvo bus

Figure 27: Van Hool ExquiCity i Trondheim. Almost central driving position and forward passenger entrance behind the front axle. Photo: AtB AS

4.6 Crash testing

4.6.1 50% OVERLAP CRASH TESTING BETWEEN A HEAVY GOODS VEHICLE AND A PASSENGER CAR

In 2024, Chalmers University of Technology and others conducted trials with frontal collisions between heavy vehicles and passenger cars. The first test demonstrated that '*compatibility between HGVs and cars must be improved for frontal impacts when less than 50% of the car width engages the truck structures"*. The report states that existing statutory requirements for underrun protection should be reviewed to ensure that geometric and structural requirements for these designs reflect demands of real-world collision.

The report notes that possibilities for improved safety systems in passenger cars require an interaction between vehicle structures to effectively utilise the energy absorption systems developed in both heavy vehicles and passenger cars. The new EU regulation for extended fronts provides an opportunity that can be utilised to achieve better compatibility between cars and heavy vehicles by allowing more design freedom at the front of heavy vehicles.

In one trial, a passenger car and a heavy goods vehicle without an energy-absorbing front structure collided head-on at speeds of 50 km/h, see Figure 28. The weight of the heavy goods vehicle was 28 tonnes, and the passenger car's weight was 1.57 tonnes[12]. The change in velocity over 0.2 seconds was approximately 6 km/h for the heavy goods vehicle and approximately 100 km/h for the passenger car. The heavy goods vehicle continued forward and stopped after 82 m, and the passenger car was thrown nearly 25 m backwards against its original direction of travel.

Figure 28: Crash test and vehicle damage with a rigid front on the heavy goods vehicle. Each vehicle had an impact speed of 50 km/h in the tests. Photo: Swedish Transport Administration/Chalmers

In a corresponding test, an energy-absorbing structure was installed on the front of the heavy goods vehicles. The final report for this test notes that the acceleration and deformation of the passenger car were improved compared to the reference test with a rigid heavy goods vehicle without an energy-absorbing front.

Figure 29: Collision trial and vehicle damage with an energy-absorbing front structure in the form of a solid plate installed on the heavy goods vehicle. Each vehicle had an impact speed of 50 km/h in the tests. Photo: Swedish Transport Administration/Chalmers

4.6.2 OBLIQUE SMALL-OVERLAP CRASH TESTING FOR PASSENGER CARS

In addition to the IIHS ‘Small Overlap Front Test’, it is relevant to describe one of the test protocols that has been under development for over 10 years within the National Highway Traffic Safety Administration's (NHTSA) NCAP system, known as ‘Small Overlap and Oblique Testing’. This protocol addresses oblique corner-to-corner collisions. In this test, a test rig (OMDB) of approximately 2,500 kg at 90 km/h approaches obliquely toward a stationary test car, impacting with approximately 35% overlap, as shown in Figure 30. Studies from 2018, showed this test series generally yielded repeatable and reproducible results.

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[12] *Equivalent to total energy of approx. 2,852 kJ.*

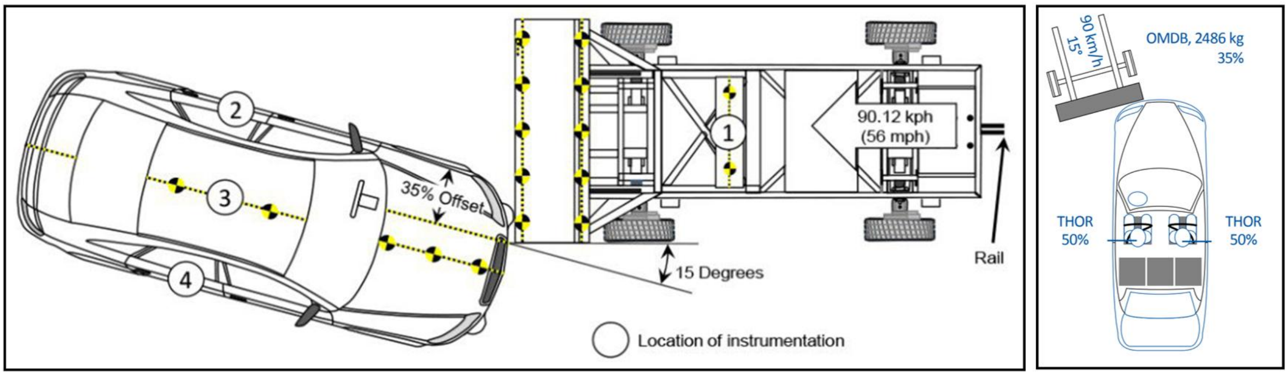

Figure 30: Test series with a 2.5-tonne test rig at 90 km/h impacting at an oblique 15-degree angle and 35% overlap against a stationary passenger car. Illustrations: left: NHTSA (2018), right: Safetwissen, carhs (2026)

4.7 Other relevant reports

In May 2023, the Norwegian Public Roads Administration received a supplementary letter of allocation from the Ministry of Transport, tasking them with further investigating crashworthiness requirements for buses. This has resulted in several reports from the Institute of Transport Economics (TØI) commissioned by the Norwegian Public Roads Administration and Ruter AS:

- Crashworthiness of buses Analysis of European data and suggestions for improvements [2082/2025].
- Literature review of active and passive measures to improve bus safety [2094/2025].
- Technical Study of collision protection for bus drivers: Development of new solution trends for collision protection [2096/2025].
- Bus accidents in Europe: Factors influencing injury risk and severity [2111/2025].
- Frontal Crash Protection for Bus Drivers: Simulation-Based Assessment of Test Methods and Structural Countermeasures [2139/2026].

5. The Norwegian Safety Investigation Authority's assessments

5. The Norwegian Safety Investigation Authority's assessments

5.1 Introduction

A large proportion of fatalities in frontal collisions between buses and other vehicles are drivers of light vehicles. From previous investigations, the NSIA has extensive knowledge of corner-to-corner collisions involving buses and structural weaknesses in bus front designs, and this is a topic that is also being addressed internationally.

The primary question in this thematic investigation is whether the lack of impact-deflecting design at the front of buses not only increases the risk to bus drivers, but may also contribute to a greater degree of damage and more severe consequences for vehicles involved in frontal collisions. During the course of the investigation, it also became clear that the NSIA needed to investigate the significance of the vehicles' active driver assistance systems in preventing such frontal collisions from occurring in the first place. The two corner-to-corner collisions in Figgjo (2023) and Eidsvoll (2024) made this particularly relevant.

The analysis begins with a review of survival aspects in frontal collisions occurring within the so-called breaking zone area. A key finding is that a small overlap between vehicles in a frontal collision has a significant impact on the severity of an accident. Following this, the functionality of active driver assistance systems in small-overlap frontal collisions is evaluated. Furthermore, passive safety and differences in force transmission between a full-frontal collision and a small-overlap frontal collision are analysed. Finally, opportunities to further develop the frontal crashworthiness of buses are assessed, with the objective of providing better protection for bus drivers, bus passengers and occupants of vehicles involved in frontal collisions.

5.2 Survival aspects in frontal collisions between buses and lighter vehicles in the breaking zone

The investigation demonstrates, unsurprisingly, that speed and the point of impact between vehicles in a collision affect the extent of injuries and the severity of the accident. In the 23 accidents between buses and lighter vehicles in the breaking zone, there was a distinct difference in vehicle damage profiles and personal injuries when distinguishing between fatal accidents and those involving serious injury.

Higher-energy accidents with a large overlap, or an approximate frontal collision, showed a greater tendency to be survivable, whereas corner-to-corner collisions with the same energy level tended to result in fatalities.

The bus in the frontal collision on the Fredrikstad Bridge in 2021 was fitted with a front underrun protection device. The investigation shows that this successfully mitigated a severe full-frontal collision by preventing the passenger car from being completely overrun by the bus. The driver of the passenger car survived.

In the corner-to-corner collision at Figgjo in 2023, the left section of the bus's front crossmember was torn off. This resulted in the bus floor overriding the bonnet of the passenger car and intruding into the passenger compartment, despite the car deflecting to the side of the bus, as it was designed to do in small-overlap collisions. The driver of the passenger car was killed; the car passengers and the bus driver sustained minor injuries.

In the corner-to-corner collision in Eidsvoll in 2024, the left section of the bus's front crossmember was bent backwards. The floor of the bus overrode the passenger car's bonnet, and the deflection of the front crossmember caused the car to be pushed backwards and rotate laterally, a kinematic behaviour this vehicle was designed for in small overlap collisions. The bus's side panel was distorted outwards and penetrated the windscreen on the inside of the passenger car's A-pillar. It was down to chance that the side panel did not intrude further into the driver's space. The driver was seriously injured, and the NSIA considers that correct seatbelt use and the deployment of three airbags were of major significance in preventing this from becoming a fatal accident.

The review of personal injuries in the fatal accidents indicates that many of the deceased sustained fractures and organ injuries typically resulting from impact against, or from, interior components. The NSIA assesses that these injuries largely originate from the intrusion of bus body components into and over the lighter vehicle's driving position.

Furthermore, the investigation has shown, through the full-frontal collision on the Fredrikstad Bridge in 2021, that front underrun protection devices on coaches are advantageous to the injury mechanics and survival aspects in a full-frontal collision between buses and other vehicles. However, the NSIA believes that an underrun protection device does not sufficiently address the challenge presented by a corner-to-corner collision.

By categorising the 23 accidents in the breaking zone according to the depth of damage to the lighter vehicles' front left corner and plotting the average damage profile, it became apparent that the damage profile is strongly correlated with the severity of the accidents, see figure 31.

Among the frontal collisions with a damage depth of ‘4’ on the front left corner, the corner-to-corner collision in Eidsvoll in 2024 was the only one of 11 accidents with an equivalent damage depth that did not result in a fatality. Among frontal collisions with the second largest damage depth of ‘3’ or less on the front left corner, there were no fatalities. The full-frontal collision on the Fredrikstad Bridge in 2021 was one of several accidents with a high total energy level and similar damage profile that did not result in fatalities.

In summary, the NSIA considers that the findings support the conclusion that weaknesses in the front corner design of buses contribute to a greater degree of damage and more severe consequences for vehicles involved in frontal collisions with a small overlap, or corner-to-corner collisions. The fatal accidents demonstrated a tendency for the bus's corner structure to give way, resulting in significant intrusion into the driving position of the lighter vehicle.

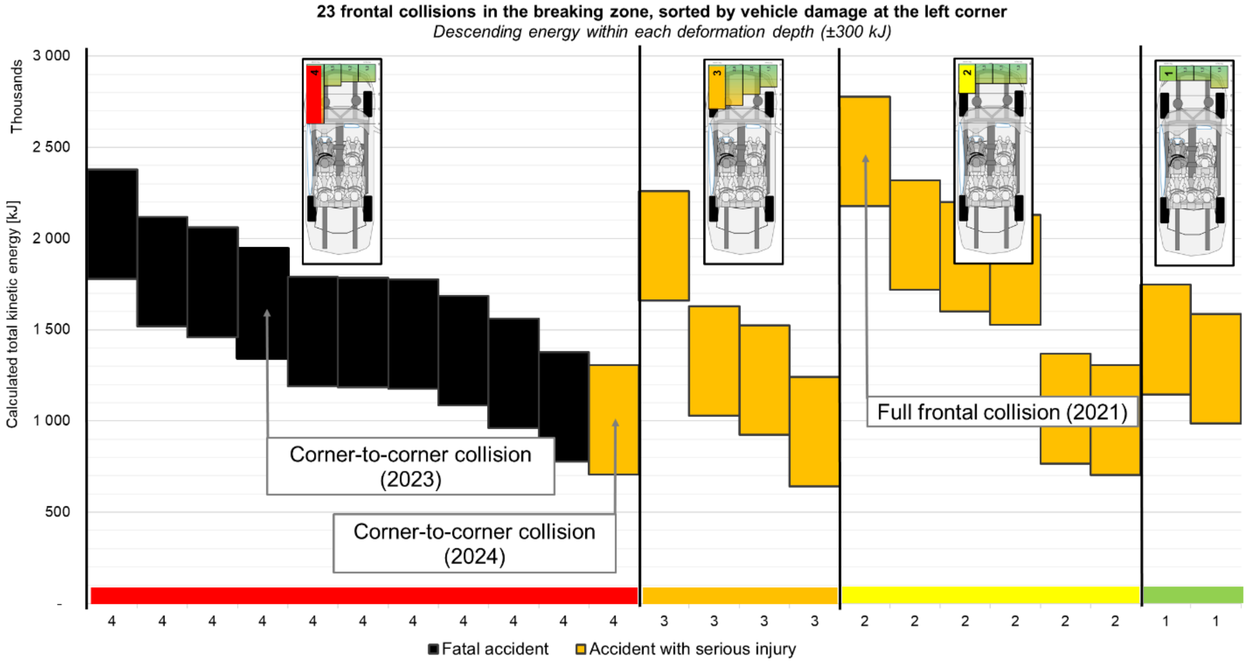

Figure 31: 23 frontal collisions in the breaking zone categorised by vehicle damage to the front left corner. The illustration demonstrates that in fatal accidents, the lighter vehicle has more pronounced damage to the front left corner than in accidents involving serious injuries. Illustration: NSIA

5.3 Active driver assistance systems and frontal collisions

5.3.1 LANE SUPPORT AND FUNCTIONAL LIMITATIONS

In all but two accidents in the high-energy range, the speed of the buses immediately prior to the collision was above 60 km/h. This corresponds to the minimum speed requirement for the activation of LDWS/LKA systems for heavy vehicles, as described in section 4.4.2.

In the accidents in the breaking zone in which the opposing vehicle was a lighter vehicle, all buses were travelling at a speed of 60 km/h or lower. This implies that lane support for buses would only have been available in a small number of the accidents in the breaking zone and low-energy range. Vehicle manufacturers are, however, free to programme lower activation speeds than the minimum requirements specified in the regulations.

Manufacturers of lighter vehicles are likewise free to programme LDWS/LKA systems with a lower activation speed than the minimum requirement of 65 km/h. In the corner-to-corner collisions in Figgjo (2023) and Eidsvoll (2024), Lane Keeping Assist (LKA) was available in both passenger cars, but the systems activated at different speeds: 60 and 65 km/h respectively. In both accidents, the cars had a speed of around 55 km/h before leaving their own lane. This meant that LKA was not active in these cars, and therefore neither warned the driver nor corrected the car back into its own lane before crossing the centreline. The NSIA assesses that the steering angle relative to the centreline before the lane change was, in both cases, within what LKA systems should normally be capable of handling, provided they are active.

If the regulatory minimum requirements are taken as a basis, lane support systems in an oncoming scenario between a heavy and a lighter vehicle will only be active when the relative speed between the vehicles is 125 km/h or higher. Among the fatal accidents in the breaking zone, the closing speed between buses and the lighter vehicles was in the range of 100–140 km/h. The investigation also shows that when the closing speed was below 100 km/h, fatal accidents were less likely to occur, regardless of overlap.

If lane support is to contribute to reducing the risk of fatal accidents in small-overlap frontal collisions, LDWS/LKA systems should be active at speeds that ensure the closing speed between the vehicles is kept below this threshold of 100 km/h. Assuming the two oncoming vehicles are travelling at approximately equal speeds, this implies that lane support systems should be active at speeds at speeds of approximately 50 km/h. A lower activation speed could provide a significant risk-reducing effect in preventing frontal collisions between buses and lighter vehicles on roads with marked centrelines.

Many vehicles are equipped with an Advanced Emergency Braking System (AEBS). However, these systems are primarily designed to prevent rear-end collisions and full-frontal collisions within the vehicle's own lane. In many vehicles, AEBS has a limited capability to detect oncoming vehicles in the opposing lane, and the systems are not designed for this purpose. In oncoming scenarios where driving speeds renders lane support systems passive, vehicles will in practice be left without active driver assistance in the phase immediately preceding a frontal collision. This is because the systems individually have functional limitations, meaning they do not cover such scenarios.

The NSIA has received feedback indicating that technological limitations greatly affect the speed range for the activation of lane support systems. However, the NSIA is also aware that certain car manufacturers have lane support systems that are active at speeds of 48–50 km/h, and that some heavy vehicles maintain system activity as low as 55 km/h after initially being activated at 60 km/h. This means that on roads with a centreline, oncoming scenarios may arise where both a heavy and a lighter vehicle have active lane support systems at relative speeds down to 103–105 km/h.

Based on information the NSIA has received, lane support systems can be kept active at lower speeds if technological solutions and assessment criteria are further developed. Examples of newer technology include systems that combine driver gaze tracking with lane support. Some manufacturers are also evaluating the activation of lane support in situations where the vehicle is accelerating or braking below a given threshold, and in which the steering input is too small to indicate an intentional lane change.

The NSIA considers that the variations in activation speed between different car models are substantial, and that this is information which consumers should be familiar with. Vehicle drivers should actively familiarise themselves with the functions and limitations of driver assistance systems (ADAS). Simultaneously, vehicle manufacturers should actively disclose the functions and limitations of driver assistance systems. In this context, the NSIA also calls on vehicle manufacturers to consider activating and maintaining lane support systems at lower speeds than prescribed by regulations, based on multiple factors rather than speed alone.

5.3.2 SUMMARY

The issues surrounding active driver assistance systems are complex and are being addressed both through Euro NCAP and new international regulations. A core safety challenge identified by the NSIA is that the speed thresholds for activating lane support systems are generally too high to allow many fatal frontal collisions between buses and lighter vehicles to be avoided using these systems.

The investigation also shows that several of the accidents occurred on bends, on roads without a centreline, or under road conditions where the centreline marking was not visible. Previous investigations have furthermore demonstrated that frontal collisions between two buses can prove fatal at speeds as low as 30 km/h.

Taken as a whole, the investigation demonstrates that lane-based driver assistance systems have distinct limitations, relating both to activation speed and road conditions. Consequently, the further development of passive safety, with a view toward more predictable vehicle structures in frontal collisions, will remain of great importance moving forward.

5.4 Further work on frontal crash protection in buses

5.4.1 POTENTIAL FOR IMPROVED FRONTAL CRASH PROTECTION IN BUSES

The basis for further work on frontal crash protection in buses includes assessing existing solutions. Heavy vehicles are required to have front underrun protection as a regulated measure to mitigate the consequences of frontal collisions. Buses were not subject to corresponding requirements when the regulations were established, probably because the front design was considered less likely to overrun lighter vehicles. However, the investigation shows that an underrun protection device on a coach (class III) can have a positive effect in a frontal collision.

The design of underrun protection devices is characterised by being relatively flat across the entire width of the front, with attachment points in the vehicle's structural chassis. However, the NSIA's investigations of frontal collisions with a small overlap show that vehicle chassis do not achieve the same level of force transmission in corner-to-corner collisions as they do in a full-frontal collision. Figure 32 illustrates the differences in force transmission within the chassis between a full frontal collision and a corner-to-corner collision involving a bus and a lighter vehicle.

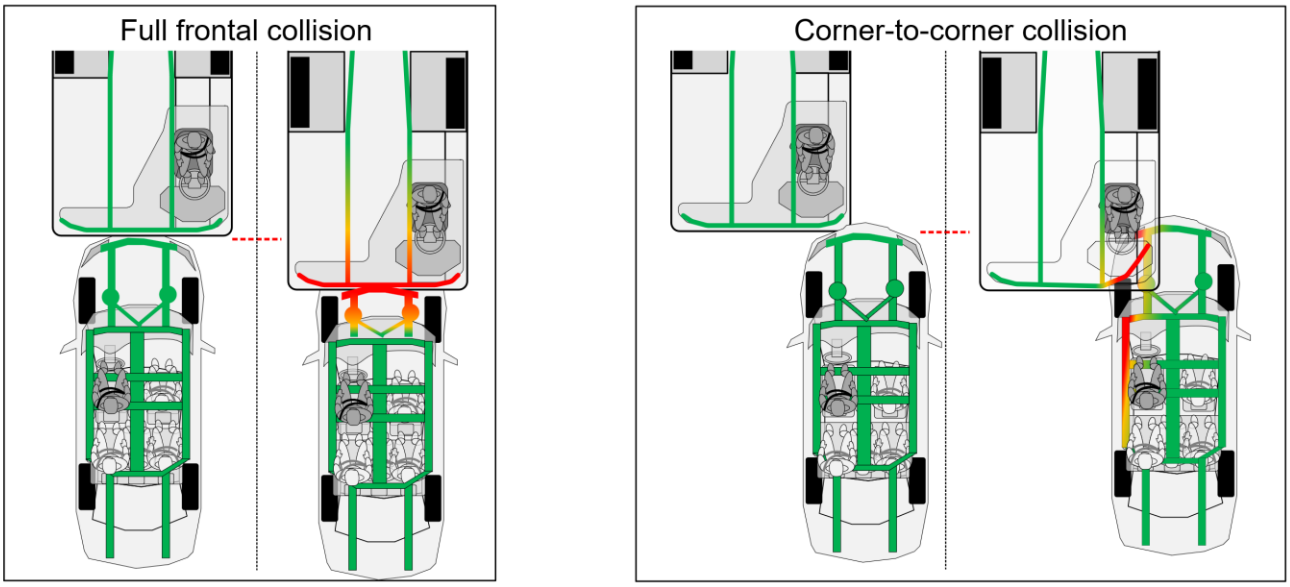

Figure 32: Illustration of force transmission between a full-frontal collision (left) and a corner-to-corner collision (right) involving a bus and a lighter vehicle. Illustration: NSIA

There was a high proportion of corner-to-corner collisions among the fatal accidents in this investigation. This applies to the accidents both in the breaking zone and in the high-energy range.

Crash tests conducted by Chalmers involving a lorry and a passenger car show that in a collision with a 50% overlap, the outer part of the underrun protection device can be sheared off, and the greatest force transmission occurs at the heavy goods vehicle's front left wheel. The tests were in an energy range higher than the breaking zone in this investigation, but they nonetheless demonstrate challenges regarding the design of the underrun protection device – namely that the outer left section is sheared off and the overrunning occurs at the left corner. The second test from Chalmers, featuring an energy-absorbing front, showed an improved effect on the passenger car, but a key learning point from the tests was the lack of deflective impact surfaces between the vehicles.

Underrun protection devices are developed to receive and cushion the entire front of the oncoming vehicle. However, the investigation shows there is a need for solutions that can both cushion and deflect the vehicles away from each other to reduce the severity of accidents. The NSIA therefore considers it appropriate to pursue the proposal from the Norwegian Public Roads Administration for '*new regulations relating to the frontal protection of buses'* (see section 4.2.2).

The Norwegian requirements for frontal protection in new buses, which came into force in October 2023, constitute a clear signal that bus drivers are entitled to better protection of their driving compartment. The driver's compartment in a bus is traditionally adjacent to both a passenger entrance and a passenger gangway. The NSIA believes that frontal crash protection can be improved by focusing attention on the division of the driver compartment in the bus.

There are examples of buses with alternative layouts of the driver compartment that have been in service for many years (see 4.5). These buses also feature either a central or nearly central driving position. When the entire area in front of the front axle is designed solely as a driver compartment, the driving compartment can be moved to a position that is less vulnerable in frontal collisions. This can be achieved without reducing the driver's field of vision, whilst providing greater scope to develop a more crashworthy front end.

5.4.2 EXAMPLE OF A PROTECTIVE AND IMPACT-DEFLECTING BUS FRONT

A frontal crash protection system that both absorbs compression forces and deflects oncoming vehicles will have a greater space requirement in order to establish a deflecting impact angle with an oncoming vehicle. The NSIA believes that there is already scope for this within existing regulations. Figure 33 shows two different existing bus fronts, alongside an example of a deflecting, and thus more crashworthy, bus front.

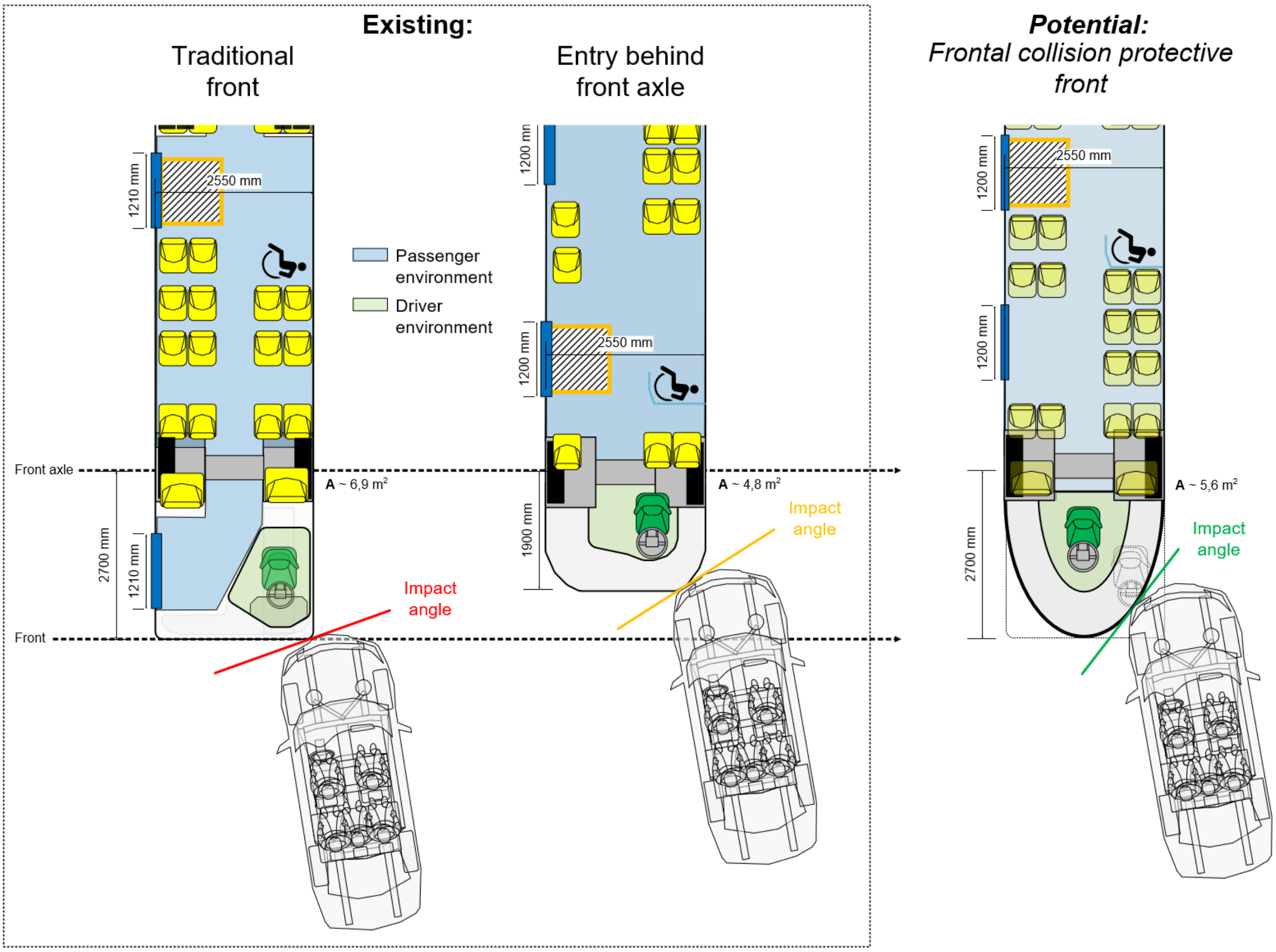

Figure 33: Left: two existing bus fronts showing differences in overhang, location of the front passenger entrance and driver's compartment. Right: an illustration of a front end that has potential for better crash protection and an improved deflecting impact angle against a vehicle approaching obliquely with approximately 35% overlap. Illustration: NSIA

The illustration shows the opportunities that present themselves when the location of the front passenger entrance and driver compartment are altered. When the front entrance is moved behind the front axle, the driver's compartment can be moved to a less vulnerable area. This will provide better protection for the bus driver, the steering gear and the braking system.

In the illustration, the passenger area (light blue) and the driver's compartment (light green) are separated. The illustration is also dimensioned[13] to show the differences in area and layout in the zone between the front and the front axle across the various solutions. A curved front results in a smaller footprint in front of the front axle compared to a traditional front end. Nevertheless, the number of passenger seats remains the same, and a curved front provides better protection in a collision and a more favourable impact angle against an oncoming vehicle. The impact angle between a lighter vehicle and a traditional bus front end (red and yellow lines) and a curved front end (green line) is shown in Figure 33.

A curved front may also provide a more aerodynamic design, without necessarily compromising existing technical requirements for buses, universal design or future requirements for direct vision and blind spots.

The investigation shows that there is both scope and significant potential within current regulations to develop improved frontal crash protection in buses. The NSIA is of the opinion that there are

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[13] General layout, overhang, width, entrances and wheelchair space are dimensioned using available information from existing buses and accessibility guidelines.

currently no regulations that set requirements for solutions that are both energy-absorbing and impact-deflecting.

The NSIA therefore submits a safety recommendation to the Norwegian Public Roads Administration to continue international efforts to develop a regulation that incorporates both of these characteristics into the front structure of buses.

5.4.3 DEVELOPMENT OF FRONTAL CRASH TESTS FOR BUSES

As a result of demanding corner-to-corner crash tests, several car manufacturers have developed a design that causes the car to glance sideways upon encountering a barrier at the outermost left corner. Such a design has been shown to nearly halve the impact forces compared to cars that come to a complete stop when impacting a barrier. This is demonstrated in the results of crash tests, described in sections 3.3.4 and 3.4.4. Such a deflective impact surface has not been developed or tested on buses.

Although the ‘Small Overlap and Oblique Testing’ series is under development within the NCAP system in the USA, the issue it addresses is highly relevant to the findings of this investigation. The test rig has an energy level of approximately 780 kJ and represents the test method that closest replicates small-overlap frontal collisions between buses and lighter vehicles.

The test series was not developed specifically for buses, but it can nevertheless serve as a common reference point for assessing crash compatibility[14] between vehicles of different shapes and sizes. The test may also be relevant as a starting point for testing deflective frontal crash performance in further work to strengthen the passive frontal crash protection of buses.

Euro NCAP plans to introduce crash tests for heavy goods vehicle in 2030 as part of the ‘Safer trucks’ programme. The NSIA is not aware of the test protocols being developed for these tests but believes that buses should also be included in this work.

Based on the investigation, the NSIA submits a safety recommendation to the Norwegian Public Roads Administration to propose to Euro NCAP the introduction of crash simulations and component tests for buses under the ‘Safer Trucks’ programme.

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[14] *Compatibility is defined as ‘the ability to function together, operate without conflict, or harmonise’.*

6. Safety recommendations

6. Safety recommendations

The Norwegian Safety Investigation Authority submits the following safety recommendations[15] for the purpose of improving road safety:

Safety recommendation ROAD No 2026/05T

The thematic investigation has covered 55 serious head-on collisions involving buses during the period 2012–2025. Corner-to-corner collisions between buses and lighter vehicles often resulted in fatalities, whereas accidents involving serious injuries at a corresponding energy level were to a greater extent full-frontal collisions.

The findings support the conclusion that the lack of an impact-deflecting design at the front of the bus contributes to a greater degree of damage and more severe consequences for oncoming vehicles involved in head-on collisions with a small overlap. There is scope within the regulations to develop improved crashworthiness, but there is no framework to propose requirements for energy-absorbing and, in particular, deflective frontal crash protection in buses.

The Norwegian Safety Investigation Authority recommends that the Norwegian Public Roads Administration continue its international efforts and work to establish a new regulation that emphasises both energy-absorbing and, specifically, deflective frontal crash protection in buses.

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[15] *The investigation report is submitted to the Ministry of Transport, which will take necessary measures to ensure that due consideration is given to the safety recommendations, cf. Regulations of 30 June 2005 No 793 on Public Investigation and Notification of Traffic Accidents etc Section 14. The Road Supervisory Authority is responsible for following up all safety recommendations for roads on behalf of the Ministry of Transport. This means, among other things, maintaining an overview of the follow-up of all the NSIA's safety recommendations in the road sector and recommending closure to the Ministry of Transport when a safety recommendation is considered satisfactorily followed up.*

Safety recommendation ROAD No 2026/06T

The thematic investigation has covered 55 serious head-on collisions involving buses during the period 2012–2025. Corner-to-corner collisions between buses and lighter vehicles often resulted in fatalities, whereas accidents involving serious injuries at a corresponding energy level were to a greater extent full-frontal collisions.

The findings support the conclusion that the lack of an impact-deflecting design at the front of buses not only increases the risk to bus drivers, but may also contributes to a greater degree of damage and more severe consequences for vehicles involved in head-on collisions. There is scope within current regulations to develop improved frontal crash protection in buses that is both energy-absorbing and impact-deflecting. Euro NCAP plans to introduce crash tests for heavy goods vehicle in 2030 under the ‘Safer Trucks’ programme, and the NSIA believes that buses should also be included in this work.

The Norwegian Safety Investigation Authority recommends that the Norwegian Public Roads Administration propose to Euro NCAP the introduction of crash simulations and component tests for buses under the ‘Safer Trucks’ programme.

Norwegian Safety Investigation Authority
Lillestrøm, 2 June 2026

Appendix

Appendix A Technical background information

Table of average vehicle damage across all accidents in each energy range

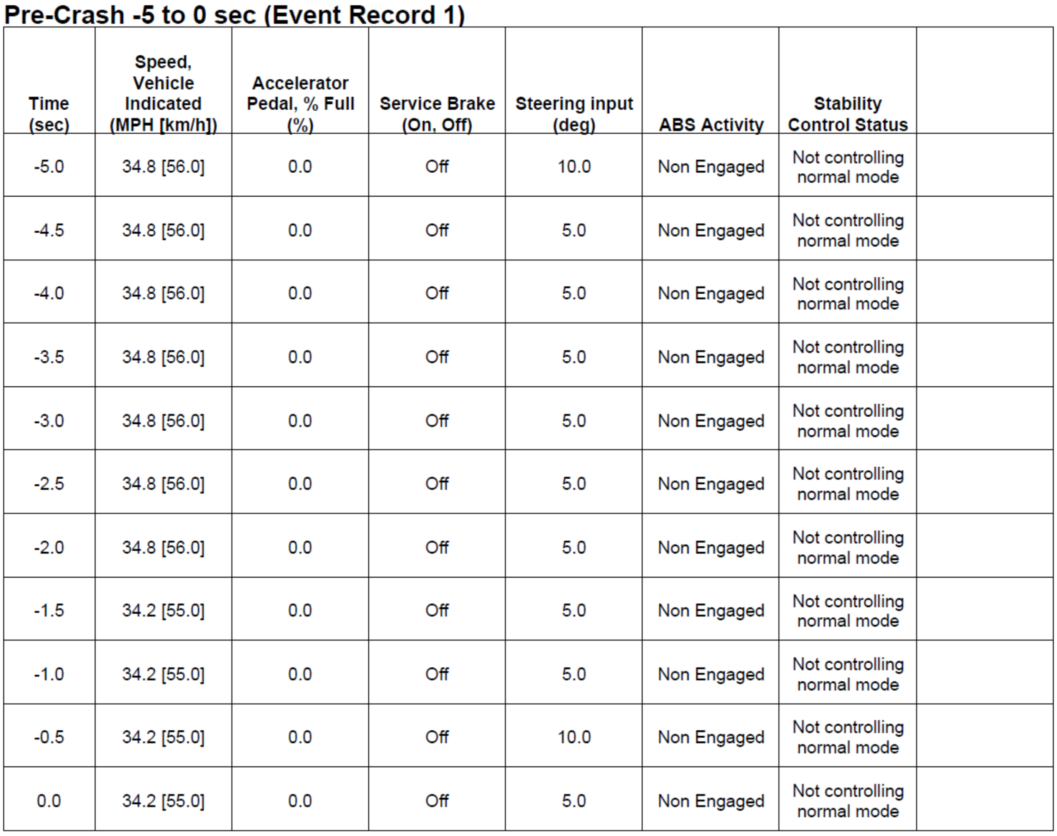
Figure 34 shows the average vehicle damage sustained by vehicles in the frontal collisions included in the thematic investigation, broken down by the various energy ranges illustrated in the study.

		BUS						OPPOSING VEHICLE					
High	**All i high 17**	0,2	0,4	0,5	0,7	1,2	3,5	0,0	0,0	0,5	1,8	2,3	3,6
	Heavy 3	1,0	1,3	1,3	1,3	1,7	4,0	0,0	0,0	0,0	0,3	1,0	1,7
	Bus 1	0,0	0,0	0,0	0,0	0,0	4,0	0,0	0,0	0,0	0,0	0,0	4,0
	Lighter 13	0,0	0,2	0,3	0,6	1,2	3,3			0,7	2,2	2,8	4,0
Breaking zone	**All in the breaking zone 26**	0,4	0,6	0,5	0,5	0,8	2,2	0,7	0,7	1,2	1,3	1,5	3,0
	Bus 3	0,7	0,7	0,7	1,0	1,0	3,7	0,7	0,7	0,7	1,0	1,0	2,7
	Lighter 23	0,3	0,6	0,5	0,4	0,7	2,0			1,3	1,3	1,6	3,0
Low	**Lighter 12**	0,3	0,2	0,1	0,2	0,5	1,3			0,5	0,8	1,1	2,3

Figure 34: Average vehicle damage in different energy ranges, describing on the same row the number of accidents, damage to the bus, and the type of opposing vehicle. Source: NSIA

Figgjo 2023 crash test compared with data from the accident

In the airbag module, six different parameters were stored every half second for the five seconds preceding the crash event, as shown in Figure 35.

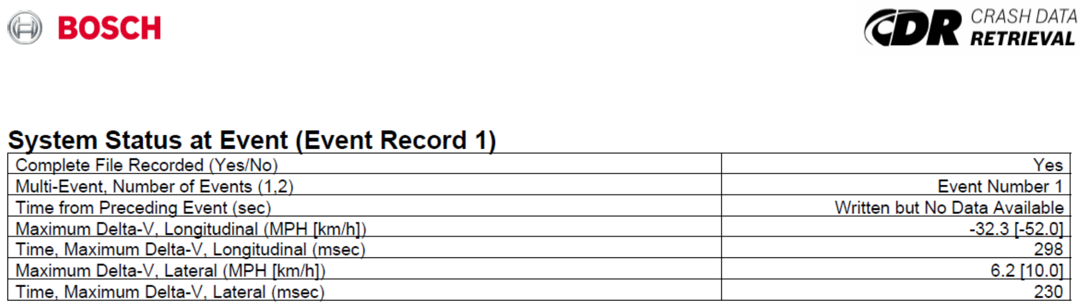


Pre-Crash -5 to 0 sec (Event Record 1)

Time (sec)	Speed, Vehicle Indicated (MPH [km/h])	Accelerator Pedal, % Full (%)	Service Brake (On, Off)	Steering input (deg)	ABS Activity	Stability Control Status	
-5.0	34.8 [56.0]	0.0	Off	10.0	Non Engaged	Not controlling normal mode	
-4.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-4.0	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-3.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-3.0	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-2.5	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-2.0	34.8 [56.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-1.5	34.2 [55.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-1.0	34.2 [55.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	
-0.5	34.2 [55.0]	0.0	Off	10.0	Non Engaged	Not controlling normal mode	
0.0	34.2 [55.0]	0.0	Off	5.0	Non Engaged	Not controlling normal mode	

Figure 35: Stored information five seconds prior to the frontal collision in the accident. Source: Bosch CDR, Norwegian Public Roads Administration

The maximum longitudinal Delta-V was calculated to be -52 km/h over 0.298 seconds, and the maximum transverse Delta-V was 10 km/h to the right over 0.230 seconds, see Figure 36.



System Status at Event (Event Record 1)

Complete File Recorded (Yes/No)	Yes
Multi-Event, Number of Events (1,2)	Event Number 1
Time from Preceding Event (sec)	Written but No Data Available
Maximum Delta-V, Longitudinal (MPH [km/h])	-32.3 [-52.0]
Time, Maximum Delta-V, Longitudinal (msec)	298
Maximum Delta-V, Lateral (MPH [km/h])	6.2 [10.0]
Time, Maximum Delta-V, Lateral (msec)	230

Figure 36: System status of stored data after the accident.

Longitudinal and transverse acceleration and Delta-V during the collision (‘Event 1’) were also stored every tenth of a millisecond, as shown below.

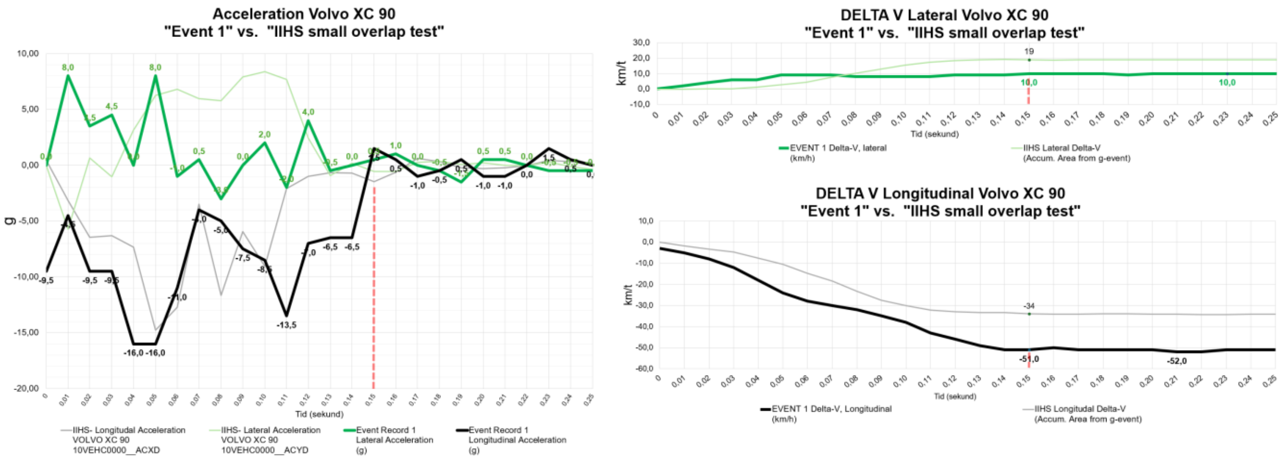


Figure 37: Longitudinal and transverse acceleration and Delta-V. Comparison of accident data from Figgjo accident compared to small overlap crash test on a Volvo XC 90. Source: IIHS, NSIA

The acceleration graphs from the car in both the accident and the test show that the impact in both cases is virtually complete after approximately 0.15 seconds.

In the Figgjo accident, the airbag module showed a change in velocity, Delta-V, of -51 km/h from an initial speed of 55 km/h, and a transverse velocity change of 10 km/h laterally. The graph indicates that the car did not stop but continued forward at around 3–4 km/h after being pushed sideways by approximately 21 cm over 0.15 seconds.

In the graphs from the crash test, the car sustained a change in velocity, Delta-V, of -34 km/h from an initial speed of 64 km/h, and a transverse velocity change of 19 km/h laterally. The graph indicates that the car did not stop but continued forward at around 30 km/h after being pushed sideways by approximately 39 cm[16] over 0.15 seconds.

The Figgjo accident and the test exhibit a relatively similar profile during the 0.15-second duration. The resulting Delta-V was approximately 52 km/h in the accident and approximately 39 km/h in the test.

Sagmoen 2024 crash test compared to the accident

The acceleration graphs from the test involving a car similar to the one involved in the Sagmoen accident show that the impact is virtually complete after approximately 0.12 seconds. In the graphs

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[16] *The lateral distance is calculated according to the formula:* $s = \frac{Delta-V\ [m/s]}{2} t$

from the crash test, the car sustained a change in velocity, Delta-V, of -59 km/h from an initial speed of 64 km/h, and a transverse velocity change of 33 km/h laterally.

Figure 22 shows images from a test of a 2016 Hyundai Tucson impacting an immovable barrier with a 25% overlap, where the front struck the barrier and rotated approximately 90 degrees, coming to a stop alongside it.

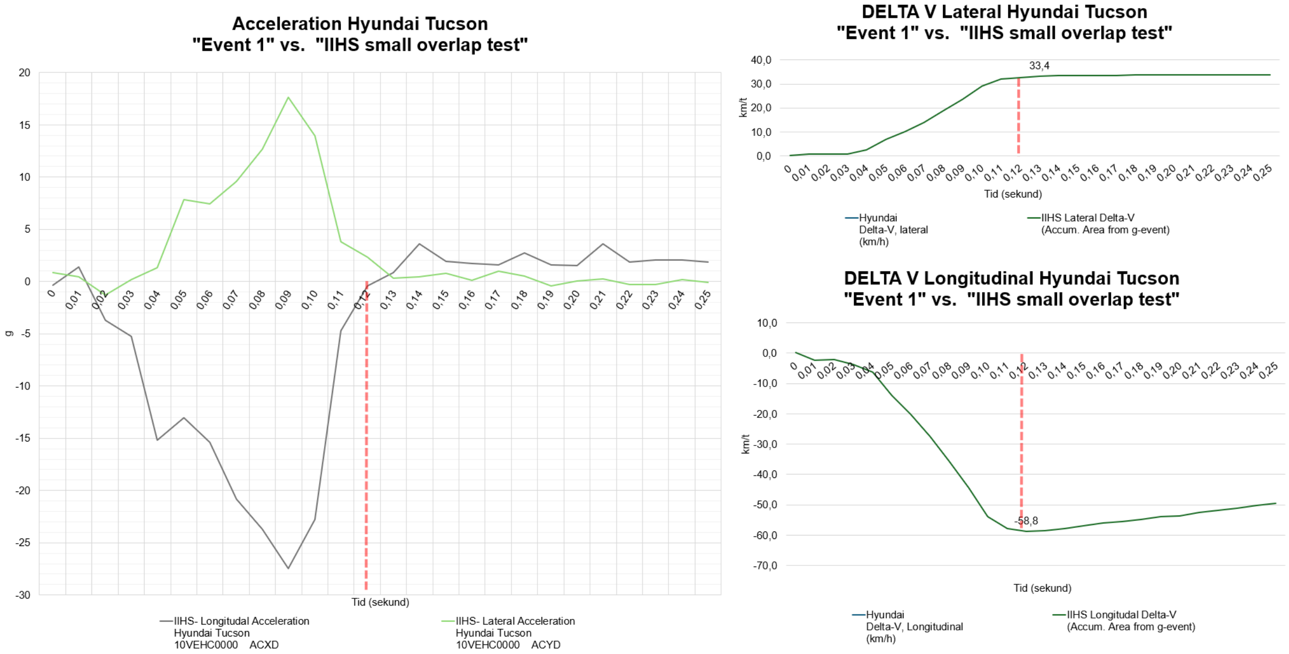

Figure 38: Longitudinal and transverse acceleration and Delta-V. Small overlap crash test on a Hyundai Tucson. Source: IIHS, NSIA