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Review of level crossing collisions involving trains and heavy road vehicles in Australia

ATSB Transport Safety Report

Safety study

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Addendum

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Executive summary

Why the ATSB conducted this study

Between 1 July 2014 and 31 August 2022, 24 rail or road users were fatally or seriously injured in collisions between trains and heavy vehicles at Australian level crossings. The ATSB conducted this safety study to improve understanding of the risks associated with level crossing collisions involving heavy vehicles. The goals of this study were to:

- Compare the severity of level crossing collisions involving heavy vehicles to collisions involving light road vehicles.
- Provide a statistical description of level crossing collisions involving heavy vehicles.
- Identify common contributing factors associated with level crossing collisions involving heavy vehicles.
- Identify systemic safety issues associated with the safety system for level crossings, including the design of level crossings used by heavy vehicles.

To accomplish these goals, the ATSB used quantitative and qualitative methods to analyse data collected by rail regulators in Australia and the United States. The ATSB also reviewed all reported level crossing collisions involving heavy vehicles in Australia from July 2014 to August 2022 (49 collisions), and collected records from rollingstock operators, rail infrastructure managers, police, and other organisations for each of these accidents.

What the ATSB found

The annual number of level crossing collisions between road vehicles and trains remained relatively constant between July 2014 and June 2022.

Data from Australian and United States rail regulators showed that level crossing collisions involving heavy vehicles were more likely to lead to injuries to the occupants of rail vehicles, to damage to rail vehicles and track, and to derailment of rail vehicles. Derailment of rail vehicles was also more likely to occur in level crossing collisions in which the road vehicle struck the train, compared to those where the train struck the vehicle. Comparison of records of the number of total road vehicles registered in Australia, and records to the number of kilometres travelled by different road vehicle types, showed that heavy vehicles had a higher rate of level crossing collisions. As a result, heavy vehicles present a greater risk of level crossing collision as a function of both likelihood (per road vehicle and road kilometres travelled) and consequence compared to light road vehicles.

The majority of level crossing collisions arose from heavy vehicle drivers entering the level crossings following some form of unintentional error or omission. In at least 14 accidents, it was likely the heavy vehicle driver intentionally entered the level crossing in a manner contrary to road rules, however even in these instances the intention was to proceed through the crossing prior to the arrival of a train.

The review of level crossing collisions identified common factors which may have contributed to the actions of heavy vehicle drivers. These included:

- In at least 12 collisions the heavy vehicle driver had regularly used the level crossing prior to the collision with the train. The drivers' previous experience at the level crossings may have led to a low expectancy for trains and contributed to them not detecting a requirement to stop and give way.
- In at least 14 collisions, the heavy vehicle driver’s view of the track or level crossing protection equipment was obstructed by vegetation, the design of the heavy vehicle cab, poor crossing lighting, or sun glare.

- Consistent with prior research showing that train horns have limited effectiveness for alerting road vehicle drivers approaching level crossings, in at least 25 accidents the horn was not effective at alerting the heavy vehicle driver to the presence of the train.

These observations were based on a partial set of the 49 collisions involving heavy vehicles, since in many instances information about the actions of heavy vehicle drivers and the factors which influenced these actions was not available from operator or police reports. The review identified that such information is typically only available when an independent no-blame transport safety investigation is conducted.

The collisions reviewed in this study mostly occurred at level crossings designed according to the required standards. However, this study identified one systemic safety issue with level crossing design standards. Of 6 collisions where the heavy vehicle driver did not identify the presence of activated flashing lights, 5 occurred on crossings with curved road approaches, all of which were right curves. Following a review of the applicable standards for designing and assessing level crossings (AS1742.7:2016 Manual of uniform traffic control devices, Part 7: Railway crossings), and research literature concerning visual attention in curved driving, the ATSB determined that methods used to calculate safe stopping distances (and determine the need and location of active advanced warning signs) for road approaches to level crossings did not account for the likelihood of detecting the level crossing ahead based on the normal visual focal points of road drivers negotiating a curved road.

The collisions primarily resulted from level crossing warnings or the presence of trains not being detected, being detected late, or being perceived incorrectly. Many of the errors and omissions which lead to level crossing accidents reflect the inherent variability of human performance.

The review identified that passively controlled level crossings, in particular, rely on the road vehicle driver visually detecting the presence of a train and identifying a requirement to stop and give way, they are susceptible to situations where drivers do not look for, or detect the presence of, a train, and there are limited effective recovery controls to prevent a collision when this occurs. The use of redundant controls, and particularly fail-safe engineering controls, improve the safety at passively controlled level crossings. The study considered one such form of control (in-vehicle alerting systems for level crossings), however there are significant barriers to the implementation of such systems.

What has been done as a result

Standards Australia reported they will review the standard AS1742.7 and determine if additional information or guidance may be provided to manage risks associated with curved road approaches to level crossings.

Safety message

This study highlights the increased risk posed by level crossing collisions with heavy road vehicles. Interventions which target these vehicles are likely to provide significant leverage in improving the overall safety at level crossings.

The accidents reviewed in this study demonstrate the potential for driver errors at level crossing to cause significant harm. As also demonstrated in this study, the performance of road vehicle drivers is inherently susceptible to unintentional errors. While the level crossing safety systems rely on road vehicle drivers always detecting a level crossing (and at passive crossings, the presence of trains) it is certain that this will fail from time to time and result in accidents in the future. The possibility of the future use of engineering controls which alert road users to a requirement to stop will almost certainly provide an enhanced level of safety at level crossings, by reducing the reliance on road vehicle drivers to attend to and detect the presence of trains.

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Introduction

Background

The Australian rail network comprised about 46,000 km of track and had an annual throughput of approximately 250 million km of combined passenger and freight journeys in 2021.[1] Across this network, records from the Office of the National Rail Safety Regulator (ONRSR) indicated there were almost 11,000 operational[2] level crossings where there is an interface between rail traffic and road vehicles.[3] At these interfaces there is a risk of collision, which is managed using different forms of traffic control equipment and associated procedures.

Relative to the volume of traffic conveyed across the rail network, collisions between trains and road vehicles at level crossings are rare. Rail safety data produced by ONRSR showed that for every million km travelled by freight trains between 2016 and 2021, there was an average of about 0.18 collisions with road vehicles at level crossings. The rate for passenger trains was about 0.10 per million km.

Though rare, level crossing collisions can have severe consequences. Collisions between passenger cars, motorcycles or bicycles often result in tragic consequences for road users. Where a heavy vehicle is involved in a level crossing collision, the rail system risks associated with the collision are much greater, including the increased potential for multiple fatalities onboard the train. In recent decades, several collisions between heavy vehicles and trains have resulted in multiple fatalities of train occupants:

- On 27 November 2008, 2 train drivers were fatally injured when a B-double combination truck collided with a passenger train in Rungoo, Queensland.[4]
- On 5 June 2007, 11 train passengers were fatally injured when a semi-trailer hit a train at a level crossing in Kerang, Victoria.[5]
- On 13 October 2002, 3 people in the cabin of a steam train were fatally injured when it collided with a B-double combination truck at a level crossing in Benalla, Victoria.[6]

To understand the trends and characteristics of level crossing collisions involving heavy vehicles requires sufficient information to enable detailed analysis. The ATSB, as the national independent investigator of rail safety occurrences, investigated about 20% of these occurrences between July 2014 and July 2022.

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1 Office of the National Rail Safety Regulator. National Rail Safety Data: Network Statistics. Downloaded from www.onrsr.com.au on 21 September 2022.

2 The ONRSR database recorded 881 level crossings at rail and road interfaces which were non-operational or decommissioned.

3 The Office of the National Rail Safety Regulator *National Rail Safety Data: Network Statistics* shows there were over 23,000 level crossings in Australia. This figure includes level crossings which separate road and rail traffic, and crossings which separate rail traffic and pedestrians.

4 ATSB External Investigation RE-2008-014, Level crossing collision at Rungoo Queensland.

5 Victorian Government Office of the Chief Investigator Transport and Marine Safety Investigations, Rail Safety Investigation Report 2007/09. Level crossing collision V/Line passenger train 8402 and a truck near Kerang, Victoria, 5 June 2007

6 ATSB investigation 2002003, Collision between steam passenger train 8382 and loaded B-double truck at Benalla, Victoria

Safety study goals

This safety study aimed to improve understanding of the risks of level crossing collisions involving heavy vehicles. The goals of this study were to:

- Compare the severity of level crossing collisions involving heavy vehicles to level crossing collisions involving other road vehicles.
- Provide a statistical description of level crossing collisions involving heavy vehicles.
- Describe common themes associated with level crossing collisions involving heavy vehicles.
- Identify systemic issues associated with the safety system for level crossings, including the design of level crossings used by heavy vehicles.

Level crossing safety systems: an overview

Level crossings are the physical interface between road and rail traffic. Both modes of transport are operated as entirely separate entities and have different rules, procedures, characteristics and operational limitations. Trains are typically significantly larger than road vehicles, and when a road vehicle enters a level crossing in the path of a train, the only action that a train driver can take is to try to alert the road vehicle driver with the train horn and apply train braking. The train may not slow significantly, if at all, before the collision occurs.

Given the limitations on braking and accelerating trains, by necessity, road vehicle drivers must give way to trains at level crossings. Road traffic law codifies the right of way of rail traffic, with the Australian road rules (model law) stating:

> A driver at a level crossing with a *stop sign* must… give way to any train or tram on, approaching or entering the crossing…
>
> A driver at a level crossing with a give way sign or give way line must give way to any train or tram on, approaching or entering the crossing.
>
> A driver must not enter a level crossing if: (a) warning lights (for example, twin red lights or rotating red lights) are operating or warning bells are ringing; or (b) a gate, boom or barrier at the crossing is closed or is opening or closing…[further conditions where a road vehicle driver must not enter a level crossing are described]

Level crossing traffic control systems use various signs, lights and other devices (level crossing protection equipment) to firstly alert an approaching road vehicle driver to the presence of the level crossing, and secondly instruct the road vehicle driver to take appropriate action to give way to trains.

Passive control level crossings control the movement of road traffic using signs and devices (including Give Way or Stop signs). Passive level crossing equipment is functionally static, meaning that there is no change to the equipment when a train is approaching compared to when no train is approaching. As such, passive control level crossings rely on road vehicle drivers (and pedestrians) detecting both the sign itself and then the approach or presence of a train by direct observation.

Active control level crossings control the movement of road traffic using devices such as flashing light signals, gates or barriers, or a combination of these. Active level crossing devices are activated prior to, and during, the passage of a train through the crossing. If the crossing devices are activated (level crossing lights are flashing and/or boom gates are down), then road vehicle drivers' attention should be drawn to their active status, and road rules require the road vehicle driver to stop and wait until the crossing devices are no longer active, removing the need for the road vehicle driver to detect the presence of a train.

Methods and sources

Overview

To analyse trends and characteristics (including accident severity) of level crossing accidents in Australia, this study used records of level crossing collisions and near misses in the national rail safety data collected by the Office of the National Rail Safety Regulator (ONRSR).

The study also used data from the United States Federal Railroad Administration (FRA) to support analyses of level crossing accident severity. The road and rail systems in the US are broadly equivalent to those in Australia.[7] Both jurisdictions (Australia and the United States) use similar forms of level crossing protection mechanisms, and the fundamentals of level crossing collisions are unlikely to be significantly different; level crossing collisions involve relatively small road vehicles colliding with comparatively larger trains. The ATSB considered that level crossing accident data from the United States provided valid data for the purpose of the analyses.

Australian level crossing collision data

Office of National Rail Safety Regulator national rail safety database

The *Rail Safety National Law Act 2012* required railway operators report all notifiable occurrences to ONRSR or another authority specified by ONRSR. The *Rail Safety National Law Regulations 2012* specified that collisions between trains and vehicles at level crossings were Category A occurrences, whereas near misses at level crossings were Category B occurrences.[8] The Rail Safety National Law does not require road vehicle operators to report level crossing accident information to ONRSR.

The national rail safety database recorded information provided to ONRSR under the reporting requirements specified in the *Rail Safety National Law*. This database commenced with the establishment of ONRSR on 20 January 2013, however coverage of different Australian jurisdictions (States) occurred gradually. ONRSR advised the dataset for level crossing occurrences was reliable from 1 July 2014 onwards. The ATSB analysis used occurrences from the national rail safety database between 1 July 2014 and 30 June 2022.

The national occurrence database recorded:

- a narrative description of the collision or near miss, which typically recorded the initial wording of the notification provided by the operator and sometimes included follow-up information
- the date, time and location of the level crossing collision or near miss
- the operator and rail infrastructure manager involved
- the primary level crossing protection equipment (flashing light, boom gate, stop sign or give way sign) at the level crossing
- the type of rollingstock and road vehicle involved in the collision or near miss
- fatalities and injuries sustained by rail passengers, rail operating crew and road vehicle occupants.

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7 The ATSB notes there are some differences between the road vehicles permitted to operate in the United States and in Australia, such that Australian regulations permit longer and heavier maximum vehicle size.

8 The regulations required that rail operators must report Category A occurrences immediately, with less-immediate reporting required for Category B occurrences. For further details see Notifiable occurrences | ONRSR.

For the time period analysed, the national rail safety database did not record:

- the level of damage sustained by road vehicles, and rail and road infrastructure
- the speed, direction, mass and length of rail or road vehicles
- the actions of the road user.

The national rail safety database recorded 283 level crossing collisions with vehicles between 1 July 2014 and 30 June 2022. Of these, 220 were collisions with light passenger vehicles, with 44 collisions involving heavy freight vehicles.[9] The remaining 20 collisions involved buses (4), special purpose machinery (5), bicycles (5), motorcycles (1), a dangerous good vehicle (1) and other vehicles (4). To analyse the severity and characteristics of occurrences involving heavy vehicles, the ATSB identified the level crossing collisions involving heavy vehicles recorded in the ONRSR national rail safety database for additional evidence collection.

A set of 47 collisions was identified in the national rail safety database, which comprised:

- 42 collisions with vehicles recorded as heavy freight vehicles[10]
- 3 collisions with buses[11]
- one collision each with vehicles coded special purpose machinery,[12] and dangerous goods vehicles.

Of the remaining collisions in the national rail safety database, the ATSB identified a subset of 216 level crossing collisions involving light road vehicles for comparative analyses. Light vehicles were defined as passenger cars and motorcycles, but not bicycles or farm or roadwork equipment. The comparative analysis also excluded collisions with hi-rail/road-rail vehicles.[13]

In July 2022, ONRSR introduced new requirements for operators submitting notifiable occurrence reports. Under the new requirements, rail operators reporting level crossing collisions and near misses were required to report the damage sustained by rail vehicles and infrastructure, whether a derailment occurred, and the cause of the collision.

ATSB finding

Prior to July 2022, the national rail safety database did not include sufficient information to enable detailed analysis of level crossing collision characteristics (Other finding).

Additional information collection

Between July and August 2022, the ATSB commenced 2 investigations into level crossing collisions involving heavy vehicles, these collisions were added to the 47 heavy vehicle level crossing collisions identified from the national rail safety database.

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[9] 1 collision involved a train and a light vehicle and heavy vehicle which had had a road traffic accident prior to the level crossing collision. This collision was included in the ATSB analysis of heavy vehicle accidents.

[10] 1 collision involving a heavy freight vehicle in the National rail safety database was excluded from the ATSB analysis because it involved the collision of a truck with a stationary train. Another was excluded because it involved a collision between a hi-rail vehicle and a truck.

[11] 1 collision in the National rail safety database was excluded from the ATSB study because it was a collision between a train and a mini-van.

[12] 1 collision involving a vehicle recorded as special purpose machinery in the National rail safety database involved a collision between a train and a truck, and this collision was included in the ATSB analysis. Collisions between trains and graders and tractors were not included in the analysis.

[13] A road vehicle fitted with retractable rail guidance wheels, to enable it to drive on rails.

For each of the 49 in-scope collisions, the ATSB sought information from rail operators, rail infrastructure managers, police, state road authorities and other parties. These records included investigation reports and level crossing assessments. Follow-up enquires were made to enhance the dataset. However, in many instances important information was not recorded in investigation reports and was not available for follow-up enquiry due to the passage of time from the events. As such, some of the information presented in subsequent sections is drawn from a partial sample of the identified level crossing collisions.

Level crossing accident data collected in United States

To support analysis of level crossing collision severity, the ATSB obtained records from the United States Federal Railroad Administration (FRA). Due to greater rail and road traffic volumes, there were about 60 times more recorded level crossing collisions in the United States than Australia, and the FRA datasets provided additional statistical power for the ATSB analyses. Regulations in the United States required that collisions between railway equipment and vehicles at level crossings (referred to as 'grade crossings' in the United States) were reported to the FRA. The regulations required that reports of level crossing collisions included the:

- type of road user involved
- speed, direction and position of the road user
- environmental temperature, light and weather conditions
- train type, consist length and speed
- level crossing equipment
- actions of the road user.

In addition, for accidents exceeding a threshold damage value (about A$16,000 in 2022), operators were required to report the:

- mass of the train consist
- cost of rail equipment and track damage
- number of derailed train cars.

These data were contained in two databases. The Highway-Rail Grade Crossing Accident (HRA) database contained data for all level crossing accidents, and the Rail Equipment Accident/Incident (REA) database contained data on accidents exceeding the damage cost threshold.

ATSB analysed data from both datasets from 2012 to 2021. After data cleaning and removal of irrelevant collisions, there were 19,495 collisions in the HRA dataset, and 2,283 records of highway rail collisions (level crossing collision) in the REA dataset. There were about 700 duplicate records in the REA dataset. The ATSB identified a final sample of 1,901 unique HRA records with matching REA records.

Descriptive statistics

Australian level crossing statistics

ONRSR provided the number of road crossings, based on information reported by rail operators. ONRSR stated that while the number of road crossings had been validated by reasonability checks, it was not possible to determine the accuracy of the data reported by operators.

The ONRSR database showed that in December 2023, there were almost 11,000 operational level crossings which managed traffic between trains and road traffic. This included almost 3,000 active control crossings, and almost 7,000 passive control crossings (there were about 1,500 operational crossings which were recorded as unprotected). ONRSR advised it was not possible to disaggregate their data on the basis of whether level crossings were on public or private roads. Table 1 shows the distribution of operational level crossings by protection type in each Australian state and territory.

Table 1: Counts of road level crossings, by primary protection type and jurisdiction

	Active – Boom gates and flashing lights	Active – Flashing lights, no boom gates	Passive – Stop sign	Passive – Give Way sign	Unprotected	Total
New South Wales	299	142	1,420	138	667	2,666
Victoria	516	214	514	378	144	1,766
Queensland	288	274	1,667	256	553	3,038
South Australia	193	107	428	49	97	874
Western Australia	249	279	1,346	112	59	2,045
Tasmania	0	109	148	12	9	278
Northern Territory	20	14	176	1	0	211

Source: ONRSR

During the development of the safety study, the ATSB received submissions from stakeholders in some jurisdictions which identified that the number of level crossings presented in Table 1 were not consistent with other records, including those stored in the Australian Level Crossing Assessment Method dataset. ONRSR also identified that there were known differences between the number of crossings identified in the ONRSR database and the ALCAM dataset, and the data had not been cross-validated between the datasets.

Australian level crossing collisions

Characteristics of all level crossing collisions and near misses

There were 283 collisions and 4,319 near misses between trains and road vehicles recorded in the Australian national rail safety database. These totals included collisions involving hi-rail vehicles, bicycles, and farm and roadwork equipment.

Key statistics involving the type of train included:

- There were 120 collisions and 1,801 near misses involving freight trains.
- 122 collisions and 1,895 near misses involved regular passenger services.

Key statistics involving the type of crossing included:

- 160 collisions and 3,133 near misses occurred at active control crossings.
- 115 collisions and 1,086 near misses occurred at passive control crossings.

Other descriptive statistics for collisions and near misses are described in Appendix A.

Characteristics of level crossing collisions involving heavy vehicles

Environmental conditions

Of the 49 collisions reviewed in the safety study, 3 occurred in dark conditions (after astronomical twilight).[14] There were a further 7 collisions when the sun's elevation was between -18° and 6°, meaning the sun was low in the sky and twilight conditions were apparent.

Information about the road conditions was recorded for 40 of the collisions. In 37 collisions the road was reported to be dry, and in 3 collisions the road was reported to be wet. Thirty-three of the 49 collisions occurred in rural locations, and 16 collisions occurred in built-up or urban areas.

Train characteristics

More than two-thirds of level crossing collisions with heavy vehicles involved freight rail operations (Table 2).

Table 2: Operation category of trains involved in level crossing collisions with heavy vehicles

Train operation category	Number of collisions
Freight train	32
Urban passenger	8
Non-urban passenger	6
Tourism and heritage	2
Other train	1
Total	**49**

The maximum reported train mass was 10,109 tonnes, with 18 collisions involving trains with a reported mass of over 1,000 tonnes. The maximum train length was 2,964 m, with 6 collisions involving trains 1,000 m or longer. Thirteen collisions involved driver only operations. Where the number of passengers was recorded, the maximum was 250 (Table 3).

Table 3: Maximum and average train mass, length and passenger numbers

	Train mass	Train length	Train passengers (passenger train only)
Number of records	42	40	11
Maximum	10,109 t	2,964 m	250
Average	1,606 t	557 m	95

Information about the time and distance of emergency braking prior to collision was available for 36 collisions (Table 4). In 13 instances, the train crew either did not brake, or braked at about the point of impact (2 seconds or less prior to impact). These included instances where the train crew saw the road vehicle slowing or stopped for the crossing, and therefore did not anticipate that a collision would occur. These instances also included situations where the train crew's vision of the

[14] Geoscience Australia defined the ending of astronomical twilight as the instant in the evening when the centre of the sun is at a depression angle of 18° below an ideal horizon. At this time the illumination due to scattered light from the sun is less than that from starlight and other natural light sources in the sky.

level crossing was blocked by curved track and vegetation, preventing the train crew from identifying the potential collision earlier.

In 4 instances, train crew made emergency brake applications for 10 or more seconds prior to the collision, including up to 213 m braking distance prior to the collision. Three of these collisions involved instances were at level crossings controlled by boom gates, and involved heavy vehicles stopped on the crossing. The other instance involved a very large freight train (5,330 tonnes) which was unable to stop after a truck driver stopped then proceeded from a Stop sign. Due to the train braking over a long distance, the collision speed in these occurrences was significantly reduced, probably leading to reduced consequences (injuries and damage) to the train and road vehicle occupants than if braking had been applied at a shorter distance to the collision point.

The average reported speed of the trains prior to braking for the collision was 62 km/h, with a maximum of 160 km/h reported. The average reported collision speed was about 51 km/h, with a maximum reported speed of 110 km/h.

Table 4: Train speed and braking prior to level crossing collisions

	Max. speed	Collision speed	Braking time	Braking distance	Stopping distance
Number of records	43	39	36	36	35
Maximum	160 km/h	110 km/h	19 s	213 m	1,312 m
Average	62 km/h	51 km/h	5 s	74 m	314 m

Heavy vehicle information

Over half (28) of the heavy vehicles involved in level crossing collision were articulated vehicles (semi-trailers or trucks with trailers). Seventeen vehicles were unarticulated vehicles (garbage trucks, flat-bed and box trucks) and 3 were buses. In terms of the classes of heavy vehicles described by the National Heavy Vehicle Regulator,[15] there were 27 General Access Vehicles, 14 Restricted Access Vehicles, and there was insufficient information to classify 8 vehicles.

The maximum recorded gross mass was 148 tonnes, and 6 vehicles had a recorded mass of 70 tonnes or greater. The greatest number of occupants recorded was 20 (a passenger bus), with the next highest being 3. Thirty-seven collisions involved single-occupant vehicles, and 3 collisions involved circumstances where the occupants had vacated the vehicle prior to the collision.

Table 5: Mass, length and occupant numbers for heavy vehicles involved in level crossing collisions

	Mass	Vehicle length	Occupants
Number of records	28	10	45
Maximum	148 t	36.5 m	20
Average	36 t	22.0 m	1.5

Reported mechanical problems were associated with 4 of the collisions identified in this study. In 2 instances, post-accident assessments identified problems with truck braking systems which may have contributed to the trucks failing to stop ahead of the crossing. In 2 other collisions, the heavy vehicles stalled on the level crossing and were unable to clear the crossing prior to the train arriving.

[15] For definitions of General Access Vehicles and Restricted Access Vehicles, see https://www.nhvr.gov.au/road-access/mass-dimension-and-loading/classes-of-heavy-vehicles.

Police records indicated that one heavy vehicle driver was affected by alcohol or other drugs, and was reported to be fatigued/drowsy prior to the collision.

Level crossing characteristics

There was a relatively even distribution of collisions involving heavy vehicles at passive control crossings and collisions at active control crossings. Considering that heavy vehicles accounted for about 18% of level crossing collisions recorded in the national rail safety occurrence database, heavy vehicles were significantly under-represented for collisions occurring at Boom gates, and over-represented for collisions at Give way signs (Table 6).

Table 6: Level crossing collisions by protection equipment type

	Heavy vehicles	Light vehicles	Total collisions[1]	Proportion, heavy
Boom gates	11	80	91	12%
Flashing lights	12	48	60	20%
Stop sign	20	66	86	22%[2]
Give way sign	6	15	21	29%[2]
None	0	7	7	0%
All crossing types	**49**	**216**	**265**	**18%[2]**

[1] 'Total collisions' only includes collisions with Heavy and Light vehicle types, and excluded collisions with rail vehicle types such as hi-rail vehicles. These are summarised in *Australian level crossing collision* data.
[2] Collisions occurring after 1 July 2022 were not included when calculating the proportion of collisions involving heavy vehicles, as the national rail safety data only covered until this date. As such, the proportion of collisions occurring at Stop signs involving heavy vehicles was 19 of 85, the proportion of collisions at Give way signs was 5 of 20, and the proportion of accidents at all crossing types was 47 of 263

Most occurrences (39) occurred on sealed roads, with 10 collisions occurring on unsealed roads. The average road speed limit, where recorded, was 77.1 km/h, and 15 collisions occurred on roads where the speed limit was 100 km/h or greater. Where recorded, the average track speed at the level crossing locations of the occurrences was 82.6 km/h, with a maximum track speed of 160 km/h.

Problems with level crossing design and maintenance

There are several standards applicable to the design and maintenance of level crossings in Australia. These include:

- *Australian Standard AS 7658:2020 Level Crossings: Rail Industry Requirements*. This standard was developed and maintained by the Rail Industry Safety and Standards Board (RISSB). It describes minimum operational and engineering requirements of the life cycle of a level crossing.
- *Australian Standard AS 1742.7(2016), Manual of uniform traffic control devices. Part 7: Railway crossings*. This standard was developed by the Australian Standard Committee MS-012. It described design guidance for the installation of level crossing protection equipment, including methods for assessing the sighting distances required at different level crossings. Additional discussion of *AS 1742.7* is provided in *Standards and other guidance relevant to placement of crossings on curved road approaches*, and the formula used to calculate sighting distances for level crossings are described in Appendix B.

Key aspects of these standards include that:

- *AS 7658* required that rail infrastructure managers establish and maintain procedures for the rail portion of the level crossing, and that an interface agreement exists with the road manager to ensure that 'all facets of the monitoring and maintenance of the level crossings is undertaken'. This includes procedures for inspection and testing and vegetation management.

The standard further required that ‘removal of plant growth shall be required to ensure retention of sighting distance’.

- *AS 7658* stated that whistle boards may be installed on the approach to level crossings.
- *AS 7658* stated that that ‘Adequacy of street lighting at a level crossing shall be assessed against the requirements in *AS/NZS 1158* [Road lighting] during a level crossing risk assessment. Street lighting provided for level crossings shall comply with AS/NZS 1158 and impacts on train drivers, road users and pedestrians shall be evaluated, and outcomes documented.’
- *AS1742.7* stated that level crossings should be located so that there is sufficient distance between the crossing and a downstream intersection to accommodate the road design vehicle[16] and a safety factor of 5 m. The intent of these provisions is to prevent so-called ‘short stacking’, where a long vehicle stops across a crossing while queueing for another intersection.

The safety study considered evidence of problems with the design or maintenance of the level crossing locations of the 49 collisions reviewed in this study. Analysis of the design of AS1742.7 is described in *Analysis of level crossing safety systems*. Two ATSB investigations, 4 rail infrastructure manager reports and one State government investigation identified problems with the design or maintenance the level crossing:

- ATSB investigation RO-2014-024 identified that a stand of trees had self-sown within the rail reserve. When a truck approached the level crossing, the driver’s view was partially obscured by this vegetation. The investigation noted that previous inspections had recorded the presence of the trees, but this had not led to the removal of the trees.
- ATSB investigation RO-2016-009 identified that the Stop sign level crossing required road vehicle drivers sight approaching rail traffic at an obtuse angle (greater than 90° but less than 180°). When a semi-trailer truck stopped at the crossing, the driver’s view of an approaching train was restricted and they did not identify the risk of collision.
- A rail infrastructure manager report noted that a Stop sign level crossing was located in a dark industrial area. There was poor lighting on the crossing itself and contrasting high levels of lighting in the background and foreground. In these dark conditions, a truck driver approaching the Stop sign level crossing did not detect that a rail safety worker was controlling the crossing or that a freight train was indexing in reverse over the crossing.
- A rail infrastructure manager and operator report noted that a temporary Stop sign level crossing had been installed without other approach signage, and with no whistle board installed for approaching trains. A train driver approaching the crossing did not sound the train horn until they identified a truck, which had stopped at the level crossing. The truck driver did not hear the horn and proceeded into the path of the train.
- A state government investigation report identified that a level crossing protected by flashing light signals was designed with a stop line placed too close to the lights assembly. When a bus stopped at the crossing while waiting for traffic to clear, the driver’s view of the near-side lights was obstructed. When traffic cleared, the bus driver, who had an unobscured view of the far-side flashing lights, proceeded into the crossing against the flashing lights.
- A rail infrastructure manager report identified that the road configuration near a Stop sign level crossing was not appropriate for some heavy vehicle classes as there was insufficient room to

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[16] The Australian Guide to Road Design (Austroads, 2017) states: The design vehicle is therefore the largest vehicle likely to regularly perform a movement at an intersection. The choice of a particular vehicle as the design vehicle depends on the number of those vehicles expected to undertake the movement. …In the absence of data or reliable information to the contrary, the selection of the appropriate design vehicle for a particular intersection or turning movement should be based on the functional classification of the intersecting roads as this reflects the composition of traffic expected at the intersection.

clear the crossing when queued at an intersection beyond the crossing. There was no signage or pavement markings to discourage road users from queuing across the crossing. A heavy vehicle driver approaching the crossing did not stop at the Stop sign (causing the train drivers to apply emergency brakes), then was unable to clear the crossing before the train arrived.

- A rail infrastructure manager and operator report identified that a level crossing flashing light assembly did not face towards a side road approaching the crossing. A heavy vehicle driver approaching from the side road did not detect the requirement to stop at the level crossing.

In total, there were at least 7 collisions between heavy vehicles and trains where problems with the design or maintenance of the level crossings were probably contributory to the collisions. Reports from a further 2 collisions identified that the sighting provided to road users was insufficient considering the requirements of *Australian Standards AS1742.7*. In these instances, the sighting deficiencies were for rail or road approaches other than those involved in the collisions, so were not contributory to the collision. Reports for 8 other occurrences identified various other minor problems, including faded signs and minor discrepancies between the signage provided and the requirements of *AS1742.7*.

In summary, the evidence available to this review did not indicate significant problems with the design or maintenance of most level crossings where collisions between heavy vehicles and trains occurred, in terms of compliance with applicable design standards. The absence of such evidence, however, is not necessarily evidence that no problems with the design and maintenance of crossings existed. As described further in *Study limitations*, this review did not involve site inspections of level crossings (other than those previously investigated by the ATSB), and the ATSB did not seek to otherwise audit the compliance of the level crossings with relevant standards.

ATSB finding

Of the 49 level crossing collisions involving heavy vehicles, at least 7 partially involved problems with the design or maintenance of the level crossings. Concerning compliance with applicable design standards, no significant issues were identified with the design or maintenance of most crossings (factor that increased risk)

Level crossing collisions in the United States

Collisions and fatalities by vehicle types

The number of level crossing collisions and fatalities recorded in the US Federal Railroad Administration (FRA) Highway-Rail Grade Crossing Accident (HRA) dataset is summarised by vehicle type (Table 7). The vehicle type variable was then categorised as Heavy (bus, truck or truck-trailer) and Light (all other vehicles), with the number of collisions and collision fatalities for each category shown in Table 8.

Table 7: Level crossing collision statistics by road vehicle type, FRA (HRA) data, June 2012 to June 2021

Vehicle type	Collisions	Proportion of collisions	Fatalities	Proportion of fatalities
Auto [1]	9,515	48.8%	811	45.5%
Truck	1,366	7.0%	103	5.8%
Truck-Trailer	3,475	17.8%	121	6.8%
Pick-up truck	2,610	13.4%	308	17.3%

Vehicle type	Collisions	Proportion of collisions	Fatalities	Proportion of fatalities
Van	562	2.9%	83	4.7%
Bus	37	0.2%	6	0.3%
Other	1,930	9.9%	349	19.6%
Total	**19,495**	**100.0%**	**1,781**	**100.0%**
[1] This category describes passenger vehicles such as sedans, but does not include motorcycles				

Table 8: Level crossing collision statistics for 'Heavy' and 'Light' vehicles (excluding pedestrian collisions)

Vehicle type	Collisions	Proportion of collisions	Fatalities	Proportion of fatalities
Heavy	4,886	25.1%	233	13.1%
Light	14,609	74.9%	1548	86.9%
Total	**19,495**	**100.0%**	**1,781**	**100.0%**

Types of trains involved

Concerning all road vehicles, 74% of level crossing collisions involved freight trains. Collisions involving heavy vehicles accounted for about 25% of all collisions with freight trains, and about 16% of collisions with passenger trains.

Table 9: Level crossing collisions by train type and vehicle type, FRA HRA data

Train type	Heavy vehicles	Light vehicles	Total
Freight	3,648	10,691	14,339
Passenger	303	1,640	1,943
Other	935	2,275	3,210
Total	**4,886**	**14,606**	**19,492**

Level crossing protection equipment

More than half (56%) of level crossing collisions were recorded at active control level crossings. Heavy vehicles were involved in about 25% of all level crossing collisions (active and passive controlled crossing combined). They were over-represented in collisions at passive control crossings, and under-represented for collisions at active control crossings (Table 10).

Table 10: Level crossing collisions by crossing level crossing protection equipment type and vehicle type

Primary protection equipment	Heavy vehicles	Light vehicles	Total	Proportion heavy
Level crossing gates	1,525	6,989	**8,514**	17.9%
Flashing light signals	392	1,494	**1,886**	20.8%
Stop sign	1,297	2,208	**3,505**	37.0%
Crossbucks only (give way)	1,283	3,298	**4,581**	28.0%

Note: 'Proportion heavy' describes the proportion of accidents at each level crossing type which involved heavy vehicles. For example, 37% of accidents at Stop sign crossings involved heavy vehicles.

Road vehicle driver actions associated with level crossing collisions

The most common road vehicle driver action associated with level crossing collisions was a failure to stop prior to a level crossing, accounting for 40% of collisions (Table 11). Heavy vehicles were proportionately more likely to be involved in collisions where:

- The road user did not stop at the level crossing (1.3 times more likely).
- The road user stopped at the crossing then proceeded into the path of an oncoming train (1.6 times more likely).

Table 11: Level crossing collisions by road vehicle driver actions and vehicle type

Road vehicle driver actions	Heavy vehicles	Light vehicles	Total
Did not stop	2,261	5,063	7,234
Stopped and then proceeded	435	777	1,212
Stopped on crossing	1,309	3,932	5,241
Went around the gates	257	2,160	2,417
Other	624	2,676	3,300
Total	**4,886**	**14,608**	**19,494**

The road user action attributed to level crossing collisions varied significantly as a function of the type of level crossing protection equipment in use. Table 12 describes the proportion of collisions attributable to different motorist actions, by crossing and vehicle type.

Table 12: Motor vehicle actions by crossing and road vehicle type

ALL VEHICLE DRIVER ACTIONS	**Did not stop**	**Stopped and proceeded**	**Stopped on crossing**	**Went around gates**	**Other**
Boom gates	2%	1%	33%	28%	36%
Flashing light signals	67%	9%	21%	0%	3%
Stop sign	59%	13%	26%	0%	2%
Give way sign	70%	8%	19%	0%	2%
HEAVY VEHICLE DRIVER ACTIONS	**Did not stop**	**Stopped and proceeded**	**Stopped on crossing**	**Went around gates**	**Other**
Boom gates	1%	2%	43%	17%	37%
Flashing light signals	64%	10%	24%	0%	3%
Stop sign	62%	15%	22%	0%	1%
Give way sign	73%	10%	16%	0%	2%
LIGHT VEHICLE DRIVER ACTIONS	**Did not stop**	**Stopped and proceeded**	**Stopped on crossing**	**Went around gates**	**Other**
Boom gates	2%	1%	30%	31%	35%
Flashing light signals	68%	9%	20%	0%	3%
Stop sign	58%	11%	28%	0%	3%
Give way sign	69%	8%	21%	0%	2%

Note: Percentages shown in this table describe the proportion of accidents for each crossing type associated with each action type. For example, 22% of Heavy vehicle collisions at Stop sign controlled crossings involved the motor vehicle driver stopping on the crossing.

Vehicle speed

Most collisions recorded in the FRA HRA dataset involved trains colliding at speed with stopped or slow-moving road vehicles. The mean recorded train speed was 47 km/h, with a maximum reported speed of 177 km/h. The mean estimated collision speed for road vehicles was about 11 km/h for heavy vehicles and about 14 km/h for other road vehicles.

Comparison of Australian and United States Level Crossing collision data

There were consistent characteristics in the level crossing collision data for Australia and the United States. There was a similar proportion of level collisions involving heavy vehicles, with 18% of collisions in Australia involving heavy vehicles, compared to 25% in the United States. Similarly, data for both countries showed that heavy vehicles were under-represented in accidents occurring at crossings protected by boom gates, and over-represented in accidents occurring at passively controlled crossings.

The FRA data showed that the most common road user action associated with level crossing collisions was a failure to stop. As described in *Errors and violations associated with level crossing collisions*, this action was also the most common road user action identified in the 49 collisions involving heavy vehicles in Australia.

Analysis of heavy vehicle collision severity and frequency

Severity of level crossing collisions involving heavy vehicles

Previous research and reviews

In 2008, the ATSB published a safety bulletin that summarised the findings from 15 level crossing collisions investigated by the ATSB and other Australian authorities between April 2006 and December 2007, of which 12 involved heavy vehicles. These collisions resulted in over 60 injuries, including 19 fatalities, and an estimated damage bill of over $100 million. Noting the increasing severity of collisions involving heavy vehicles, the ATSB bulletin summarised that:

> with the increased size (of a heavy road vehicle) comes an increased consequence in the event of a level crossing collision. It used to be somewhat rare to hear of a train derailing or of significant casualties on board the train as a result of a collision with a road vehicle. This is not the case today.

Analyses of US level crossing collision datasets have previously shown that when heavy vehicles were involved in a collision, there was a much greater likelihood of a derailment occurring (Chadwick, Saat and Barkan, 2012).[17] Other research noted that the damage costs of level crossing collisions involving commercial vehicles (which includes heavy vehicles) are 3-4 times greater than collisions involving other road vehicles (Hellman and Poirier, 2019).

Injuries and fatalities to rail passengers and crew

Australia

The ATSB's analysis of the national rail safety database identified 47 injuries to rail passengers and crew in 285 level crossing collisions with road vehicles,[18] 7 of these injuries were classified by the ATSB as serious as they resulted in hospital admission. The majority of injuries to rail occupants (7 serious and 34 minor) resulted from 49 reported collisions involving heavy vehicles, this included 18 passengers and a conductor who sustained injuries after a collision between a passenger train and a truck on 15 July 2016 at Phalps Road, Victoria.

There were no fatalities of railway employees or passengers resulting from a level crossing collision in the period July 2014 to August 2022.

United States

In the collisions recorded in the FRA HRA dataset, there was an average of 25 rail injuries (injuries to rail passengers or staff) per 100 collisions involving a heavy vehicle, compared to 3.5 per 100 collisions involving light vehicles. A Mann-Witney U test[19] found that the difference in average rail injuries by vehicle type was statistically significant ($p<.005$).

Fatalities to rail occupants were extremely rare, with 7 collisions (out of 19,495) resulting in 11 rail fatalities. There were 5 separate collisions involving heavy vehicles which each caused one rail

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[17] Chadwick, Saat and Barkan (2012) categorised buses as other vehicles, not heavy vehicles.

[18] This included 283 collisions recorded in the national rail safety dataset from July 2014 to July 2022, and 2 additional collisions involving heavy vehicles, which occurred in July and August 2022.

[19] This non-parametric test was conducted because the data for injuries and fatalities was not distributed normally, and parametric tests such as t-tests were therefore not appropriate. For more information see https://www.healthknowledge.org.uk/public-health-textbook/research-methods/1b-statistical-methods/parametric-nonparametric-tests.

fatality, whereas one collision involving a light vehicle resulted in 5 fatalities[20] (another collision with a light vehicle resulted in one fatality). Table 13 shows the total number of fatalities and injuries of rail and road users recorded in the FRA datasets.

Table 13: Fatalities and injuries by road user type in US level crossing collisions, 2011 to 2021

	Total collisions	Rail fatalities	Rail injuries	Road fatalities	Road injuries
Heavy vehicles	4,886	5	1,230	228	1,143
Light vehicles	14,609	6	504	1,542	5,249

Fatalities and injuries to road users

Australia

There were 23 road fatalities from 283 level crossing collisions recorded in the national rail safety database, with 5 fatalities resulting from collisions involving heavy vehicles and 17 resulting from collisions with non-heavy vehicles (one fatality involved a collision with a cyclist). The average number of road fatalities per collisions involving heavy vehicles (0.11 fatalities per collision) was greater than collisions involving non-heavy vehicles (0.08 fatalities per collision), however the difference was small.

The ATSB review of 49 heavy vehicle collisions identified that road vehicle drivers and passengers sustained 33 injuries from level crossing collisions with heavy vehicles (0.67 injuries per collision), including 12 serious injuries. This included 17 injuries (6 serious) sustained by the occupants of a passenger bus which was struck by a train at Draper Street in Brisbane in 2015.[21] The national rail safety database showed that there were 60 injuries to road users in the 216 collisions involving light vehicles (0.28 injuries per collision).

United States

Analysis of the FRA HRA dataset (19,495 collisions) showed there were 1,770 total road fatalities. A Mann-Witney test showed that the average number of road fatalities per collision was statistically significantly lower for collisions involving heavy vehicles (0.05 fatalities per collision), compared to collisions involving light vehicles (0.11 fatalities per collision; $p<.001$).

Similarly, there were fewer injuries to road users for collisions involving heavy vehicles (0.23 per collision), compared to collisions involving light vehicles (0.36 per collision; $p<.001$).

Rail damage

Australia

The national rail safety database did not record estimated damage for level crossing collisions. As such it was not possible to compare the damage sustained in Australian level crossing collisions involving heavy vehicles, compared to collisions involving light vehicles. For the 49 collisions reviewed in this study, there was typically insufficient information to quantify the damage sustained by rail vehicles, road vehicles or infrastructure in most collisions.

The ATSB reviewed the damage reported in various sources, and identified that:

- 11 collisions resulted in the derailment of at least 1 rail car.

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[20] Highway-Railroad Grade Crossing Collision, Commerce Street, Valhalla, New York on February 3, 2015. National Transportation Safety Board.

[21] Serious Injury Collision, Draper Street, Cairns on15 June 2015. Transport and Main Roads, Queensland Government.

- In 16 instances the rail vehicle sustained substantial damage, which required major repairs or significantly affected the performance of the vehicle. In 31 instances rail vehicles sustained only minor damage such as scratches or small dents.
- In 33 instances the road vehicle sustained substantial damage, including several collisions where the vehicle was destroyed. In 13 instances the road vehicle sustained minor damage.
- In 23 collisions there was no reported damage to infrastructure. In 10 instances there was minor infrastructure damage reported, and in 7 instances there was substantial infrastructure, such as large sections of destroyed track.

The following examples illustrate the significant rail damage resulting from collisions with heavy vehicles:

- A collision between a truck, trailer and dog combination with a grain train resulted in extensive damage to the locomotive, with total repair costs estimated at $480,000.
- A collision between a prime mover and trailer with a freight train resulted in damage to 20 m of track, 1,250 sleepers and 90 tonnes of ballast, with an estimated repair cost for infrastructure assets of over $300,000.
- A collision between a prime mover and a grain train led to the derailment of the train, resulting in significant damage to two locomotives and multiple wagons.

United States

The FRA Rail Equipment Accident/Incident (REA) dataset recorded the estimated rail equipment (rollingstock) and track damage for accidents which exceeded the damage threshold (about A$16,000). Of 1,901 level crossing collisions recorded in this dataset, the average equipment damage for collisions involving heavy vehicles was around USD$78,000, compared to USD$31,000 for collisions involving light vehicles. The average track damage for level crossing collisions involving heavy vehicles was USD$31,000, compared to USD$19,000 for collisions involving light vehicles. Mann-Witney tests showed both of these differences were statistically significant ($p<.001$).

Derailment

Australia

A mixed-methods approach was used to identify the number of derailments resulting from heavy vehicle and light vehicle level crossing collisions:

- All level crossing collisions (heavy and light road vehicles) in the national rail safety database were cross referenced with those also classified as derailments and/or identified as a derailment in the accident description field.
- For collisions involving heavy vehicles, operator and rail infrastructure manager reports were used to supplement the data from the nation rail safety database. Combined these methods identified that 11 of the 49 collisions resulted in derailment (9 of 47 collisions prior to July 2022).
- For collisions involving light vehicles, there was only one of 216 collisions that resulted in derailment. This was a collision between a passenger train and an abandoned light vehicle.

Fisher's exact test was conducted to examine the relationship between road vehicle type and derailment for the 283 heavy and light vehicle collisions in the national rail safety database. The relationship was significant (one-tailed $p<0.001$), showing that collisions involving heavy vehicles were more likely to lead to derailment.

United States

The FRA data showed that there were 141 derailments in 4,886 collisions involving heavy vehicles, compared to 43 derailments in 14,609 collisions involving light vehicles.[22] Fisher's exact test was showed that the difference in distribution between derailments and vehicle type was also significant in the FRA data (one-tailed p $p<.001$).

Summary of analysis of accident severity

Consistent with previous research, level crossing accident data from Australia showed that collisions involving heavy vehicles were more likely to result in injury to rail and road vehicle occupants, and more likely to cause derailment of rollingstock. Due to limitations in the available data, it was not possible to compare the accident damage sustained to rollingstock, infrastructure and road vehicles in level crossing collisions involving heavy vehicles and light vehicles, for collisions occurring in Australia.

The data from the US was broadly consistent with the analysis of the Australian data, showing that collisions involving heavy vehicles resulted in more frequent injury to rail occupants and more frequent derailments. The data also showed that rail damage was significantly greater for collisions involving heavy vehicles.

In contrast to the Australian data, the US data showed there were significantly more injuries to the occupants of light road vehicles involved in level crossing collisions, compared to occupants of heavy road vehicles. The difference between these data sources is probably explained by the small number of collisions in the Australian sample, and thus the influence of a single multi-injury accident in the Australia data, which substantially increased the average number of road vehicle injuries in heavy vehicle collisions.

ATSB finding

Level crossing collisions between trains and heavy vehicles were associated with greater levels of rail injuries and rail damage than collisions involving light vehicles (Factor that increased risk).

Over-representation of heavy vehicles in level crossing collisions

Previous research and reviews

The Independent Transport Safety Regulator for New South Wales (ITSR) described level crossing statistics for Australia from 2000 to 2009 (ITSR, 2011). The ITSR report showed that heavy vehicles were over-represented in level crossing collisions, accounting for 20% of collisions and 23% of fatal collisions while making up only 2.5% of vehicle registrations and 6% of kilometres travelled. The report also showed that level crossing collisions involving heavy vehicles had double the fatality rate per collision as collisions involving light vehicles.

The industry body Austroads (2010) reviewed level crossing collisions occurring in Australia and New Zealand from 2003 to 2007. This report found that of 405 total collisions, 20% involved heavy vehicles, with 14% being articulated heavy vehicles.

22 Derailments were only reported in the FRA REA dataset. The ATSB determined that it was highly unlikely for a level crossing accident to result in derailment and not exceed the damage threshold for reporting in the REA dataset. Therefore, the Chi-Square analysis assumed that all level crossing accidents which were not reported in the REA dataset did not result in derailment.

Analysis of level crossing collisions in Canada showed that occupants of heavy vehicles accounted for 40% of all level crossing collision fatalities from 1983 to 2001 (Caird, 2002). This review noted that light trucks, accounting for 27% of fatalities, typically operated in rural and industrial urban areas where there are more level crossings. A later analysis of Canadian accident records found heavy vehicles were overrepresented in level crossing collisions at rural, passive level crossings where the driver of the vehicle did not stop (Rudin-Brown et al., 2014).

Data used to normalise collision numbers by vehicle type

The Bureau of Infrastructure and Transport Research Economics (BITRE) *Australian Infrastructure and Transport Statistics - Yearbook 2022* provided estimates of the number of kilometres travelled by vehicle type, by financial year. This data showed that between the financial years 2014-15 and 2021-22, heavy vehicles travelled on average 21.65 billion km each year and light vehicles travelled on average 1.83 trillion km.

The Australian Bureau of Statistics *Motor Vehicle Census* provided estimates of the total number of registered motor vehicles by vehicle type, by calendar year. This data showed that from 2015 to 2021, there were on average 707,000 heavy vehicles registered in Australia,[23] and about 18.47 million light vehicles.

Comparison of heavy vehicle and light vehicle level crossing collision rates

As described in *Australian level crossing collision data*, from 1 July 2014 to 30 June 2022, there were 47 level crossing collisions involving heavy vehicles, and 216 collisions involving light vehicles. As shown in Table 14, heavy vehicles were over-represented in level crossing collisions as a function of both the number of collisions per vehicle (around 2 times greater), and the number collisions per kilometre travelled (around 4 times greater).

Table 14: Ratios of collisions by vehicle type to distance travelled and number of registered vehicles

	Heavy Ratio of collisions to billion km travelled	**Heavy** Ratio of collisions to million registered vehicles[3]	**Light** Ratio of collisions to billion km travelled	**Light** Ratio of collisions to million registered vehicles
Median	0.25	6.04	0.12	1.52
Mean	0.27	7.97	0.12	1.47
Std. deviation	0.13	3.87	0.02	0.24

[3] There was an imperfect overlap between the coverage of the collisions recorded in the safety study from July 2014 to August 2022, and the Motor Vehicle Census which produced estimates on an annual year basis. Collisions occurring in the calendar years 2014 and 2022 were not included in this analysis.

Caution should be exercised in making inferences regarding whether the over-representation of heavy vehicles in level crossing collisions necessarily indicates a greater level of risk. It may also reflect a greater likelihood of encountering level crossings, or a greater likelihood of encountering crossings of higher risk. It is plausible that heavy vehicles are more likely to be operated on rural roads, which are less likely to have level crossings removed through grade separation or be protected by higher level active controls (boom gates). There are no known data describing the rate at which different types of vehicles encounter and traverse level crossings of different types and characteristics, and thus this explanation could not be tested.

[23] The ATSB analysis categorised the ABS and BITRE categories of 'Light rigid trucks', 'Heavy rigid trucks', 'Articulated trucks' and 'Buses' as Heavy vehicles. Other vehicle types were categorised as Light vehicles.

ATSB finding

Heavy vehicles are involved in level crossing collisions at a greater rate per road kilometre travelled than light vehicles (Factor that increased risk).

Number of level crossing collisions over time

Prior to the establishment of the Office of the National Rail Safety Regulator (ONRSR) in 2013, records of the number of level crossing collisions in Australian jurisdictions were collected by state and territory regulators. The ATSB collected rail collision information from these regulators, and published various statistics including the number of level crossing collisions. The ATSB publication *Australian Rail Safety Occurrence Data 1 July 2002 to 30 June 2012* showed that in the decade to July 2012, there was a notable drop in the number of level crossing collisions with vehicles. The number of collisions declined from 82 in the year to July 2002 to 49 in the year to July 2012.

As described in *Australian level crossing collision data* the national rail safety database was reliable from 1 July 2014 onwards. As such, there was a transitional period from the discontinuation of reporting of state and territory regulator collision statistics in July 2012, to the availability of annual totals commencing 1 July 2015.

There was a substantial drop in the number of level crossing collisions from 49 in the year to July 2012, to 30 in the year to July 2015. From July 2014, the number of level crossing collisions has remained relatively constant, at around 30 to 40 per year (Figure 1). A Mann-Kendall test was conducted on the number of collision per financial year between July 2014 and June 2022 (Figure 2), the test did not identify any statistically significant trend ($p = 0.61$).

Figure 1: Level crossing collision with vehicle, Financial year totals 2002 to 2022

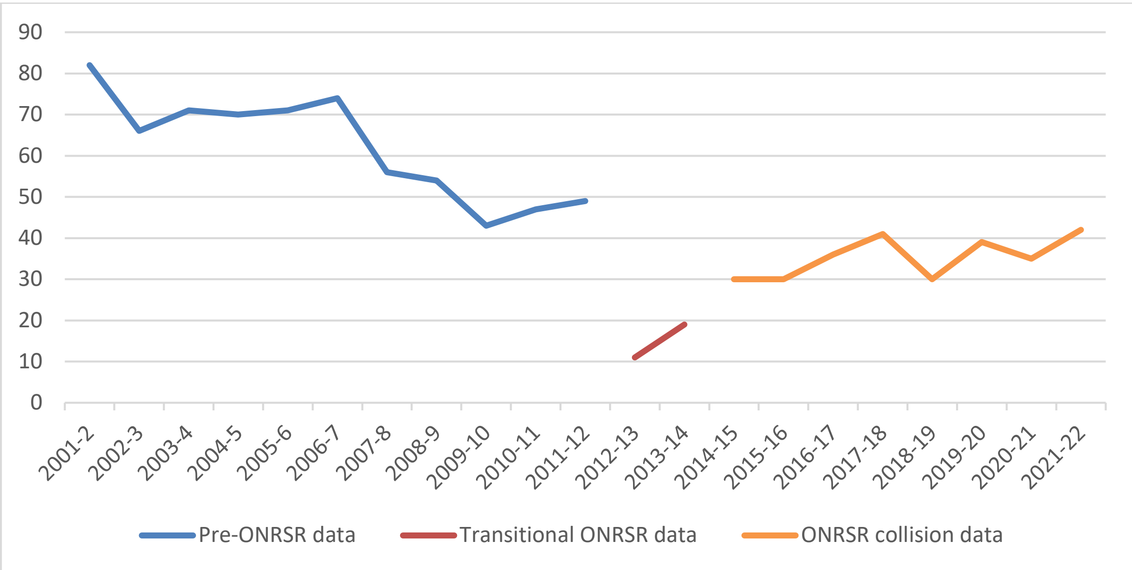
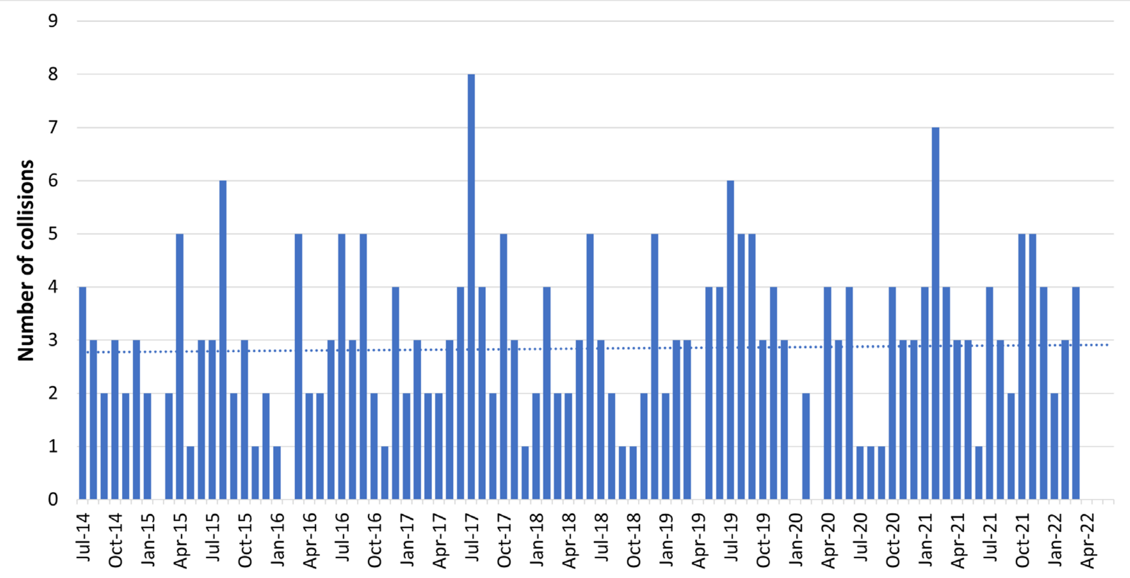


Figure 2: Monthly level crossing collisions, July 2014 to June 2022, with regression line



ATSB finding

The annual number of level crossing collisions between road vehicles and trains remained relatively constant between July 2014 and June 2022 (General finding).

Level crossing collision sequence and derailment

Level crossing collisions can either involve the train striking a vehicle (TSV) or a vehicle striking the train (VST). In TSV collisions the impact involves the front of the train striking either a moving or stationary road vehicle, whereas in VST collisions the impact involves a road vehicle striking the side of a moving or stationary train. These different scenarios generally produce significantly different physical forces on the train, affecting the likelihood of derailment (Cherchas et al., 1982). Chadwick (2017) found that VST collisions were disproportionately more likely to result in derailment.

In addition to different direction of the physical forces exerted upon the trains in these scenarios, there is also an expected difference in the speed of the road vehicle at the time of the collision. For instance, in 13 collisions which involved a heavy vehicle stopping foul of the level crossing, the road vehicle was stationary. In many of these collisions, the train drivers identified the stationary vehicle and commenced braking, and the train speed was thus also reduced.

The national rail safety database did not include information about whether road vehicle struck, or was struck by, the train. Of the 49 collisions between trains and heavy vehicles reviewed in this study, there were at least 39 TSV collisions of which 7 (17.9%) resulted in derailments. Of 7 VST collisions, 4 (57.1%) resulted in derailment. Fisher’s exact test showed a significant association between collision sequence and derailment (one-tailed $p = 0.046$), such that VST collisions were more likely to lead to derailment.

Of 4,886 collisions involving heavy vehicles recorded in the US FRA dataset there were 4,354 TSV collisions, of which 110 (2.3%) resulted in derailment. Of 532 VST collisions, 31 (5.8%) resulted in derailment. Fisher’s exact test showed that VST collisions were significantly more likely to result in derailment (one-tailed $p < .001$).

ATSB finding

Although level crossing collisions between heavy vehicles and trains were more likely to involve the train striking the heavy vehicle, accidents where the heavy vehicle struck the train were more likely to cause a derailment (Factor that increased risk).

Analysis of heavy vehicle level crossing collisions in Australia

This section provides an overview of the characteristics of the 49 heavy vehicle accidents in Australia between July 2014 and August 2022. This section first describes the actions of heavy vehicle drivers associated with the level crossing collisions. The analysis then focuses on some of the factors identified in the study which may have contributed to the actions of the heavy vehicle drivers.

Actions of heavy vehicle drivers

The ATSB reviewed various sources of evidence to determine the circumstances which led to the road user entering the level crossing and not giving way to the train. There were 3 main types of road vehicle actions which precipitated level crossing collisions:

- **Did not stop**. These instances involved a road vehicle not stopping and entering the level crossing. This includes instances where the driver commenced braking late and was unable to stop in time to prevent entering the crossing.
- **Stopped and proceeded**. These instances involved a road vehicle stopping prior to the level crossing, then proceeding into the crossing.
- **Stopped on the crossing**. These instances involved the road vehicle stopping foul of the level crossing while waiting for traffic ahead to clear, and instances when the vehicle was stopped on the crossing due to a road accident or other event (mechanical problem of the road vehicle).

Unsurprisingly, the different actions associated with level crossing collisions varied depending on the type of level crossing protection equipment in use. There was one collision where there was insufficient information to determine the action of the road vehicle driver. The number of collisions associated with each action and the distribution by crossing type is shown in Table 15Table 15: Heavy vehicle driver actions preceding level crossing collisions, by level crossing primary protection type

	Did not stop	Stopped and proceeded	Stopped on crossing	Total, all actions
Boom gates	0	0	11	11
Flashing lights only	8	3	1	12
Stop sign	11	7	1	20[1]
Give way	5	1	0	6
Total, all crossing types	**24**	**11**	**13**	**49**

[1] There was insufficient evidence to identify the road user action for one accident at a Stop sign level crossing.

ATSB finding

All level crossing collisions involving heavy vehicles resulted from the heavy vehicle driver not giving way to trains. There were three actions associated with the collisions:

- There were at least 24 collisions where the heavy vehicle did not stop prior to entering the crossing.
- There were at least 11 collisions where the heavy vehicle stopped at the crossing then proceeded into the path of a train.
- There were at least 13 collisions where the heavy vehicle entered a level crossing and stopped foul of the train line. (Factor that increased risk).

Collisions at boom gate crossings

All 11 collisions at crossings protected by boom gates involved the road user stopping foul of the crossing. In at least one of these collisions, the driver was unintentionally foul of the crossing due to misjudging the length of their vehicle relative to the available distance on the far side of the crossing.

In 3 collisions, records indicated that the heavy vehicle driver had been unable to exit the level crossing due to unanticipated events. In 2 of these collisions, the heavy vehicle was involved in a collision or near collision with another road vehicle and became stuck. In the other collision, the heavy vehicle reportedly entered the crossing while queueing for an adjoining road, but encountered a mechanical problem and was unable to move from the crossing.

Collisions at flashing light crossings

Most collisions at crossings protected by flashing light signals (8 of 12) involved circumstances where the heavy vehicle driver did not stop before entering the crossing. In 6 of these cases, the heavy vehicle driver observed the flashing lights late on the approach and braked and skidded into the crossing. This meant that at the time of collision, most of the road vehicles were either travelling at a very slow speed or had in fact come to a stop foul of the crossing. In one of the cases, the driver detected the crossing and braked, however records indicated that the vehicle had defective brakes.

In 3 of the 12 collisions the heavy vehicle driver stopped at the crossing and inadvertently proceeded into the path of a train. Various unique factors contributed to each of these collisions:

- In one accident the stop lines at the level crossing were placed too close to the primary level crossing flashing light assembly. This meant that the driver of a passenger bus, who was seated very close to the front of the vehicle, was unable to see the flashing level crossing lights. In that instance, the level crossing also included a secondary flashing light assembly at far side of the crossing, however the bus driver did not look at those lights and inadvertently proceeded into the crossing just before the arrival of a train.
- In another accident, the truck driver heard the train driver sound the train horn and mistakenly thought this was an invitation to enter the crossing ahead of the train.
- In another accident, the truck driver was distracted by something related to the performance of their vehicle and did not pay attention to the level crossing.

One collision involved a heavy vehicle stopping on the crossing (prior to the activation of the flashing lights) and being unable to clear the crossing prior to the arrival of a train due to another heavy vehicle being stuck on the road ahead.

Collisions at Stop sign crossings

In 11 instances, the heavy vehicle driver did not stop at the Stop sign crossing. In 3 cases, the driver braked too late and inadvertently entered the crossing, indicating the crossing was not detected in time to stop. In 4 collisions the drivers attempted to conduct a 'rolling stop'[24] and thus intentionally did not stop prior to entering the crossing, and probably failed to detect the presence of a train. In one collision, the truck driver reportedly stated they had not stopped or looked for trains before proceeding through the crossing.

In 7 of the 19 collisions at Stop sign level crossings, the heavy vehicle driver stopped their vehicle at the crossing and inadvertently proceeded into the path of an oncoming train.

There was one reported collision where the heavy vehicle driver detected the train and mistakenly determined it was safe to enter the crossing. As such, the other accidents probably indicated problems with either the sighting at the level crossing, the drivers' behaviour when looking for trains, or the conspicuity of the trains, all of which may have led to the heavy vehicle drivers entering the crossing without identifying a train was approaching.

Collisions at Give way sign crossings

In 5 of the 6 collisions at Give way crossings, the road vehicle driver either did not see the train until they were on the crossing or did not see the train at all. This included one collision where a truck driver did not stop at a level crossing ahead of an approaching train, causing the train drivers to apply emergency brakes. The driver then stopped at an intersection ahead of the crossing, while still foul of the train line.

Errors and violations associated with level crossing collisions

Inadvertent failure to detect level crossing equipment

Research and background

In order to give way to trains at level crossings, road vehicle drivers must first identify that they are approaching a level crossing. The level crossing safety system provides information to drivers about the presence of an upcoming level crossing using roadside signs and roadway pavement markings. In the case of active level crossings, the presence of the crossing is also indicated by boom-gates across the roadway and/or flashing light beacons.

Yeh and Multer (2008) note that some road vehicle drivers inadvertently miss cues relating to the presence of a crossing, reducing their ability to stop in time. The section *Factors affecting heavy vehicle driver* provides discussion about some of the reasons for these errors.

Analysis of heavy vehicle level crossing collisions

As identified in *Actions of heavy vehicle drivers* there were 24 collisions in which the heavy vehicle driver did not stop prior to entering the level crossing. One plausible reason for these collisions was that the drivers did not detect they were approaching a level crossing until it was too late.

To identify the instances where level crossing equipment was not detected, records including police reports, train driver statements, rail infrastructure manager reports and ATSB investigation interviews were reviewed. The ATSB identified:

- There were no instances of heavy vehicle drivers not detecting the presence of a boom-gate controlled active level crossing.

24 A 'rolling stop' refers to a road vehicle driver approaching an intersection and slowing their vehicle, before proceeding through the intersection without coming to a complete stop.

- There were at least 6 collisions where the heavy vehicle driver did not detect that they were approaching an active flashing lights-controlled level crossing until it was too late to stop. In several of these instances, braking occurred before the crossing, however due to the speed and mass of the heavy vehicles there was insufficient distance for them to stop. In one example, an ATSB investigation identified that the road-train truck driver commenced braking at about 180 m from the crossing while travelling at 90 km/h but was unable to stop.
- There were at least 3 collisions at Stop sign level crossings where the heavy vehicle driver did not identify the level crossing until it was too late to stop. In one of these collisions, the heavy vehicle driver reported to police that they were completely unaware of the crossing, and a rail infrastructure manager report identified that sun glare obscured the driver’s vision of the crossing. In the other 2 collisions, the driver identified the level crossing too late to stop.
- There were 5 collisions where the heavy vehicle driver did not stop prior to entering a level crossing controlled by Give way signs. The road rules for Give way sign-controlled crossings do not require a vehicle driver to come to a complete stop, except to give way to trains if one is approaching the crossing. Due to this, the failure of the drivers to stop may have resulted from a failure to detect the presence of the level crossing, or a failure to detect the presence of trains. There was insufficient evidence to determine which of these ‘failures’ contributed to the 5 accidents at Give way sign crossings.

This analysis indicates that in a subset of collisions, heavy vehicle drivers did not detect the presence of the upcoming level crossing. While only a minority of instances, these collisions reflect a dangerous state in the level crossing system. If a driver does not identify the presence of a Passive control crossing, they will not be looking for trains, and there are limited redundant controls to alert them of the requirement to stop. AS1742.7 states that Stop sign crossings are required to be installed when visibility on the road approach to a crossing does not provide adequate visibility for a road vehicle driver to see an approaching train, and this poor visibility will further reduce the likelihood of the train being detected visually by opportunistic (rather than deliberative) scanning. The train horn may provide an aural indication of a requirement to stop, however there are known limitations with the audibility of train horns (see *Train horn audibility*).

Concerning collisions at active level crossings, the errors were mainly a failure to detect that the crossing was activated, rather than not detecting the crossing. This also presents a highly dangerous condition, since a driver approaching an active control level crossing and perceiving the crossing as not active (lights not flashing), will parse that information as indicating the crossing is safe and no train is approaching. This highlights the importance of ensuring that the signal produced by active level crossings are conspicuous.

Deliberate violation of level crossing rules

Research and background

Part of the safety system for level crossings are the procedural risk controls for level crossing users, including road rules applicable to road vehicle drivers. When road vehicle drivers intentionally disobey the requirements of road rules at level crossings, they greatly reduce the effectiveness of the safety system.

Research has identified that some road vehicle drivers deliberately violate road rules requiring them to stop at level crossings. For example, one study showed that of 22 drivers, 3 did not stop at rural Stop sign level crossings (Beanland and colleagues, 2017). These drivers noted trains were infrequent and suggested there was ample sight distance to look for trains (Stop sign crossings are often installed where there is not adequate distance to look for trains while approaching the crossing).

Gou and Bellavigna-Ladoux (2003) noted that a common form of deliberate non-compliance at level crossings is conducting a ‘rolling stop’. This involves slowing the vehicle until a decision is made to proceed into the crossing, without coming to a complete stop. When conducting a 'rolling stop' a road vehicle driver will necessarily spend less time at the stop point for a passive level crossing and therefore will probably conduct less time scanning for oncoming trains, increasing the likelihood of an incorrect decision to proceed into the crossing when it is not safe.

Heavy vehicle drivers may be more likely to engage in 'rolling stop' behaviour when approaching a Stop sign level crossing. As described in the ATSB investigation RO-2007-001, *Level crossing collision at Back Creek, NSW*:

> Stresses on driveline components (engine, transmission etc) are generally highest on large vehicles when starting from rest, increasing the risk of a failure under some conditions (inappropriate driving or clutch operation). Consequently, heavy road vehicle drivers will, at times, attempt to avoid a complete stop and execute what is commonly referred to as a 'rolling stop'. A rolling stop is where a driver slows their vehicle such that they can make the decision to proceed without coming to a complete stop, that is, without having to depress and release the clutch.

The design standards for level crossings (Appendix B) include a variable for the acceleration capabilities of the design vehicle, and in doing so provide allowance for the increased time required by heavy vehicle drivers to depress and release clutch and engage the required gears to proceed from a stop and through the crossing. This may not, however, translate to heavy vehicle drivers always ensuring their vehicles come to a stop at Stop sign controlled crossings, since they may seek to avoid placing stresses on drivetrain components or simply prefer to maintain forward movement.

Another common violation occurs when road vehicle drivers enter a level crossing and stop foul of the rail tracks. A common scenario is the driver entering the crossing while the road ahead was blocked by other traffic, mistakenly anticipating traffic ahead would clear and they will be able to proceed through. This is contrary to road traffic laws. For example, the Australian road rules (model law) states:

> A driver must not enter a level crossing if: …the driver cannot drive through the crossing because the crossing, or a road beyond the crossing, is blocked.

These violations have been attributed to various factors; road vehicle drivers may perceive there to be a low level of risk associated with entering a crossing and waiting for traffic to clear. These actions may also be influenced by social pressure and perceived social norms (Yeh and Multer, 2008). In one study, 30% of drivers reported that they would violate boom gate crossing rules if they did not detect a train and they saw another driver do so (Witte and Donohue, 2000).

Analysis of heavy vehicle level crossing collisions

In at least 4 collisions, the heavy vehicle drivers engaged in deliberate non-compliance with level crossing rules for Stop signs by conducting a 'rolling stop' on approach to the crossing. In another collision, the heavy vehicle driver did not stop at a Stop sign and did not look for trains. These actions increased the risk of collision by reducing the likelihood that the drivers would identify the presence of trains.

There were at least 6 collisions where the heavy vehicle driver intentionally entered the level crossing when traffic or another blockage prevented them from proceeding clear of the train lines. This did not include instances where the driver mistakenly thought their vehicle was clear of the crossing, or instances where the driver had an accident or breakdown on the crossing.

In an additional 3 collisions, the heavy vehicle driver intentionally entered and stopped foul of the crossing, but did not exit the crossing in time to prevent a collision. In these 3 accidents there was no evidence of a blockage preventing the heavy vehicle from clearing the crossing and were considered intentional non-compliance with level crossing rules for the purpose of this analysis.

In addition, there were 2 collisions where the driver of the heavy vehicle was engaged in high-risk behaviour prior to unintentionally entering the level crossing or unintentionally stopping foul of the crossing. In one instance, the driver was distracted by their mobile phone, and in another the driver was found to be drug affected. These accidents were not considered intentional violations of level crossing rules in this analysis; these drivers did not intentionally enter the level crossing.

ATSB finding

In at least 14 collisions it is likely that the heavy vehicle driver intentionally entered the level crossing in a manner which was contrary to road rules. These included 6 collisions where the driver intentionally entered the crossing without being able to driver clear of the crossing, 4 collisions where the driver engaged in a 'rolling stop' while approaching a Stop sign level crossing, 3 collisions where the driver remained stopped foul of the crossing while there was no obstacle preventing them from exiting, and one collision where the driver did not stop or look for trains at a Stop sign crossing (Factor that increased risk).

Failure to detect trains at passive control crossings

Research and background

At passive control crossings, road vehicle drivers must visually search for and detect the presence of a train to determine when they can and cannot proceed through a crossing. There are no recovery controls to prevent a collision if a road vehicle driver does not detect that a train is approaching.

Road vehicle drivers sometimes do not look for oncoming trains when approaching a passive control crossing. Research using head movement measurements of heavy vehicle drivers found that less than 60% looked in at least one direction of the train line when approaching a passive control level crossing (Ngamdung and da Silva, 2012). Failure to look for trains may be associated with a number of factors, including not identifying the presence of a crossing, distraction or preoccupation, or a low expectancy of the presence of a train at the crossing.

Even when road vehicle drivers look in the direction of approaching train, they may not detect the train nor identify a requirement to stop. Rudin-Brown and colleagues (2014) identify that many level crossing collisions result from so-called ‘Looked But Failed to See’ errors.

Analysis of heavy vehicle level crossing collisions

As identified in *Actions of heavy vehicle drivers* there were 26 collisions at passive control level crossings. Of these collisions, at least 2 involved the heavy vehicle driver detecting the train before entering the crossing:

- In one instance, the driver of the heavy vehicle stopped for a Stop sign level crossing and identified that a train was nearby. The train’s lead locomotive cab was unoccupied, and was conducting an indexing movement across the crossing at low speed. The truck driver incorrectly determined that they could transit the crossing safely, and the train scraped the side of the truck prior to it clearing the crossing.
- In one instance, the driver approached a Stop sign level crossing and, according to the rail operator report for this collision, the truck was unable to stop for the crossing due to a mechanical problem.

Concerning the other collisions at passive control level crossings, there was limited information to determine whether the heavy vehicle driver looked for trains and detected the presence of a train before proceeding into the crossing. Heavy vehicle drivers were almost never interviewed, except in collisions which were investigated by the ATSB. Driver statements were sometimes included in police reports; however drivers may be disinclined to inform the police if they had not looked for trains.

While there was very limited direct evidence concerning whether a heavy vehicle driver looked for trains, the ATSB considered that an indirect indicator of heavy vehicle drivers attempting to comply with the requirement to look for and give way to trains was whether the heavy vehicle slowed or stopped during the approach to the crossing. However, it is acknowledged that this indirect evidence cannot rule out the possibility that some drivers may have slowed when approaching the level crossing due to other factors, such as the road condition near the crossing, or to accommodate the type and weight of their load.

The ATSB reviewed rail operator, rail infrastructure manager and police reports to classify the braking behaviours of heavy vehicles approaching passive control crossings.

- In at least 12 collisions, the driver either slowed or stopped while approaching passive control crossings but either did not detect the train, or deliberately entered the crossing ahead of the train.
- In at least 4 collisions, the driver did not slow or stop for the crossing until too late. In one of these collisions, the ATSB report found the driver did not approach the crossing with sufficient caution to stop after noticing the train. In another collision, the rail infrastructure manager report stated the vehicle was travelling too fast to stop at the crossing. In another collision, the driver stated they did not detect the presence of the crossing, and only commenced braking after seeing the train shortly before the collision.
- In one collision, the rail operator report stated that the heavy vehicle driver reported that they had not slowed or looked for trains at the Stop sign crossing.
- In 7 collisions, there was insufficient evidence available to determine whether the heavy vehicle slowed on approach to the passive control level crossing.

The analysis therefore identifies that in at least 46% (12 of 26) of collisions the observed braking behaviour indicated that the heavy vehicle drivers made some attempt to comply with the requirement to look for and give way to trains, however probably did not detect the presence of the train.

An alternative explanation in these cases was that some the heavy vehicle drivers who slowed or stopped when approaching passive control level crossings did identify the presence of a train, but elected to enter the crossing, in an attempt to ‘beat the train’ through the crossing. There was no direct evidence of any heavy vehicle drivers deliberately proceeding in front of an approaching train, although drivers may be unlikely to make admissions of such behaviours to police or to rail operator investigations. In 2 cases, the heavy vehicle driver was fatally injured in the accident and there was limited information concerning whether they had observed the train prior to entering the crossing. In 4 cases, the heavy vehicle drivers stated that they had looked for trains prior to entering the crossing. In other cases, other circumstances related to the accident indicated it was unlikely the heavy vehicle driver had deliberately entered the crossing. Considering all the available evidence of the 12 cases where heavy vehicle drivers slowed or stopped while approaching passive control crossings, the ATSB determined the drivers had probably not detected the presence of a train.

ATSB finding

Of 26 collisions at passive control crossings, there were at least 12 collisions where the heavy vehicle driver slowed or stopped but probably did not detect the train, and entered the crossing into the path of the approaching train (Factor that increased risk).

Factors affecting heavy vehicle driver behaviour at level crossings

Overview and prior research

The analysis of level crossing collision data showed that collisions typically occurred in fine weather, in daylight, on dry, sealed roads. Previous analysis found that most level crossing accidents did not involve alcohol or excessive speed (ATSB, 2002), which are common causes for other road accidents (OECD, 2021).

The majority of collisions probably involved some form of unintentional lapse, where the heavy vehicle driver did not identify a train was approaching the crossing. Even in the subset of collisions where a deliberate violation of road rules was identified, the heavy vehicle driver probably intended and expected to clear the crossing safely.

The safety systems approach to accident analysis seeks to understand the contextual factors associated with individual errors and violations. This involves identifying factors that exist within the system which increase the likelihood of errors and other failures (latent conditions). For the level crossing safety system, this includes considering how the experiences and tasks of road users shape their performance at level crossings. It also includes considering the design of vehicles, trains and level crossing equipment, and whether these support the tasks of the human operators at level crossings (road vehicle and train drivers).

Familiarity and expectancy

Research

When drivers become familiar with a particular crossing or a particular type of crossing, and when the driver has previously not observed trains at that crossing (or type of crossing), an unconscious expectancy for no trains at that crossing or that type of crossing may form (Rudin-Brown and colleagues, 2014). Researchers have argued that drivers generally expect there to be no trains present at level crossings (Eck, 2002), and that these expectations are ‘the greatest challenge’ in overcoming safety problems at passive level crossings (Salmon and others, 2013) and the ‘root of unintentional noncompliance at…level crossing’ (Eck, 2002).

Research has shown that drivers familiar with a level crossing are more frequently involved in level crossing collisions than drivers unfamiliar with an area (Abraham and colleagues, 1998). A coronial investigation into 12 fatal level crossing collisions in Victoria found that all except 3 drivers were very familiar with the crossing and all but one never or rarely saw a train at the level crossing (Coroner’s Court of Victoria, 2013).

There are several ways that this low expectancy of trains can contribute to level crossing collisions. Low expectancy for trains may influence deliberative, planned behaviour where a driver enters a level crossing contrary to the requirements of road rules. Reason (1990) identifies that routine violations of rules are often the product of environments where violations are infrequently punished, which may be taken to mean formal punishment in the case of law enforcement, or other negative consequences such as collisions. As Yeh and Multer (2008) summarise, a low expectancy and low frequency of trains at level crossings may cause drivers to simply disregard crossing protection equipment.

The other way low expectancy for trains can influence level crossing collisions is at the unconscious level, affecting how road vehicle drivers scan for and detect important information about the crossing and the presence of trains. Reason (1990) identifies that people engaged in well-practiced, routine tasks are vulnerable to unintentional slips of attention. In these contexts, attention and behaviour is highly influenced by the ‘motor schema’ or ‘script’ for the task, and there is a high likelihood that an operator will miss cues which indicate a need to divert from the typical routine.

The task of driving a road vehicle is generally highly-practiced, and occurs in roadway environments where other demands and distractions are often prevalent. In this context, road vehicle drivers are required to depart from the active and dominant motor schema of continuing to drive along the road, and adopt a motor schema of looking and preparing to stop for trains. For motorists with a low expectancy for encountering a train at a crossing, there is a high likelihood that they may miss cues which identify they need to stop for trains.

Other psychological theories identify that experiences form the basis for 'schemas' or 'mental models' of the task environment. These mental models influence where a person will search for information, what they are looking for, and which information they will detect (Wickens and McCarley 2008; Wickens and others 2013). Drivers with a low expectancy of trains may therefore be less likely to look for trains, or look for activated flashing lights. Even in situations where a driver looks directly at a train or flashing light assembly, they may not detect the requirement to stop and proceed into the crossing, reflecting a so-called 'looked-but-failed-to-see' error.

Analysis of heavy vehicle level crossing collisions

As described in *Errors and violations associated with level crossing,* 9 accidents were due to the heavy vehicle driver intentionally stopping foul of a level crossing. There was insufficient evidence to establish whether any of these drivers were familiar with the level crossing, or what expectancy they had when entering the crossing. It is possible, however, that some or all these drivers previously queued over the same crossing or other intersections, with no negative consequences. It is also possible that these drivers had observed other drivers queueing over level crossings, normalising the behaviour and reducing the expectancy of negative consequences.

There were 12 collisions where the ATSB identified that the heavy vehicle driver was familiar with the level crossing prior to the collision with the train, and all of these involved the driver either not stopping at the crossing or stopping and proceeding into the path of the train. There were 6 collisions where the heavy vehicle driver was familiar with a passive control level crossing and did not detect the presence of the train. In 5 collisions, the heavy vehicle driver was familiar with a crossing protected by flashing lights and did not detect that the lights were activated.

The heavy vehicle drivers were typically engaged in driving for business or employment, and the collisions often occurred on routes they traversed several times a day or week. Some examples included:

- One driver reported that they travelled across the same level crossing about 20 times per day for work, and was not expecting a train.
- One driver reported they had been driving the same route for 2 months and the train they collided with was the first train they had seen at the level crossing.

It was not possible to precisely describe the effects of familiarity for each of these 12 collisions. However, it is highly likely that in some collisions the drivers' familiarity with the level crossings and low expectancy for encountering trains affected their attention to and perception of the crossing environment. With a low expectancy of trains, the drivers may have either not allocated sufficient attention to the crossing or have looked but not detected a requirement to stop.

In one collision the heavy vehicle driver entered a level crossing after identifying that the level crossing lights were flashing and detecting the train. The driver heard the train driver sound the train horn and mistakenly thought this was an invitation to enter the crossing ahead of the train. They reported to police that they had previously been 'let through' the crossing in similar circumstances, and therefore had an expectancy that they could cross ahead of the train.

ATSB finding

There were at least 12 level crossing collisions where the driver of the heavy vehicle had regularly used the level crossing prior to the collision with a train. This included 6 collisions where the heavy vehicle driver proceeded into a passive control crossing without identifying the presence of a train, and 5 collisions where the heavy vehicle driver did not identify activated flashing level crossing lights. The drivers' previous experience at the level crossings likely led to a low expectancy for trains and, in at least some collisions, contributed to them not detecting a requirement to stop and give way. (Factor that increased risk).

Distraction and divided attention

Research

Distraction occurs when a driver’s attention (meaning where the driver is looking, what they are manipulating/touching, and what they are thinking about) is diverted from activities critical for safe driving towards a competing activity (Parnell and others, 2016). There is a significant body of evidence demonstrating that distraction impairs driving performance and contributes to accidents (Young and others, 2007).

The task of driving a road vehicle often requires attending to complex road environments. Due to a limited ability to attend to multiple sources of information at once, road vehicle drivers operating in complex or cluttered areas (such as where there are multiple intersections, signs, or road users) may be less likely to attend to and detect trains (Rudin-Brown and others, 2014).

Reviews of level crossing collisions have identified that distraction can be a contributory factor to driver non-compliance (Rudin-Brown and others, 2014). In-cab studies of heavy vehicle drivers have shown that drivers sometimes attend to other tasks (including texting or eating) while negotiating level crossings (Ngamdung and da Silva, 2012), or may be distracted by factors at the crossing such as poor surface conditions (Eck, 2002).

Analysis of heavy vehicle level crossing collisions

Records indicated that at least 6 of the heavy vehicle drivers were probably distracted prior to the collision, or were dividing their attention between driving the vehicle and another task or thought. In some of these instances, the driver was reportedly focussed on other traffic or complicated road signage, and did not detect the level crossing flashing lights or the approaching train. In one example, an ATSB investigation obtained in-vehicle video footage which showed the truck driver was distracted by re-affixing a mobile phone mount which had fallen from the truck windscreen. The truck driver did not notice the flashing active crossing warning lights and proceeded into the crossing, colliding with a freight train.

Obstructed vision due to vegetation, sun glare and poor crossing lighting

Research

For a road vehicle driver to detect an oncoming train at a passive level crossing, the train needs to be visible within their field of view. In some instances, however, the design and maintenance of level crossings is such that the driver’s view is obstructed.

Another visual problem encountered by road vehicle drivers approaching a level crossing is disabling sun glare. Disability glare occurs when light enters the eye and ‘washes out’ the image being perceived (Sanders and McCormick, 1993). The disabling effect of glare is greatest when the sun is in the direct line of sight of the driver. Thus, sun glare is greatest at the times just before sunset and just after sunrise, when the sun is low in the sky and thus objects which are being viewed at ground level fall in a narrower angle relative to the sun.

After sunset, night-time darkness affects the ability of drivers to safely negotiate level crossings by reducing the availability of visual cues, particularly for passive control crossings. Where level crossings are unlit, level crossing signage may be difficult to detect. Yeh and Multer (2008) note that illumination of level crossings improves the detection of the crossings at night.

Analysis of heavy vehicle level crossing collisions

In at least 9 collisions reviewed by this study, the view of the heavy vehicle driver was probably obstructed by nearby vegetation. In at least 8 instances, vegetation probably obstructed visibility of the rail track, which may have reduced the ability of the driver to detect oncoming trains. In one instance, vegetation obstructed the visibility of the rail track and the level crossing protection equipment.

In one collision, the rail infrastructure manager and police reports identified that the driver of the heavy vehicle was probably unable to detect the presence of the level crossing due to sun glare.

In another collision, the rail infrastructure manager identified that a Stop sign was located in a dark industrial area, with poor lighting on the crossing itself and contrasting bright lights from surrounding industrial installations and other road traffic. The infrastructure manager report found that when a heavy vehicle approached the crossing at night, the poor lighting conditions reduced the driver's ability to detect an approaching train.

Obstructed visibility due to vehicle design

Context

In addition to environmental obstructions, the visibility of trains and level crossing equipment may be affected by vehicle design characteristics. Heavy vehicles often have large 'A' and 'B pillars, planar mirrors, and other structures like exhaust snorkels. Research has shown that restricted fields of view in heavy vehicles are a common cause of other road accidents (Blower, 2007; Niewoehner and Berg, 2005).

The *Australian Design Rule 93/00 – Forward Field of View* specified the allowable restrictions within the drivers' forward 180° field of view for passenger and heavy vehicles supplied to the Australian market.[25] The regulations did not prescribe any requirements for field of view behind the driver.

The design standards for level crossings (*Australian Standard AS1724.7:2016*) required that the sighting opportunity available to road users is provided at visual angles which do not require excessive head movement or sight obstruction by the vehicle itself. The standard states that for the sighting distance when stopped at a level crossing, the maximum allowed viewing angles are 110° to the left and 140° right.

The combination of vehicle design which does not prohibit restricted visibility behind the driver seated position, and crossing design which allows for rail traffic to approach from obtuse angles (greater than 90°), leads to a potential zone of restricted visibility where the driver may need to lean forward to view along the train track.

Analysis of heavy vehicle level crossing collisions

In at least 5 collisions reviewed in this safety study, the design of the heavy vehicle cab probably restricted the driver's view of the crossing equipment or train. These included 3 collisions which had previously been investigated by the ATSB:

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[25] Vehicle Standard (Australian Design Rule 93/00 – Forward Field of View) 2018.

- RO-2015-016: The ATSB found that the truck 'A' pillar and air snorkel probably restricted the driver's view of the flashing lights as the truck approached the crossing.
- RO-2016-009: The ATSB found that the truck driver's view of the track when looking left was restricted by the structure of the cab and the absence of windows behind the driver. When seated in an upright position, the viewable area was limited to 90°, meaning only 29 m of track was visible. This could be extended by up to 104° (60 m) by hunching forward.
- RO-2017-011: The ATSB found that the truck driver would not have been able to see the approaching train from their stopped position, due to their line of sight being obscured by the truck's B-pillar.

In another collision, the shallow-nosed design of the bus cab meant that when the driver was stopped at the stop line, they were very close to the stop line and had a restricted view of the flashing crossing lights on the near-side of the crossing, contributing to them entering the crossing into the path of a train. In the other collision, the driver identified that large air cleaners on their vehicle may have obstructed vision of the train at the passive control level crossing.

This analysis demonstrated that the visibility of some heavy vehicle drivers was restricted by objects around the level crossings, the design of the heavy vehicle and the crossing, and the environmental conditions at the time of the collisions.

ATSB finding

Of the 49 level crossing collisions involving heavy vehicles, there were at least 14 collisions where the heavy vehicle driver's view was obstructed by vegetation, the design of the heavy vehicle cab, poor crossing lighting, or sun glare (Factor that increased risk).

Train horn audibility

Australian Standards and other requirements

Locomotives operating in Australia must be equipped with train horns, which are used to ensure individuals in and around the rail corridor are aware that rail traffic is approaching. The Rail Industry Safety Standards Board (RISSB) *Code of Practice for Rail Traffic Horn Use* stated that:

> For the rail traffic horn to achieve its intended purpose, it shall be designed to be audible and distinctive (i.e., from road vehicle horns) and to a level where the intended receiver can hear it and understand its meaning. The rail traffic horn is intended to be heard above the general background noise and other potential distractions, such as: a) plant and machinery at worksites and depots; and b) personal devices and background noise at level crossings.

The Australian Standard for *Railway Rolling Stock Audible Warning Devices (AS 7532:2016)* described requirements for the audibility of train horns:

- The country warning device must produce at least 88 dB at 200 m ahead of the rolling stock, and at least 106 dB at 30 m ahead of the rolling stock.
- The town warning device must produce at least 90 dB at 100 m from the rolling stock and 101 dB at 30 m from the rolling stock.

AS 7532:2016 did not specify the types of train horns accepted for use, or the frequencies at which the train horn must produce sound.

The RISSB *Code of Practice for Rail Traffic Horn Use* stated that activating the train horn was a requirement at passive control level crossings, and optional at active control crossings. The code of practice also required that the train horn must be sounded at the whistle board, where placed, and may be sounded at other locations including during the approach to and on the crossing.

Research on effectiveness of train horns

Research examining level crossing collisions in the US between December 1995 and August 1996 found that 55 of 60 train drivers sounded the locomotive horn prior to the collision, but only 4 of 14 road vehicle drivers reported hearing the horn (described in Yeh and Multer, 2008). In a 2013 coronial review of 12 fatal level crossing accidents in Victoria, the Coroner noted that none of the drivers had heard the locomotive horn (Coroner's Court of Victoria, 2013). These reviews highlight that in many collisions it is evident that train horns were unreliable for alerting road users to the presence of a train.

Supporting the utility of train horns, Yeh and Multer (2008) identified that initiatives prohibiting the use of train horns (whistle bans) in US jurisdictions have led to increased rates of level crossing collisions. For example, they report analysis conducted by the FRA in 1995 was reported:

> An "Accident Prediction Formula" that calculated the likelihood of an accident at a grade crossing based on its physical characteristics (e.g., the number of tracks and highway lanes, types of warning devices, rural or urban location, road condition) and operational aspects (e.g., number of highway vehicles and train volume, speed, type, and schedule) found that the risk of a grade crossing accident was 84 percent higher when the train horn was silenced (FRA, 1995).

Follow-up analysis conducted by the FRA (2000) found that:

> Consistent with the results of the previous study, the analysis showed that the whistle ban impacted safety, with a 62 percent increase in accidents at whistle-ban crossings protected with gates, 119 percent increase at whistle-ban crossings protected by flashing-lights only or another type of active warning device, and a 27 percent increase at whistle-ban passive crossings.

Several laboratory studies have investigated the acoustic qualities of train horns, and the audibility of train horn sound in simulated conditions. Findings from this research include:

- Different types of train horns produce different patterns of sound. 5-chime horns were found to produce a much greater volume of sound at higher frequencies (above 800 Hz) than 3-chime horns (Rapoza and Raslear, 2001).
- Train horn sound is attenuated as a function of the distance of the train from the vehicle, consistent with the inverse square law for sound. Because a vehicle travelling at a greater speed will need to detect the train from further away in order to stop, the train horn must be proportionally louder (proportional to the square of the distance between the train and road vehicle).
- The level of sound available to road vehicle drivers is affected by the sound-attenuating properties of the vehicle body, referred to as insertion loss.
- Train horn sound is also attenuated by whether the road vehicle windows are open or closed, whether the engine is running, and whether the radio and/or fan is on (Rapoza and Raslear, 2001; Casali and others 2002; Dolan and Rainey, 2005).

There were mixed findings regarding the detectability of train horns.

- Raslear and Rapoza (2001) used a probability model to predict the likelihood that road vehicle drivers would detect an approaching train in time to prevent collision. The model predicted that a road vehicle driver approaching a passive control level crossing would almost always detect a 5-chime warning horn. However, a 3-chime warning horn would only be detectable 75% of the time when the train was travelling at 32 km/h, dropping to 25% of the time when the train was travelling at 64 km/h.
- Dolan and Rainey (2005) conducted a laboratory study which involved producing simulated train horn sounds at different volumes, along with simulated background noises to replicate different vehicle conditions. They found that 50% of participants could detect the simulated train horn sound at a volume of 10 dB below the simulated background noise. One limitation of

the applicability of this research is that the participants were not driving a vehicle and were primed to listen for the train horn signal.

- Casali and others (2002) measured the sound produced by a 5-chime train horn, and the sound attenuating properties of a sample of 1990s model trucks under different operational conditions (engine on/off, windows up/down, radio on/off). This research concluded that the noise produced by the train horn only exceeded the 'masked threshold' (being 13 dB louder than background noise) when the engine was at idle and the windows were down.

In summary, there is no known research which has examined how frequently real drivers respond to train horns in real driving conditions. Consolidation of the research indicates that the requirement to use a train horn improves the safety of level crossings overall, however collision case-studies indicate that there are numerous instances where the train horn is not effective for alerting drivers to the presence of a train. There is a research gap, therefore, in identifying the circumstances in which train horns are not effective, and how often train horns are not effective for preventing collisions.

Analysis of heavy vehicle level crossing collisions

Records indicated that in at least 44 of the 49 level crossing collisions reviewed in the study the train crew sounded the horn as required prior to the collision. There were at 2 instances where the horn was not sounded as required at the whistle board, and 3 instances where there was insufficient information to determine whether the horn had been sounded.

Considering the effectiveness of the train horn for alerting heavy vehicle drivers to the presence of trains, the ATSB noted that:

- There were 13 collisions which involved the heavy vehicle driver stopping foul of the crossing. In most of these, the heavy vehicle driver was not able to exit the crossing due to being blocked by traffic or another form of impediment, and thus detecting the train via the train horn was unlikely to have prevented these collisions. In 3 of the collisions the ATSB did not identify evidence of a blockage preventing the heavy vehicle from clearing the crossing.
- In 3 collisions, the heavy vehicle driver had identified the presence of a train but did not stop. These included 2 collisions where the heavy vehicle driver encountered a mechanical problem and was unable to stop, and one collision where the truck driver heard the train horn and mistakenly interpreted this to be permission to entering the crossing. The detectability of the train horn was not considered to have affected these collisions.
- There were 3 additional collisions where there was insufficient information to determine whether the vehicle driver detected the presence of the train.

Excluding these instances, the ATSB identified 25 collisions where the train horn was sounded and not detected by the heavy vehicle driver. The heavy vehicle drivers, not detecting the presence of a train, proceeded into the path of the train resulting in collision. It is possible that had the train horn, or another warning, been more conspicuous to the heavy vehicle drivers, then these 25 collisions may not have occurred.

The safety study reviewed collisions only, and did not examine the number of near misses and other instances where heavy vehicle drivers were alerted to the presence of the train by the train horn.

Other audible warning devices

Australian Standard AS1742.7 (Railway level crossings) states that flashing light signals *may* include the provision of audible warning devices. Further, the standard *requires* that where active control of pedestrian traffic is provided (red flashing man signal), an audible signal *shall* be provided. The safety study did not analyse the effectiveness of other audible level crossing warning devices, such as audible 'bells' provided at some level crossings. The ATSB observes, however, that such audible warnings are produced at a much lower volume than locomotive horns, and thus are likely to be less audible to approaching road vehicles. Audible level crossing signals are primarily engineered to be effective for alerting pedestrians.

ATSB finding

Previous research and review of collisions has identified that train horns are sometimes not effective for alerting road vehicle drivers to the presence of trains. Consistent with this, in at least 25 collisions, the horn was not effective at alerting the heavy vehicle driver to the presence of the train (Factor that increased risk).

Visual conspicuity of trains

Research

Due to the safety system for passive control level crossings relying on road vehicle drivers visually detecting the presence of a train in order to identify a requirement to stop and give way, there has been substantial interest in the extent to which the visual characteristics of trains make them difficult to detect. The concept of conspicuity refers to the material characteristics of an object which affect the likelihood it will be detected. The greatest determinant of visual conspicuity is the level of contrast between the object and its surrounding environment.

Trains are often constructed with dark colours, and may be poorly lit, reducing their conspicuity for road vehicle drivers, particularly at night (Rudin-Brown and others., 2014; Yeh and Multer, 2008). A review conducted by the Australian Centre for Rail Innovation (ACRI) identified Australian case studies where factors such as dull colour schemes, dirty train exterior and low contrast between the train colour and the surrounding environment may have reduced the conspicuity of freight trains (ACRI, 2022). The ACRI *freight train visibility review* identified 30 opportunities to increase the conspicuity of trains, of which 2 were carried forward to field testing (flashing train beacons and conversion of headlights from halogen to LED). The results of this testing showed that LED conversion of locomotive headlights resulted in improved visibility in misty conditions only, with insignificant improvement in clear weather conditions. The beacon light was only effective at improving visibility in situations where the train and observer were close to the crossing, and the level crossing angle was obtuse (between 90° and 180°) (Kassa, Wan and White, 2023). Other research has examined the effects of some common treatments for improving train conspicuity:

- Studies have shown that trains equipped with auxiliary alerting lights (additional to the train headlight) are detected at greater distances (Carroll et al 1995).
- Trains which have reflectorised markings installed on freight cars (wagons) are detected at greater distances than unmarked cars (see Edquist and others (2009), for a review).
- Several studies have examined the benefits of strobe lighting on trains, however only small effects have been observed (Cairney, 2003).

In addition to poor illumination, the visual image of a freight train available to a road vehicle driver approaching a level crossing may provide a low likelihood of detection. When a driver is approaching a level crossing and attending to the road, an approaching train will be in the driver's peripheral field of view. There will often be no visual cues indicating the presence of a train in the driver's central (foveal) field of view, where detection of objects is most likely (Edquist and others, 2009; Yeh and Multer, 2008).

The human perceptual system is particularly adapted to detecting movement, and vision in the peripheral field of view is particularly sensitive to movement. Unfortunately, due to the geometry of a collision, a train will typically present as an unchanging retinal image to the driver. That is, the train will not appear to move across the driver's retina when it is on a collision course with the road vehicle driver (Rudin-Brown and others, 2014). These perceptual challenges are similar to those described in the ATSB report *Limitations of the see-and-avoid principle*, which provides additional discussion of visual performance limitations in the aviation context.

Relevant industry standards

Australian Standard *AS 7531:2015 Lighting and Visibility* described the requirements for rolling stock lighting and visibility. This standard required that all locomotives and self-propelled passenger rolling stock have at least one white headlight on each leading end. For new and modified rolling stock, the standard required locomotives and self-propelled rolling stock have active visibility lights, which were required to flash for at least 15 seconds after the horn is sounded. The standard stated that the primary purpose of these lights was to enhance the visibility of the train from the perspective of a driver of a road vehicle approaching a crossing.

AS7531:2015 also required all new and modified locomotives and lead vehicles of passenger trains to have high-visibility colour livery applied. Under this requirement, at least one square metre of the forward-facing area of locomotives and passenger rolling stock was required to be yellow, orange, red or white.

In December 2023 (after the study period of 1 July 2014 to 31 August 2022), the Rail Industry Safety and Standards Board approved *AS7531:2023*. This version of the standard included additional rolling stock lighting and visibility design principles, and provided additional requirements for high-visibility livery. The lighting and visibility design principles added to the standards in the 2023 revision included the following:

> …The overall design for conspicuity of the rolling stock shall be effective to allow for rail traffic crew, track workers and interfacing road and pedestrian users to identify oncoming rolling stock with sufficient time to respond and avoid an incident.

In January 2024, ONRSR announced that it would develop a Code of Practice for train visibility in Australia, with a final draft expected by mid-2024. The intent of this code was to 'assist rail transport operators to strengthen the overall safety management systems that underpin their operations where trains interact with people, drivers and vehicles - with an emphasis on risk controls for train visibility'. ONRSR stated that it would consider the Code of Practice when conducting compliance activities, and that the code would be admissible to proceedings related to compliance with the Rail Safety National law.

Analysis of heavy vehicle level crossing collisions

The ATSB reviewed operator reports and other records to identify how conspicuity equipment such as headlights, visibility (ditch) lights and livery had been utilised for the trains involved in the 49 collisions with heavy vehicles reviewed in this study. Overall, this information was reported infrequently, with key observations being:

- In 24 collisions, the records indicated that the train headlight was on prior to the collision with the vehicle, while in one collision, records indicated the headlight was off. In 24 collisions there was insufficient evidence to establish status of the headlight.
- For 8 collisions, records indicated that the train had visibility (ditch) lights installed, whereas in 4 collisions the train did not have visibility lights. There were 37 collisions where information about the train visibility lights was not reported.
- In 10 collisions, operators reported on the installation of reflective delineators. Four trains had reflective delineators installed on rollingstock, and 6 did not.

Of the 26 collisions at passive control level crossings, 2 occurred at night and in both of these cases the train had its headlights activated. In one of these collisions, the train was being operated in the reverse direction, meaning the train headlights were not effective at illuminating the train in the direction of travel towards the crossing.

In summary, due to limitations in available data from operator reports and other documents, this study was not able to evaluate whether trains involved in level crossing collisions were equipped with the lighting and other visibility equipment required by Australian standards. Furthermore, since this study only examined trains which were involved in collisions, it was not possible to identify factors associated with greater of poorer conspicuity, or for that matter the effectiveness of different types of equipment used to enhance train conspicuity. This is discussed further in *Study limitations*.

Other observations which may be useful for further analysis of train conspicuity include:

- Very few of the collisions reviewed in this study occurred at night, when problems associated with conspicuity are probably greatest.
- The majority of collisions (at least 39 of 49 collisions) involved the train striking the heavy vehicle, indicating that problems associated with train conspicuity are more likely to involve the conspicuity of the locomotive, rather than the other rollingstock.

Analysis of level crossing safety systems

Curved road approaches

Standards and other guidance relevant to placement of crossings on curved road approaches

Australian Standard for level crossing design

The criteria for the placement of level crossing protection equipment were described in Australian Standard AS 1742.7:2016 *Manual of uniform traffic control devices.* AS 1742.7 stated that level crossings:

> should be located to avoid sub-standard geometric features of the road, such as sub-standard curves…. If this cannot be avoided, special attention should be given to the signing and marking of these features as well as the railway crossing itself. Sub-standard geometric features can lead to increased numbers of crashes not involving trains as well as having an effect on the incidence of vehicle/train collisions.

The standard required that if a level crossing was located on a curved road, then appropriate curve signs were to be used, or alternatively additional level crossing warning signage may be placed along the curve. The standard further stated that:

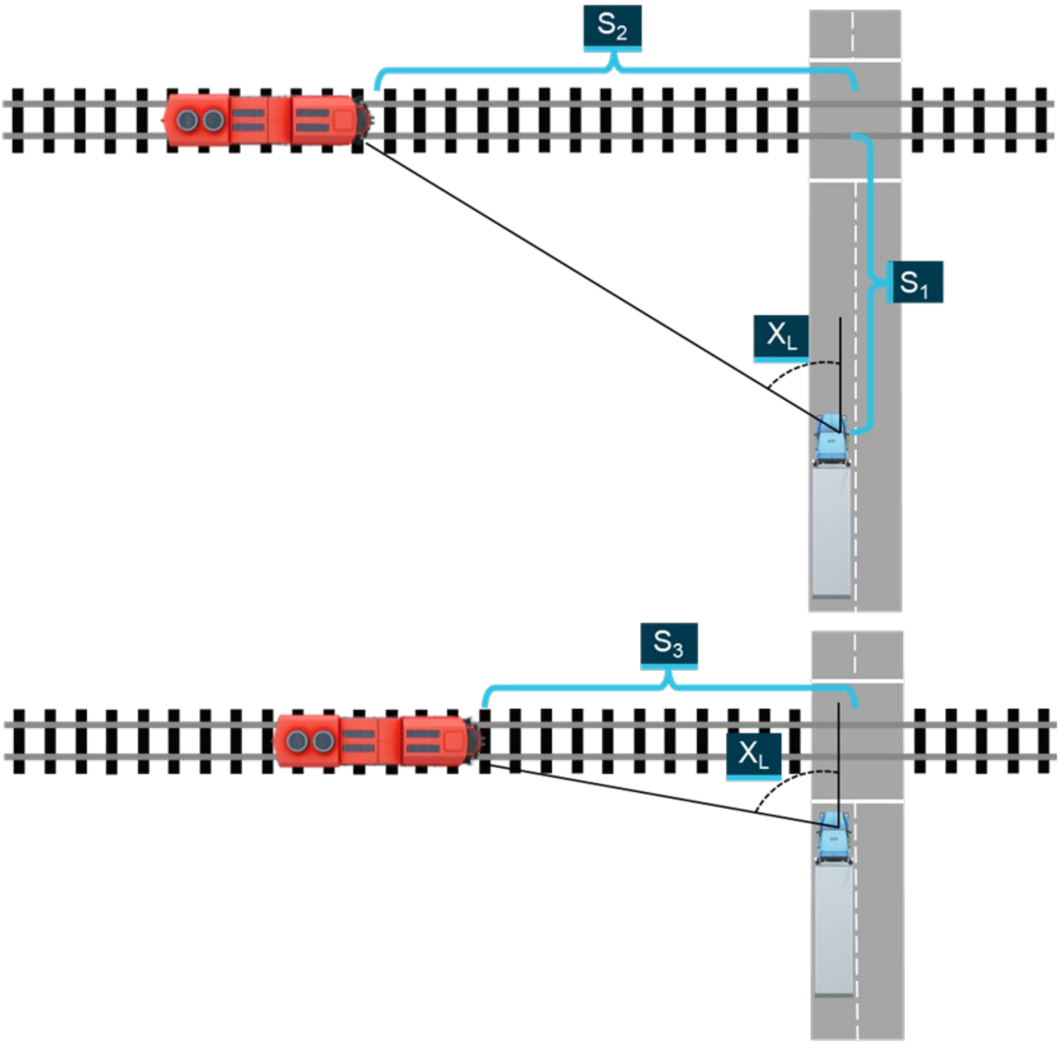
> Where a crossing is located on a curve it may be necessary to adjust the orientation of the primary control device so that it is visible to approaching drivers from any point along the SSD [safe stopping distance] sight line. It may also be necessary to repeat the control device in advance. Where a curved approach leads to an active level crossing, an RX-11 [railway crossing flashing lights active advance warning signal] assembly may also be used to provide additional visual warning to road users.

AS 1742.7 sought to ensure that the placement of the primary active level crossing control device (such as the flashing light assembly) provided sufficient time and distance for the road user to identify a crossing ahead and stop after identifying the control device is activated. This distance was referred to as S_1 or the safe stopping distance (SSD).

Sighting distances described in AS 1742.7, and shown in Figure 3, were defined as:

- S_1, the minimum road distance which must be available to the road design vehicle, at the point the driver is able to detect a requirement to stop prior to the nearest rail.
- S_2, the minimum distance of a train from the crossing at which a road vehicle driver at distance S_1 from the crossing can proceed at speed and safely clear the crossing ahead of the train.
- S_3, the minimum distance of an approaching train from the centre of the crossing, when the driver of the road vehicle, stopped at the crossing, must first see an approaching train in order to safety cross the tracks.
- X_L, sighting angle (left).

Figure 3: Sighting distances for level crossings described in Australian Standard AS 1742.7:2016



Source: Image created by ATSB, illustrating concepts described in AS 1742.7:2016

AS 1742.7 provided guidance 'in order to ensure that a motor vehicle driver can see along the prescribed sight triangles without excessive head movement'. This was achieved through the provision of maximum sighting angles for the S_2 and S_3 distances.

AS 1742.7 provided instructions for calculating S_1 at each crossing, considering various factors related to the expected road user and the road construction (the formula for calculating S_1 is provided in Appendix B). The standard did not require additional S_1 distance for crossings placed on or after curved road approaches.

Procedural guidance for level crossing sighting surveys

Level crossing sighting surveys are conducted to determine if level crossings comply with requirements including those described in AS 1742.7. The Australian Level Crossing Assessment Model (ALCAM) Level Crossing Assessment Handbook was produced by the National ALCAM Committee as a guide for trained surveyors, providing methods for carrying out ALCAM surveys of level crossings in Australia and New Zealand. These procedures stated that to measure the available sighting distance for primary level crossing protection equipment (S_1), surveyors should:

- Drive all approach roads in the vicinity of the crossing to obtain the maximum sighting distance when the crossing control can be clearly seen, and record the available sighting distance available for each approach.
- Calculate the required safe stopping distance position for the roads passing through the crossing. If there are side roads turning towards the crossing or if the crossing is approached from a nearby intersection, safe stopping distances for these roads were also to be determined.
- Compare the available and required (calculated) safe stopping distances.

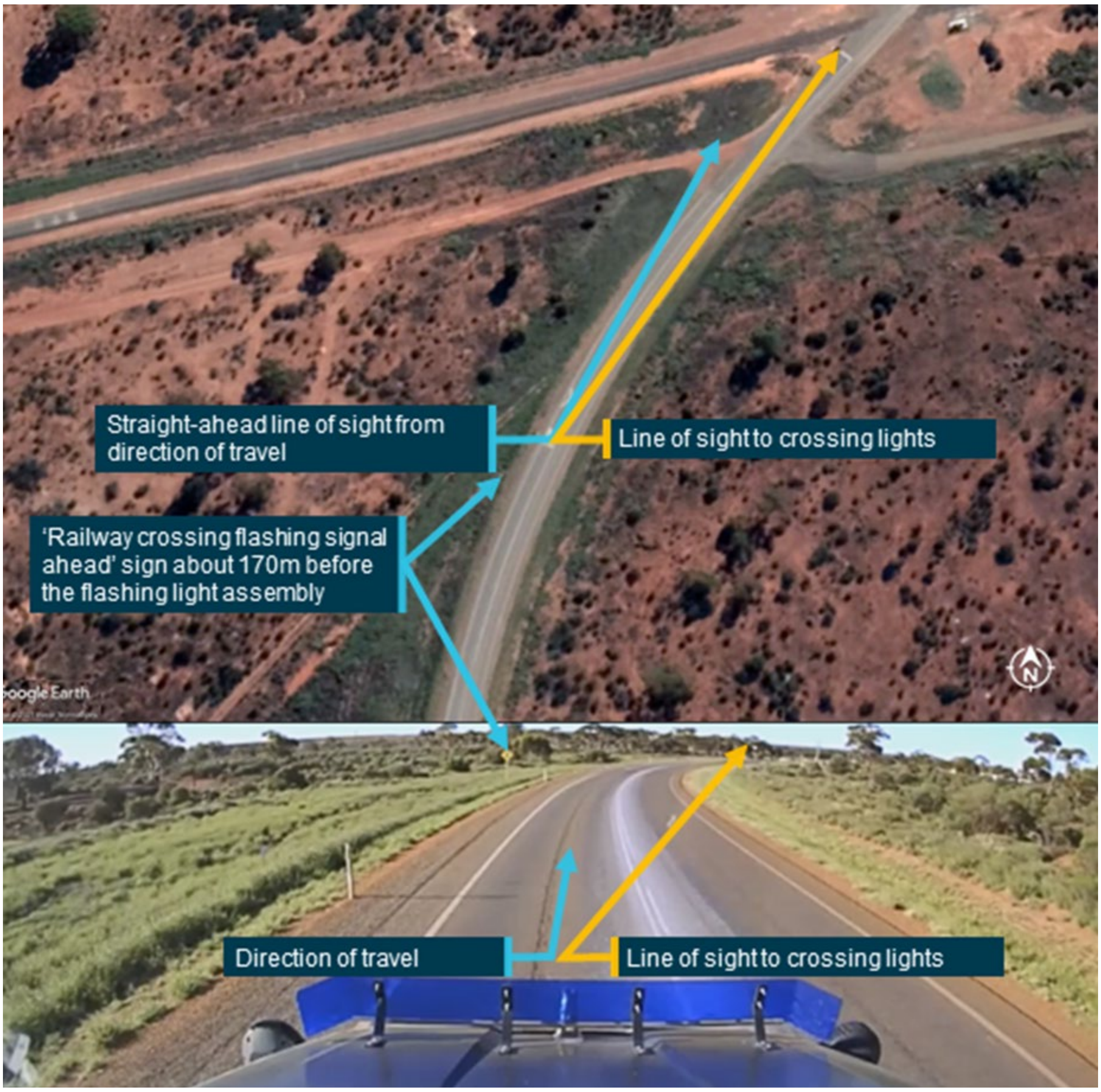
The handbook also identified that additional warning signs may be installed where the road approach to level crossings is curved, observing that ‘duplicated advance warning signs are generally placed on curved road approaches where visibility to the left-hand sign assembly is restricted by roadside vegetation, terrain or structures’.

Level crossing collisions

Of 6 collisions where the road driver braked too late to stop at a flashing light level crossing, 5 occurred at crossings on or following a curved road approach. All 5 were right curves. None of these collisions occurred at crossings with active advanced flashing lights (RX-11) installed. Three of the collisions had previously been investigated by the ATSB:

- ATSB investigation RO-2015-016, Level crossing collision between freight train 8834N and road-train truck, Tullamore Rd, Narromine, NSW, on 23 September 2015. This investigation found that ‘The viewing angle approaching the railway crossing (from the southwest) through the right-hand curve meant that at higher road speed there was reduced opportunity for the truck driver to identify that the flashing lights were operating’.
- ATSB investigation RO-2017-005, Level crossing collision between freight train 8426N and road-train truck, Cobb Highway, Ivanhoe, NSW, on 11 July 2017. This investigation noted that it was possible the driver did not identify the flashing crossing lights due to a focus on negotiating the curved approach to the crossing.
- ATSB investigation RO-2021-003, Level crossing collision between freight train 2C74 and road-train truck Yarri Road, Parkeston, Western Australia, on 22 February 2021. This investigation noted that the truck driver’s sighting of the flashing crossing lights was through a curve. With the truck driver distracted by another activity and possibly only looking directly ahead of the vehicle, they were probably not effectively looking through the curve to the crossing lights. Figure 4 illustrates the driver’s view of the level crossing while navigating this curved road.

Figure 4: Image showing overhead and driver view of level crossing relative to vehicle line of travel, from ATSB investigation RO-2021-003



Source: ATSB investigation RO-2021-003, Level crossing collision between freight train 2C74 and road-train truck Yarri Road, Parkeston, Western Australia, on 22 February 2021.

Records from ALCAM surveys showed the recorded S_1 distances for the road approaches travelled by the heavy vehicles, for the 5 collisions in this study which occurred on curved road approaches to flashing light level crossing (no boom gates installed). The ATSB reviewed satellite imagery to identify the position of the road vehicle at the point at which the S_1 distance was identified, and the visual angle from that position to the level crossing protection equipment (flashing lights). These distances and angles are shown in Table 16.

Table 16: Visual angle identified for sighting of flashing lights at selected level crossing collisions at crossings with curved road approaches

Collision number	Curvature	Measured S_1 distance	Angle to lights at S1 sighting	Road approach speed limit (km/h)
Collision 1	Right	250 m	24.5°	100
Collision 2	Right	275 m	24.5°	80
Collision 3	Right	220 m	20.2°	80
Collision 4	Right	120 m	16.0°	100
Collision 5	Right	274 m	2.8°	100

Level crossing collisions investigated in other jurisdictions have also been attributed to the effects of curved road approaches, with examples including:

- Canadian Transportation Safety Board Railway Investigation Report R13T0192, Crossing collision involving passenger train and double decker bus on 18 September 2013. This collision occurred at a level crossing protected by flashing lights and boom gates. The investigation identified that 'while negotiating the … [left] curve on the approach to the crossing, the [bus] driver would have generally gazed toward the tangent point at the centreline of the road and made anticipatory glances toward the occlusion point where the view of the road ahead was obstructed by trees, shrubs, foliage, and roadway signage. In addition to distractions that likely influenced the driver, the additional driver workload associated with negotiating the left-hand curve[26] on approach to the crossing likely decreased the driver's ability to detect the activated (flashing lights)'.
- Canadian Transportation Safety Board Railway Investigation Report R16D0092, Crossing collision involving passenger train and tractor-trailer 20 September 2016. The collision occurred at a crossing protected by flashing lights and boom gates. The investigation noted that the left curve approaching the crossing obstructed visibility of the level crossing equipment, and the crossing only became completely visible at 730 ft (223 m) from the crossing. The report found that 'While the tractor-trailer driver was negotiating the curve, his visual attention was probably focused more on the outside of the curve rather than far ahead. Therefore, the driver did not immediately notice that the warning system was activated.' The investigation noted that once the curve straightened, the driver had only 500 ft (152 m) to sight the crossing, which was insufficient distance to stop the heavy vehicle.
- US National Transportation Safety Board Highway Accident Investigation Report HAR1402, Highway-Railroad Grade Collision involving freight train and truck on May 28 2013. The collision occurred at a Stop sign level crossing, and the investigation found that vegetation and a sharp horizontal curve near the crossing limited the truck driver's ability to see oncoming trains.

Visual perception during curved road approaches

During vision, light energy passes through the eye and is focussed by specialised anatomy onto photoreceptor cells at the back of the eye. The centre of the focussed image falls upon the centre of the retina (the fovea) where there is the greatest concentration of photoreceptors, and particularly cone photoreceptors which are used for detail and colour vision. In combination with head and eye movements which bring objects into the centre of the field of view, this is referred to as visual fixation, and can be colloquially understood of as the process of looking at something.

[26] As driving is on the right-side of the road in Canada, this would be the equivalent of a left curve in Australia.

Visual acuity (the ability to perceive detail) is greatest for objects which are directly fixated upon, and acuity declines as objects become more eccentric to the centre of the fixation point. When objects are more peripheral to the field of view, they will be less likely to be detected, and perceived less accurately with longer reaction times (see Carrasco and others, 1995 for example). Wolfe and colleagues (2019) found that drivers were more likely to detect brake lights of vehicles on the road straight ahead, and were slower and less accurate when detecting brake lights of vehicles which were in more peripheral locations.

There are no known standards for the visual angle provided for roadside signs and signals.

Research on visual fixations during curved road driving

When navigating straight roads, drivers primarily focus on the straight-ahead position the vehicle will be in the future, with experienced drivers focusing on the visual focus of expansion (which corresponds to the horizon straight ahead) (Underwood, 2007). The visual information about the vehicle’s current and future positions are located within the same field of view, so the driver is not required to look outside their straight-ahead orientation to steer the vehicle.

Scanning behaviour on curved roads is significantly more complex, since a driver must intermittently look towards the vehicle’s current and future positions to steer the vehicle (Transportation Safety Board of Canada, 2015).

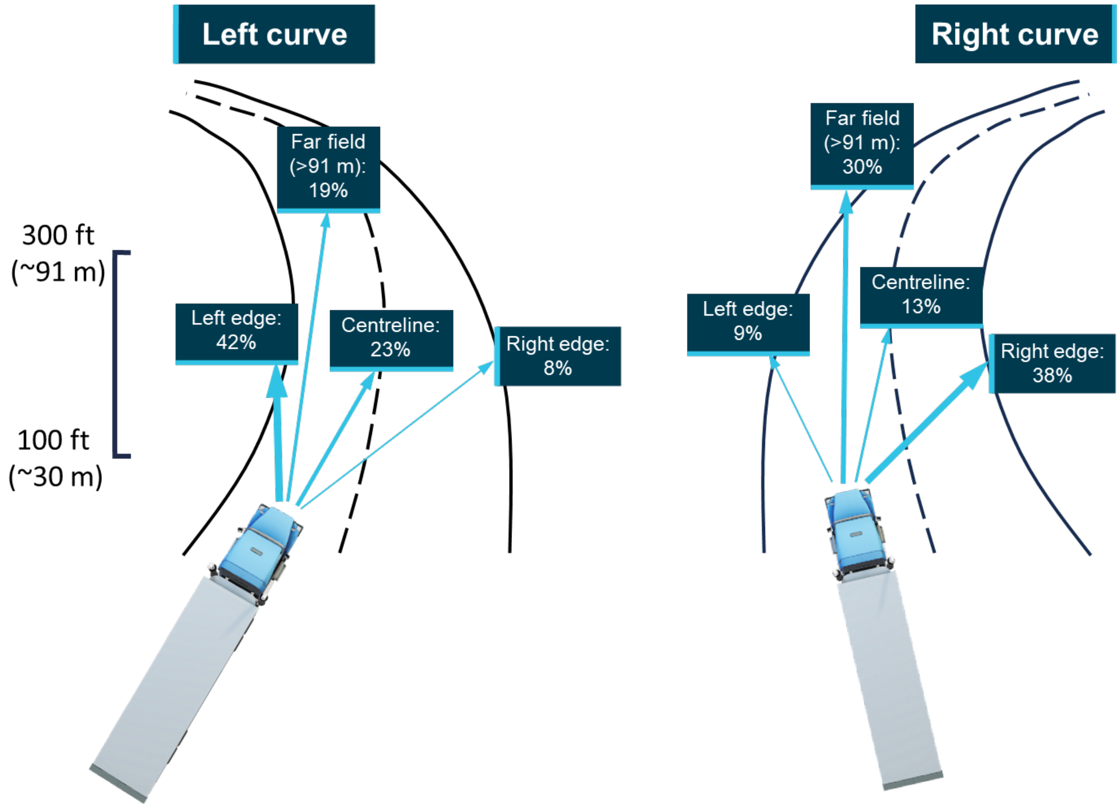
Research shows that during driving on curved roads, visual attention is primarily focussed on the 1–2 second headway position of the vehicle, and these ‘guiding fixations’ are thought to provide the driver with just-in-time information to control steering in the curve (Lehtonen and others, 2014). Due to the geometry of a curve, drivers must look at more obtuse visual angles to observe locations further along the roadway, with such glances described as ‘look ahead’ fixations.

Shinar and others (1977) found that the mean fixation for drivers was straight ahead for right curves, and 3.6° to the left for left curves,[27] with only 5% of the time directed at the opposite side of the road for left curves and 24% for right curves. This was similar to the result found by Cohen and Studach (1977), they showed that when approaching and travelling through a left curve, drivers fixated on the left side of the road and to a lesser extent the middle of the road. Further, when navigating a right curve, drivers fixate on both sides and the middle of the road.

Olsen and others (1989) also examined driver fixation through left and right curved roads during day-time driving (Figure 5). They found that for left curves, the drivers’ fixation was primarily on the left and centre of the road between 100 and 300 ft (30–91 m) in front of the vehicle. With the opposite result (right and centre) for right curves.

[27] All the research discussed below was conducted in regions where driving is on the right-side of the road. However, in the text in this report, directions have been reversed for Australian conditions (left switched with right).

Figure 5: Percentage of drivers' fixation time per road region for left and right curved rural roads during daytime



Researched was conducted in a region where driving is on the right-side of the road. Directions have been reversed for Australian conditions.

Source: ATSB, based on Olson and others (1989). *Driver eye fixations under different operating conditions.* The University of Michigan Transportation Research Institute.

Lehtonen and others (2014) used eye-tracking methods to measure the distribution of drivers' visual attention while negotiating a curved road. This research showed that the majority of drivers' fixations were within 3–4° of the 2-second headway position of the vehicle. Between 65–85% of fixations during curved driving were 'guiding fixations' (5° either side of the 2-second headway position), while 2–28% of fixations were 'look ahead' fixations (more than 5° either side of the 2-second headway position). The distribution of fixations by angular eccentricity from the 2-second headway position resembled a normal distribution, such that look-ahead fixations with smaller angular eccentricity were much more common than fixations at greater visual angles.

Another study (Lehtonen and others, 2013) showed that while driving along a curved rural road, drivers typically fixated within 6° either side of the future position of the vehicle, although look-ahead fixations (more than 6° of the headway position of the vehicle) were frequent. Between 8–33% of fixations were categorised as look ahead fixations. Under higher cognitive load look-ahead fixations were shorter and directed closer to the position of the vehicle. The average look-ahead fixation was made 8.0 seconds and 112 m prior to the fixation point under lower workload conditions, and 6.9 seconds and 95 m prior under higher workload conditions.

Lehtonen, Lappi and Summala (2012) found that drivers navigating curved roads regularly glanced towards the furthest visible point on a roadway prior to an obstruction (occlusion point). These fixations on the 'occlusion point' were interpreted as visual anticipation of potential hazards and the upcoming road alignment. Fixations on this occlusion point were significantly less frequent for right curves[27] and in conditions where the driver was under increased cognitive load. Drivers were also less likely to fixate on the occlusion point over consecutive runs, although this effect was not statistically significant.

This research was conducted in Finland (where road vehicles drive on the right side of the road and the driver sits on the left side of the vehicle). Explaining the much lower rates of occlusion point fixation for (Finnish) left curves, Lehtonen and others (2012), suggested:

> The difference might be related to physical differences in the curves. The left hand curve had a smaller radius and greater inclination than the right hand curve. In the left hand curve the occlusion point was located at an angle of 25 degrees left in the beginning of the straight road section, compared to 12 degrees in the right hand curve. Inspection of video recordings suggests that in the left hand curve the occlusion point had such a high eccentricity that drivers were not able to fixate it without a head turn which might explain the smaller amount of looking time.

Notably, each of the 5 level crossing collisions on curved roads identified in the safety study occurred on right curved road (again noting that in Finland vehicle driver on the opposite side of the road). There is no known dataset which describes the number of left and right curved roads approaching level crossings in Australia.

In summary, research has found that while most fixations are focussed on the immediate future position of the vehicle on curves, drivers do engage in scanning of locations further along a curve including at locations which are eccentric in visual angle to the driver. Some of this behaviour is thought to be anticipatory searching along the most distant viewable part of the curve, to identify upcoming hazards.

The degree of the curve, however, may affect the rate at which these anticipatory glances occur. The results reported by Lehtonen and others (2014) indicate that where the occlusion point of the curve required the driver to turn their head to fixate upon it, anticipatory glances were less frequent. This may also have an adverse implication for fixation upon objects as drivers proceed along a curve (and towards an upcoming level crossing), as an object will become more obtuse to a vehicle travelling a curve until the vehicle reaches the maximum turning point.

The observation that anticipatory scanning is reduced under increased workload may have implications for heavy vehicle drivers. Case study examples suggest that driving a heavy vehicle along a curved road requires focussed attention towards vehicle handling, particularly in degraded road conditions such as uneven road surface and worn shoulders[28] or wet roads.

The implication for road vehicle drivers approaching a level crossing along a curved road approach is that they will rely on these anticipatory look-ahead fixations to identify level crossing protection equipment, as this equipment will often not fall within the normal focal point of their guiding fixations. This provides a lower opportunity for drivers to detect level crossings and advanced warning signs compared to when navigating a straight road, when the future position of the vehicle will fall within the guiding fixations. To the extent that look-ahead fixations are constrained by factors such as workload, or do not capture particularly eccentric locations on a curved road, there is an increased likelihood that level crossing protection equipment will not be detected.

It was not possible to determine to what extent roadside and pavement signage warning drivers of the presence of an upcoming level crossing affects the frequency and eccentricity of their look ahead fixations for a level crossing. Drivers may slow their vehicle or engage in more conscious scanning when they encounter such warning signs. This behaviour would reduce the risk of level crossing protection equipment not being detected.

Prior investigations and changes to Australian Standards

In July 2016, the ATSB published an investigation report into a level crossing collision between a road-train truck and a freight train, which occurred on a flashing lights-controlled level crossing

[28] Such as those encountered by the driver of RO-2015-016.

with a curved road approach in Narromine, NSW. The report identified that the then-current version of AS 1742.7 (2007 version):

> (did) not provide guidance for assessing stopping sight distance for active railway crossings, in particular the standard requires additional considerations for curved approaches.

Then, in March 2018, the ATSB published a report into a similar accident at Ivanhoe, NSW. This report identified that AS 1742.7 had been updated to the 2016 revision, including providing consideration to the treatment of crossings with curved road approaches. The ATSB report stated that:

> In response to the ATSB findings, Standards Australia commenced a review of AS 1742.7:2016, with respect to railway crossing approaches, in particular curved approaches, and the location signage.
>
> Standards Australia received the project proposal for a Revised Text Amendment (RTA) to AS 1742.7:2016 in early 2017. The committee met on 9 August 2017 to initiate the project and established a working group to commence drafting the RTA. It is anticipated the standard will be published in the last quarter of 2018 subject to Standards Australia standards development process. The committee reviewed a draft of the ATSB investigation report for the 11 July 2017 occurrence and concluded there was no need to carry out any further amendment for update to AS 1742.7 beyond the scope of the current revision.

In January 2019, AS 1742.7(2016) was updated. Prior to the revised text amendment, the standard included the following paragraph:

> Where a crossing is located on a curve it may be necessary to adjust the orientation of the primary control device so that it is visible to approaching drivers from any point along the SSD [safe stopping distance] sight line. Some duplication of devices may be needed.

The revised text amendment replaced this paragraph with:

> Where a crossing is located on a curve it may be necessary to adjust the orientation of the primary control device so that it is visible to approaching drivers from any point along the SSD sight line. It may also be necessary to repeat the control device in advance. Where a curved approach leads to an active level crossing, an RX-11 assembly may also be used to provide additional visual warning to road users.

Additional evidence from Standards Australia

In July 2023, the ATSB met with representatives from the Standards Australia technical committee responsible for AS 1742.7: 2016. The committee provided advice about how the standards should be applied in the case of curved road approaches, with observations including:

- The standards are expected to be applied by trained and competent surveyors.
- The inclusion of text stating that level crossing owners may use active advanced warnings is significant, since crossing owners will need to justify why they have not utilised this form of protection equipment.
- The signage and pavement markings required and recommended in the standard would affect the behaviour of road drivers. For example, a road driver who is alerted to the presence of an upcoming crossing may expect and search for a crossing. This means crossing equipment located outside a primary field of view may be detected more readily.

Standards Australia provided additional analysis in September 2023, which stated:

> AS 1742.7 provides sufficient information for practitioners to assess and implement appropriate traffic control devices for traffic approaching a railway level crossing, including a crossing on a curve.
>
> It is noted that Australian Standards provide principles and minimum requirements. In practice, when assessing and installing traffic control devices at a railway level crossing, experienced practitioners are expected to consider not only the relevant Australian Standards, but also other factors and State/Territory jurisdictional guidelines to ensure the risk of a crash is reduced so far as is reasonably

practicable. Engineering judgements are often required leading to a solution which may be above what Australian Standards require/specify.

Summary

Research has shown that when driving on a curved road, road vehicle drivers mainly fixate on the immediate headway position of the vehicle and rely on anticipatory look-ahead fixations to observe objects further ahead. This provides less opportunity to detect level crossing protection equipment, compared to driving on a straight road, especially on right curved roads where an advanced warning sign is located not duplicated on the right side.

Standards and guidance for designing and assessing level crossings do not identify the difference in driver sighting behaviour while navigating curved roads. The treatment of curved roads in the standards indicates that road designers and assessors must primarily consider if there is a clear line of sight through a curve. The standards do not convey that while there may be a line of sight through a curve, if this occurs through a large visual angle then there is an increased chance of drivers not sighting the level crossing.

The standards include the provision of active advanced warning on locations along a curved approach road, which would provide a mechanism of locating the crossing warnings within drivers' central fields of view on curved roads. However, there was no guidance which indicates under what conditions the placement of advanced warning signs is necessary, and the use of these warnings is not mandatory.

This review identified that of 6 collisions which involved a heavy vehicle driver not stopping at a level crossing protected by flashing lights, 5 occurred following a right curved approach road and none of these locations had active advanced flashing light warnings. In 4 of these cases, the assessed available sighting distance was measured from a location where the sighting of the level crossing was from a large visual angle.

The ATSB considers that the absence of procedures or guidance which account for the normal sighting behaviour of drivers on curved roads for determining safety stopping distances and location of advanced warning signs reflects a condition of significant risk.

ATSB finding

The methods used in the Australian Standard AS 1742.7:2016 to calculate safe stopping distances, and determine the need and location of advanced warning signs for road approaches to level crossings, did not account for the likelihood of detecting the level crossing ahead based on the normal visual focal points of road drivers negotiating a curved road. While the standards included guidance for the use of active warning signs for curved road approaches to flashing light controlled crossings, this was not mandatory. There were 6 collisions in which driver of a heavy vehicle did not detect that level crossing flashing light signals were activated until it was too late to stop. In 5 of these collisions, the drivers approached the crossing along a right curved approach road and none of these crossings had active advance flashing light signals (Factor that increased risk, Safety issue)

Safety systems at passive controlled level crossings

Safety system theory and level crossings

This report has described the development of level crossing collisions involving heavy vehicles, including describing the actions of the heavy vehicle drivers which led to the collisions with trains.

The systems safety approach identifies that rather than being the product of individual actions and events, safety is an emergent property of a system. While individual errors and violations affect the development of adverse events, these actions and omissions typically occur in a context where they 'made sense at the time'. The systemic approach seeks to understand the latent conditions which shaped the behaviour of individual operators and contributed to the conditions at the time of an accident.

The systemic approach also seeks to understand the redundancies available in the system, with the concept of 'defences-in-depth' referring to the use of multiple, overlapping risk controls to prevent catastrophic accidents. Administrative controls, such as procedural rules, provide the weakest form of protection against the likelihood and consequence of individual errors by frontline personnel. In contrast, engineering controls provide the greatest level of protection through providing a physical fail-safe barrier which prevents or reduces harm.

The safety system at passive controlled level crossings does not include any engineering controls to alert road vehicle drivers (or pedestrians) about the presence of a train. At passive control crossings, road vehicle drivers must visually search for and detect the presence of a train in order to identify when they can or cannot proceed through a crossing. As such, the design of passive controlled level crossings is primarily dependent on the actions of road vehicle driver to detect both the crossing and detect the presence of trains. If a road vehicle driver does not look for trains, or looks for trains but does not detect that one is approaching, there are limited effective recovery controls to prevent a collision from occurring. The driver may be alerted to the presence of a train by the train horn, however in many instances this is not effective (see *Train horn audibility*).

With no limited effective recovery controls for instances where the road user does not attend to the crossing or does not detect the presence of a train, the safety system for passive level crossings inherently relies on the road user always attending to upcoming crossings, and always detecting trains.

A human-centred approach to level crossing errors

A large subset of heavy vehicle drivers involved in level crossing collisions were aware that they were approaching or proceeding through a level crossing. The breakdown in safety predominantly occurred due to the drivers not detecting that a train was approaching a crossing. This study identified that of 26 accidents at passively controlled crossings:

- In at least 20 collisions the heavy vehicle driver probably did not detect the presence of the train, or detected the train when it was too late to stop.
- In at least 1 collision the heavy vehicle driver detected the train but incorrectly determined that they could transit the crossing safely.
- In 1 collision the heavy vehicle driver detected the train but records indicated the truck had defective brakes and could not stop.
- In 4 collisions there was not sufficient evidence to determine whether the heavy vehicle driver had detected the presence of a train.

Overall, in a large majority of the 26 collisions at passive controlled level crossings, the heavy vehicle driver unintentionally proceeded into the crossing without detecting the presence of the train. These collisions reflected unintentional slips and lapses, where the drivers unintentionally deviated from the intended course of action (to give way to trains).

Reason (1990) notes that such errors typically occur in the context of a routine, well-practiced task where behaviour is largely automatic. Attention is captured by a distraction or other demand, and the operator misses the cues to depart from the 'normal' routine.

Applying this conceptual framework to level crossing collisions, driver errors take place in the context of the highly-practiced task of road vehicle driving, in roadway environments where other demands and distractions are often prevalent. Road vehicle driving can become highly automatic, and many road vehicle drivers will recall the experience of arriving at a common destination without a recollection of the journey. The phenomenon of 'highway hypnosis' or 'driving without attention mode' describes the degradation of vigilance towards the roadway associated with factors including monotonous driving conditions (Karrer and colleagues, 2005). In the context of a potential level crossing collision, drivers are required to depart from the current (and often automatic) schema of continuing to drive the motor vehicle along the road, and adopt a schema of looking and preparing to stop for trains.

The task of approaching a passive control level crossing is thus consistent with the conditions described by Reason (1990) as being conducive to the development of errors involving inattention. Road vehicle drivers are vulnerable to becoming 'captured' by focus on other aspects of road vehicle driving, and not attend to the roadside or the rail track to detect level crossings and trains.

As described in *Factors affecting heavy vehicle driver behaviour at level crossings* above, there are various factors which may contribute to road vehicle drivers not looking for, or detecting the presence of, a train at a passive control level crossing. As highlighted by Edquist and others (2009), when considering the perceptual and cognitive factors inherent in the task of approaching a passive control level crossing:

> Alerting the road user to the presence of a crossing is therefore unlikely to be sufficient to avoid all potential collisions. The optimal approach is to provide some form of active warning of train approach for road users at all crossings. …When there is sufficient information about the presence of a crossing, safety can still be significantly improved by providing information about the presence of a train. This information is more targeted to the needs of the road user (i.e., 'can I safely traverse this crossing NOW?'). Information about train presence can be provided by the crossing infrastructure, or by an in-vehicle system, or from the train itself.

This is consistent with analysis by the Transportation Safety Board of Canada[29] (TSB), which found that:

> Safety defences at passive railway crossings do not always function as intended. In the absence of low-cost alert systems, the risk of accidents at passive crossings will continue.

The US National Transportation Safety Board (NTSB) safety study of collisions at passive control level crossings[30] made a similar conclusion, arguing that the long-term objective to reducing collisions at level crossings should be to eliminate passive control crossings.

In summary, many of the collisions and near misses identified in this study speak to the inherent variability of human performance, in the context of a system which is conducive to unintentional errors. Level crossing safety may be improved by the introduction of other risk controls to reduce the frequency of level crossing collisions or reduce their consequences.

Potential safety improvements for passive control crossings: the case for in-vehicle warning systems

Background

One proposed method for improving the safety of passive level crossings is using in-vehicle alerting technology to alert road vehicle drivers of a requirement to stop and give way to an approaching train. Such applications would reduce the safety system's reliance on the driver to

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[29] Transportation Safety Board (2012) Railway Investigation Report R12W0182. Crossing accident at Broadview, Saskatchewan on 9 August 2012.

[30] National Transportation Safety Board (1998) Safety at Passive Grade Crossings Volume 1: Analysis.

search for and detect the presence of a train, by attracting the driver's attention and thereby providing a salient cue to the driver to stop.

In-vehicle alerting systems for level crossings have been proposed by previous investigations and reviews of level crossing collisions. Following a review of collisions at passive control level crossings, the NTSB (1998) noted:

> The Safety Board concludes that in-vehicle safety advisory and warning systems and other intelligent transportation systems applications proposed have the potential to reduce accidents and injuries at passive grade crossings by alerting drivers to an oncoming train.

Reporting on an accident at a passive control level crossing, the Canadian TSB found:

> the development and use of low-cost advance active warning devices to alert drivers of a train's presence may present a more effective alternative defence for passive level crossings [than ensuring there is adequate sightlines at all crossings and trains are highly conspicuous].

In the Australian context, a 2009 Parliamentary committee *Level crossing safety* recommended that:

> the Australian Government support the ongoing research into Intelligent Transport Systems to speed the implementation of this important new technology
>
> the Government, through the Australian Transport Council, encourage further research into the feasibility of a cut-in warning system which would warn motor vehicle drivers of on-coming trains as they approach a level crossing.

Then, in 2013, the Coronial inquest into multiple fatal level crossing collisions (including the collision at Kerang, Victoria) recommended rail operators, infrastructure managers and regulators:

> … cooperate with each other to implement innovative in-vehicle warning systems as the next stage of warning road vehicles who fail to respond to existing level crossing paraphernalia that a train is approaching.

In summary, there is broad agreement among informed stakeholders both within Australia and internationally on the inherent challenges of relying on road users to attend to and detect the presence of trains at passive control crossings. Multiple stakeholders have endorsed the development of in-vehicle alerting technology for level crossings to improve the safety at passive control level crossings.

Current maturity of in-vehicle level crossing warning systems

The ATSB sought information about the development and trial of level crossing alerting technology following the recommendations made in the Coroners Court of Victoria's *Coronial Investigation of Twenty-six Rail Crossing Deaths in Victoria, Australia* (2013). The Victorian Government Department of Transport and Planning advised that trials had been conducted, however the technologies were found to be unreliable. The Department further advised that the development of technology was being monitored, with a 5- to 10-year timeframe expected for a viable technology. Trials of level crossing technology cited by the Department included:

- In 2013, the La Trobe University Centre for Technology Infusion reported on the development and evaluation of 5.9 GHz Dedicated Short Range Communication (DSRC) system which provided audio and visual alerts to road users approaching a crossing. Field trials were conducted in rural and urban locations, involving 124 participants over 4.5 months. The trials included variants where trains and vehicles communicated directly, and variants where the vehicles communicated through a roadside unit intermediary.
  The results of the field trials showed that connectivity between vehicles was dependent on there being a clear line of sight between receiving units, and that the system provided much less connectivity range when no roadside unit was deployed.

- The Collaborative Research Centre for Rail Innovation (2014) reported on a separate trial of the La Trobe University DRSC system. This report noted that ‘drivers experienced a high number of hardware issues with the Latrobe system: display falling off, warning messages when no train was approaching. Further, participants had to start the system manually every time they started driving, which was found annoying. All of this resulted in a low usage of the system during the trial’.

A review of international research into level crossing warning systems identified the US Federal Railroad Administration Rail-Crossing Violation Warning (RCVW) project (Withers and Utterback, 2021). This RCVW detects the status of active control level crossings. This system would produce in-vehicle messages for all vehicles approaching an active crossing of the requirement to stop (inform message), and an alert if the vehicle is not predicted to stop based on its speed (warning message). Field testing has shown that system provided a reliable warning system for active control level crossings, using currently available technology. Notably, this technology does not detect whether a train is approaching the crossing (relying on existing active crossing equipment), and thus does not provide a solution for passive controlled crossings.

In summary, there is no known research which has demonstrated a proof-of-concept for a system for providing alerts to road vehicle users when approaching level crossings. Research conducted at Australian level crossings indicated that the available technology was not reliable. Given this research is a decade old, additional research is now required to determine whether technological advancement will now provide a useable platform for providing warnings to drivers approaching level crossings.

Human factors considerations for in-vehicle level crossing warning systems

In addition to the absence of mature technology for providing in-vehicle level crossing warnings, there are potentially significant implications for how such warnings would affect the behaviour of road vehicle drivers at level crossings. The phenomenon of behavioural adaptation has been observed in response to other changes to the road traffic system, where there is an observed aggregate change in the behaviour of road users following system changes, often resulting in the estimated benefits of the changes to be under-achieved. For example, research has identified that drivers presented with adaptive cruise control attended more frequently to a secondary task and had lower reaction times (Rudin-Brown and Parker, 2004). Similar results have also been observed in studies of adaptation to forward collision warning systems (Reinmueller and others, 2010).

In the case of in-vehicle level crossing warnings, it is possible that road vehicle drivers may adapt to the presence of the warnings, and that this may affect their attention to traditional level crossing control equipment (Wullems and others, 2014).

Simulator research showed that participants who drove a vehicle equipped with an in-vehicle alerting system were less likely to comply with level crossing rules when there were no trains present. Drivers also approached the crossings at faster speeds and glanced less frequently at the rail track (Larue and others 2015). These changes were only observed when the driver was presented with a visual warning, and driving behaviour improved when an aural warning was presented.

As identified by Wullems and others (2014), the potential for over-reliance on in-vehicle warnings and changes to driving behaviour at level crossings presents potential hazards, unless the systems are perfectly reliable. Any failure of the system would produce a potentially very hazardous system state, particularly if the road user does not identify the failure.

It may also be hazardous to incrementally introduce the equipment necessary to provide in-vehicle warnings. If road vehicle drivers were to come to expect in-vehicle warnings for potential level crossing collisions, then level crossings and/or trains which were not equipped with the equipment required to produce these warnings would potentially become less safe than they are currently.

Other barriers to the implementation of in-vehicle level crossing warning systems

Any foreseeable system for providing in-vehicle level crossing warnings requires road vehicles be equipped with devices for receiving and displaying warnings, and the potential benefit of any warning system would depend on the installation uptake of such equipment. Considering the size of the road vehicle fleet (over 20 million road vehicles were registered in Australia in 2022), this could be a complex and costly exercise, requiring the co-ordination of stakeholders outside the rail industry. However, with advancements in navigation systems in many on-road vehicles today that allow for software updates, this is likely to be less complex in the future.

A final barrier to the implementation of in-vehicle level crossing warning systems relates to the ownership of risk at level crossings, and how responsibility for in-vehicle warnings could be managed. The existing regime for level crossing safety includes shared responsibility between rail and road infrastructure managers (as reflected in level crossing interface agreements), and with railway operators and road vehicle drivers for complying with relevant rules and procedures. Wullems and others (2014) identified that the introduction of in-vehicle level crossing warning systems would pose unresolved questions relating to where responsibility lies for ensuring that warnings are produced by rail vehicles and/or infrastructure, and being received by road vehicles. The ongoing monitoring, management and maintenance of such a system may require significant cost for rail industry organisations.

Wullems and others (2014) further identified that failures in the system which led to collision may produce a liability for rail operators or infrastructure managers, whereas in the existing regime these stakeholders can discharge their responsibility by providing compliant level crossing infrastructure and operating rollingstock correctly.

Whereas the use of in-vehicle warnings has been mooted as a low-cost method for improving safety at passive control crossings, there are significant changes required to implement such technology which may involve significant cost. The size of these costs is unknown, and will need to be more precisely understood to evaluate the safety case of potential alerting technologies, should fit-for-purpose technologies emerge.

ATSB Finding

Of 26 collisions at passive control level crossings, a large majority involved the heavy vehicle driver not detecting the presence of the train. These crossings rely on the road vehicle driver detecting the presence of a train and identifying a requirement to stop and give way, and are susceptible to situations where motorists do not look for, or detect, the presence of a train. There are limited effective recovery controls to prevent a collision when this occurs (Factor that increased risk).

Discussion

Study limitations

This study reviewed level crossing collisions involving heavy road vehicles, to understand their characteristics and trends, and in turn to identify risk factors and opportunities for safety action. This study did not review the characteristics and trends of heavy vehicle movements across level crossings which did not result in a collision. This limited the inferential capability of the study, such that it was not possible to quantify how specific characteristics of the vehicles, crossings, or other variables identified in the study contributed to the development of collisions.

Similarly, the study did not conduct an in-depth review of the characteristics and trends of level crossing collisions involving other road vehicles. As such, it was not possible to quantify how the different characteristics of heavy vehicles, or the different road and crossing conditions they may be exposed to, contributed to the observed differences in collision frequency and consequence. A richer dataset for all level crossing collisions would support such analysis.

Another limiting feature of this study was that the information used to understand the characteristics of level crossing collisions involving heavy vehicles was primarily drawn from investigation reports produced by rollingstock and infrastructure managers, and from police reports. These reports were produced in the context of the operator and infrastructure managers' specific interests and/or legal requirements, and not with a view to support broader analysis such as this.

The data used in this study was obtained from sources that included either live databases where the data can be updated through additional data gathering or data cleaning exercises. For one level crossing accident reviewed in this study, the source material included an Office of the Chief Investigator investigation that was ongoing at the time the study was published.

The ATSB did not conduct any site inspections or audits against relevant standards of the level crossings involved in the occurrences in this safety study. Previous ATSB investigations of level crossing collisions have included site inspections and other analyses of the crossings, and the safety study utilised records from these observations. Otherwise, the safety study relied on observations of level faults or deficiencies recorded in rail infrastructure manager reports and other documents.

Information about the factors which affected the performance of heavy vehicle drivers was infrequently reported in operator and police reports. In most instances, these reports only identified that the road vehicle driver failed to give way, and these records rarely assessed human factors causes which could explain the drivers' errors.

In contrast with operator and police reports, investigations conducted by the ATSB seek to understand the operation of the overall safety system, and to identify opportunities to improve that system. The objective is not to attribute blame or liability. The ATSB also has strict limitations on how information collected from involved parties can be used outside of the no-blame investigation process, which probably increases the likelihood of obtaining evidence such as statements from heavy vehicle drivers.

The independent no-blame investigations conducted by the ATSB were much more likely to provide sufficient information to describe the actions of the heavy vehicle drivers, and to provide information which explained these actions. As shown in Table 17, the proportion of collisions where the ATSB was unable to code key details about the heavy vehicle driver's actions or the factors associated with those actions was much greater for collisions not investigated by the ATSB.

Table 17: Counts of collisions where road vehicle driver actions and related variables could not be coded due to missing information

Variable	Unable to code variable, investigated by ATSB (n=10)	Unable to code variable, not investigated by ATSB (n=39)
Driver action	0	1 (2.4%)
Driver detected crossing	1 (10%)	7 (17.9%)
Driver slowed for passive control crossing	0	5 (12.2%)
Driver detected train	0	13 (31.7%)
Driver familiarity with crossing	1 (10%)	31 (79.5%)
Driver restricted vision of train/crossing	1 (10%)	18 (46.2%)

There are some important caveats in drawing conclusions based on these differences. Most importantly, the collisions not investigated by the ATSB were different events, and may not have involved the factors identified in the collisions investigated by the ATSB. Also, the ATSB typically allocates more time and resources to conducting an investigation than a rail organisation would, and it is difficult to distinguish the effects of this resourcing with the benefits of conducting no-blame investigations.

Nonetheless, the ATSB considered that the information obtained in this study demonstrated that meaningful understanding of why heavy vehicle drivers enter level crossings contrary to the road rules was typically only available following an independent no-blame investigation. As these actions represent the fundamental breakdown of safety at level crossings, this supports the benefit of regularly investigating significant collisions at level crossings.

ATSB Finding

Information which supports an understanding of the factors associated with heavy vehicle drivers entering a level crossing without giving way to trains is typically only available when an independent no-blame transport safety investigation is conducted (General finding)

Overall observations as to heavy vehicle level crossing risk

The information reviewed in this safety study indicated that heavy vehicles pose a greater risk at level crossings than light vehicles, as a function of greater accident consequence for rail users. The collisions involving heavy vehicles resulting in more significant consequences was consistent with the observations of previous research, and can be easily understood as a simple reflection of the increase in physical forces imparted on a rail vehicle as the mass of the road vehicle involved in a collision increases (for a fixed speed).

Also consistent with previous analyses, this study identified that heavy vehicles are more likely to be involved in level crossing collisions, compared to light vehicles, per road distance travelled. The increase in level crossing collision frequency for heavy vehicles may be partially explained by a greater exposure to level crossings, and in particular greater exposure to level crossings with lower levels of protection (especially in rural areas). The study was unable to test the extent to which different exposure to level crossing hazards explained the difference in collision rates.

Nonetheless, the over-representation of heavy vehicles in level crossing collisions is likely to be due, in some part, to the fundamental physical property of heavy vehicles: that they are larger and take longer to stop prior to a crossing, and clear a crossing, as a function of both time and distance. Although the design of level crossings seeks to accommodate the stopping limitations of heavy vehicles (see Appendix B), it is inevitable that a heavier vehicle will be less likely to stop within a specific distance and time, all other factors being equal. Stated alternatively, all safety improvements at level crossings seek to increase the margins available for a road vehicle to stop and give way to trains, and any improvements which increase the ability of heavy vehicles to stop at level crossings will have a greater benefit to smaller vehicles whose braking capabilities are generally greater. As such, it is likely that heavy vehicles will continue to be over-represented in level crossing collisions.

The characteristics of heavy vehicle driving may also represent systemic risk factors which partially account for the over-representation of heavy vehicles in level crossing collisions. Plausible mechanisms for such systemic effects include:

- The handling characteristics of heavy vehicles may contribute to a greater tendency of heavy vehicle drivers to engage in 'rolling-stop' violations at level crossings, compared to the drivers of other road vehicles.
- The louder operating noises produced by heavy vehicle engines and heavier cab construction may result in heavy vehicle drivers being less likely to hear train horns, compared to the occupants of other road vehicles.
- The construction of heavy vehicle cabs may also provide more visual obstructions, making it more difficult for heavy vehicle drivers to detect trains and level crossing equipment.
- The nature of heavy vehicle driving is often one of repeated journeys along the same route. This familiarity can contribute to the expectancy that level crossings along the route will not be occupied by trains.

As identified in *Study limitations*, this study did not include data from heavy vehicle movements across level crossings that did not result in a level crossing collision, and did not conduct a thorough review of collisions involving non-heavy road vehicles. Due to this, it was not possible to accurately determine the characteristics of heavy vehicles that contributed to the greater frequency of level crossing collisions (per road distance travelled).

Overall observations as to level crossing collision characteristics

Of the 49 level crossing collisions involving heavy vehicles, at least 7 were partially attributable to problems with the design or maintenance of the level crossings. Generally, however, the collisions reviewed in this study occurred at level crossings designed according to the required standards. Also, there were no collisions attributed to the crossing providing insufficient sighting for a stopped heavy vehicle to start up and clear the crossing prior to a train arriving.

However, the study identified one systemic problem with the design criteria for level crossings. The methods used to calculate safe stopping distances for road approaches to level crossings did not account for the effect on sighting a level crossing from the normal focal points of drivers negotiating a curved road. While this problem did not only relate to heavy vehicles for the design of level crossings, heavy vehicle drivers are likely to be particularly affected in situations where insufficient sighting distance is provided.

The majority of level crossing collisions arose from heavy vehicle drivers entering the level crossings following some form of unintentional error or omission. Even in the case where heavy vehicle drivers deliberately engaged in actions contrary to the road rules, the intention was to proceed through the crossing prior to the arrival of a train. The collisions were primarily caused by level crossing warnings or the presence of trains not being detected, being detected late, or being perceived incorrectly. This form of omission or misperception can also affect other road users, and the forms and causes of errors observed in heavy vehicle drivers were consistent with the errors made by the drivers of other road vehicles, both at level crossings and in other areas of the road network.

As described in *A human-centred approach to level crossing errors*, many of the errors and omissions which lead to level crossing accidents reflect the inherent variability of human performance. While the level crossing safety system continues to heavily rely on road vehicle drivers adhering to the administrative controls of road rules and other procedures to prevent collisions between vehicles and trains, it is a certainty that from time to time, this will not occur and so collisions will continue to occur. However, the use of engineering controls which alert road users to a requirement to stop will almost certainly provide an enhanced level of safety at level crossings, by reducing the reliance on road users to attend to and detect the presence of trains.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). In safety studies, these are referred to as ‘factors that increase risk’. In addition ‘other findings’ may be included to provide important information about topics other than safety factors.

Safety issues are highlighted in bold to emphasise their importance. A safety issue is a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the review of level crossing collisions between trains and heavy road vehicles.

Factors that increased risk

- Of the 49 level crossing collisions involving heavy vehicles, at least 7 partially involved problems with the design or maintenance of the level crossings. Concerning compliance with applicable design standards, no significant issues were identified with the design or maintenance of most crossings.
- Level crossing collisions between trains and heavy vehicles were associated with greater levels of rail injuries and rail damage than collisions involving light vehicles.
- Heavy vehicles are involved in level crossing accidents at a greater rate per road kilometre travelled than light vehicles.
- Although level crossing collisions between heavy vehicles and trains were more likely to involve the train striking the heavy vehicle, accidents where the heavy vehicle struck the train were more likely to cause a derailment.
- All level crossing collisions involving heavy vehicles resulted from the heavy vehicle driver not giving way to trains. There were three actions associated with the collisions:
  - There were at least 24 accidents where the heavy vehicle did not stop prior to entering the crossing.
  - There were at least 11 accidents where the heavy vehicle stopped at the crossing then proceeded into the path of a train.
  - There were at least 13 accidents where the heavy vehicle entered a level crossing and stopped foul of the train line.
- In at least 14 collisions it is likely that the heavy vehicle driver intentionally entered the level crossing in a manner which was contrary to road rules. These included 6 collisions where the driver intentionally entered the crossing without being able to driver clear of the crossing, 4 collisions where the driver engaged in a 'rolling stop' while approaching a Stop sign level crossing, 3 collisions where the driver remained stopped foul of the crossing while there was no obstacle preventing them from exiting, and one collision where the driver did not stop or look for trains at a Stop sign crossing.
- Of 26 collisions at passive control crossings, there were at least 12 accidents where the heavy vehicle driver slowed or stopped but probably did not detect the train, and entered the crossing into the path of the approaching train.

- There were at least 12 level crossing collisions where the driver of the heavy vehicle had regularly used the level crossing prior to the collision with a train. This included 6 accidents where the heavy vehicle driver proceeded into a passive control crossing without identifying the presence of a train, and 5 accidents where the heavy vehicle driver did not identify activated flashing level crossing lights. The drivers' previous experience at the level crossings likely led to a low expectancy for trains and, in at least some collisions, contributed to them not detecting a requirement to stop and give way.
- Of the 49 level crossing collisions involving heavy vehicles, there were at least 14 collisions where the heavy vehicle driver's view was obstructed by vegetation, the design of the heavy vehicle cab, poor crossing lighting, or sun glare.
- Previous research and reviews have identified that train horns have limited effectiveness for alerting road vehicle drivers to the presence of trains. Consistent with this, in at least 25 collisions, the horn was not effective at alerting the heavy vehicle driver to the presence of the train.
- **The methods used in the Australian Standard AS 1742.7:2016 to calculate safe stopping distances, and determine the need and location of advanced warning signs for road approaches to level crossings, did not account for the likelihood of detecting the level crossing ahead based on the normal visual focal points of road drivers negotiating a curved road. While the standards included guidance for the use of active warning signs for curved road approaches to flashing light controlled crossings, this was not mandatory. There were 6 collisions in which driver of a heavy vehicle did not detect that level crossing flashing light signals were activated until it was too late to stop. In 5 of these collisions, the drivers approached the crossing along a right curved approach road and none of these crossings had active advance flashing light signals (**Safety issue).
- Of 26 collisions at passive control level crossings, a large majority involved the heavy vehicle driver not detecting the presence of the train. These crossings rely on the road vehicle driver detecting the presence of a train and identifying a requirement to stop and give way, and are susceptible to situations where motorists do not look for, or detect, the presence of a train. There are limited effective recovery controls to prevent a collision when this occurs.

Other findings

- Information which supports an understanding of the factors associated with heavy vehicle drivers entering a level crossing without giving way to trains is typically only available when an independent no-blame transport safety investigation is conducted.
- The annual number of level crossing collisions between road vehicles and trains remained relatively constant between July 2014 and June 2022.
- Prior to July 2022, the national rail safety database did not include sufficient information to enable detailed analysis of level crossing collision characteristics.

Safety issues and actions

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues. The ATSB expects relevant organisations will address all safety issues an investigation identifies.

Depending on the level of risk of a safety issue, the extent of corrective action taken by the relevant organisation(s), or the desirability of directing a broad safety message to the rail industry, the ATSB may issue a formal safety recommendation or safety advisory notice as part of the final report.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

The initial public version of these safety issues and actions are provided separately on the ATSB website, to facilitate monitoring by interested parties. Where relevant, the safety issues and actions will be updated on the ATSB website as further information about safety action comes to hand.

Standards and guidance for placement of crossing equipment on curved road approaches

Safety issue description

The methods used in the Australian Standard AS 1742.7:2016 to calculate safe stopping distances, and determine the need and location of advanced warning signs for road approaches to level crossings, did not account for the likelihood of detecting the level crossing ahead based on the normal visual focal points of road drivers negotiating a curved road. While the standards included guidance for the use of active warning signs for curved road approaches to flashing light controlled crossings, this was not mandatory. There were 6 collisions in which driver of a heavy vehicle did not detect that level crossing flashing light signals were activated until it was too late to stop. In 5 of these collisions, the drivers approached the crossing along a right curved approach road and none of these crossings had active advance flashing light signals.

Issue number:	RS-2021-001-SI-01
Issue owner:	Standards Australia
Transport function:	Rail: Infrastructure
Current issue status:	Open – Safety action pending
Issue status justification:	Australian Standards have indicated they will conduct a review of AS1742.7. The ATSB will review the status of this safety issue after considering any changes to AS1742.7 resulting from the Australian Standards review.

Response by Australian Standards

Standards Australia provided additional analysis in September 2023, which stated:

> AS 1742.7 provides sufficient information for practitioners to assess and implement appropriate traffic control devices for traffic approaching a railway level crossing, including a crossing on a curve. It is noted that Australian Standards provide principles and minimum requirements. In practice, when assessing and installing traffic control devices at a railway level crossing, experienced practitioners are expected to consider not only the relevant Australian Standards, but also other factors and State/Territory jurisdictional guidelines to ensure the risk of a crash is reduced so far as is reasonably

practicable. Engineering judgements are often required leading to a solution which may be above what Australian Standards require/specify.

Proactive safety action by Standards Australia

Action Number:	RS-2021-001-PSA-205
Action organisation:	Standards Australia
Action status:	Monitor

Following receipt of the ATSB draft report, Australian Standards committee MS-012 advised they considered the general principles and information in Australian Standard AS1742.7 Railway Crossings were adequate. However, given the findings of the ATSB report, MS-012 will initiate a review of the Standard and consider whether further information or clarifications could be provided to practitioners to further emphasise risks and how to treat them.

The committee stated they would meet in April 2024 to initiate the review, and once approved the review was expected to take 24 months for a revised standard to be published.

ATSB comment

The ATSB will monitor the outcomes of the MS-012 review of AS1742.7 to assess whether changes to standard significantly address the issue identified in the safety study.

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- Office of the National Rail Safety Regulator
- Rail operators
- Rail infrastructure managers
- Australian Level Crossing Assessment Model Committee
- Federal Railroad Administration
- Rail Industry Safety and Standards Board
- New South Wales Police
- South Australia Police
- Victoria Police
- Queensland Police Service
- National Heavy Vehicle Regulator

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Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the following directly involved parties:

- Office of the National Rail Safety Regulator
- Australian Standards technical committee MS-012
- Australian Level Crossing Assessment Model committee
- National Heavy Vehicle Regulator
- Austroads
- Rail Industry Safety and Standards Board

Submissions were received from:

- Office of the National Rail Safety Regulator
- Australian Level Crossing Assessment Model committee
- Austroads

- Rail Industry Safety and Standards Board

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Glossary

Active protection level crossing	Uses either flashing lights and/or booms gates to warn motorists that a train is approaching the level crossing
ALCAM	Australian Level Crossing Assessment Model
AS 1742.7:2016	Australian Standard AS 1742.7:2016, Manual of uniform traffic control devices. Part 7: Railway crossings
AS 7531:2015	Australian Standard AS 7531:2015 Light and Visibility
AS 7532:2016	Australian Standard AS 7532:2016 Railway Rolling Stock Audible Warning Devices
AS 7658:2020	Australian Standard AS 7658:2020 Level Crossing: Rail Industry Requirements
ACRI	Australian Centre for Rail Innovation
BITRE	Bureau of Infrastructure and Transport Research Economics
B-double combination trucks	Heavy vehicle combination consisting of a prime mover towing 2 semi-trailers with the first semi-trailer attached directly to the prime mover and the second semi-trailer attached to the first semi-trailer
FRA	US Federal Railroad Administration
Heavy vehicle	Road vehicle with a gross vehicle mass or aggregate trailer mass greater than 4.5 tonnes, includes: semi-trailer; road trains; buses and b-double combination trucks
HRA	Highway-Rail Grade Crossing Accident
ITSR	Independent Transport Safety Regulator
NTSB	US National Transportation Safety Board
ONRSR	Office of the National Rail Safety Regulator
Passive protection level crossing	Uses signs (stop or give way) to warn motorists of a level crossing
RCVW	US Federal Railroad Administration Rail-Crossing Violation Warning
REA	Rail Equipment Accident/Incident
RISSB	Rail Industry Safety Standards Board
Rolling stop	Road vehicle driver approaches an intersection, slow the vehicles before proceeding through the intersection without coming to a complete stop
TSB	Transport Safety Board of Canada
TSV	Train Struct (Road) Vehicle
VST	(Road) Vehicle Struct Train

Appendices

Appendix A – Descriptive statistics for level crossing collisions recorded in National rail safety database

Collisions

Rail vehicle operation category	Number of collisions
Freight train	120
Urban passenger	59
Non-urban passenger	63
Tourism and heritage	14
Tram	3
Track maintenance train	9
Road rail vehicle	5
Other train	10

Road vehicle type	Number of collisions
Light passenger	220
Heavy freight	44
Buses	4
Special purpose machinery	5
Other	11

Level crossing equipment type	Number of collisions
Boom gates	97
Flashing lights	63
Stop signs	92
Give way signs	23
None	8

Fatality and injury type	Number of injuries
Fatality, rail user	0
Serious injury, rail user	2
Minor injury, rail user	36
Fatality, road user	23
Serious injury, road user	31
Minor injury, road user	60

Appendix B – Summary of sighting distance provisions in Australian Standard AS1742.7:2016

The design criteria for level crossings in Australia are specified the Australian Standard AS 1742.7:2016, *Manual of uniform traffic control devices. Part 7: Railway crossings*. This standard prescribes the sighting distances required for drivers approaching a level crossing, to enable them to safely identify if it is safe to enter and proceed through a crossing.

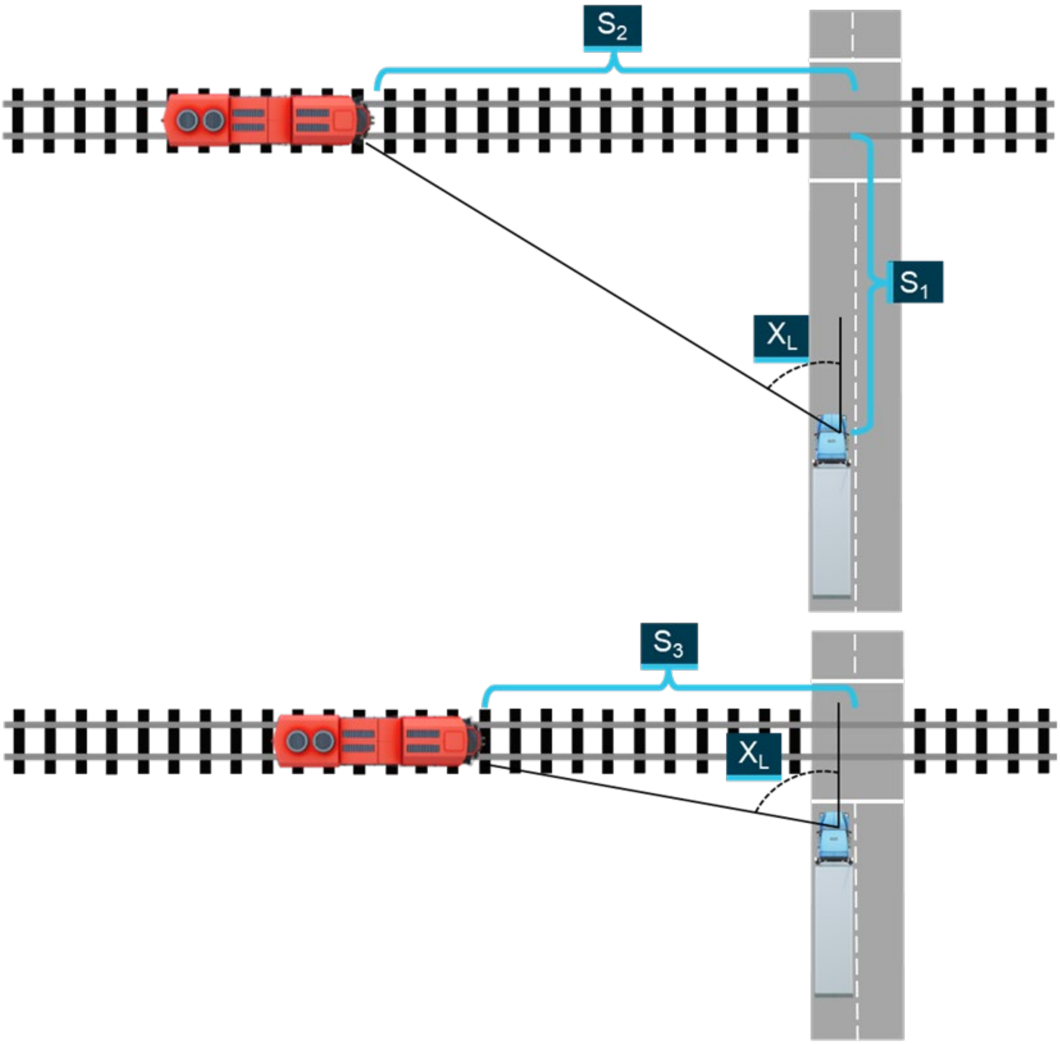
The standard seeks to ensure that the driver of a design vehicle will have sufficient time and distance to identify a crossing ahead (S_1) and stop after identifying a requirement to stop. In the case of active control crossings, this would be the detection of flashing lights and/or a lowered boom gate, whereas in the case of a Stop sign controlled crossing, this would be the presence of the Stop sign.

The standard also specifies the minimum distance for a driver to approach the crossing, look along the rail line to check for trains, and then continue and cross safely ahead of any undetected trains (S_2). This is applicable in the case of Give way controlled crossings, where the driver is not required to stop unless a train is detected.

For vehicles stopped at a level crossing, the standard specifies the distance required to be visible along the track from the 'stop line'. The distance (S_3) is required to be sufficient for the vehicle to start up and clear the crossing prior to the arrival of any train beyond the visible distance.

These distances are illustrated in Figure 6.

Figure 6: Illustration of level crossing sighting distances specified by AS 1742.7:2016



These are expressed in the standards as

$$S_1 = \frac{(R_T + B_T)V_v}{3.6} + \frac{{V_v}^2 \times S_c}{254(d+G)} + L_d + C_v$$

$$S_2 = \frac{V_T}{V_v}\left(\frac{(R_T + B_T)V_v}{3.6} + \frac{{V_v}^2 \times S_c}{254(d+G)} + \frac{W_T}{\sin Z} + 2C_v + C_T + L\right)$$

$$S_3 = \frac{V_T}{3.6}\left(J + G_s\left(2\frac{\frac{W_R}{\tan Z} + \frac{W_T}{\sin Z} + 2C_v + C_T + L}{a}\right)^{1/2}\right)$$

These formulae contain variables relevant to the physical characteristics of heavy vehicles. Specifically:

- *d* is the coefficient of deceleration
- B_T is the expected brake delay (in seconds)
- *L* is the length of the design vehicle (in metres)
- *a* is the average acceleration of the design vehicle in starting gear (in metres per second squared)
- *J* is the sum of the perception time and time to depress clutch (in seconds)
- G_s is a grade correction factor
- V_V is the 85th percentile road vehicle speed in the vicinity of the crossing
- V_T is the speed of the train approaching the crossing (km/h)
- Z ($_L$ indicates left direction) is the angle between the road and the railway at the crossing (in degrees)
- C_V is the clearance from the vehicle stop or give way line to the nearest rail line (generally 3.5m)
- S_C is the unsealed road correction factor (1.2 for compacted gravel, 1.0 for sealed roads)
- R_T is the total perception reaction time in seconds (generally assumed to be 2.5s)

In the case of heavy vehicles, AS 1742.7 specifies values for design vehicles for defined categories of heavy vehicles, with greater vehicle length, slower braking and acceleration, and longer reaction times expected for heavier vehicles.[31] The effect of this is that for crossings expected to carry heavy vehicles, AS 1742.7 requires longer sighting distances are provided.

The ATSB modelled the distances required by AS 1742.7 using a standard case of a crossing on a flat, sealed road, where the road speed was 100 km/h,[32] the track speed was 110 km/h and the road to track angle was 90°. The calculated stopping distances for different types of heavy vehicles are shown in Table 18.

Table 18: AS1742.7 calculated stopping distances for heavy vehicle types

Vehicle type	Length (m)	GCM (t)	S_1(m)	S_2(m)	S_3(m)
Level 1 – Semi trailer	20.0	50	276	305	408
Level 2a – B-double	26.0	69	271	305	490
Level 2b – Pocket road train	30.0	85	286	324	532
Level 3a – Double road train	36.5	91.5	263	308	585
Level 3b – B-triple	42.0	91.5	283	333	613
Level 4a – AAB Quad	53.5	143	296	358	757
Level 4b – AAB Quad	60.0	150	333	401	803

[31] The dimensions, acceleration and deceleration characteristics of various types of heavy vehicles up to 70 m and 200 t road trains were determined via computer simulation and field tests, as described in the Austroads research report *Heavy Vehicle Sight Distance Requirements at Rail Crossings (Stage 2).* These values were utilised in the development of AS 1742.7 (2017 revision).

[32] Regulations in some jurisdictions prescribe lower speed limits (90 km/h) for larger categories of heavy vehicles. The effect of lower speed limits will be to reduce the sighting distances required for these vehicles when approaching level crossings.

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, international agreements.

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.