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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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This document was prepared by Technical Committee ISO/TC 269, *Railway applications*, Subcommittee SC 2, *Rolling stock*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

It is generally accepted that avoiding collisions is a key operating principle of railway systems. This can be achieved, for example, by dedicated lines, eliminating level crossings and providing sophisticated control (signalling) systems.

The safety performance of railways has improved significantly in recent years, to the extent that train crashes, derailments and overturning are now very rare events. However, this document includes evidence which suggests that, despite advancements in train control and other active safety measures, these incidents will continue to occur, albeit at a much-reduced rate of incidence. Collisions and derailments can still occur due to incidents such as infrastructure failures, landslides or incursions from road traffic.

Railway administrations in different countries have conducted extensive accident investigations and research into collision events. These and other countries have reached consensus that there is benefit in managing collision energy and vehicle dynamics in collision conditions. This is achieved by designing rail vehicle structures to have better collision performance in certain prescribed conditions; such vehicles are said to have a "crashworthy structural design".

Many countries have static structural standards; these are complemented (e.g. in Europe and North America) with structural crashworthiness standards. The aims of crashworthy structural designs are generally to:

— reduce the risk of vehicles overriding;

— absorb collision energy in a controlled manner;

— maintain survival space and structural integrity of the occupied areas;

— limit the car body deceleration;

— reduce the risk of derailment;

— limit the consequences of hitting an obstruction on the track.

Some countries have investigated the effect of train crashes on passengers in rail vehicles, aiming to establish a causal link between occupant fatalities or injuries and the design and layout of train interior fixtures, such as seats, tables, luggage racks, stanchions and interior glazing. These investigations culminated in the modelling and testing of deceleration events, as prescribed for the crashworthy structural design, to apply measures to the design of rail vehicle interiors which provide a favourable environment for passengers and staff in these conditions. These measures are collectively considered as interior passive safety and will aid:

— containment;

— compartmentalization;

— reducing and controlling the risk of injuries in secondary impacts that occupants can experience in train crashes and derailments, by incorporating energy absorption in seats and tables and non-aggressive shapes for interior equipment (tables, grab poles, seats, luggage racks).

Specifically, the aim of interior passive safety is to reduce injuries and injury severity to limits which are not life threatening, nor a threat to mobility or cognitive function. However, it is recognized that in the catastrophic and chaotic events associated with vehicle collisions, derailments and overturning, passenger injuries will still occur.

Interior passive safety principles are based on extensive research (e.g. the European Union (EU)-funded SafeInteriors research project (2006–2010), and work conducted by the US Department of Transportation (DoT) Federal Railroad Administration (FRA) and the Volpe National Transportation Systems Center). This research has concluded that the aims of preventing occupant fatalities, and reducing the number and severity of injuries, are best achieved through combining vehicle structural crashworthiness with interior passive safety.

Application of the principles of interior passive safety can also be expected to reduce the consequences of minor incidents, such as slips, trips and falls, that can result from unexpected vehicle movements caused by, for example, emergency braking or track irregularities.

This document describes the worldwide state of the art regarding interior passive safety on passenger rail vehicles.

Railway applications — Rolling stock — Interior passive safety

1 Scope

This document reports worldwide best practice to minimize the risk of death and injury to occupants of rail vehicles in the event of a collision or derailment.

This document investigates recent interior designs for passenger areas in heavy rail vehicles (e.g. coaches, fixed units, trainsets), including refurbished interiors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 17343:2023, *Railway applications – General terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 17343:2023 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
structural passive safety
crash energy management
CEM
design to preserve the structural integrity of a rail vehicle during a collision or derailment

Note 1 to entry: It usually includes the objectives of reducing the *risk* (3.19) of derailment and overriding, providing *survival space* (3.2) for occupants, and minimizing the risk of detached or loose objects or debris.

3.2
survival space
residual space
portion of the vehicle interior designed to have limited or no structural deformation

Note 1 to entry: This can apply both to the general vehicle structure and to smaller subdivisions such as the space between seats or between a seat and a table.

Note 2 to entry: In terms of occupant interior passive safety, this is regarded as the space required for an occupant to survive and to avoid crush-type injury and entrapment.

3.3
containment
keeping occupants within vehicles

Note 1 to entry: Containment predominantly prevents occupant excursion via windows and doors.

3.4
compartmentalization
control of occupant trajectory length within a vehicle

Note 1 to entry: This generally refers to an interior design strategy with the goal of limiting occupants' travel within a small, defined space during a collision, i.e. between rows of seats, or a seat and table, to prevent occupants from travelling large distances and impacting other more hostile objects with larger velocities.

3.5
primary impact
collision of a rail vehicle with another rail vehicle or an obstacle on the track

3.6
secondary impact
contact of an occupant with a fixed interior feature, or another occupant or occupants, following a *primary impact* (3.5) or other accident

3.7
proof load
load which represents, or is intended to be equivalent to, an exceptional maximum load that can be encountered when in normal service and which, when applied and removed, results in no damage, loosening of fixings or deformation that would require repair or replacement

Note 1 to entry: Normally, a proof load is a static or quasi-static load which has been derived from more complex dynamic conditions.

[SOURCE: UNIFE REF 001[1], 3.17]

3.8
ultimate load
load which represents, or is intended to be equivalent to, an exceptional load outside of normal service conditions due to overloading or accident which can result in significant damage or permanent deformation that will require repair or replacement

Note 1 to entry: An ultimate load may be a static, quasi-static or dynamic load.

3.9
slips, trips and falls
accidental or involuntary movement of a person arising from and/or resulting in contact with an object or surface

Note 1 to entry: A person can slip when they lose their footing, trip when they catch a foot on or in something, and fall when they come down suddenly.

Note 2 to entry: Slipping is defined to be a fall because of sliding due to a sudden loss of all or part of the support base (the area spread by the feet and any other support) in a way that the gravity line moves beyond the support area. Tripping is most often caused by an obstruction, followed by uneven surfaces, preventing normal foot movements and leading to a loss of balance. The size and location of any defects affects the severity of the trip. Finally, falling is usually defined to be a fall from a height.[2][3]

3.10
handhold
handrail
any device on board a transport vehicle that is designed to allow passengers to use their hand grip to manoeuvre through the vehicle or provide passengers with a more stable ride while on board the vehicle

[SOURCE: ISO 10865-1:2012[4], 3.4, modified — Admitted term "grab bar" deleted.]

3.11
grab rail
handhold (3.10) designed to support and to permit transfer of body weight, usually found in locations adjacent to showers, bathtubs, WC suites, and wash basins in a bathroom or toilet

[SOURCE: ISO 6707-1:2020[5], 3.3.2.76, modified — Admitted term "grab bar" deleted.]

3.12
light injury
moderate injury
person who is hospitalized for one day to three days or requires one day to three weeks off work

Note 1 to entry: See also *minor injury* (3.13), *serious injury* (3.14) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: For the technical evaluation of occupant injury, the abbreviated injury scale (AIS, see Annex E) is used by researchers and accident investigators to evaluate levels of attributed injury. The AIS system is an anatomically based injury severity scoring system. It is linked to injury acceptance reference values (IARVs) or injury criteria used by some countries to limit the injury potential of train furniture.

[SOURCE: ISO/TS 17755-2:2020[6], 3.57, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.13
minor injury
person who is hospitalized or off work for less than one day

Note 1 to entry: See also *light injury* (3.12), *serious injury* (3.14) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: See also Note 2 to entry in 3.12.

[SOURCE: ISO/TS 17755-2:2020[6], 3.61, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.14
serious injury
person who is hospitalized for four days or more or has more than three weeks off work

Note 1 to entry: See also *minor injury* (3.13), *light injury* (3.12) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: See also Note 2 to entry in 3.12.

[SOURCE: ISO/TS 17755-2:2020[6], 3.73, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.15
life threatening
injured person who must immediately receive emergency rescue and medical treatment to prevent a certain and impending death

Note 1 to entry: See also *minor injury* (3.13), *light injury* (3.12) and *serious injury* (3.14). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

[SOURCE: ISO/TS 17755-2:2020[6], 3.56, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry.]

3.16
fatality
death
person who has died as a result of injuries sustained during an accident

Note 1 to entry: In this context, there is no limitation of time after the accident. Fatalities also include death from natural or accidental causes sustained while involved in the activities of attempting rescue or escaping from the dangers of the accident.

Note 2 to entry: Fatalities are composed of all persons discovered or declared dead at the location of the accident, during their transportation to the hospital or after their admission to the hospital.

Note 3 to entry: These definitions vary between countries; ISO/TS 17755-2[6] relates predominantly to fires in buildings.

[SOURCE: ISO/TS 17755-2:2020[6], 3.37, modified — Terms “fatal casualty” and “fatal injury” deleted. References to fire either replaced by “accident” or deleted in the terms, definition and notes to entry. “including blast and defenestration, except when a death occurred in sites with the right of extraterritoriality” deleted from Note 1 to entry. Note 3 to entry added.]

3.17
value of preventing a fatality
VPF
sum of money used in *cost benefit analysis* (3.18) for the valuation of safety benefits and disbenefits in decision-making processes

3.18
cost benefit analysis
CBA
means used to assess the relative cost and benefit of a number of *risk reduction* (3.20) alternatives

[SOURCE: ISO/TS 16901:2022[7], 3.7, modified — Note 1 to entry deleted.]

3.19
risk
combination of the probability of occurrence of harm and the severity of that harm

[SOURCE: ISO/IEC Guide 51:2014[8], 3.9, modified — Note 1 to entry deleted.]

3.20
risk reduction
actions or means to eliminate hazards or reduce *risks* (3.19)

[SOURCE: ISO 10377:2013[9], 2.22]

3.21
fatalities and weighted injuries
FWI
composite measure of *risk* (3.19) or harm that combines *fatalities* (3.16) with physical injuries and cases of shock/trauma, which are weighted according to their relative severity

Note 1 to entry: The measurement is the number of fatalities, *serious injuries* (3.14) and *minor injuries* (3.13) from the consequences of accidents, where 1 serious injury is considered equivalent to 0,1 fatalities, and 1 minor injury is considered equivalent to 0,01 fatalities.

[SOURCE: RSSB[10], modified — Note 1 to entry added.]

4 Strategic objectives

4.1 Road transport comparison

Although travel by rail is generally safer than by car or bus, many of the safety measures adopted in the United Kingdom (UK) and the United States of America (US) are derived from the automotive industry, as described in the following paragraphs.

European automotive regulations (UN/ECE 80[11]) require impact testing using a sled to achieve a change of velocity (Δv) of between 30 km/h and 32 km/h (8,3 m/s to 8,9 m/s); this gives acceleration levels between 8*g* and 12*g*.

It is worth noting that the reduced levels of acceleration (and the increased time period of the pulse) set out in GMRT2100[14] are based on trains being significantly heavier than road vehicles, and that there is potentially more space in the front of a rail vehicle to provide a “crumple zone” than in a road vehicle. Clause A.2 describes the derivation of the pulse.

US automotive regulations 49 CFR 571_208 (FMVSS208)[15]: The platform is decelerated from 48 km/h to 0 km/h (30 mph to 0 mph) in a distance of not more than 0,914 m (3 feet), without change of direction and without transverse or rotational movement during the deceleration of the platform and the departure of the vehicle. The deceleration rate is at least 20*g* for a minimum of 0,04 s. This therefore gives a change of velocity (Δv) of at least 0,04 × 20 × 10 = 8 m/s; which is similar to UN/ECE 80[11].

In 2023, the US DoT FRA developed an "Engineers' Protection System" (comprising an airbag and knee bolster fitted in the driver's cab).[16] The analysis and testing thereof used a test pulse derived from the acceleration measured in the engineer's cab during a single multilevel rail car impact with a rigid wall at 58,9 km/h (36,6 mph).

The APTA standard for seats (APTA PR-CS-S-016-99, Rev. 3.1, 2023[17]) uses a scaled version of the aerospace crash test pulse in SA AS8049[18]. This is a triangular pulse, maximum 8*g* over 250 ms, giving a minimum Δv of 35,3 km/h (21,95 mph or 9,81 m/s).

Some recent work conducted by Transport Research Laboratory (TRL) for Transport for London in the UK assessed the potential reduction in injuries on buses simply by implementing geometric criteria (e.g. eliminating or relocating sharp edges).

4.2 Rail context

Rail systems aim to transport passengers and goods from place to place safely, comfortably and economically. Active train control systems play a major part in this, notably in reducing the number of train collisions; however, unforeseen circumstances still occur which can lead to collisions or derailments. Such circumstances are often outside the immediate control of the railway system, such as weather-related events or incursions of obstacles (such as debris, landslips and road vehicles) into the railway.

Further, operational events such as emergency braking, coupling trains in operation, and traversing switches and crossings lead to accelerations affecting occupants.

Annex A gives further details of the application of interior passive safety on rail vehicles in the UK and the US.

4.3 Structural passive safety

There exist many examples worldwide of static structural standards, and these are complemented by rail vehicle design standards for dynamic structural crashworthiness in North America and Europe. These aim to preserve the structural integrity of the interior during a collision or derailment, with the objectives of preserving occupant survival space and minimizing the risk from detached or loose objects or debris.

For example, EN 15227:2020[19] states:

> "The objective of the passive safety requirements described in this European Standard is to reduce the consequences of collision accidents. The measures considered in this European Standard provide the means of protection when all possibilities of preventing an accident have failed. It provides a framework for determining the crash conditions that rail vehicle bodies can be designed to withstand, based on the most common collisions and associated risks.
>
> This European Standard adds to the basic strength requirement defined in EN 12663-1:2010+A1:2014[20] by setting additional requirements for structural passive safety in order to increase occupant safety in case of collisions.
>
> In the event of a collision, application of this European standard provides protection for the occupants of new designs of crashworthy vehicles through the preservation of structural integrity, reducing the risk of overriding and limiting decelerations. This protection does not extend to interactions between the occupants and the vehicle interior ..." © CEN, reproduced with permission

Interior passive safety is therefore generally considered in the context of the first principle of vehicle structural design and structural passive safety, i.e. the use of structural passive safety components to preserve space and limit longitudinal decelerations up to specific collision speeds. Structural passive safety also helps to prevent override and lateral buckling. Experience of crash tests varies between countries, with some reporting reductions in fatalities and injuries from structural passive safety alone in relatively high-speed collisions, while in other cases, the use of structural passive safety without considering interior passive safety has led to increases in injuries from secondary impacts.[21] Therefore, in general, it is concluded that designing the interior to control secondary impacts is necessary to reduce the risk and/or the severity of injuries.

4.4 Minimization of injury

The second principle of interior passive safety is to minimize the risk of injury to train occupants in the event of a collision or derailment. Even if the possibility of injury cannot be eliminated, the seriousness of potential injuries can at least be reduced; this improves the chances of injured persons being able to evacuate themselves.

A further outcome is a likely reduction in the injuries to occupants arising from slips, trips and falls, by minimizing or eliminating sharp contours and edges.

If there remains sufficient occupant survival space, and interior components such as seats, tables, fire extinguishers, etc. have not detached from the structure, minimization of occupant injuries is achieved by the following three main control measures:

a) Containment of occupants:

- to prevent occupants from being ejected from the vehicle by careful design of doorways (e.g. EN 14752[22]) and glazing (e.g. ISO 22752[23]).

b) Compartmentalization:

- in the event of a collision or derailment, occupants are contained within a small area of the vehicle (e.g. between rows of seats, between a seat and table) and, equally, that heavy items such as luggage or on-board equipment are contained in their respective areas.

c) Reduction of the consequences of secondary impacts:

- minimizing the trajectory length of an occupant before collision with interior fitments or another occupant by careful design of seats, tables, partitions and luggage racks;
- careful design of interior components, including glazing (see EN 17530[24]) to reduce point loads on the human body, and avoiding trapping risks by good geometric design and selection of materials (see JIS E 7103[25], JIS E 7104[26] and JRIS R 1010[27]);
- consideration of the potential impact surface, e.g. impact surface mechanical performance and its ability to absorb impact energy, and the shape of features and components.

Careful design of the interior of a rail vehicle can also reduce the risk of injuries from other mechanisms such as:

- electric shocks from damaged electrical fittings or exposed wiring;
- injuries from broken glass in windows, partitions and draught screens.

4.5 Interior passive safety principles

4.5.1 General design considerations

Experience from research and accident investigations in the UK (see RSSB Report T910[28]) and the US (see Clause B.2) has shown that the vehicle layout, in particular the seating and the arrangement of screens, partitions and grab rails or poles, plays a key role in determining potential trajectories for occupants in the event of a collision.

NOTE Annex B contains examples of accident statistics from various countries.

Inside the vehicle, compartmentalization measures have the objective of managing the risk of uncontrolled movement of occupants in the vehicle interior space. Vehicle interior layouts that offer good levels of compartmentalization limit the length and number of potential trajectories from a given occupant location (seated or standing) and therefore reduce the risk of injury.

Interior layouts are subject to a wider range of, sometimes contradictory, considerations, for example:

— operational needs and aspirations, including passenger density, boarding and alighting times;

— the type of service (distance, speed, duration);

— vehicle ambience and security.

4.5.2 Component design

It is intended that, once a component design is successfully validated (e.g. for a seat or table), it can be used in another vehicle design without the need for further validation, when the vehicle category is similar, and the installation is mechanically equivalent. Validation can consist of calculations, static or dynamic testing, or a combination thereof.

When satisfactorily completed, the component can then be used in a wide range of vehicle layouts provided that the limiting, worst case, conditions tested are not exceeded. It is therefore acceptable for a component, having been successfully tested, to be used in a given vehicle interior without recourse to further testing, provided that the effective design limits established are not exceeded.

5 Benefits of interior passive safety in train collisions

As indicated in the introduction of this document, train crashes, derailments and overturning are very rare events. Because of this, there is very little data upon which to base a realistic analysis of the direct benefits of interior passive safety measures.

However, it is considered that these measures are likely to lead to reductions in the number and severity of injuries in collisions and derailments, which in turn lead to a better chance of escape. For example, a vehicle interior designed with these principles can reduce the risk of an occupant sustaining a head injury or a broken limb, which is likely to mean that the occupant is able to self-evacuate in the event that the train was involved in an accident.

Other perceived benefits would include reduced injuries and their severities in “other incidents” (see LOC&PAS TSI[29] clause 7.5.2 and Powell & Fletcher[30]. There is also the potential for improvements to reputation and the public perception of the safety of travelling by rail, even extending to reductions in lawsuits.

The RSSB Business Case for GMRT2100 issue 4 (Annex F of Reference [31]) gave a benefit to cost ratio of 1,9 based on reductions in injuries from slips, trips and falls alone (thus ignoring the benefits of improved signalling systems in preventing collisions).

Further details of potential benefits and costs are given in Annex C.

6 Examples of rail vehicle interior structural design criteria

6.1 Global standards for vehicle structural integrity

In Europe, high-level legislation for mainline passenger rail vehicle structural integrity is set out in the LOC&PAS TSI[29] (the equivalent being the NTSN[32] in the UK). The TSI requires compliance to parts of the European standards EN 12663-1[20] and EN 15227[19], which would otherwise be voluntary standards.

In the US, Passenger Equipment Safety Standards 49 CFR 238[33] are federal regulations required by law. These are supported by (voluntary) APTA standards shown in Table 1.

Table 1 — Selection of APTA standards for passenger rail vehicles

Reference	Title
APTA PR-CS-RP-001-98[34]	Passenger Equipment Roof Emergency Access
APTA PR-CS-RP-003-98[35]	Developing a Clearance Diagram for Passenger Equipment
APTA PR-CS-RP-019-12[36]	Pushback Coupler in Passenger Rail Equipment
APTA PR-CS-S-020-03[37]	Passenger Rail Vehicle Structural Repair
APTA PR-CS-S-034-99[38]	Design and Construction of Passenger Railroad Rolling Stock

Other rail vehicle structural standards and codes are listed in Table 2.

Table 2 — Other rail vehicle structural standards and codes

Reference	Title
PRIIA 305 (US)[39]	Requirements Document For PRIIA Diesel-Electric Passenger Locomotives
UIC 566 (worldwide)[40]	Loadings of coach bodies and their components
TB/T 3548 (China)[41]	Strength design and test accreditation specification for rolling stock — General
TB/T 3500 (China)[42]	Crashworthiness requirements and verification specification for car body of EMU/DMU
TB/T 3501 (China)[43]	Test method for crash test of rolling stock
JIS E 7103 (Japan)[25]	Rolling Stock – General requirements of car body for passenger car
JIS E 7105 (Japan)[44]	Rolling stock – Test methods of static load for body structures
JIS E 7106 (Japan)[45]	Rolling Stock – Car body structure for passenger cars – General rules for design

6.2 Standards for interior equipment

ISO 22752[23] (bodyside windows) contains static loading requirements which are relevant to the safety of rail vehicle occupants.

The same can be said of the European Standards EN 14752[22] (doors) and EN 17530[24] (interior glazing). EN 14752[22] is called up in the LOC&PAS TSI[29]. UIC 566[40] includes proof loading requirements for interior equipment such as luggage racks, coat hooks, seats, tables and doors.

GMRT2100[14] is the Railway Group Standard in the UK for rail vehicle structures. GMRT2100 issue four[13] and later issues include aspects of interior passive safety based on the outcomes of the European SafeInteriors research programme and research required to satisfy various recommendations made by various public inquiries into UK rail disasters.

It was originally intended that UIC and UNIFE would publish a joint Technical Recommendation document (TecRec), but this never came to be. There exists a draft UNIFE Technical Report[1], and a UIC International Railway Solution (IRS 50564-3)[46], both of which have very similar content to GMRT2100[14] in respect of interior passive safety. GMRT2100[14] is mandatory in the UK. UIC 566[40] and the IRS[46] are voluntary standards.

The US APTA standards for passenger vehicle interior equipment are listed in Table 3.

Table 3 — US APTA standards for passenger vehicle interior equipment

Reference	Title
APTA PR-CS-S-006-98[47]	Attachment Strength of Interior Fittings for Passenger Railroad Equipment
APTA PR-CS-S-011-99[48]	Cab Crew Seating Design and Performance
APTA PR-CS-S-012-02[49]	Door Systems for New and Rebuilt Passenger Cars
APTA PR-CS-S-016-99[17]	Passenger Seats in Passenger Railcars
APTA PR-CS-S-018-13[50]	Fixed Workstation Tables in Passenger Rail Cars

Japanese standards for passenger vehicle interior equipment include JRIS R 1010[27] (luggage racks) and JIS E 7104[26] (passenger seats). Further, Japanese standard JIS E 7103[25] requires that:

> "the facility shall be designed to have sufficient strength taking such factors into consideration such as the vibrations and impacts in running, the pushing force of hands or bodies of a passenger and possibility that two or more passengers may use the same facility at the same time".

Chinese standards include TB/T 3263[51] (passenger seats) and TB/T 3286[52] (luggage racks and hat hooks).

Standards in the UK (GMRT2100[14] and RIS-2780-RST[53]) and the US (49 CFR 238[33]) generally require equipment fitted inside rail vehicles to be designed to meet the same load cases as set out for exterior-mounted equipment. The European Technical Specification for Interoperability (TSI)[29] also requires the attachments of "fixed devices including those inside the passenger area" to be designed in accordance with EN 12663-1[20].

US Standard APTA PR-CS-S-006-98, Rev. 2, 2021[47] requires body mounted equipment generally to withstand ultimate inertial accelerations of $8g$ longitudinal, $4g$ lateral and $4g$ vertical, applied separately. Given that in EN 12663-1:2010+A1:2014[20], there is a recommended ultimate factor of 1,5, the APTA accelerations are slightly greater than the European requirements of $3g$ or $5g$, $1g$ and $(-1 \pm 2)g$, respectively.

Where there are specific static proof and ultimate loading requirements for interior mounted items (such as seats, tables, grab handles, grab poles, grab rails and luggage stowage), and when the acceleration loads set out in EN 12663-1:2010+A1:2014[20] applied on the corresponding mass are less severe than the specific requirements, separate assessments against the acceleration loads set out in EN 12663-1:2010+A1:2014[20] are not always necessary because the specific requirements are derived from service and accident conditions, are therefore more onerous and any requirements relating to EN 12663-1:2010+A1:2014[20] are therefore satisfied.

To maintain a continuous load path for all load conditions and to absorb energy requires ductile behaviour. Many interior elements will, however, use some non-ductile components (e.g. a table), where the tabletop is often made from a non-ductile composite or wood-based material, but the legs and mountings are made from ductile materials such as steel or aluminium. As a result, the overall assembly or sub-structure can exhibit the desired behaviour when overloaded through plastic deformation of the ductile parts when subject to the loadings set out in this document.

It is accepted practice for what can be considered minor items, where an installation has been used for an extended period in service in a similar or more arduous environment and has performed satisfactorily with no records of consistent unscheduled maintenance, this can be taken as evidence of acceptable performance. Where adopted, this approach is generally documented.

In some cases, quasi-static inertia proof loads (mass × specified acceleration) have been applied dynamically using a dynamic test pulse, scaled to the acceleration level required where necessary. The required acceleration level is sustained for at least 80 ms for consistency with the dynamic test pulse.

6.3 Material selection for rail vehicle interiors

Materials can play a part in achieving the aim of reducing the number and severity of occupant injuries (e.g. from abrasion, lacerations or stab wounds) in the event that parts of a vehicle interior are fractured, deformed or dislodged under impact conditions. This fact is recognized in GMRT2100[14].

Therefore, the suitability of materials used in vehicle interiors, in addition to fulfilling structural and impact requirements, usually takes into account other foreseeable material requirements, for example:

— fire performance;

— durability, including behaviour under fatigue loading;

— safety in manufacture;

— repair and disposal;

— the potential for degradation due to ageing or environmental factors such as temperature, humidity, sunlight, etc.

Compromises are therefore always required when selecting materials.

The principles of reducing injury from vehicle interior components include ensuring the following:

— When items are broken or ruptured, sharp spikes, splinters or fragments are not formed where an occupant could come into contact with them, and, for composite panels or substructures, aggressive internal components (e.g. metallic inserts) are not exposed to occupants.

— When loaded beyond the specified proof loads (i.e. the ultimate load, which is generally around 1,5 times the quasi-static load, see EN 12663-1:2010+A1:2014[20], 5.4.3), vehicle interior structures or sub-structures are designed to collapse in a controlled and predictable manner and have good post-yield plasticity and/or energy absorption properties.

— Non-ductile or brittle materials are therefore designed to withstand the ultimate load, or are only used where the consequences of their failure are mitigated, for example by alternative load paths.

6.4 Structural energy absorption and collapse: UK practice from GMRT2100

GMRT2100[14], A.4, states:

> "All interior fixtures, including seats and tables, shall meet the following requirements when the specified proof, ultimate and dynamic loads are applied:
>
> a) Elements that form part of a primary load path shall include ductile materials.
>
> b) All attachments to the primary structure shall remain intact.
>
> c) A continuous load path shall be maintained, without abrupt changes in force levels due, for example, to buckling, snap-through or fracture.
>
> d) Sharp objects or fracture surfaces that are likely to cause injury shall not be produced."

NOTE The term "snap-through" relates to a sudden movement of a structure with a relatively large deflection, often without structural failure. It can also relate to a mechanical fuse where the modification of the shape or performance an item or device is beneficial to the safety of a vehicle occupant.

This ensures that the complete structure exhibits post-yield plasticity and energy absorption, when loaded beyond the specified proof loads. It controls the risks of injury to vehicle occupants in the event of an accident and represents UK practice.

Items such as seats and tables cannot generally be made entirely from ductile materials; however, a complete seat or table assembly can be designed to behave in a ductile manner and absorb useful amounts of energy by using suitable materials for critical components where impact is most likely to occur, and for the attachments to the primary vehicle structure.

Large items such as seats and tables have the potential to cause serious injury if they become detached. It is therefore good practice to ensure that all items remain attached for the conditions specified.

Discontinuous load paths, abrupt jumps in force levels and the exposure of otherwise concealed parts also have the potential for additional injury. Where items are loaded during an impact, it is good practice to ensure that they do not break away or become partially detached, and that the fixings to the vehicle structure are the last components to fail when the seat or table assembly is subject to overload.

6.5 Secondary impact assessment

6.5.1 Considerations for persons with reduced mobility

See Annex D.

6.5.2 Secondary impact principles

In a collision or derailment, a vehicle typically experiences a primary impact or a series of impacts, and a very rapid deceleration. Some of the vehicle's kinetic energy is retained by the occupants and objects, which is then dissipated by secondary impacts inside the vehicle.

The severity of a secondary impact injury is dependent upon the occupant's kinetic energy and the rate of energy dissipation (the relative deceleration at the point of contact) on impact. The rate of energy dissipation is related to the stiffness of the contact surface, the concentration of energy per unit area at the point of contact and the body region involved.

To minimize the severity of injuries, design for interior passive safety would therefore take account of the following:

a) the occupant's velocity and kinematics at the point of contact;

b) the characteristics of features or structures impacted;

c) probable impact areas relative to the occupant and their proximity to vital organs.

6.5.3 Secondary impact review

UK practice, as stated in GMRT2100[14], is to subject areas which are accessible to occupants in normal service to a secondary impact review; this examines the general features and detailing of the vehicle interior considering the risk of injury due to secondary impact against surfaces or items.

The design and installation of the interior (with the exception of seats and tables, which are subject to separate specific requirements) are examined for potentially aggressive features with respect to:

a) exposed corners and edges;

b) recesses;

c) protrusions.

The secondary impact review is often simplified, since in a rail vehicle there will be many items which are repeated throughout the train, such as handholds, partitions, draught screens and doors; therefore, it is only necessary to assess one example of an item or component that is repeated.

A further possible simplification of the review is to use a risk-based approach, e.g. in areas which are infrequently used. A risk-based approach includes the following considerations for determining, sorting and assessing the level of risks for an occupant to be injured in a train accident because of projection to the train's interior surfaces:

— The likelihood of occupants being positioned in a zone, including the frequency of occupation.

— The credible approach path of occupants during an accident, addressing the credibility of their trajectory to impact a given item/surface. It generally assumes a given initial position of the occupant.

  — For initially standing occupants, priority is given to exposed surfaces in a height range from 1,1 m to 1,9 m from the floor. The 1,1 m covers the height of the head of a 6-year-old child and the height at which a tall person would hit a surface during his/her fall.

  — For initially seated occupants, priority is given to exposed surfaces up to 1,5 m from the floor. Regardless of the height of 1,5 m, the undersides of overhead luggage racks are included as priority surfaces.

— Exposure of a surface, e.g. edges and corners are exposed only where a theoretical 100 mm diameter sphere can make contact (165 mm diameter for surfaces with a predominant probability to be impacted by the head of an occupant); see 6.6.2. The exposure is inherent to the integrated items in the train, and excludes the notion of a credible approach path.

— Compartmentalization ability of a surface/item, e.g. a transverse seat or a transverse partition is efficient to limit occupant excursions in the case of accidents leading to longitudinal accelerations, and therefore these surfaces are regarded as a priority.

— Repeated items and/or radius of an item in a train. Typically, an interior item of the same design that is implemented several times in a train has more probability to be impacted during an accident compared to a unique item, even though the credible approach trajectory is estimated as low.

— Surface rigidness, addressing the ability of an impacted surface to deflect locally (shore hardness) or globally.

— The shape of the rigid surfaces:

  — Radii ≥ 20 mm for head impact;

  — Radii ≥ 5 mm to 10 mm for limb impact.

— Constraints that can limit changes to meet interior passive safety design rules, including:

  — manufacturing and/or geometrical constraints (including aesthetics);

  — overriding requirements, such as sightlines, persons with reduced mobility (PRM) TSI[57] and human factors.

6.5.4 Secondary impact design scenarios

The initial effect of many rail vehicle accidents is predominantly longitudinal, but even in these cases, due to the dynamics of the train or external influences such as, for example, track curvature, switches and crossings, some or all of the vehicles involved can come to rest having been subject to large lateral, vertical, yaw, pitch or roll movements. Accidents due to defective track or landslides can include significant non-longitudinal effects from the outset.

NOTE Some countries have measures to detect defective track and landslides (such as concrete reinforced slopes and rockfall detecting systems), which can help to prevent derailments.

The Railway Group Standard (GMRT2100[14]) used in the UK assumes a nominal 5*g* longitudinal crash pulse as the principal design scenario (see Clause A.2). This pulse is derived from post-accident collision research, and generates secondary impact velocities (of at least 5 m/s) and loadings which have been shown to be consistent with the severity of injuries encountered in typical accidents. Where dynamic assessments are used, this pulse therefore permits injury criteria to be assessed.

The collision pulse used in the US is of a triangular shape, with an 8*g* peak and a duration of 250 ms; this yields secondary impact velocities around 10 m/s. The pulse represents an in-line train-to-train collision in which the cars remain upright and in-line and the occupant volume is severely challenged or crippled.

Specific interior design scenarios have not been developed for situations where lateral, vertical, yaw, pitch and roll accelerations, or a combination of these, occur. For this type of scenario, any additional risks can be controlled using design relating to shape and geometry and proof loads.

6.5.5 Containment and compartmentalization

The general principle of containment is to prevent occupants from being ejected from the vehicle, on the basis that this can allow better control of the potential for injury.

The principle of internal compartmentalization is that, in the event of a collision or derailment, passengers or staff are contained in the area of the vehicle where they are located, and equally, that heavy items such as luggage or on-board equipment are contained in their respective areas. The principal objectives are to prevent long excursions through the vehicle and therefore reduce the velocity of secondary impacts and interaction with other occupants.

Research has shown that unidirectional seating provides a better level of restraint for seated occupants compared to bay seating, as the occupants' movements are restricted to the immediate area (e.g. see RSSB research report T910[30], and US DoT report numbers 61614[54], 54597[55] and 35576[56]).

Bay seating is provided on many European trains because of passenger preference. Where fixed tables are installed, bay seating can also give a level of constraint by limiting the distances in which occupants can be displaced. Bay seating without tables provides a lower level of constraint.

Longitudinal seating is often preferred for suburban operations where station-to-station times are short, and passenger boarding and alighting times are critical. Longitudinal seating arrangements will not always appear to give the same control as transverse seating, but when groups of longitudinal seats are sub-divided, for example, by armrests, grab poles or draught screens, it is considered that the risk is adequately controlled.

Aspects of vehicle layout design, such as the location of draught screens and grab poles, can influence the risk of injury to standing occupants. Other design considerations include the relationships between standing areas and seating areas, and operational parameters, e.g. whether standing occupants are unlikely (such as for intercity services where seat reservations are required) or if a metro style operation is envisaged. Grab poles, grab rails and grab handles can provide elements of constraint for standing occupants.

6.5.6 Minor impacts with interior features

Accident investigations and research (see RSSB Research Report T910[28]) have shown that the majority of injuries in an accident or collision can be attributed to impact against seats and tables. The causes of a significant proportion of injuries were uncategorised. This research therefore recommended consideration of the potential effects of impacts with other interior features.

Accident injury data are often not able to directly identify the effects or influence of other interior features; however, the detail design of these features (e.g. partition edges, luggage racks, coat hooks, magazine racks, table lights) can significantly influence injury levels.

6.6 Geometric criteria

6.6.1 Standards with geometric requirements

Linked to the need to reduce the consequences of slips, trips and falls, GMRT2100[14] contains detailed geometric requirements for interior equipment to reduce the risk of injury.

Similarly, Japanese standard JIS E 7103[25] requires that:

> "the facility installed in an area where it is likely to touch with human bodies shall be free from sharp edge, protrusion and the like so that human bodies, clothes and other articles are not injured or damaged".

In addition, US standard APTA PR-CS-S-006-98, Rev. 2, 2021[47] requires that:

> "To the extent possible, all interior fittings in a passenger car shall be recessed or flush-mounted. Sharp edges and corners shall be either avoided or padded to mitigate the consequences of an impact with such surfaces. Where protrusions are unavoidable, rounded edges shall be used. Materials that may fracture to reveal sharp edges or dangerous inserts shall not be used. Wherever possible, use shall be made of energy-absorbing features in areas where passenger impact may occur."

6.6.2 Geometric principles

The following geometric principles are set out in GMRT2100[14] for the secondary impact assessment.

An assessment of what constitutes an exposed rigid edge:

— that which can be contacted by a 100 mm diameter sphere;

NOTE 1 A 165 mm sphere is used in the automotive industry to assess head injury potential (see clause 5.3.2 and Annex V of Directive 74/60/EEC[58]). It is understood that the SafeInteriors[59] research recommended the use of a smaller diameter sphere in the rail environment, to facilitate an indication of potential injuries to limbs as well.

— that with a Shore hardness greater than 50 (as set out in clauses 5.1.6, 5.2.4, 5.3.5, 5.7.2 and 5.8 and Annexes V and VI of Directive 74/60/EEC[58]).

Minimum radii: GMRT2100[14] states that radii of 3 mm should be used, except:

— for longitudinal partitions, edge radii of at least 10 mm and a minimum edge thickness of 35 mm, unless the partition is shielded by a grab pole, grab rail or other feature;

— for transverse partitions, edge radii of at least 5 mm, and a minimum overall thickness of 20 mm, unless the partition is shielded by a grab pole, grab rail or other feature;

— 20 mm is preferable where there is a risk of head injury.

NOTE 2 It is understood that these radii are also derived from the SafeInteriors[59] research recommendations.

Details, formulae, figures and guidance are provided to enhance and assist users with implementing these requirements.

Details are also provided regarding recesses, to reduce the risk of hand or foot entrapment; GMRT2100[14], G.B.4.10, states:

"When subject to secondary impact, gaps between items or recesses could be significant causes of injury due to entrapment. For locations around seats where hands could become entrapped, it is good practice to ensure that there are no gaps or recesses smaller than 25 mm in width with a depth greater than 20 mm. For areas where feet could become entrapped, for example beneath seats, it is good practice to ensure that any gaps are either smaller than 100 mm × 50 mm or greater than 300 mm × 150 mm."

The dimensions are understood to be based on the anthropometric measurements set out in ISO/TR 7250-2[60], and are intended to ensure that recesses or gaps are too small for fingers or feet, or large enough that fingers or feet can be easily moved out. GMRT2100[14] also suggests the use of concealed, recessed or domed fasteners to reduce the risk of injury from impacting them.

The APTA table standard APTA PR-CS-S-018-13[50] specifies minimum geometry requirements for the table top radii of 25,4 mm (one inch) for aisle-side corners and 4,76 mm (3/16 inches) radii for top/bottom edges. It also specifies a maximum gap of 50,8 mm (2 inches) between the table top and the wall to minimize the risk of entrapment.

For reference, it is understood that reference is made in some train technical specifications to EN 1176-1; this requires gaps to be less than 8 mm or greater than 25 mm, to reduce the risk of finger entrapment.

6.7 Computer simulations, calculations and testing

As computing power increases and simulation methods are continuously improving, there is increasing reliance on simulation with consequent reduction in the need for costly testing. It is common practice to validate simulations with testing (e.g. European Standards EN 12663-1[20] and EN 15227[19] describe when tests are needed as part of the verification process for rail vehicle static and collision performance, respectively).

This principle is already used in the UK railway standard GMRT2100[14].

Proprietary software models of the standard automotive anthropomorphic test devices (ATDs) are already available, which are compatible with typical finite element analysis software (such as Ansys LS-DYNA, Altair® Optistruct® and Altair® Radioss®1)). These ATD models have already been validated, which means that validation is generally only needed for the items being tested (seat, table, cab desk, etc.).

1) Ansys LS-DYNA, Altair® Optistruct® and Altair® Radioss® are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

However, one drawback is that the automotive Hybrid III ATD (HIII) is not fully biofidelic in the abdominal and lower chest area for impacts with tables; that is to say, the ATD test does not necessarily give a realistic indication of the actual levels and types of injury that would be sustained by a person. This is because these ATDs were developed to assess injuries from impacts with a steering wheel and the effects of a seatbelt, neither of which is relevant to a table or cab desk. There is, therefore, likely to be a need for further testing and validation as and when improvements to rail-specific ATDs are made. Nevertheless, the costs of such validation testing would only apply once.

NOTE The 50th percentile Hybrid III is based on typically Western populations (US, Europe) and is therefore not necessarily representative of, for example, Asian populations.

The APTA standard[17] permits the use of either the Test Device for Human Occupant Restraint (THOR) ATD or the HIII Rail Safety (HIII-RS) ATD in assessing seats and tables. THOR was developed by the US National Highway Traffic Safety Administration (NHTSA) for automotive applications, whereas the HIII-RS was developed in the UK specifically for rail.

6.8 Possible re-use of existing component test results

One of the fundamental principles of standardization is to reduce costs. Many standards therefore allow a reduction or elimination of validation processes where it is possible to make use of validation evidence from previous projects, provided that the extent of design changes is limited. European Standards such as EN 12663-1[20] and EN 13749[61] and UK railway standards such as GMRT2100[14] are examples of where reduced validation is permitted.

EN 12663-1:2010+A1:2014[20] states:

> "Where a vehicle body is a development of an earlier design for which the safety has been demonstrated and similar service conditions apply, then earlier data may be used, supported by comparative evidence. Areas of significant change shall be re-analysed. Where the global load path is maintained and the stresses remain below the acceptable limits it is sufficient to demonstrate the acceptability of the changes only by analysis." © CEN, reproduced with permission

EN 13749:2021[61] states:

> "Where the design is a development of an earlier product any previous data, or other evidence of satisfactory performance that is still applicable, can be offered as validation of the revised product.
>
> In the case of an existing design of bogie frame intended for a new application, or a modification to an existing design, a reduced programme can be used, depending on the significance of the differences. If the differences are small, analysis, supported if necessary, by measurements made during a limited test programme, will be sufficient to validate the design." © CEN, reproduced with permission

GMRT2100[14], A.6.1, G A.6.2, G A.6.4 and G A.6.5, state:

> "Where an item has already been dynamically tested in accordance with this document, and compliance demonstrated, additional testing for a new installation shall not be required if it can be demonstrated that all of the following conditions are satisfied:
>
> a) The proposed layout in terms of occupant safety is equivalent to or better than the arrangements previously tested.
>
> b) Dynamic load data has been obtained from the original test series to define the dynamic load requirements for the item's installation, attachment points and fixings.
>
> c) The item's fixings and corresponding vehicle structure can resist all loads resulting from static proof and dynamic collapse loads.
>
> d) The item's design and mounting arrangements are mechanically equivalent to those for which test data has been obtained.
>
> This reduces the costs of verification where appropriate conditions are satisfied, assisting in controlling the risks of injury to people inside the vehicle in the event of an accident and represents GB practice.

Typically, the critical parameter for the risk of injury will be the potential free flight distance for a passenger in any given location; for seats this will be the relative seat pitches proposed.

It is good practice to demonstrate that the original test data is sufficient to fully define the dynamic mounting loads and that the new installation arrangement can satisfactorily withstand these loadings:

a) For seats, the squabs, cushions, headrests, frames, pedestal and fasteners need to be mechanically equivalent to the design tested.

b) For tables and other components, it is good practice to demonstrate mechanical equivalence of the assembly and attachment points."

US railway standard APTA PR-CS-S-018-13, Rev. 2, 2022[50] also contains a similar statement regarding tables:

"If a structurally identical table installed in a similar physical arrangement ... has been tested in accordance with the requirements of this standard, then at the discretion of the purchaser and in lieu of added testing, the manufacturer may provide test data in accordance with ... this document to demonstrate that the table is in compliance with all the requirements of this standard."

6.9 Open bay seating

The UK standard does not currently specify dynamic test requirements for open bay seating (bay seating without tables).

These tests are required in prescribed conditions by the APTA seat standard APTA PR-CS-S-016-99, Rev. 3.1, 2023[19]:

"Open bay seating in rail vehicles should be limited to the lowest extent practical, unless the configuration complies with all the requirements in this standard. Open bay seats used at the end of a row to prevent seats from facing a bulkhead [vehicle end] wall, windscreen, vestibule wall or similar structure are considered an acceptable justification for the use of open bay seats. To compromise on operators' desire to use unlimited open bay seats, up to 50 percent of a rail vehicle's seating capacity may be open bay seats without conducting the forward-facing ATD sled tests in the open bay configuration. Unlimited open bay seats may be used if the seats comply with all the requirements in this standard, including the forward-facing ATD sled tests, in the open bay configuration."

Where seats are configured in open bays, the design of the leading edge of the seat pad or base can limit force levels in the lower limbs and allow energy to be absorbed before the upper body contacts the seat back. Suitable features can include a generous contact surface and a progressive crushing characteristic for the leading edge of the seat.

Annex A
(informative)

Interior passive safety experience from UK and US

A.1 Case study from Great Britain

Interior passive safety has been mandated for new designs of train in the UK since 2010. Previous UK codes of practice, developed following extensive research into the consequences of train crashes, were not consistently applied. RSSB developed a business case[31] for mandating interior passive safety on the basis of the reduction in injuries from slips, trips and falls alone.

One of the reasons that the cost benefit analysis (CBA) used data from slips, trips and falls is that this offered a much larger database than injuries from train accidents, mostly because train accidents are relatively few and far between. RSSB has been compiling risk assessments and cost-benefit analyses from data collected over many years. These are based on the well-documented concepts of the value of preventing a fatality (VPF), currently around EUR 2 million, and the measure of fatalities and weighted injuries (FWI), e.g. one fatality is considered statistically equivalent to 10 serious injuries.

The analysis showed a benefit to cost ratio of 1,9, even including the costs of full dynamic testing (see Clause C.3). This was based on a reasonably conservative assumption that injuries from slips, trips and falls (and their severity) would be reduced by around 40 %.

In 2022, the RSSB database clearly shows that there has been a reduction in injuries of 41 %.

A.2 Derivation of the deceleration pulse used in GMRT2100

In the late 1980s, British Rail Research was conducting a programme of assessing the structural integrity of rail vehicles in collisions (this concentrated on the British Rail “Mark 1” design). The 1988 Clapham Rail disaster led to a recommendation (see Hidden[62], recommendation 56) to: “extend [this] programme of research to include dynamic testing of full-scale simulations of collision retardations in order to improve the design of internal furniture under conditions of passenger impact.” This was to be complemented by studies into dynamic simulation (see Hidden[62], recommendation 57) and participation in European railway studies of performance of passenger stock, including collision resistance (see Hidden[62], recommendation 58).

Much of the subsequent research was conducted by The engineering link Ltd (a train engineering services company set up as part of the privatization of British Rail). The work is summarized in a British Rail Research document[63]. This describes the structural requirements in GMRT2100 issue 3[12] (energy absorption of 1 MJ at train ends and 0,5 MJ at intermediate ends) and a draft code of practice; this latter document was published as BR BCT 609[64] in July 1996, and was supported by research into designs of “crashworthy” seats and tables.

It is acknowledged that similar research has taken place in the US.

The injury criteria in BR BCT 609 were based on extensive research and differ from automotive and aerospace criteria for many reasons; these include the use of seatbelts in cars and the existence of bay tables on trains. This document appears to be the first instance of the crash test pulse. Lewis[63] states that the specified pulse is “determined from past accident analyses”; see Table A.1.

Commonly accepted injury criteria are shown in Annex E.

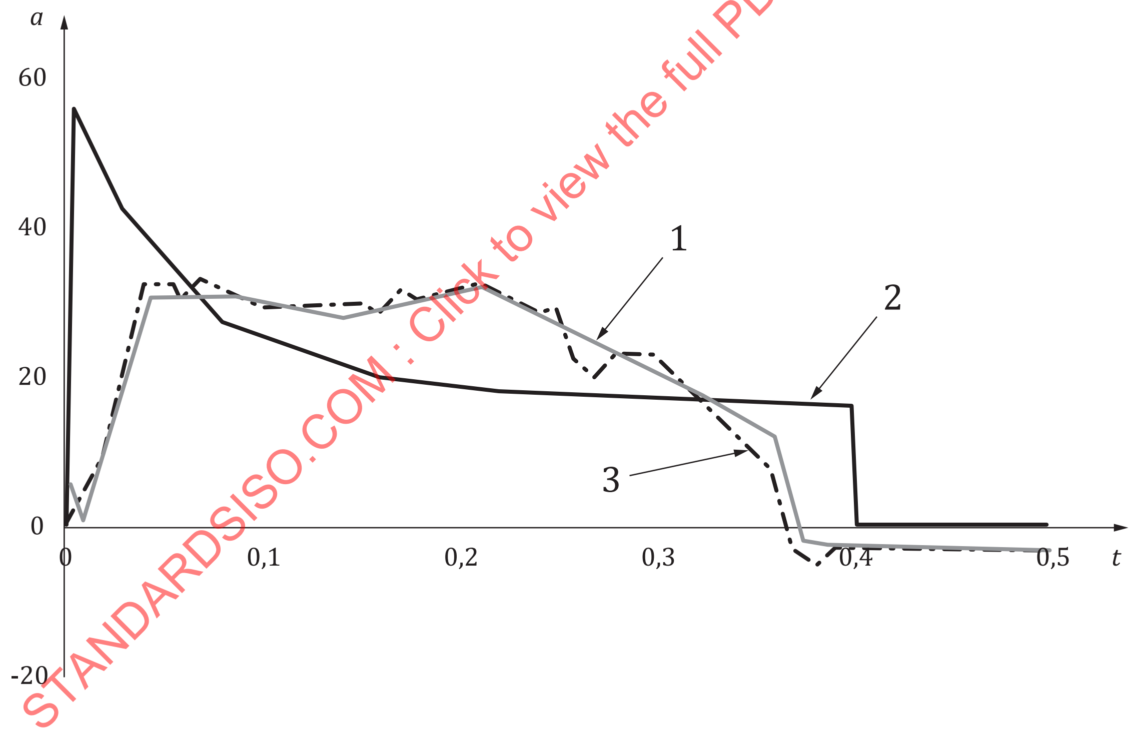
Table A.1 — Collision scenarios assessed for deceleration

Collision scenario	Designation for impact speed of:	
	9 m/s (32 km/h)	6,5 m/s (23 km/h)
Unmodified Mk1 vehicle striking unmodified vehicle: collapse at constant load	C1	C5
Unmodified Mk1 vehicle striking unmodified vehicle: collapse at decreasing load	C2	C6
Mk 1 vehicle, modified to meet the full requirements of then-current British Rail crashworthiness specifications, striking similar crash-worthy vehicle	C3	C7
Unmodified Mk1 vehicle striking unmodified Mk1 vehicle with vehicle overriding	C4	C8

A clue as to the accident analyses is found in the T910 report[28]; the referenced document is described as "unnumbered British Rail Research report", although some of the outputs of that document are illustrated in the T910 report.

The above proposed pulses were modified during testing for practicability, i.e. whether the HyGe sled used by MIRA could reproduce the proposed pulses in practice (see Figures A.1 to A.17). They were then subject to further modification in order to take account of over-riding effects.

Notably, the C3 pulse will probably result in a velocity change (Δv) of 9 m/s; similar to that specified in the APTA pulse.



Key

a acceleration (m/s²)

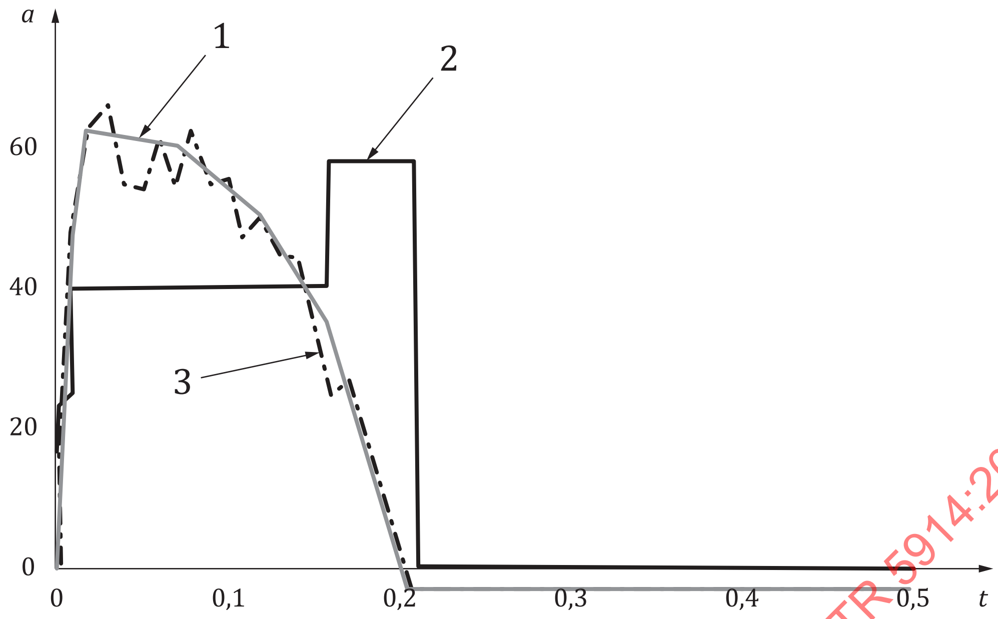
t time (s)

1 madymo pulse

2 BRB proposed pulse

3 HyGe pulse

Figure A.1 — Deceleration pulses from collision scenarios — C2 acceleration time response



Key

a acceleration (m/s^2)

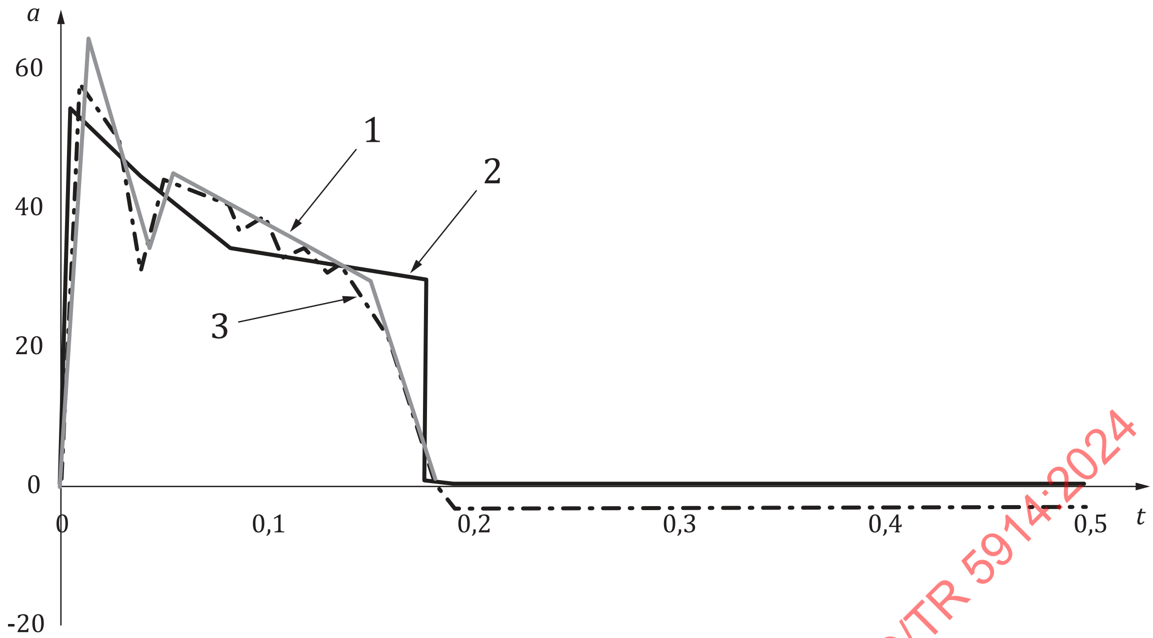
t time (s)

1 madymo pulse

2 BRB proposed pulse

3 HyGe pulse

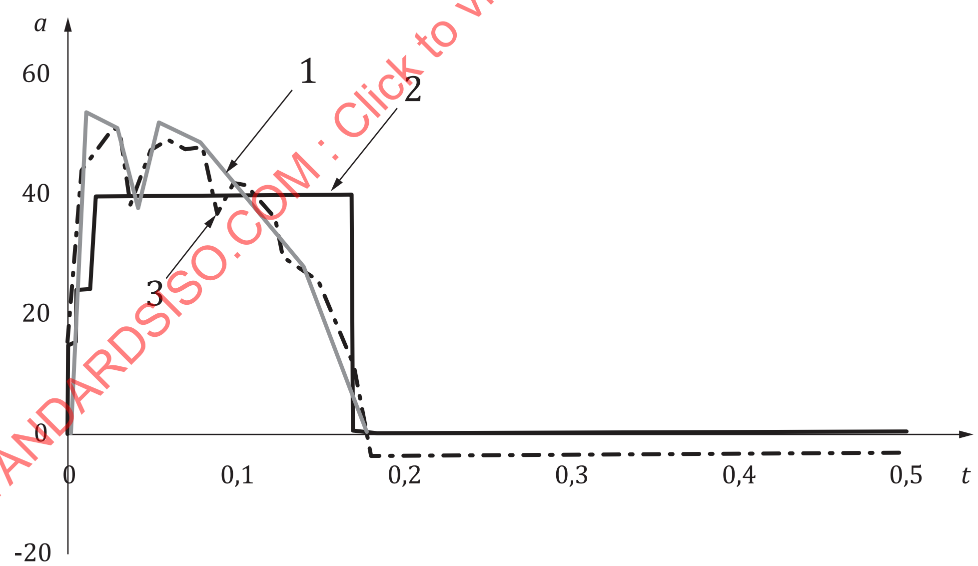
Figure A.2 — Deceleration pulses from collision scenarios — C3 acceleration time response



Key

a	acceleration (m/s^2)
t	time in (s)
1	madymo pulse
2	BRB proposed pulse
3	HyGe pulse

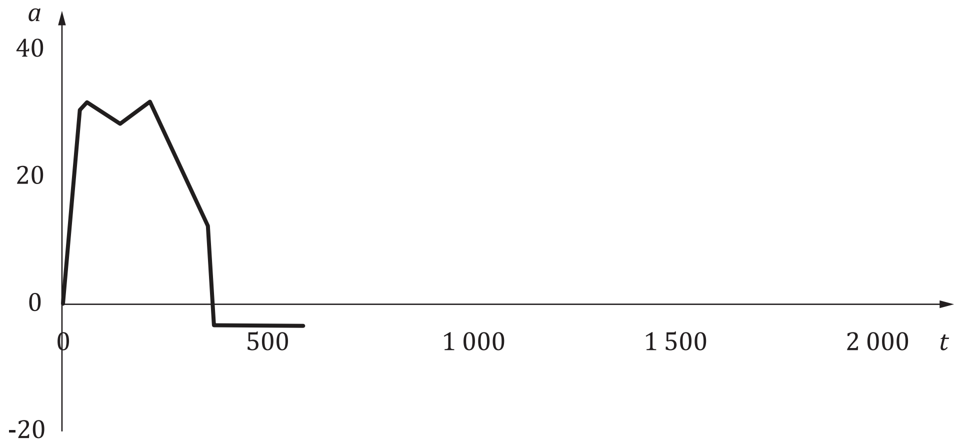
Figure A.3 — Deceleration pulses from collision scenarios — C6 acceleration time response



Key

a	acceleration (m/s^2)
t	time (s)
1	madymo pulse
2	BRB proposed pulse
3	HyGe pulse

Figure A.4 — Deceleration pulses from collision scenarios — C7 acceleration time response

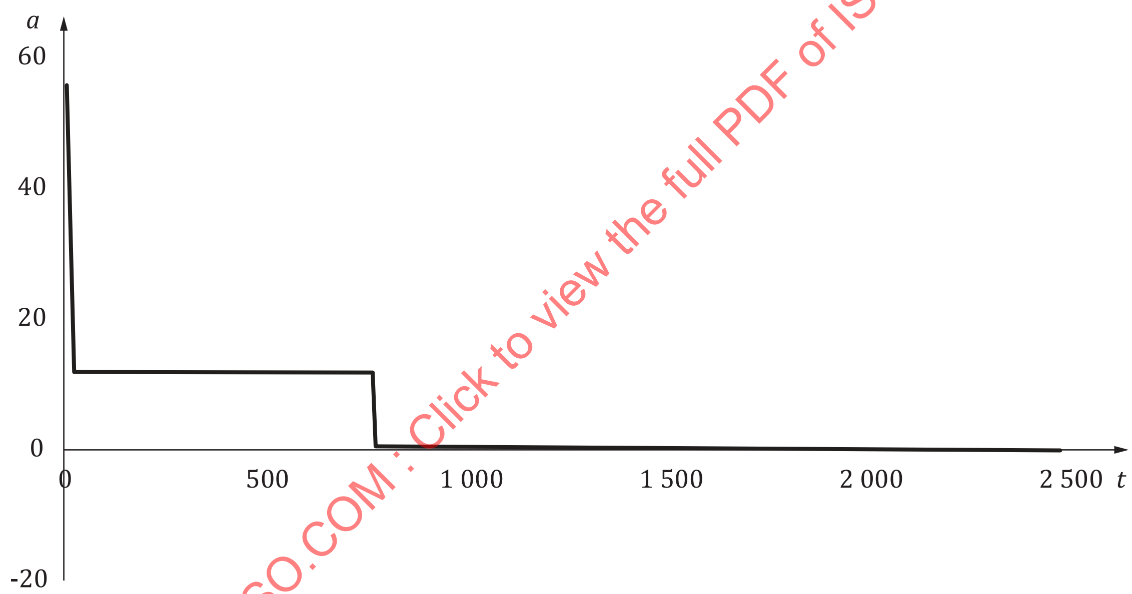


Key

a acceleration (m/s²)

t time (ms)

Figure A.5 — Simplified C2M pulse

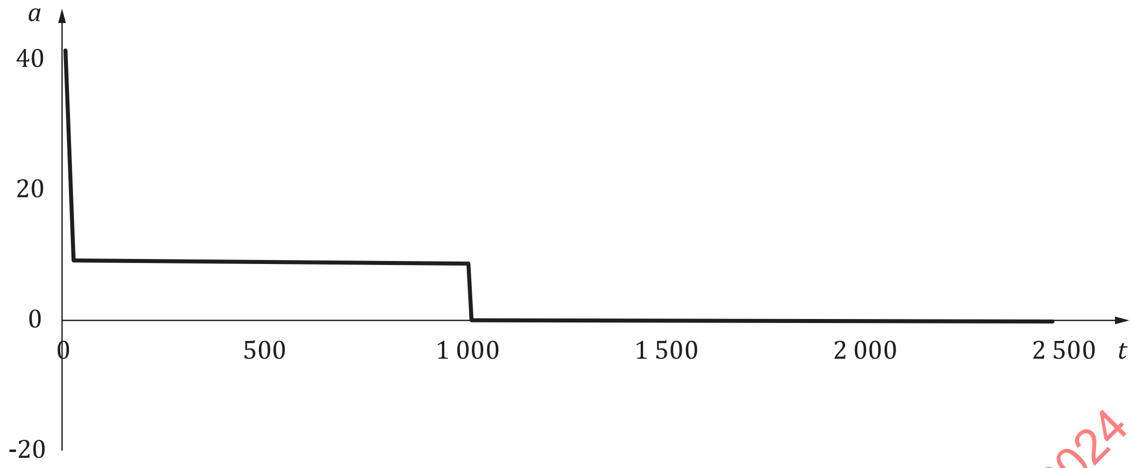


Key

a acceleration (m/s²)

t time (ms)

Figure A.6 — Simplified C4 pulse

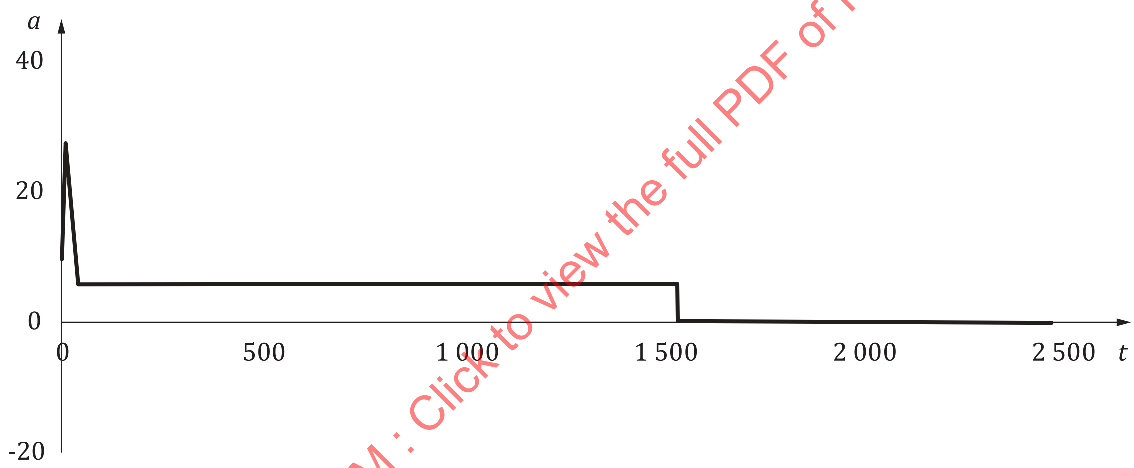


Key

a acceleration (m/s²)

t time (ms)

Figure A.7 — Simplified C4MS “medium severity” pulse

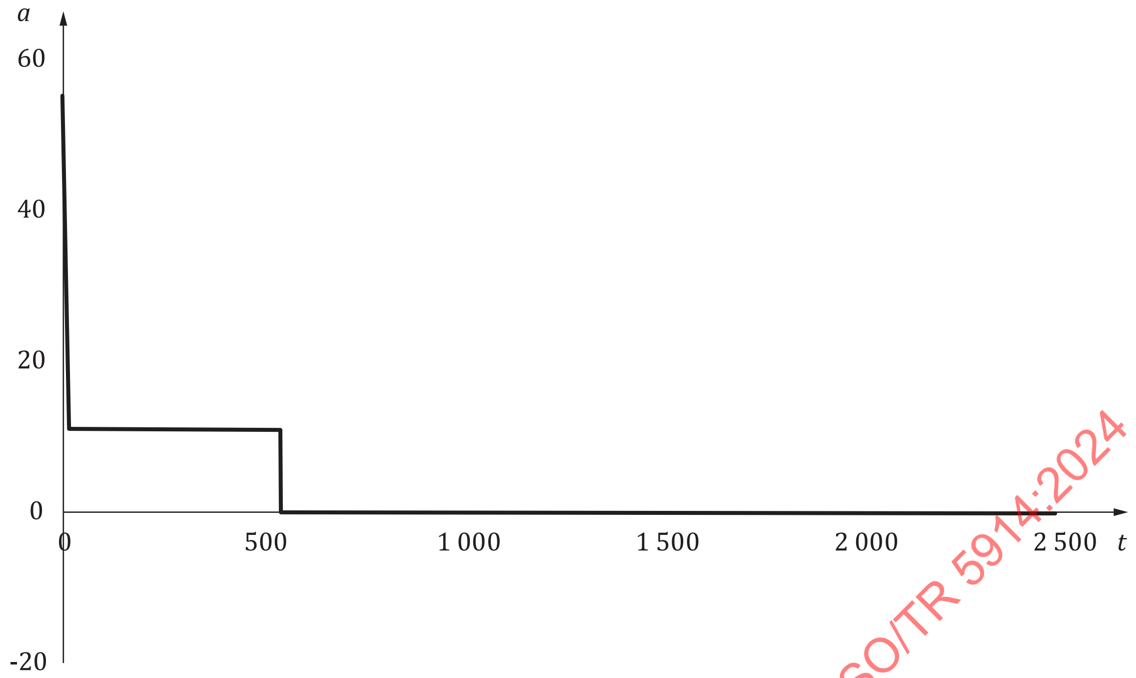


Key

a acceleration (m/s²)

t time (ms)

Figure A.8 — Simplified C4LS “low severity” pulse

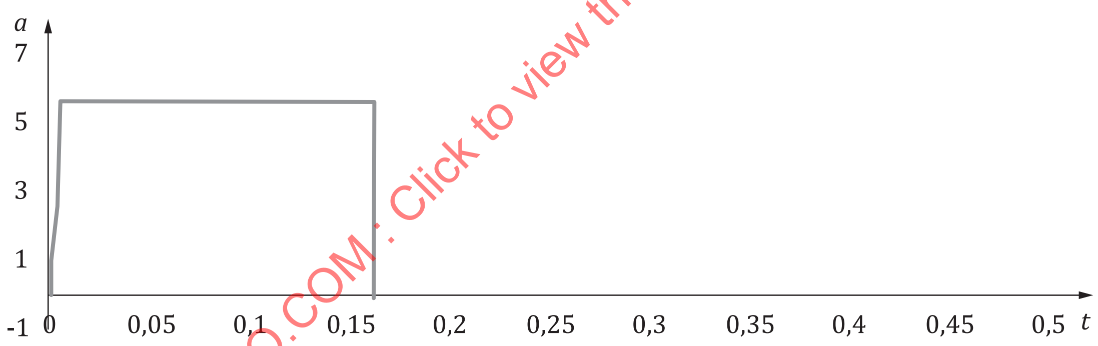


Key

a acceleration (m/s²)

t time (ms)

Figure A.9 — Simplified C8 pulse

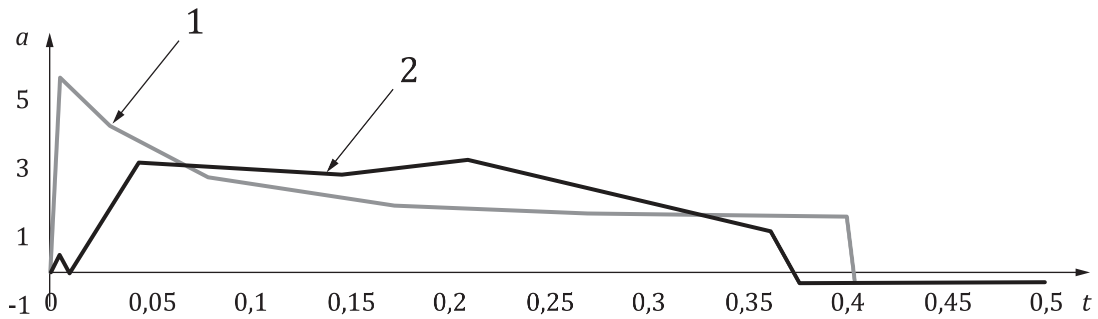


Key

a acceleration (*g*)

t time (s)

Figure A.10 — British Rail research C1 pulse



Key

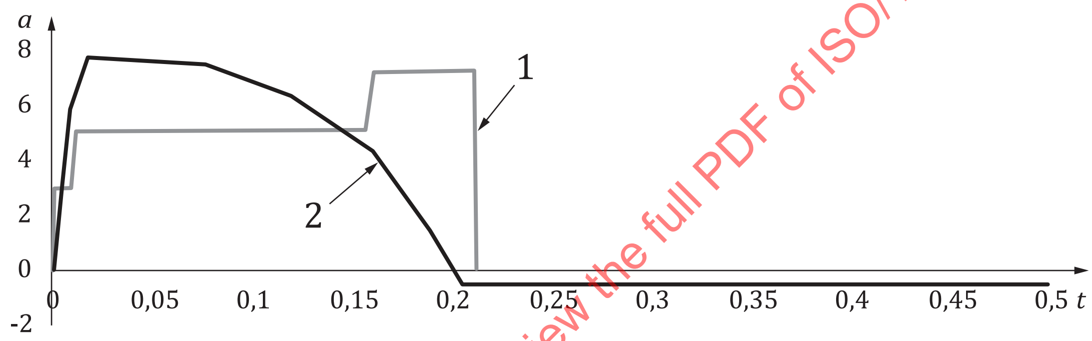
a acceleration (*g*)

t time (s)

1 C2 (British Rail research) pulse

2 C2M (MIRA modified) pulse

Figure A.11 — C2 pulse



Key

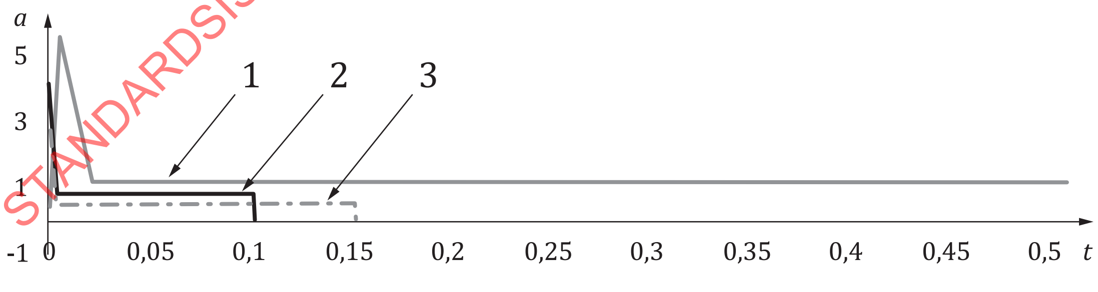
a acceleration (*g*)

t time (s)

1 C3 (British Rail research) pulse

2 C3M (MIRA modified) pulse

Figure A.12 — C3 pulse



Key

a acceleration (*g*)

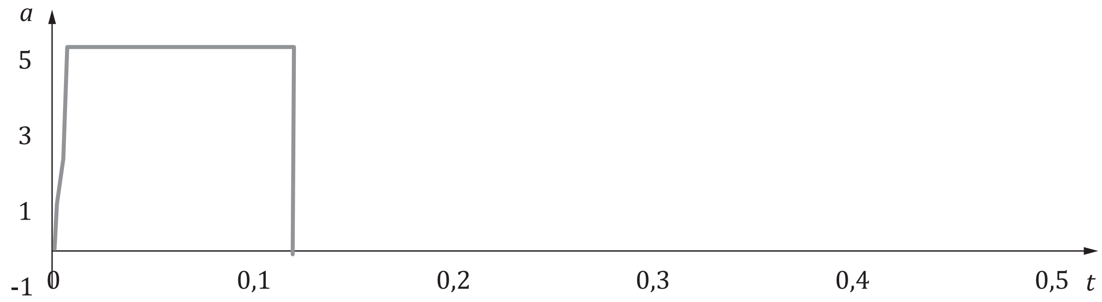
t time (s)

1 C4 (British Rail research) pulse – extends to 0,774 s

2 C4MS (MIRA modified) pulse

3 C4LS (MIRA modified) pulse

Figure A.13 — C3 pulse

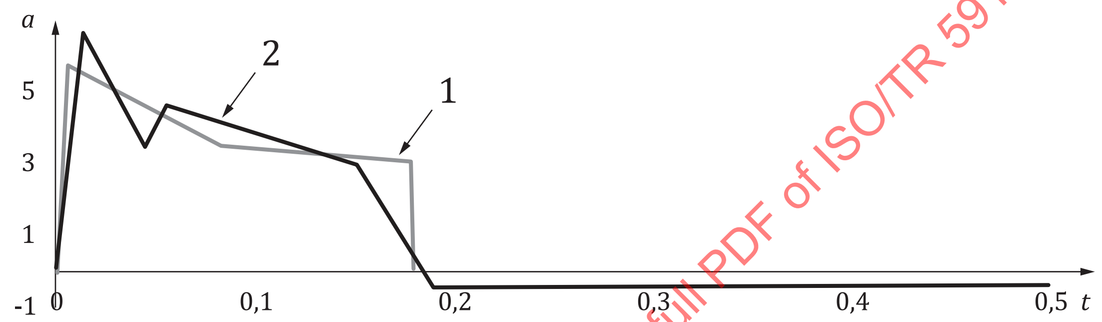


Key

a acceleration (*g*)

t time (s)

Figure A.14 — British Rail research C5 pulse



Key

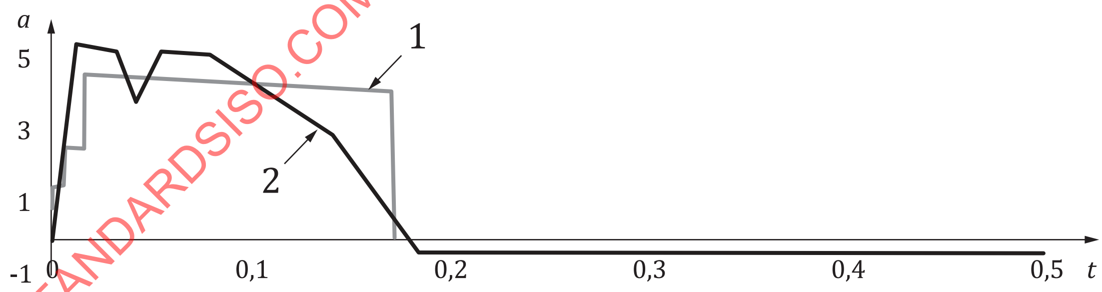
a acceleration (*g*)

t time (s)

1 C6 (British Rail research) pulse

2 C6M (MIRA modified) pulse

Figure A.15 — C6 pulse



Key

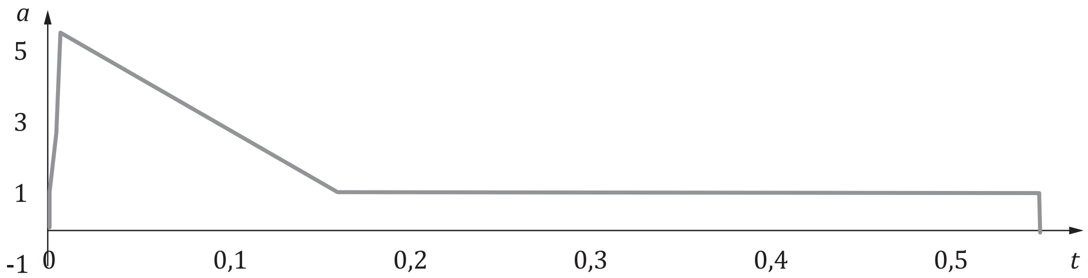
a acceleration (*g*)

t time (s)

1 C7 (British Rail research) pulse

2 C7M (MIRA modified) pulse

Figure A.16 — C7 pulse



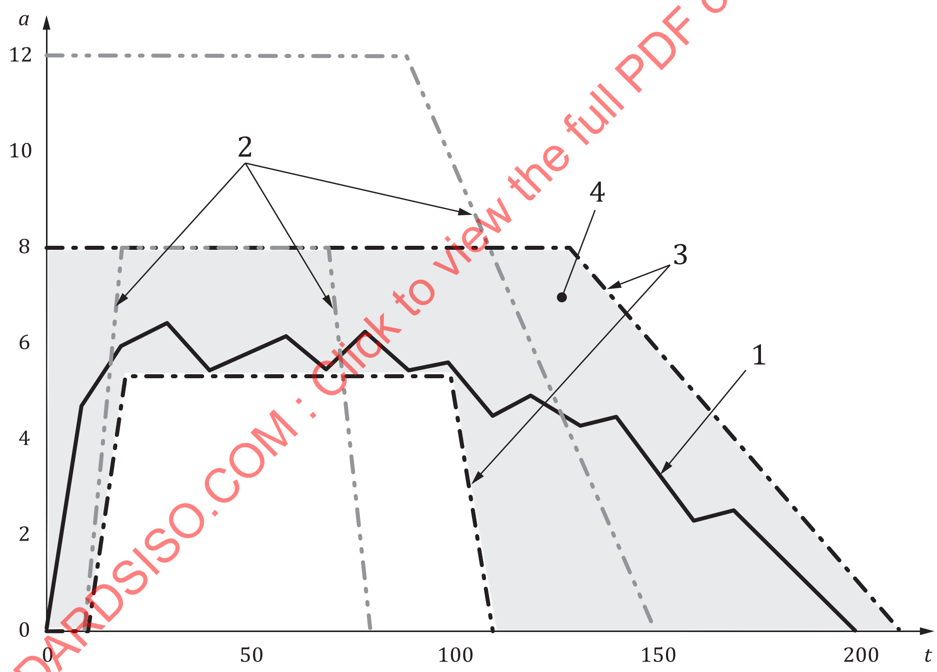
Key

a acceleration (*g*)

t time (s)

Figure A.17 — British Rail research C8 pulse

The proposed pulses were modified yet again in an attempt to align them with the UN/ECE 80[11] automotive pulse; see Figure A.18. This requires a sled Δv of between 30 km/h and 32 km/h (8,3 m/s to 8,9 m/s); not much different from the 9 m/s. However, the UN/ECE 80[11] pulse contained very high acceleration levels (between 8*g* and 12*g*); this can be related to the relatively short "crumple zones" and generally lighter mass of road vehicles. With an anticipated acceleration level of 7*g*, it was agreed to reduce the acceleration but increase the time period to achieve the necessary Δv.



Key

a acceleration (*g*)

t time (ms)

1 C3 Hyge pulse

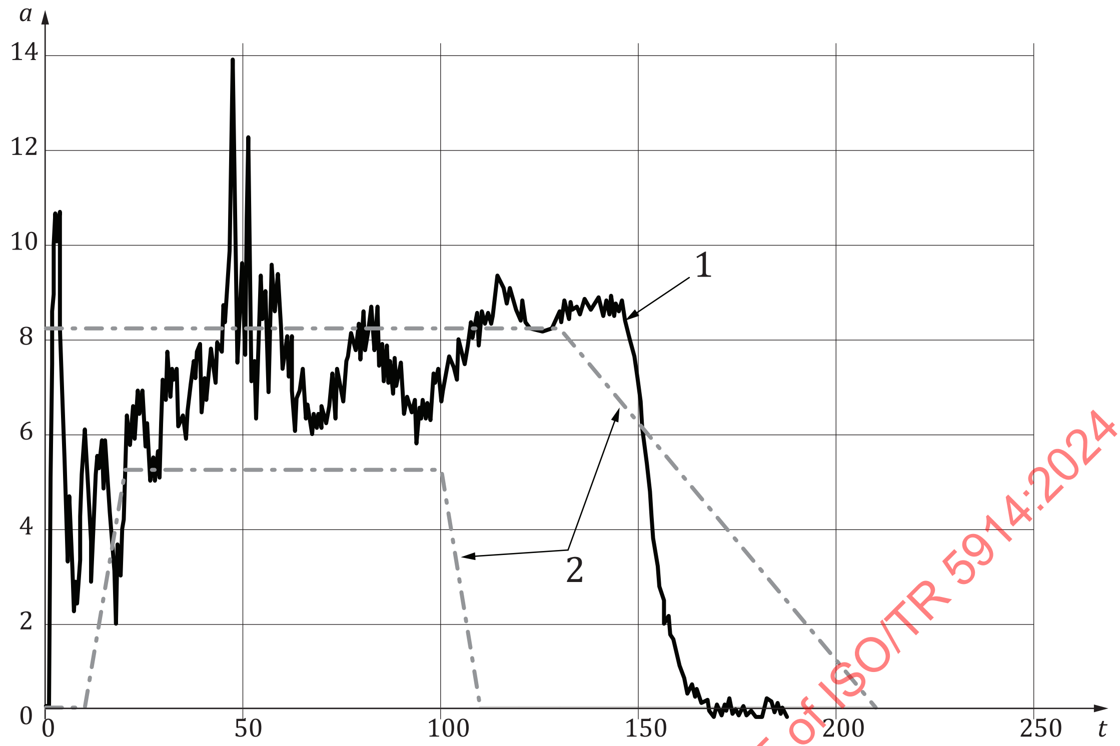
2 UN/ECE 80[11] upper and lower limits

3 proposed railway upper and lower limits

4 proposed railway envelope

Figure A.18 — Design deceleration pulse comparison

One of the activities in the SafeTrain[65] project was a correlation between modelling conducted by GEC Alstom and testing conducted by Cranfield; see Figure A.19.



Key

a acceleration (*g*)

t time (ms)

1 test pulse

2 proposed railway upper and lower limits

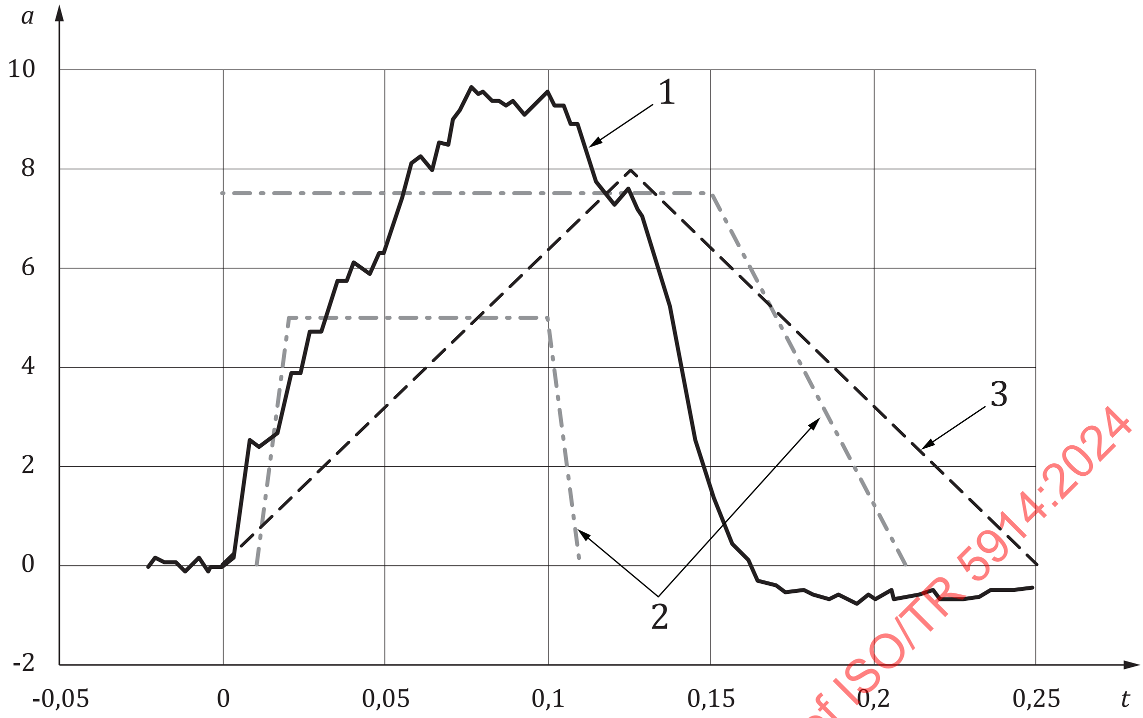
Figure A.19 — Design and test pulse comparison

An analysis of typical train masses under the collision scenarios in EN 15227:2020[19] (with acceleration limits of 5*g* and 7,5*g*) supports the use of the theoretical 5*g* over 100 ms pulse, for all three collision scenarios.

The limits were further revised for GMRT2100 issue 4[13] to align them with the accelerations prescribed at the time for body-mounted equipment and the acceleration limits set out in EN 15227:2020[19]: a lower bound of 5*g* and an upper bound of 7,5*g*.

The draft UNIFE Technical Report[1], along with UIC IRS 50564-3[46], imposes a more restrictive 6*g* upper bound, with the aim of achieving a Δv of between 5 m/s and 6 m/s; however, feedback from some test houses suggests that the resulting corridor is too restrictive and difficult to achieve in practice.

For comparison, the equivalent APTA triangular pulse (see key 3 in Figure A.20)[66] results in a Δv of 9,81 m/s, although a reduction for testing permits this to be reduced to 7,36 m/s:



Key

a acceleration (*g*)
t time (s)
1 test pulse
2 upper and lower limits from GMRT2100[14]
3 APTA triangular pulse

Figure A.20 — Comparison of APTA and GMRT2100 design and test deceleration pulses

The collision scenarios in EN 15227:2020[19] for mainline vehicles are intended to represent:

a) two identical trains colliding;

b) a train colliding with a freight wagon equipped with side buffers (or a heavy-haul locomotive colliding with a freight wagon with a central heavy-duty coupler);

c) a collision with a road vehicle on a level crossing;

d) an impact with a low obstacle.

These scenarios were derived from surveys of rail vehicle collisions in Europe, as noted in References [67], [68] and [69]. EN 15227:2020[19], Annex A, sets out a methodology for assessing the parameters of design collision scenarios, where it is deemed that the four scenarios are not representative. The methodology in EN 15227:2020[19], Annex A, can only be used by non-European operators, as it is effectively prohibited by European legislation (TSIs). It is possible that a potential input to the assessment is the UIC annual safety report[70].

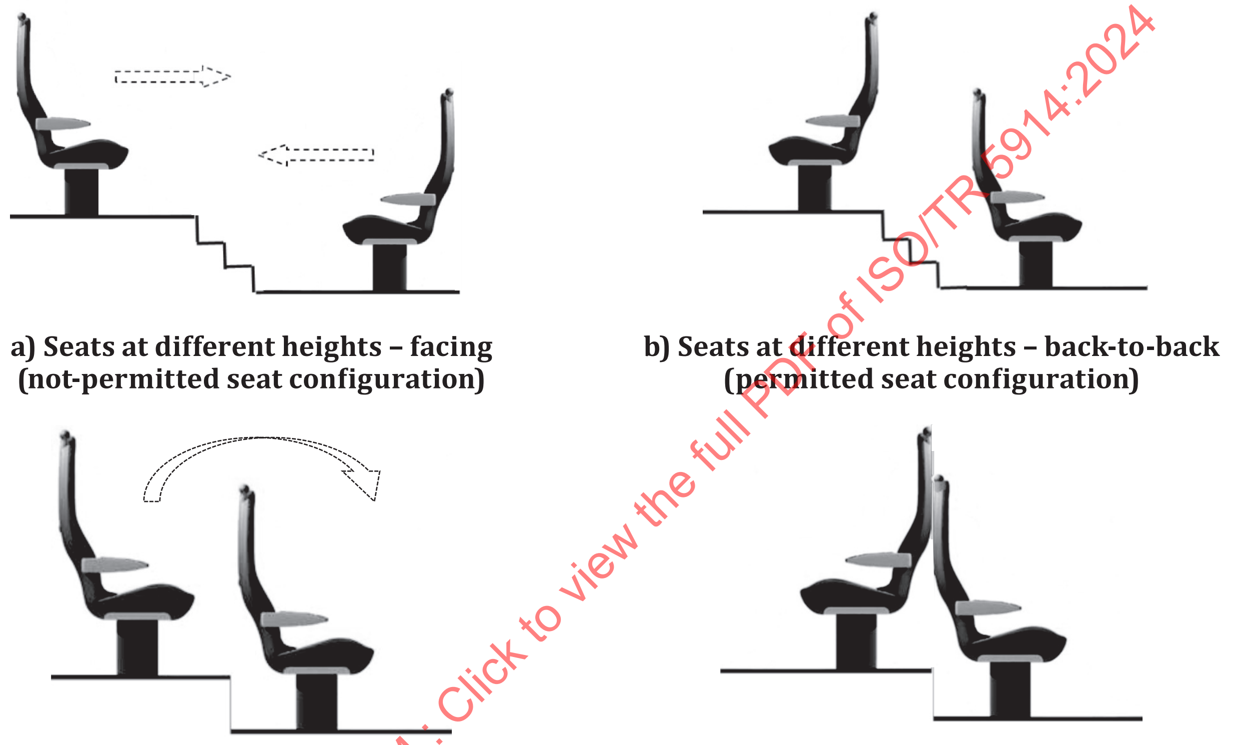
In EN 15227:2008[2)], there was a 7,5*g* deceleration limit imposed for scenario 3, with a 5*g* deceleration limit for scenarios 1 and 2. In EN 15227:2020[19], the decelerations in scenario 3 are a function of the characteristics of the deformable obstacle, which are defined in the standard. (This characteristic is a load-deflection curve with a maximum of 4 500 kN, which would nominally equate to a 7,5*g* instantaneous deceleration for 61-tonne impacting vehicle or a 5*g* instantaneous deceleration for a 92-tonne impacting vehicle.)

2) Cancelled and replaced by EN 15227:2020.

EN 15227:2020[19] modified the acceptance criteria; there is no longer a deceleration requirement in scenario 3, and the limits for scenarios 1 and 2 are dependent on calculation of a moving average over 30 ms or 120 ms, with limits of 10*g* and 5*g*, respectively. It also requires that body-mounted equipment withstands 5*g* as an ultimate case; this is therefore slightly higher than the requirement in EN 12663-1:2010+A1:2014[20] (3*g* × 1,5 ultimate factor is only 4,5*g*), which is unlikely to make much difference in practice.

A.3 Examples of interior layout considerations

Figures A.21 and A.22 illustrate examples of configurations that would be permitted or not permitted when applying GMRT2100[14] in the UK.



a) Seats at different heights – facing (not-permitted seat configuration)

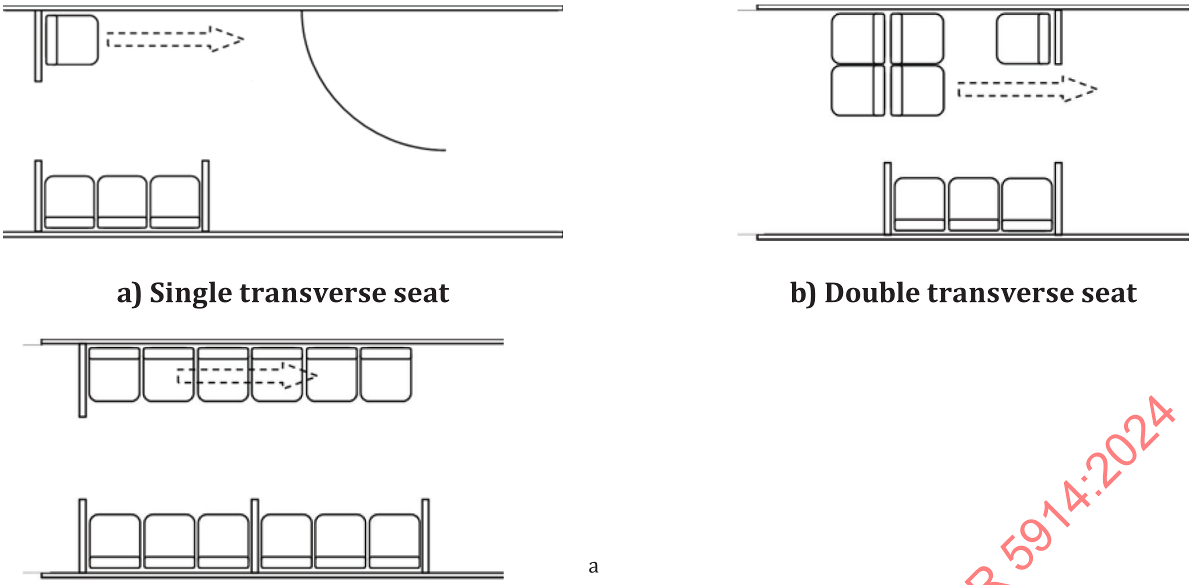
b) Seats at different heights – back-to-back (permitted seat configuration)

c) Seats at different heights – unidirectional (not-permitted seat configuration)

d) Seats at different heights – back-to-back (permitted seat configuration)

NOTE The dotted arrow represents potentially injurious passenger trajectory in a longitudinal collision event.

Figure A.21 — Seating layout configurations



a) Single transverse seat

b) Double transverse seat

c) Longitudinal seating

a This arrangement shows fixed longitudinal seating. Where tip-up seats are used (e.g. to accommodate bicycles), the dividing partition could take the form of an armrest which is raised with the seat, to ensure there is sufficient space for a bicycle.

NOTE The dotted arrow represents potentially injurious passenger trajectory in a longitudinal collision event.

Figure A.22 — Seating layout configurations

A.4 US perspective on structural and interior crashworthiness

A.4.1 Structural crashworthiness requirements

NOTE This clause contains US terminology (such as “grade crossings”).

In September 1994, the US Secretary of Transportation convened a meeting of representatives from all sectors of the rail industry with the goal of enhancing rail safety. The Secretary announced that the DoT would develop safety standards for rail passenger equipment over a five-year period. In November 1994, Congress passed the Federal Railroad Safety Authorization Act of 1994. Under the Act, the Secretary of Transportation tasked the FRA with prescribing regulations establishing minimum standards for the safety of cars used by railroad carriers to transport passengers, with consideration of the crashworthiness of the cars and interior features that can affect passenger safety, among other requirements. The resulting federal regulations were published in 1999 in Title 49 of the Code of Federal Regulations Part 238 (49CFR238[33]) Passenger Equipment Safety Standards (PESS).

Structural requirements for Tier I passenger rail equipment, i.e. equipment operating at speeds not exceeding 201 km/h (125 mph), are prescribed in 49CFR238[33] Subpart C. A principal requirement, which had been industry practice for decades, is that all passenger equipment must resist a minimum static compression end load of 3 559 kN (800 000 lbf) applied along the line of draft, i.e. at the buffer centre line such as EN 12663-1:2010+A1:2014[20] without permanent deformation of the car body structure. Additional requirements are specified for vertical strength of the anti-climb mechanism (445 kN (100 000 lbf)) and horizontal strength at the base of the collision posts (1 334 kN (300 000 lbf)) and corner posts (667 kN (150 000 lbf)).

Structural requirements for Tier II equipment, i.e. equipment operating at speeds exceeding 201 km/h (125 mph), but not more than 257 km/h (160 mph), are identified in 49CFR238[33] Subpart E. These requirements include a minimum energy absorption of 13 MJ in the first two cars at each end of a train, and a peak deceleration of 8*g* on the occupied volume of a car during a 48 km/h (30 mph) head-on impact with a like train.

In 2018, the FRA published new regulations pertaining to Tier I alternative equipment in 49CFR238[33] Appendix G and Tier III equipment, i.e. equipment operating at speeds exceeding 201 km/h (125 mph), but not more than 354 km/h (220 mph) on dedicated track without grade crossings, in 49CFR238[33] Subpart H. Each vehicle that complies with Tier I alternative and Tier III equipment requirements must resist a minimum quasi-static end load applied on the collision load path of:

a) 3 559 kN (800 000 lbf) without permanent deformation of the occupied volume; or

b) 4 448 kN (1 000 000 lbf) without exceeding local plastic strains of 5 % and without vehicle shortening greater than 1 per cent over any 4,57 m (15 foot) length of occupied volume; or

c) 5 338 kN (1 200 000 lbf) without crippling the body structure.

Tier I alternative and Tier III trainsets must also comply with dynamic collision scenario requirements for a 32 km/h (20 mph) like train impact with a cab car leading or a 40 km/h (25 mph) impact with a locomotive leading.

Requirements for crashworthy equipment have two main goals:

— preserve the integrity of the occupied volume;

— limit the severity of secondary impacts.

The first goal is achieved with structural requirements for car body strength and energy-absorbing sacrificial crush zones. The second goal is achieved with interior requirements to compartmentalize occupants, ensure interior fixtures remain attached to the car body, and absorb energy when impacted by occupants. Crashworthy equipment must strike a balance between these two competing goals, recognizing that the car body structural requirements affect the crash pulse to which occupants are exposed in an accident.

A.4.2 Interior crashworthiness requirements

Attachment strength requirements for interior fixtures are defined in 49CFR238.233 and 49CFR238.733. Prior to the publication of the PESS in 1999, US design practice for attachment strength requirements had been based on car body decelerations of 6*g* longitudinally, 3*g* laterally and 3*g* vertically. As noted in the section-by-section analysis contained within the PESS, the FRA determined that, due to injuries caused by broken seats and other loose fixtures observed during accident investigations, 6/3/3*g* design practice was inadequate. Beginning in 1999, interior fixture requirements in the PESS specify that interior fittings within a passenger car must be attached to the car body with sufficient strength to withstand the individually applied accelerations acting on the mass of the fitting: 8*g* longitudinally, 4*g* laterally and 4*g* vertically. The 8*g* longitudinal pulse was based on single degree of freedom collision dynamics analyses. The increase from 3*g* to 4*g* for lateral and vertical accelerations was similarly scaled.

Prior to the 1999 rule, attachment strength was based only on a scalar acceleration value acting on the mass of the interior fixtures. There was no consideration for the mass of occupants impacting interior fixtures or the duration of the car body deceleration, both of which influence fixture attachment and the severity of secondary impacts. There were no requirements for dynamic crash testing to evaluate collision safety for train passengers, even though similar requirements existed for seats in automobiles and planes.

Additional requirements in 49CFR238.233 specify that passenger seats must withstand the longitudinal inertial force of 8*g* acting on the mass of the seat as well as the load associated with the impact into the seatback of an unrestrained 95th-percentile adult male initially seated behind the seat when subjected an 8*g* triangular crash pulse with a duration of 250 ms. This crash pulse is consistent with the structural car body requirements mentioned above.

Beginning in 1999, a series of industry safety standards were published by the American Public Transportation Association (APTA) to address interior crashworthiness associated with passenger seats, cab (driver) seats, interior fixtures and workstation tables, in APTA PR-CS-S-016-99[17], APTA PR-CS-S-011-99[48], APTA PR-CS-S-006-98[47] and APTA PR-CS-S-018-13[50], respectively. These safety standards specify minimum strength, crashworthiness and fire safety requirements for the design and procurement of seats, tables and interior fixtures for use in passenger railcars that are operated on the general railroad system of transportation, regardless of the tier of operation. The passenger seat and table standards specify dynamic sled testing using the 8*g* crash pulse to demonstrate compliance with performance requirements, including component attachment, occupant compartmentalization and injury criteria, to establish a minimum level of crashworthiness. The 8*g* pulse is an idealized representation of the deceleration time history associated with an in-line train collision in which the occupied volume is challenged, i.e. the crush zone is exhausted, and the occupied volume is loaded or crippled, i.e. structural crushing of occupant volume is initiated.

The concept of structural passive safety is to absorb collision energy by judiciously deforming crush zones, typically sections of the car body that are unoccupied. These zones are designed to crush at a lower force than the occupied volume. Energy can be absorbed by crush zones at the ends of cars throughout the train, not only at the collision interface. The effect is to decelerate the moving train gradually while preserving the occupied volume.

The car body acceleration (or deceleration) is proportional to the net force acting on the car body during a collision. The maximum acceleration that a car body will experience is based on the largest reaction force that the car body can generate. This peak force occurs in collisions in which the speed is high enough to begin deforming the occupied volume.

The crashworthiness approach in Europe is driven by EN 15227:2020[19]. The standard limits the car body deceleration to an average of 5*g* over any 120 ms duration and 10*g* over any 30 ms duration. It has been determined that a reasonable and achievable goal is to limit the average deceleration to 5*g* for a collision up to 36 km/h (22,4 mph). This goal is achievable by designing crush zones that deform at lower forces than the preserved occupied volume, as noted above. For equipment built to EN 15227:2020[19], it is likely that the maximum deceleration that a car body will experience will occur at a collision speed over 36 km/h (22,4 mph).

Presumably, the 36 km/h (22,4 mph) collision requirements in EN 15227:2020[19] were based on a preponderance of low-speed accidents, current structural passive safety technology and advanced signalling controls. While it is practical to design structural passive safety systems to preserve occupied volume only up to a given speed, it is also practical to ensure that occupants are protected from secondary impacts with seats, tables and interior fixtures at the maximum deceleration that a car body can experience, especially when it is likely to occur with a collision speed only slightly higher than the structural passive safety design collision scenario. It is not possible to preserve the occupied volume for all collisions, but it is probably possible to limit secondary impact injuries for higher speed collisions. This has been the approach in the US in requiring design and analysis using an 8*g* crash pulse, which is based on an in-line collision with sufficient speed to challenge or cripple the occupied volume.

Depending on the structural car body design and train configuration, the occupant volume is likely to be compromised at in-line train collision speeds between 40 km/h (25 mph) and 48 km/h (30 mph). A collision in which the occupant volume is crippled represents the most severe crash pulse that the equipment will experience. Collisions at higher speeds will result in more occupant volume crush, but not higher car body decelerations. Thus, while it is reasonable to specify a design collision scenario with a specific collision speed, this structural design collision speed does not need to limit the interior design collision speed. Defining the crash pulse based on occupant volume crippling can ensure a high level of protection from secondary impacts with seats and tables in a collision of any speed.

The 8*g* pulse was originally based on computer analyses of in-line train-to-train collisions in which the cars remain in-line and the occupant volume was challenged or crippled. It was subsequently supported by data from a series of full-scale train impact tests,[71][72][21] as well as collision dynamics analyses of selected accidents.[73][74] The triangular shape of the 8*g* pulse was informed by the 16*g* 180 ms crash pulse used for Federal Aviation Administration (FAA) requirements to test airplane seats.

Annex B
(informative)

Accident statistics

B.1 European accident statistics

The European Union Agency for Railways publishes annual reports[75][76] into the progress of improving safety across the EU’s railways. Clearly, the data for 2020 will be affected by the reduction in the numbers of passenger journeys due to the COVID-19 pandemic, but there are still several key points worthy of note, as follows:

— “Significant accidents and resulting casualties have decreased steadily since 2010; the safety levels registered for 2020 are historically the highest. Major accidents resulting in five or more fatalities have become rare: no such accidents have occurred in the past 2 years, and only two have been registered in the past four years. The number of fatal train collisions and derailments has decreased continuously since 1990. In 2020, though, a peak (of eight such accidents) was registered.”

— “The rates of significant accidents, fatalities, and fatalities and weighted serious injuries (FWSIs) per million train-km have decreased substantially since 2010. Despite the reduction in passenger fatalities, taking into account the significant drop in passenger-km (due to the COVID-19 pandemic), passenger fatality rate has increased compared with 2019, showing a slightly rising trend since 2017.” ... “After a significant decrease until 2018, both the railway passenger fatality rate and the railway employee fatality rate show a slightly increasing trend in the past 2 years.”

— “Despite an overall decrease in the number of significant accidents since 2010, the number of ‘internal’ accidents (collisions, derailments, fires in rolling stock and other accidents) is stagnating and the overall toll of railway accidents remains high: the economic cost of significant accidents alone was estimated at about EUR 3,2 billion in 2020. Despite an overall decrease in the number of significant accidents since 2010, the number of ‘internal’ accidents (collisions, derailments, fires in rolling stock and other accidents) is stagnating and the overall toll of railway accidents remains high: the economic cost of significant accidents alone was estimated at about EUR 3,2 billion in 2020.”

— “In total, 1 331 significant accidents, 687 fatalities and 469 serious injuries were reported in the EU-27 countries in 2020, the lowest values ever recorded. The 12 % decrease in significant accidents between 2019 and 2020 is statistically significant; the difference between the 2020 figure and the average of the four preceding years is also significant. The decrease occurred across all accident categories except collisions and other accidents; statistically significant reductions in serious injuries, fatalities and suicides have also been observed. However, collisions of trains and other accidents increased in 2020 compared with 2019 and with the average for 2016–2019.”

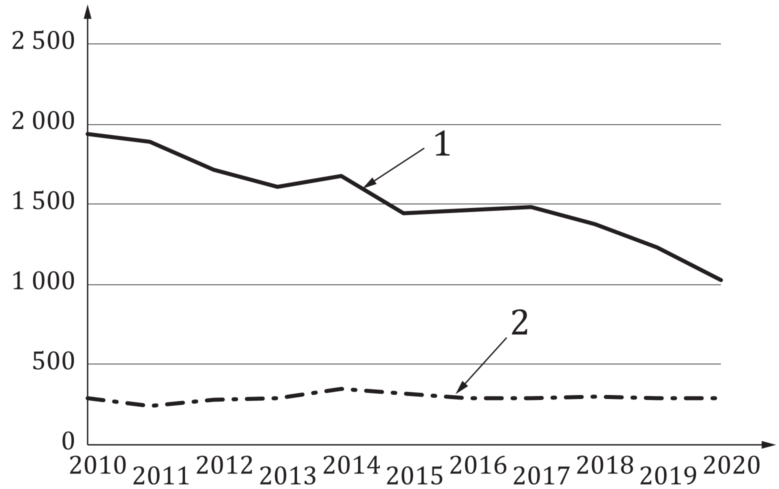
— “Fatal train collisions and derailments are situated between significant and major accidents; despite the downwards trend in recent years, in 2020 eight fatal collisions and derailments were registered. The accident rates (taking into account the underlying changes in traffic volume) follow the same pattern, with the 5-year moving average decreasing steeply since 1990 but flattening in recent years.”

— “The overall fatality rate in 2020 was around 0,2 fatalities per million km (one fatality for every 5 million train-km on average), whereas the overall passenger fatality rate was 0,046 passenger fatalities per billion passenger-km (around one fatality for every 22 billion passengers-km).”

— 2022 (2020 data) collisions and derailments represent around 2,5 % of all railway fatalities.

Unfortunately, most of these reports do not include the age of the rolling stock concerned, so is it not possible to draw any conclusions regarding differences between older trains and newer, EN 15227[19]-compliant trains.

Figures B.1 to B.3 give accident data for the EU.



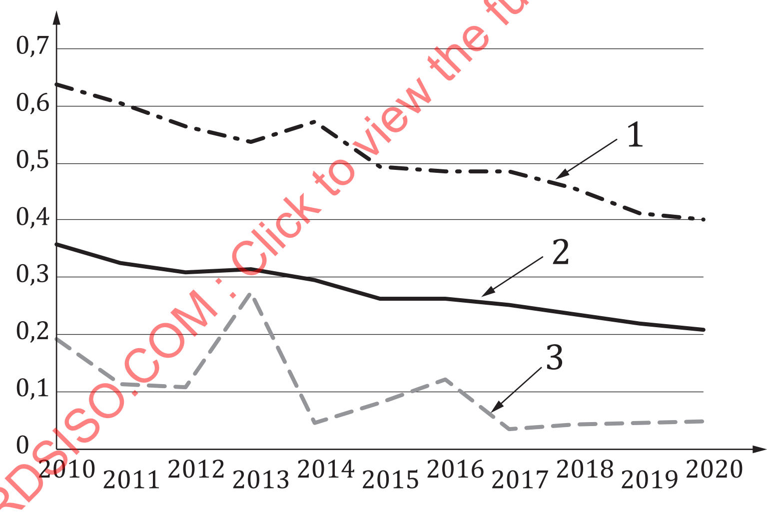
Key

1 number of accidents to persons and level crossing accidents

2 number of collisions, derailments, fires in rolling stock and other accidents

NOTE The source of the data is Common Safety Indicators (CSIs) as reported by National Safety Authorities (NSAs) to the European Agency for Rail (ERA).

Figure B.1 — Number of railway “internal” and “external” significant accidents (EU-27, 2010 to 2020)



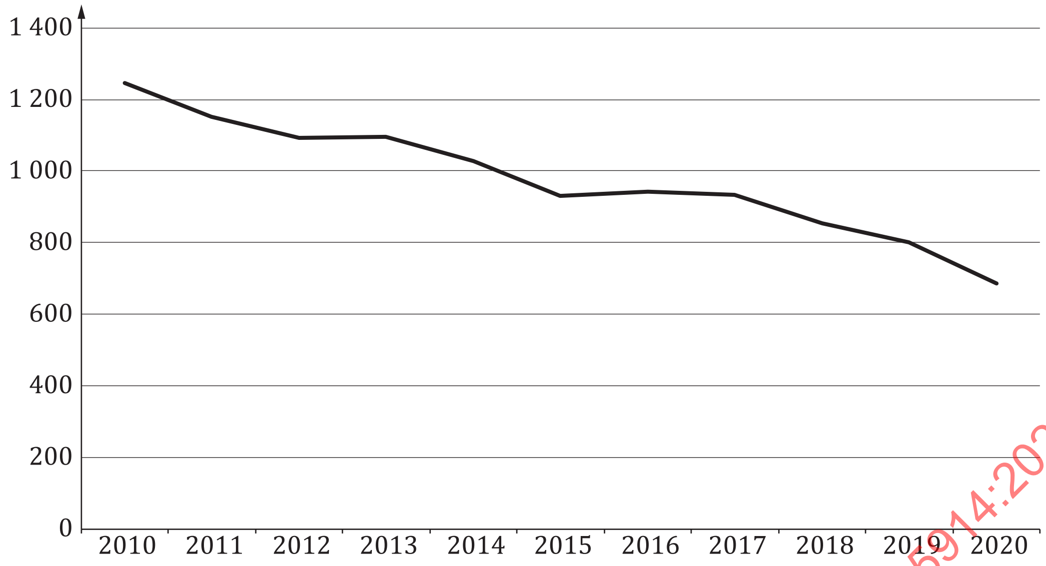
Key

1 significant accident rate per million train km

2 fatality rate per million train km

3 passenger fatality rate per billion passenger km

Figure B.2 — Trends in accident and fatality rates (EU-27, 2010 to 2020) per million train-km



NOTE Source: Reference [95].

Figure B.3 — Number of persons killed in railway accidents (EU, 2010 to 2021)

B.2 US passenger rail accident statistics

To put US accident statistics in context, it is worth highlighting some of the legislative initiatives and regulatory changes that have been implemented to improve safety of passenger train operations over the last 20 or more years. Rail equipment can have a useful life of 30 to 40 years. As a result, it can take decades to realize the full benefit of new regulations and standards implemented to improve rail safety.

The US structural and interior crashworthiness regulations and safety standards are described in Annex A. Measures have also been taken to prevent accidents from occurring in the first place. Congress passed the Rail Safety Improvement Act (RSIA) in 2008, which directed the FRA to mandate the implementation of positive train control (PTC). In late 2020, PTC was fully implemented for freight and passenger trains, which will prevent many types of passenger train accidents, such as train-to-train collisions and overspeed derailments.

Also to minimize the occurrence of accidents, the FRA has made several amendments to the Track Safety Standards specified in the Code of Federal Regulations, Title 49, Part 213 (49CFR213)[77]. The goal of these amendments has been to improve track quality and promote the safe interaction of rail vehicles with the track over which they operate. The focus of the amendments is briefly described below:

— 1998: The FRA amended the Track Safety Standards (49CFR213) to update and enhance its track safety regulatory program, including standards specifically addressing high speed train operations up to 200 mph.

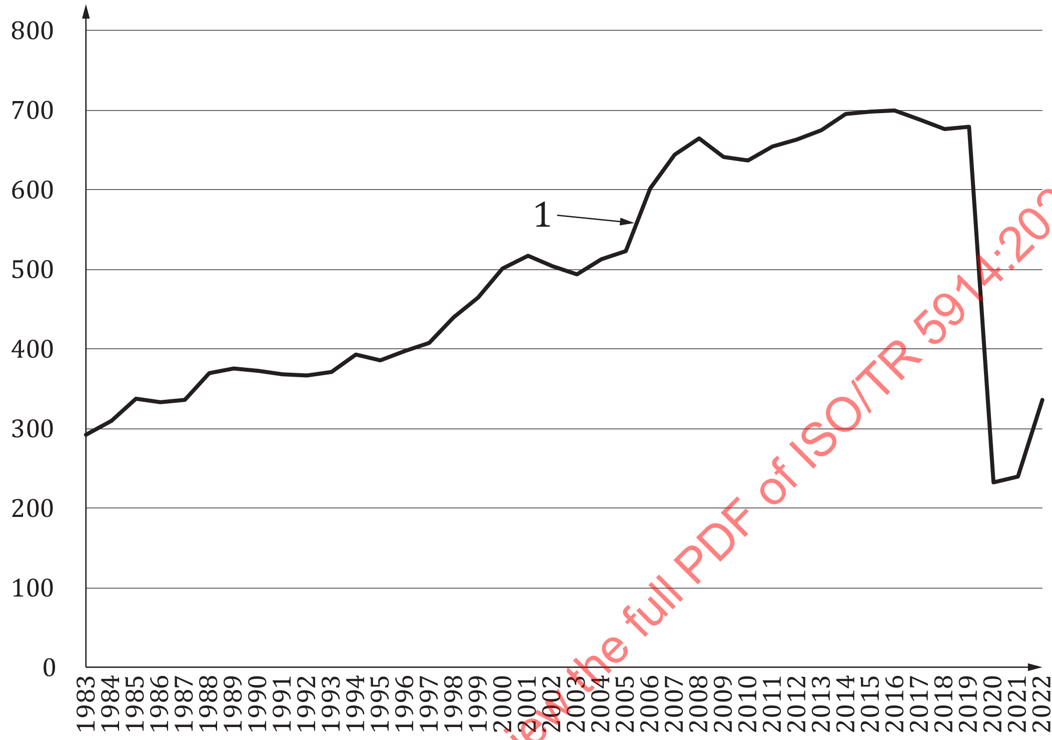
— 2009: The FRA amended the Track Safety Standards (49CFR213) to promote the safety of railroad operations over continuous welded rail (CWR).

— 2011: The FRA amended the Track Safety Standards (49CFR213) to promote the safety of railroad operations over track constructed with concrete crossties.

— 2013: The FRA amended the Track Safety Standards (49CFR213) to promote the safe interaction of rail vehicles with the track over which they operate under a variety of conditions at speeds up to 354 km/h (220 mph). The final rule revised standards for track geometry and safety limits for vehicle response to track conditions.

— 2014: The FRA amended the Track Safety Standards (49CFR213) to enhance rail flaw detection processes. The FRA established minimum qualification requirements for rail flaw detection equipment operators, as well as revising requirements for effective rail inspection frequencies, rail flaw remedial actions and rail inspection records.

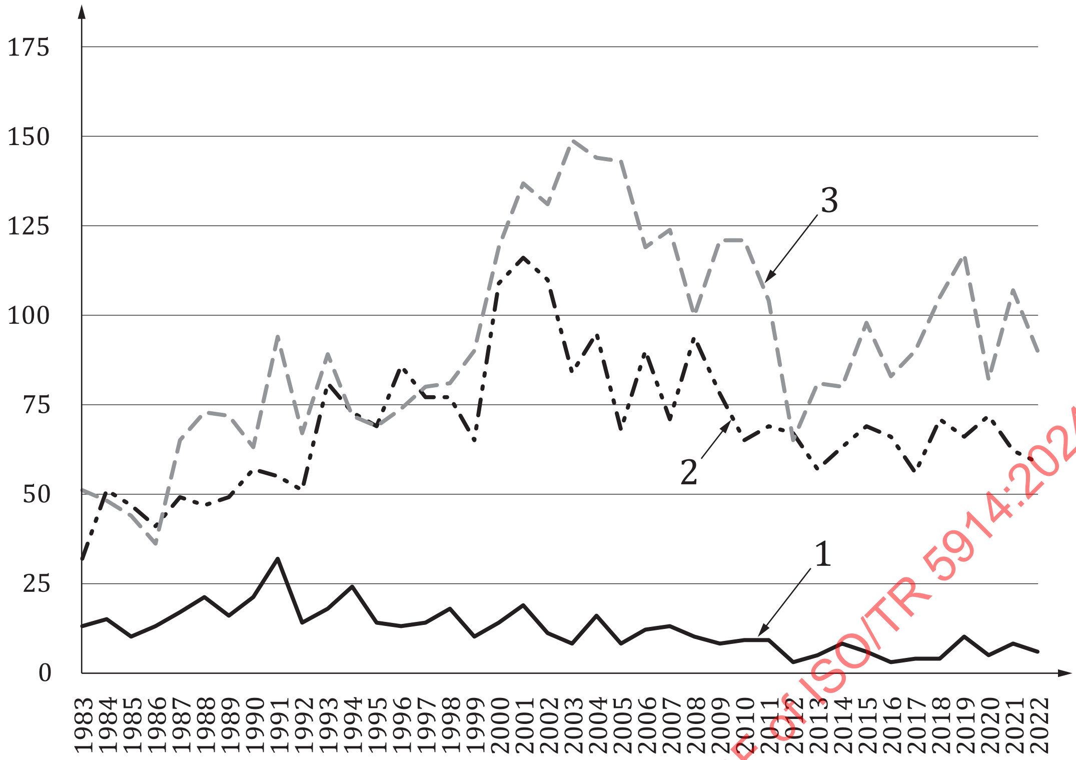
The statistics used for Figures B.4 to B.8 include 40 years of passenger rail history. Included in the plots are commuter and intercity train accident data, but not subway, tram or grade-crossing accident data. The fatality/injury data include passengers and crew on passenger trains only. All trendlines are linear. All plots were developed from accident data publicly from the FRA, see Reference [93].



Key

1 passengers transported (millions)

Figure B.4 — US annual commuter and intercity passengers (millions), 1983 to 2022



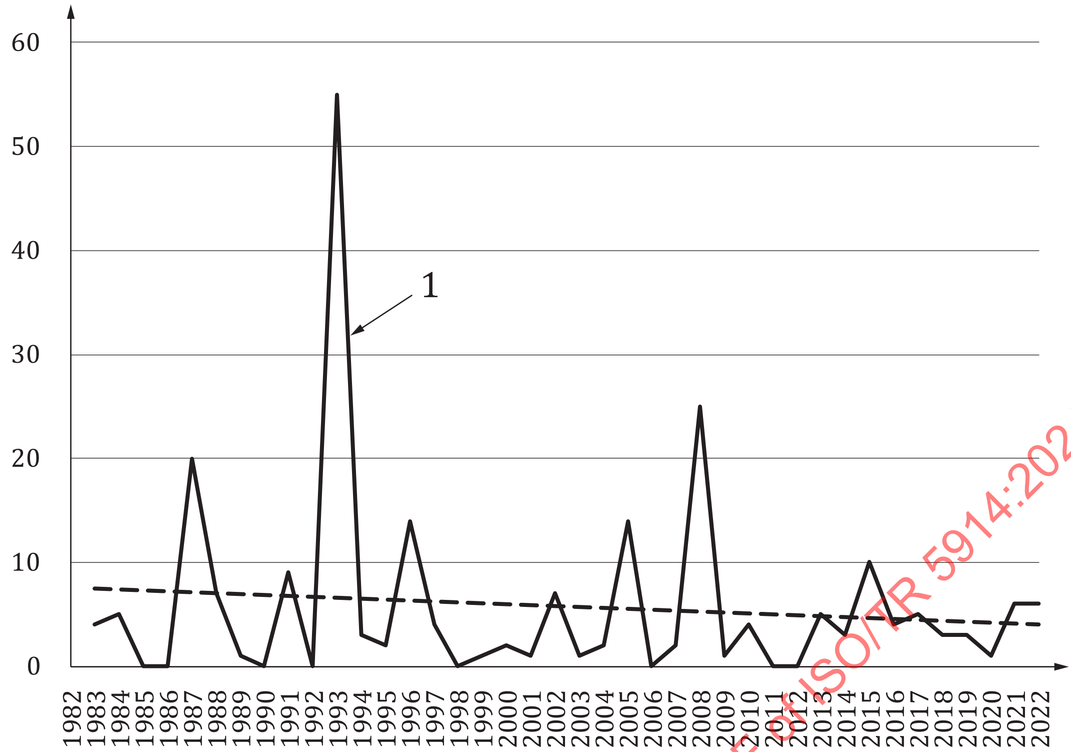
Key

1 collisions

2 derailments

3 other types, e.g. obstructions

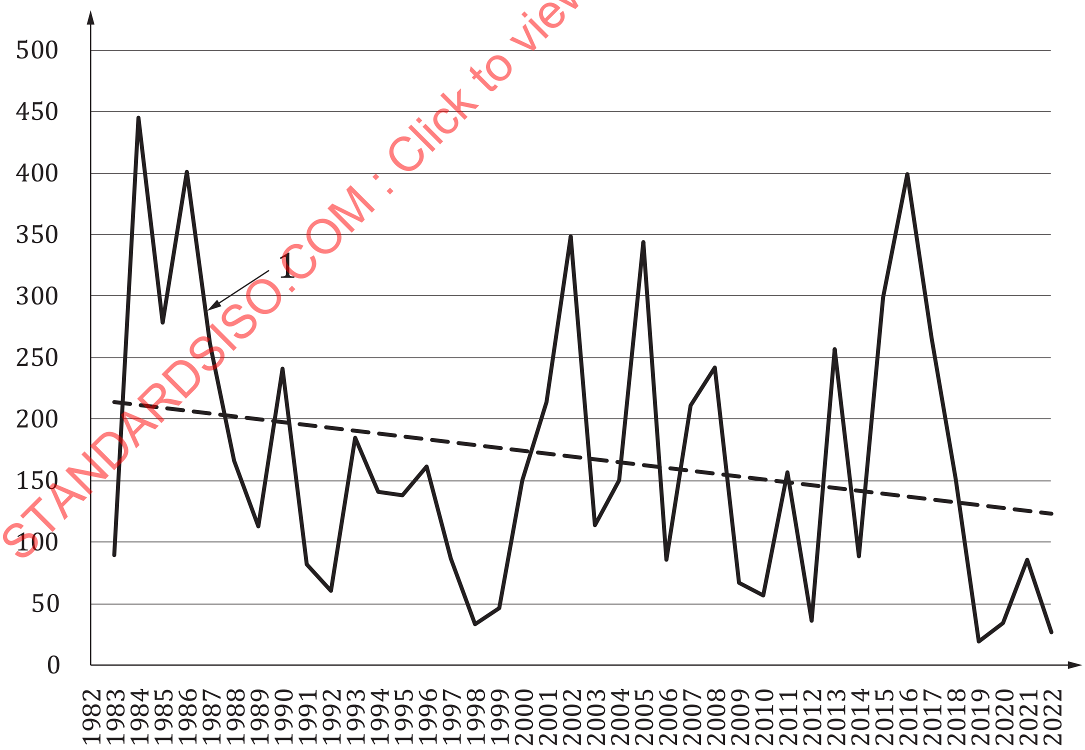
Figure B.5 — Number of US passenger train accidents by type



Key

1 fatalities

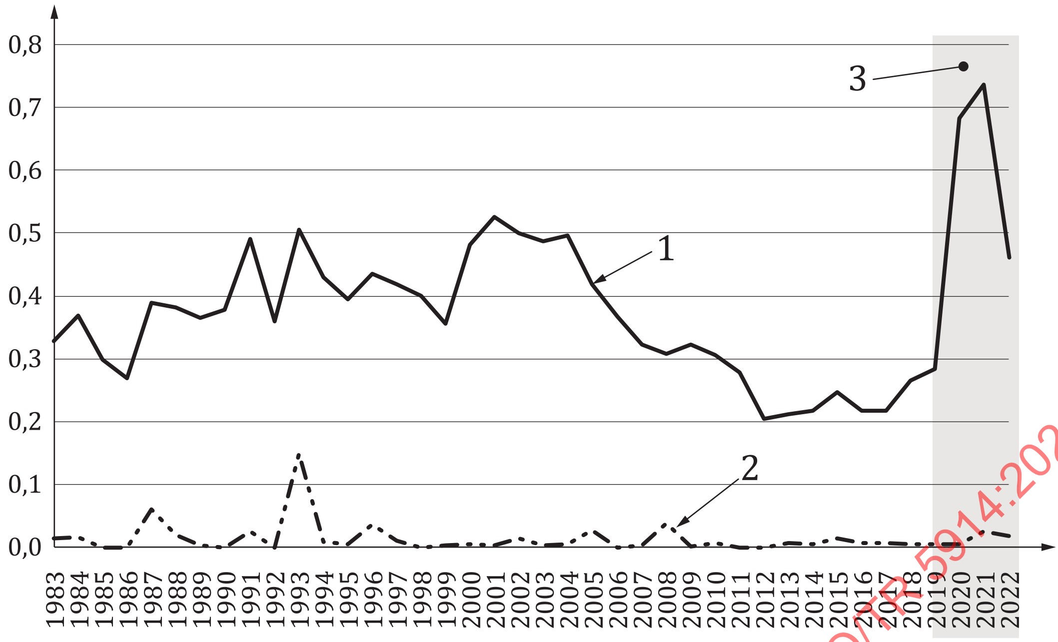
Figure B.6 — Number of US passenger train accident fatalities



Key

1 injuries

Figure B.7 — Number of US passenger train accident injuries



Key

1 train accidents per million passengers transported

2 train fatalities per million passengers transported

3 ridership reduction due to the COVID-19 pandemic

NOTE Dotted lines show the linear trend.

Figure B.8 — Rate of US passenger train accidents and fatalities

Observations:

— Passenger train ridership had been increasing until the effects of the COVID-19 pandemic started in 2020.

— All types of passenger train accidents have been decreasing since the early 2000s.

— Injuries and fatalities from passenger train accidents also have been decreasing.

— The overall safety improvements are most likely attributed to several factors, including:

  — the introduction of new equipment that is compliant with structural and interior collision safety regulations and standards;

  — gradual removal of aging, non-compliant equipment from service;

  — implementation of PTC;

  — 22 % complete in 2016;

  — 100 % complete in 2020;

  — improved track safety standards.

Accident-avoidance strategies such as PTC and improved track safety standards can reduce the number of accidents. Collision mitigation strategies such as structural and interior crashworthiness regulations and standards can minimize the consequences of accidents. Both strategies are necessary and complementary to reduce the total number of injuries and fatalities for passengers and crew travelling on passenger trains.

B.3 Japanese accident statistics

B.3.1 General

In October 2008, Japan Transport Safety Board (JTSB) was launched as an administrative body based on Article 3 of the National Administrative Organization Act, the so-called “Article 3 Commission”, and merged the investigation functions of the railway and air accident investigation commission as well as the marine accident inquiry agency.

As a new organization, the scope of investigation has increased to three modes: railway, air and marine accidents.

Their aim is to:

a) Conduct investigations to determine the causes of accidents and serious incidents involving railways, aircraft and ships, as well as the causes of damage caused by accidents.

b) Encourage improvements by providing recommendations and opinions to related administrative agencies and parties involved in accidents etc., regarding policies and measures for preventing the recurrence of accidents and incidents and reducing damage caused by accidents.

c) Conduct investigations and research necessary for promoting the measures of JTSB, such as accident investigations, recurrence prevention and damage mitigation.

They not only investigate the cause of the accident, but also publish the reports and accident statistics every year.

Until the inauguration of JTSB, these research and publication activities were led by Aircraft and Railway Accidents Investigation Commission (ARAIC), which was a commission belonging to Japan’s Ministry of Land, Infrastructure and Transport (MLIT).

Statistics other than accidents, such as train ridership, have been published by MLIT.[78]

This annex describes the railway accident statistics published by JTSB and ridership by MLIT, respectively, from 2012 to 2022. It considers accidents in railway operations, but excluding trams. In Japan, there is no category for “heavy rail” or “urban rail” and these are included. However, trams are eliminated because they do not comply with the scope of this document.

Regarding accidents at level crossings, accidents with pedestrians, motorcycles and bicycles are also eliminated. Only accidents with automobiles are described.

This annex is based on a report published by JTSB[79] and therefore only includes cases investigated by JTSB.

B.3.2 Number of accidents

JTSB investigates the following types of accidents:

a) train collision;

b) train derailments (except those relating to snow plough cars at work);

c) train fire;

d) other accidents:

   1) those resulting in the deaths of passengers, crew members, etc.;

   2) those resulting in five or more casualties (limited to those resulting in deaths);

   3) those occurring at level-crossings without a gate and resulting in deaths;

   4) those resulting in one or more fatalities and deemed likely to be caused by wrong operation by railway staff or by breakdown, damage or destruction of vehicles or railway facilities, etc.;

5) only those cases deemed to be particularly exceptional;

e) serious incidents.

JTSB investigates the accidents and publishes reports for each one, as well as a summary in its annual report.

The number of railway accidents in this decade is shown in Figure B.9.

These accidents are classified in four categories: fire, derailment, collision and level-crossing accidents.

NOTE Accidents with pedestrians, motorcycles and bicycles are not counted, as mentioned in B.3.1.

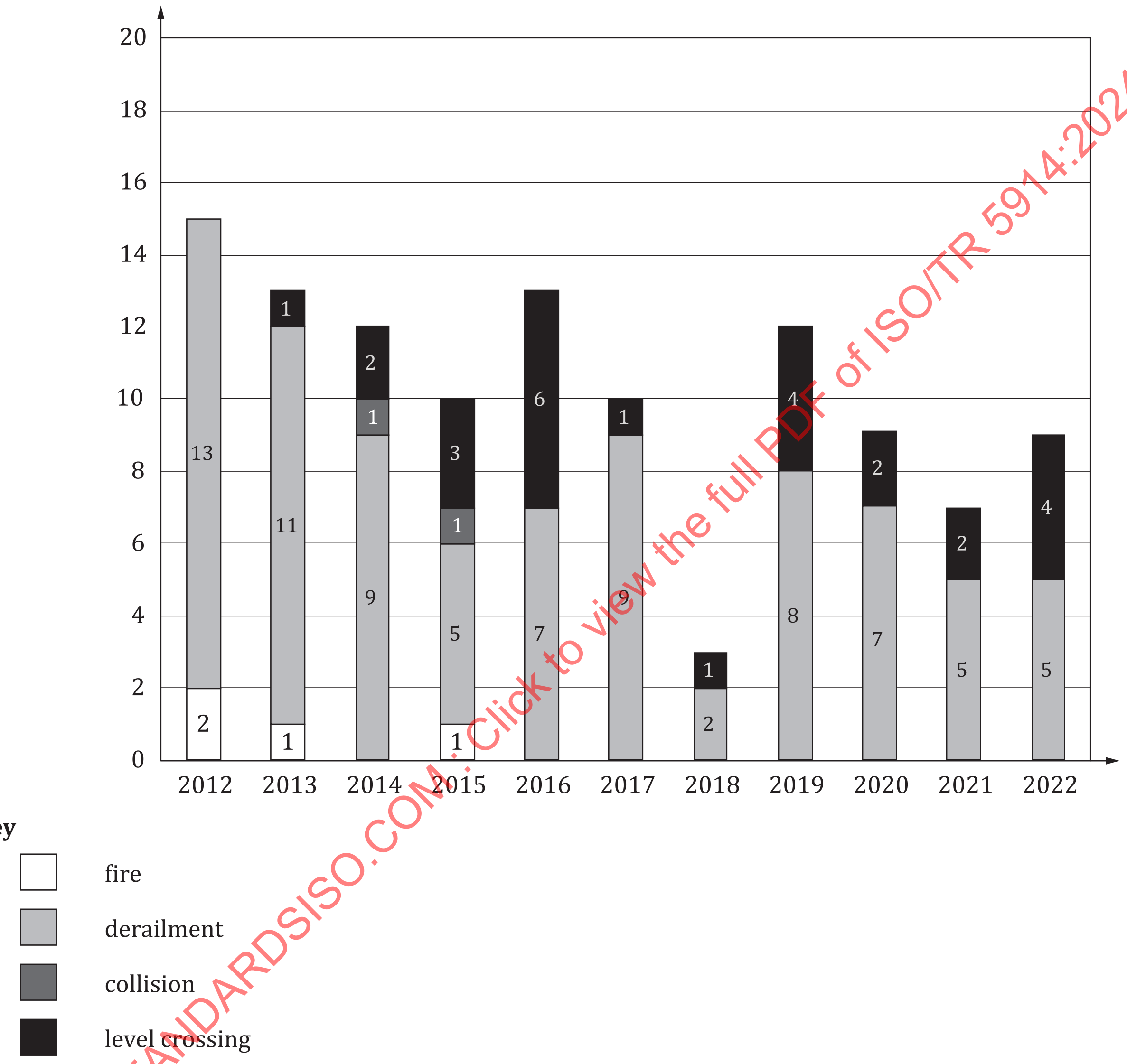


Figure B.9 — Number of railway accidents in Japan, 2012 to 2022

B.3.3 Fatalities and injuries in railway accident

The numbers of fatalities and injuries are shown in Figure B.10. The numbers do not include fatalities and injuries outside of trains, such as pedestrians and car drivers.

The definitions of fatalities and injuries (heavy injury, minor injury) in Japan are:

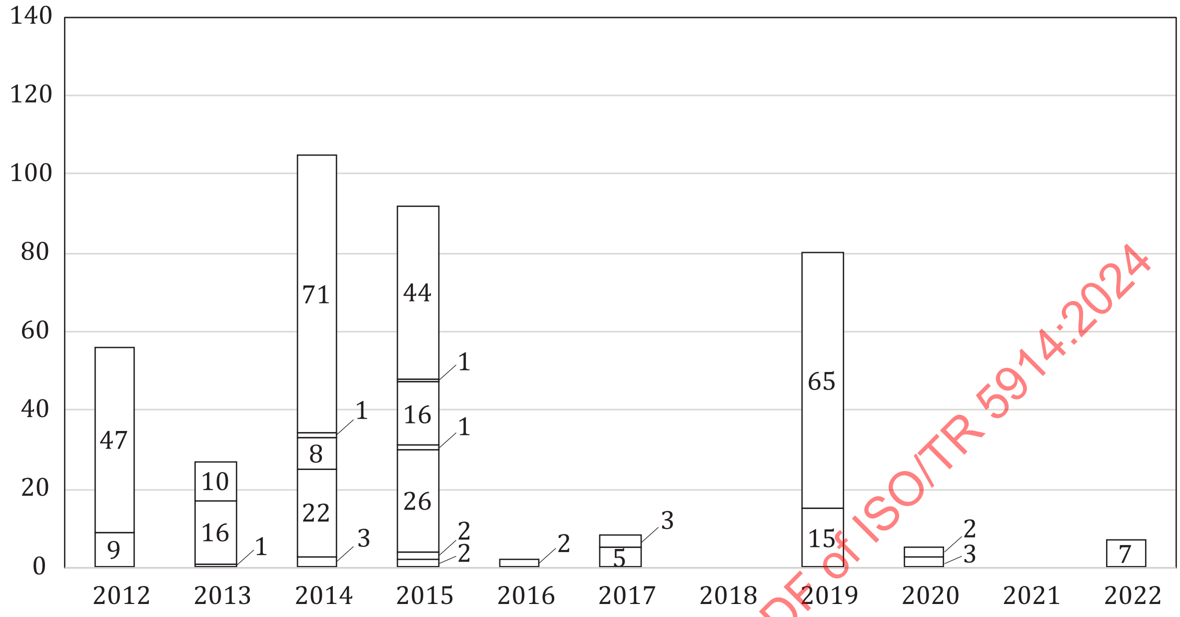
— fatality resulting from a traffic accident occurring within 24 h of the accident;

— serious injury resulting from a traffic accident requiring medical treatment for 30 days or longer;

— slight injury resulting from a traffic accident requiring medical treatment for less than 30 days.[94]

NOTE These definitions differ from 3.12 to 3.16.

Also, the status of some injuries is “unclassified” when injury levels were unknown.



Key

2012: derailments: 9 fatalities, 47 slight injury

2013: derailments: 1 fatality, 16 slight injury; level crossing accidents: 10 slight injury

2014: derailments: 3 fatality, 22 slight injury, 8 unclassified; collisions: 1 serious & 71 slight injury

2015: fire: 2 fatality, 2 serious & 26 slight injury; derailments: 1 fatality, 16 slight injury; level crossing: 1 serious & 44 slight injury

2016: derailments: 2 slight injury

2017: derailments: 5 slight injury, unclassified

2018: —

2019: derailments: 15 fatality, 65 slight injury

2020: derailments: 3 slight injury; level crossing: 2 slight injury

2021: —

2022: derailments: 7 slight injury

Figure B.10 — Number of fatalities and injuries in railway accidents in Japan, 2012 to 2022

On 30 June 2015, there were two fatalities recorded, but this case was a criminal case, in which one man committed suicide in Shinkansen by burning himself and an old lady was found dead after being overcome by smoke. This is the only fatality case during the period.[80]

There were two collision cases. One occurred on 15 February 2014 when, due to heavy snowfall in Tokyo, a Tokyu commuter train failed to stop properly. The brake force could not be obtained because of the significant reduction of the coefficient of friction between the surface of the brake shoe lining and the tread of the wheel due to snow.[81]

The other case occurred on 17 February 2015 when a shunting locomotive failed to stop at its predetermined position and disturbed the adjacent truck, causing the freight train to collide with the shunting locomotive.[82]

B.3.4 Accident rates in Japan

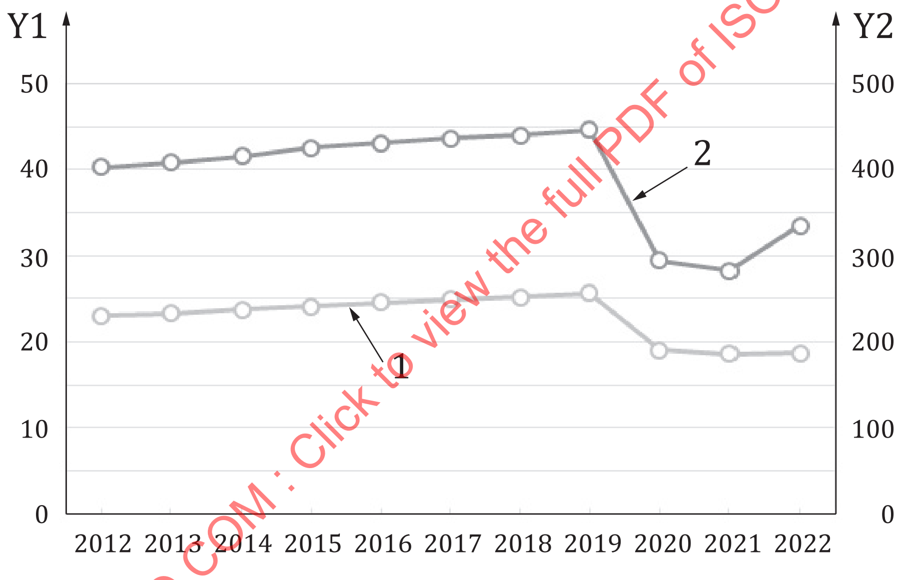
The accident rates were calculated and summarized using the accident statistics from JTSB and train operation statistics from MLIT. The latter depicted annual data within the Japanese fiscal year (April to March), therefore the data were recalculated into the ordinary year (January to December).

Also, in 2022, Japan suffered from the COVID-19 pandemic. Its effect clearly appeared in Japanese statistics. The Japanese government did not impose a curfew or lockdown like in other countries due to constitutional regulations (there is no such legislation in Japan), but instead recommended to close schools and offices. On 7 April 2020, the first state of emergency was declared for the first time in Japan. People in Japan were asked not to go outside and stay home; thus, the number of passengers and commuters plummeted. The number of passengers and train services plummeted sharply from 2020 to 2022. Although the number of passengers recovered in 2022, but the number of trains has not fully recovered, because train operators are reluctant to raise the number of trains until they are satisfied that the recovery of passengers is sufficient.

Figures B.11 and B.12 show the number of passengers and train services.

However, the rate of accidents (see Figure B.13) and the rate of fatalities (see Figure B.14) do not show significant changes during this period.

Derailment and level-crossing accidents seem to be lower than other years, but 2017 is lower than these years.



Key

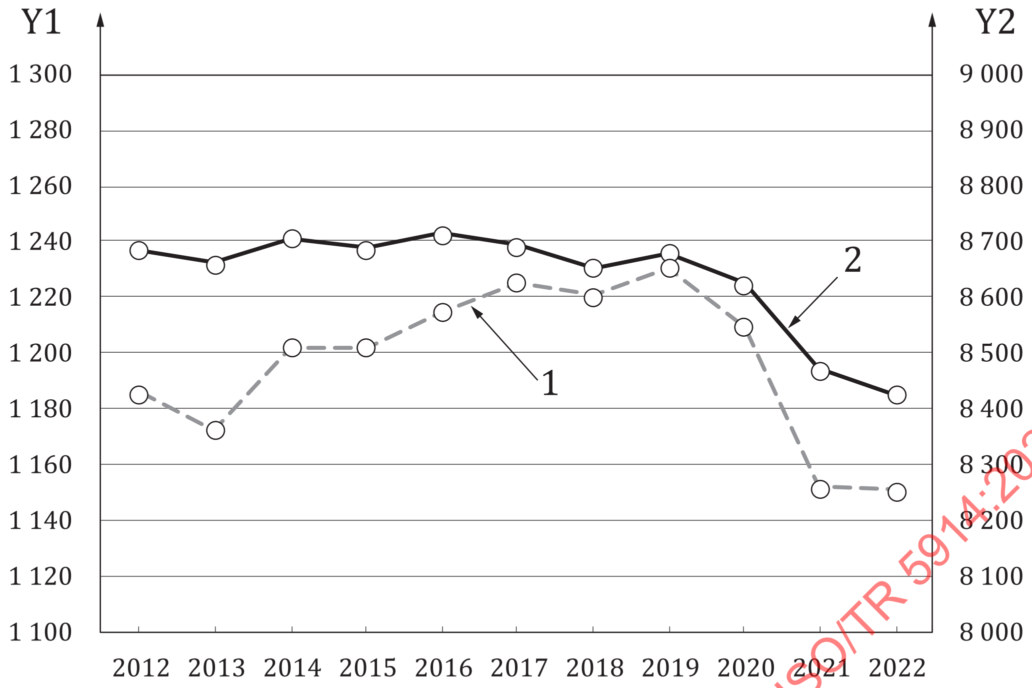
Y1 billion passengers

Y2 billion passengers-km

1 billion passengers

2 billion passenger kilometres

Figure B.11 — Number of passengers



Key

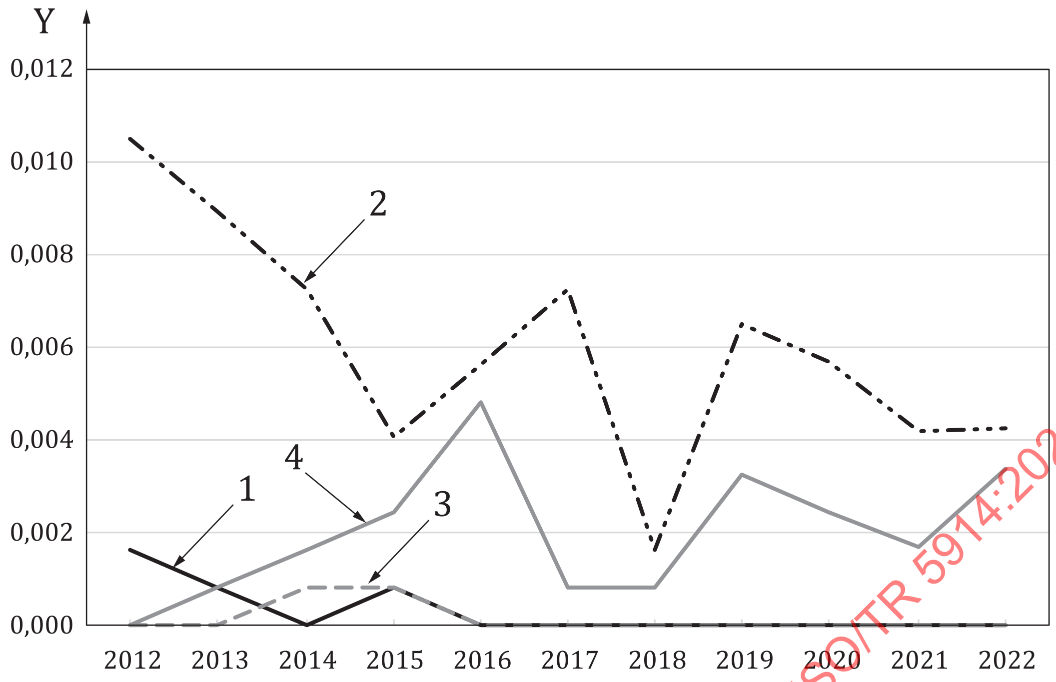
Y1 million carriage-km

Y2 million train-km

1 million carriage-km

2 million train-km

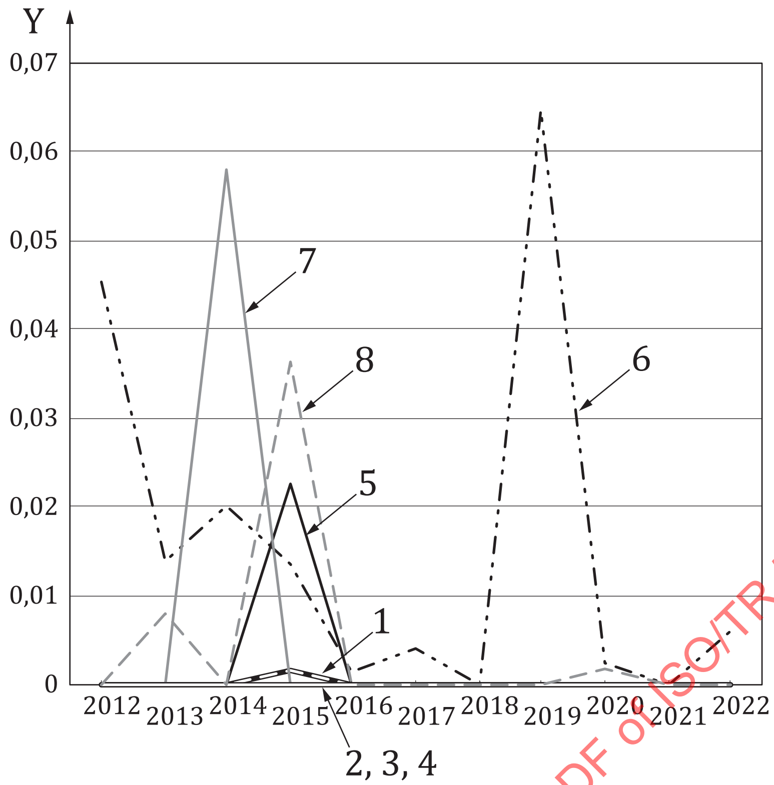
Figure B.12 — Number of train services



Key

Y accidents/million train-km
1 fire
2 derailment
3 collision
4 level crossing

Figure B.13 — Accident rates in Japan per million train-km, 2012 to 2022



Key

Y number of fatalities or injuries/million train-km

1 fire fatalities

2 derailment fatalities

3 collision fatalities

4 level crossing fatalities

5 fire injuries

6 derailment injuries

7 collision injuries

8 level crossing injuries

Figure B.14 — Fatality and injury rates in Japan per million train-km, 2012 to 2022

Annex C
(informative)

Costs and potential benefits of interior passive safety, based on UK practices

C.1 Calculating benefit to cost ratio

The RSSB states[83]:

> "Cost-benefit analysis (CBA) weighs the expected costs of one or more options against the expected benefits to support a decision for the option(s) to be implemented. It can be used by railway companies to assist in taking safety-related decisions.
>
> [RSSB's] "'Guidance on the use of cost-benefit analysis when determining whether a measure is necessary to reduce risk so far as is reasonably practicable' describes how CBA can be used to inform a decision. Further information on the wider decision-taking process can be found in Taking Safe Decisions document, which sets out the industry consensus view of how safety is taken into account when taking decisions.
>
> "CBA might be used within an application of the Common Safety Method on Risk Evaluation and Assessment (CSM RA). Further information about the CSM RA is available from the Management of Change page on RSSB's website.
>
> "In the rail industry, safety benefits are incorporated into a CBA by multiplying the expected risk reduction associated with a measure by the value of preventing a fatality (VPF)."

NOTE The CSM RA is set out in European legislation[84].

CBA can therefore be used to assess the comparative benefits of various options for reducing the frequency and severity of collision, thereby helping to inform the industry where best to allocate financial resources. See RSSB documents Taking Safe Decisions[85], Cost-Benefit Analysis[86] and the ERA's Implementation Guidance for CSIs[87].

C.2 Potential benefits of interior passive safety

The ERA annual report[76] indicates that approximately 2,5 % of passenger fatalities are attributable to collisions and derailments. This equates to 687 × 0,025 = 17 fatalities and 469 × 0,025 = 12 serious injuries.

On the basis that 10 serious injuries can be considered equivalent to one fatality, the number of total "equivalent" fatalities is around 18. Using a VPF of EUR 2 million, the equivalent "cost" of this is EUR 36 million. The ERA report on Achievement of Common Safety Targets[75] includes the following definition:

> "Fatalities and weighted serious injuries (FWSIs)" means a measurement of the consequences of significant accidents combining fatalities and serious injuries, where 1 serious injury is considered statistically equivalent to 0,1 fatalities.

RSSB produced a CBA[31] for the inclusion of interior passive safety measures in GMRT2100 issue four[13], which was based on an estimated net reduction in injuries (from only slips, trips and falls) of 40 %.

Therefore, it could theoretically be worth the European rail industry spending up to 0,4 × EUR 36 million = EUR 14,4 million per year on interior passive safety measures.

Clearly, investing in technology to reduce the numbers of collisions and derailments is a good idea; however, despite increased use of the European Train Control System (ETCS), etc. there is no decreasing trend. Further, there are some types of incident (e.g. landslides) which are not possible to prevent by using signalling systems.

See also Brell[88].

C.3 Costs of implementing geometric and material criteria

C.3.1 General

A conservative estimate of the additional cost to a European train manufacturing project of implementing a standard for interior passive safety is described in C.3.2 to C.3.8.

C.3.2 Design and material costs

Design and material costs can add between EUR 75 000 and EUR 150 000 to a project.

The costs for the supplier and manufacturer to cover engineering work, prototype development, materials, in-house costs and retests in the event of failure can be dependent on their experience (see Table C.1).

NOTE Drivers' cabs are not currently included.

Table C.1 — Design and material costs

Design or material element	Cost
Additional design and prototyping costs for areas exposed to secondary impacts: — seat radius + table thickness — table radius and thickness — toilet radius and flush parts — luggage racks radius — luggage stacks radius — tip-up seats radius — shielding parts (poles, rails, covers, etc.)	EUR 13 000 to EUR 70 000
Engineering to define the worst-case configurations	EUR 2 000 to EUR 20 000
Engineering specific to design for injury potential and structural integrity	Up to EUR 60 0000
Total	**EUR 75 000 to EUR 150 000**

If new materials are envisaged for interior passive safety reasons, industry best practice is described by a CEN Working Group set up to define a process to support the introduction of new materials to meet the minimum requirements in the railway sector. It identifies requirements of plans for design, manufacture, maintenance and proof of compliance (e.g. testing) applicable to new materials for all rolling stock and its on-board equipment.

NOTE Suppliers of passenger seats for European applications will need to make changes to seat designs to comply with fire testing requirements in EN 45545-2:2020[89], which comes in to force in 2024. The incremental costs of design/material changes for improved crashworthiness can therefore be lower.

C.3.3 Tooling costs

Tooling costs can be in the range of EUR 100 000 to EUR 200 000.

The need for generous radii can force the use of different materials and manufacturing techniques. Interior fittings compliant with the principles of interior passive safety can require a different assembly line to that for standard components. In some cases, such additional tooling and equipment costs (see Table C.2) are treated by manufacturers as continuous product improvements, so it is difficult to quantify the additional tooling and manufacturing costs specific to interior passive safety. In many cases, these can be considered cost neutral for a new project, because components such as extrusions, castings, panels are likely to be to a new design, even before interior passive safety requirements are considered.

Table C.2 — Additional costs

Additional element	Cost
Additional/modified tooling to the following interior components exposed to secondary impacts: — seat radius + table thickness — table radius and thickness — toilet radius and flush parts — luggage racks radius — luggage stacks radius — tip-up seats radius — shielding parts (poles, rails, covers, etc.)	Zero to EUR 100 000
Setting up a dedicated assembly cell (if required)	EUR 100 000
Total	**EUR 100 000 to EUR 200 000**

C.3.4 Marginal increase in cost of seats

The marginal increase in the cost of seats can be approximately EUR 30 000 per rolling stock project.

This is difficult to quantify, as seat manufacturers tend to continue evolving seat designs anyway.

C.3.5 Increased costs associated with approvals

Increased costs associated with approvals can be approximately EUR 20 000 per rolling stock project.

For those railway administrations for whom compliance to interior passive safety standards is mandatory (e.g. UK, US, Netherlands) or is a contractual requirement on a new rolling stock project, there will be an additional cost for design and build conformance assessment by an accredited assessment body. The assessment of interior passive safety conformance forms part of a broader assessment workstream and the delta cost has been estimated to be EUR 20 000 per rolling stock project.

C.3.6 Other costs associated with interior passive safety

On high-density commuter rolling stock, where the unidirectional high-back seat spacing is required to be less than approximately 760 mm, interior passive safety requirements must be carefully designed to avoid an impact on train capacity. Seat pitches of < 720 mm do not allow the target population (95th percentile adult male) to sit without a forced modification to posture.

Crashworthiness is possible to be achieved with pitches as low as 720 mm. Indeed, in theory at lower pitches, there is less relative acceleration between the impacting dummy and the seat back and less impact energy; although any impact absorbing material (if fitted) must be carefully designed to avoid a reduction in the available space envelope between the seats.

There is an issue around survival space when considering seats which are typically fixed back to train architecture (partitions, etc.) and cannot simultaneously deflect as the occupied seat in front deflects to invade their space envelope; see Figure C.1.

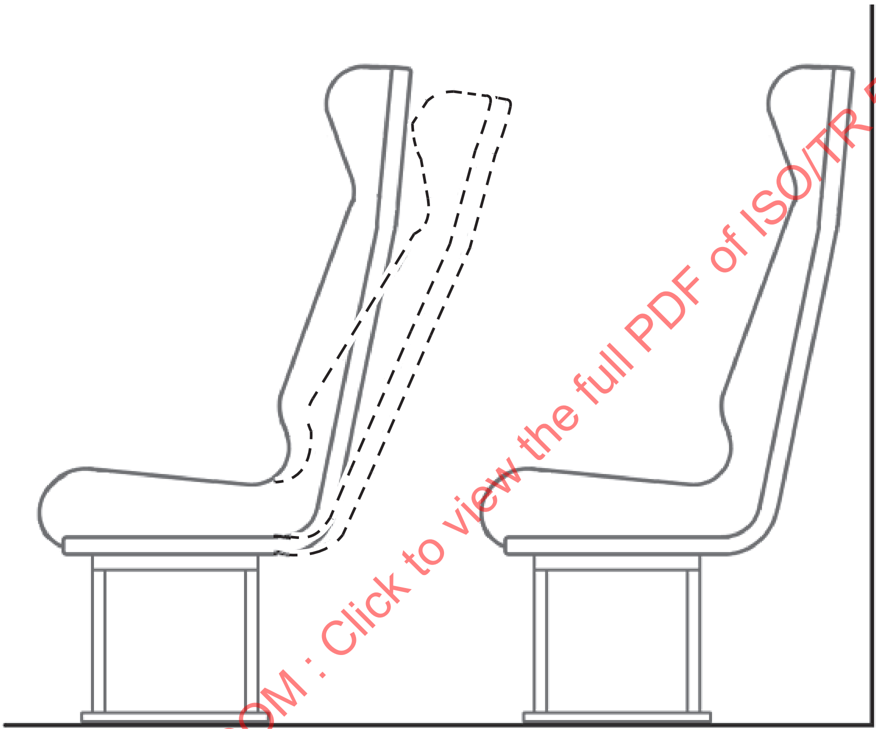
In practice, most manufacturers mitigate the issue without affecting train capacity by nominating the seats closest to the fixed partitions as priority seats under the ADA[90] or PRM TSI[57] requirements, i.e. to have a space of 230 mm between the front of the seat pad and the back rest of the seat in front, to facilitate access for PRM. This is also usually convenient, as it is good practice to have priority seats adjacent to entrance vestibules and draft screens, which are the fixed structures most affected. Usually, the vehicle seat plan can be accommodated in this way and allows survival space to be respected.

Therefore, a zero cost has been assigned to any work required to ensure that interior passive safety requirements do not negatively affect train capacity.

C.3.7 Costs of dynamic testing requirements on seats and tables

C.3.7.1 Dynamic testing with ATDs

Dynamic testing with ATDs can add between EUR 80 000 and EUR 225 000 to a project. The source for this cost estimate is based on recent values provided by Alstom, and on experience of recent testing to the current mandatory requirements for interior passive safety in the UK.



NOTE The seat on the right is constrained by a partition.

Figure C.1 — Constrained seat

An example breakdown of costs for dynamic testing of seats using ATDs is given in Table C.3.

NOTE The costs associated with developing a rail-specific ATD are included in the testing costs (i.e. are reflected in the cost of hiring the test facility and instrumentation).

An example breakdown of costs for dynamic testing of tables using ATDs is given in Table C.4. In practice, it is likely that a combined test with seats and tables would be done for maximum effectiveness and to minimize costs to the project.