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The Transport for London (TfL) Bus Safety Standard: Occupant Friendly Interiors

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Version	Date	Description	Editor	Technical Reviewer
1.1	30/07/2022	Corrections to Table 2-1 Added reference to TfL for latest specification in the executive summary and recommendations	AE	PSM & DH

Executive Summary

Bus Safety Standard (BSS)

The Bus Safety Standard (BSS) is focussed on vehicle design and safety system performance and their contribution to the Mayor of London's Transport Strategy. This sets targets to for deaths and serious injuries from road collisions to be eliminated from London's streets by 2041 and to achieve zero deaths in accidents involving buses in London by 2030.

To develop the standard a large body of research and technical input was needed, so Transport for London (TfL) commissioned TRL (the Transport Research Laboratory) to deliver the research and consult with the bus industry. The delivery team has included a mix of engineers and human factors experts, to provide the balance of research required.

All TfL buses conform to regulatory requirements. TfL already uses a more demanding specification when contracting services and this requires higher standards in areas including environmental and noise emissions, accessibility, construction, operational requirements, and more. Many safety aspects are covered in the specification such as fire suppression systems, door and fittings safety, handrails, day time running lights, and others. However, the new BSS goes further with a range of additional requirements, developed by TRL and their partners and peer-reviewed by independent safety experts. Accompanying the specification there are guidance notes to help inform the bus operators and manufacturers of what the specification is aiming to achieve and some practical tips on how to meet the requirements.

For each safety measure considered, a thorough review was completed covering the current regulations and standards, the specification of the current bus fleet and available solutions.

Full-scale trials and testing were also carried out with the following objectives. Firstly, the tests were used to evaluate the solutions in a realistic environment to ensure that a safety improvement was feasible. Secondly, the testing was used to inform the development of objective test and assessment protocols. These protocols will allow repeatable testing according to precise instructions so that the results are comparable. The assessment protocol provides instructions for how to interpret the test data for a bus or system, which can be a simple pass/fail check, or something more complex intended to encourage best practice levels of performance. These assessment protocols will allow TfL to judge how well each bus performs against the BSS, and will allow a fair comparison in terms of safety if they have a choice between models for a given route.

It is important to ensure the money is spent wisely on the package of measures that will give the most cost-effective result. TRL has developed a cost-benefit model describing the value of implementing the safety measures, both in terms of casualties saved and the technology and operational costs of achieving that. Input from the bus industry has formed the backbone of all the research and the cost-benefit modelling. This modelling has helped inform the decisions of TfL's bus safety development team in terms of implementing the safety measures on new buses.

This research was completed in 2018. The detailed specification, assessment procedures and guidance notes have been incorporated into the Transport for London specification for buses, which is a continuously updated document to keep pace with the latest technological and research developments. This report is not the specification for a bus and should not be used as such. Bus operators, manufacturers, and their supply chain should consult with TfL for the specification.

Occupant Friendly Interiors

Overall, the occupant-friendly interiors measure has been particularly challenging. Current regulations heavily constrain designs for reasons of accessibility, so making safety improvements without conflicting with regulations and other priorities such as passenger flow and comfort is difficult. Nevertheless, beneficial changes have been identified. The process has been to examine CCTV footage to help understand how passengers are injured in harsh manoeuvres (e.g. emergency braking) and collision events. Following this, existing bus designs were reviewed to identify potentially injurious features and how they could be redesigned to reduce the risk of injury, e.g. move the handrail to reduce risk of a head strike. An assessment scheme for occupant-friendly interiors has been developed to allow bus manufacturers to incorporate safety considerations alongside the existing constraints from regulation, accessibility, flow etc. It is hoped that this will give the manufacturers a guide for producing the best compromise, without being too design prescriptive.

In summary, the methodology consisted of four main steps:

- Problem size: Analysis of UK national data to determine the number and nature of casualties in the London region.
- Injury mechanisms and identification of potential hazards: Analysis of CCTV footage and examination of current buses to understand passenger injury mechanisms better and identify potential hazards and design changes to help mitigate injury.
- Assessment procedure: Development of a procedure to assess a bus's interior safety based on a visual inspection. Additionally, development of potential design changes to improve the safety of bus interiors to support the development and implementation of the assessment procedure.
- Cost-benefit: Analysis to estimate break-even costs, discounted payback period and benefit-to-cost ratios for implementation of the assessment procedure.

Problem size

Analysis of the national Stats19 data for London showed that on London buses/coaches the majority of the bus occupant casualty problem is associated with non-collision events (83% of serious injuries) and standing passengers (51% of serious injuries), although a significant proportion of casualties are seated (29% of serious). The bus is often accelerating or braking at the time of the incident.

Injury mechanisms and potential hazards

The CCTV analysis and bus examinations highlighted issues with:

- Handrails, mainly in relation to their position.

  Examples included, for standing passengers, vertical and horizontal handrails in the head impact zone in the wheelchair area and, for seated passengers, handrails behind middle doors in alignment with the likely trajectory of an aisle-seated passenger

  It should be noted that, generally, handrails in roughly these positions are required by regulation. The main regulatory requirement (Regulation 107) is for the fitment of an adequate number of handrails such that a standing passenger can reach at least two, at least one of which is not more than 1.5 m above floor level.

- Restraint, i.e. inadequate restraint of a passenger's movement in the event of a braking or collision event in terms of compartmentalisation.

  Examples included passengers sat on seats: behind the wheelchair area – no partition to restrain movement; above the rear wheels – seat backs in front not high enough to restrain movement; rear middle seat – nothing to restrain movement; and aisle forward facing bay seat – passenger falls into aisle.

- General injurious features, i.e. protrusions, sharp corners and edges.

  Examples included protrusions such as bolt heads and sharp corners and edges on items such as steps and passenger information displays

It should be noted that not all the issues identified above were observed on all the buses examined. Indeed, many of the buses exhibited good features, although, usually, all buses exhibited at least one issue.

The CCTV analysis also showed that a smaller proportion of seated passengers were injured (2%) compared to standing passengers (6%), indicating a smaller risk of injury for seated passengers. For seated passengers, the results showed a smaller proportion of those seated on the upper deck were injured (0.3%) compared to those seated on the lower deck, (1.5% to 6%), indicating a much smaller risk of injury for passengers seated on the upper deck. Likely contributory factors to this result were that this area contained more features associated with injury and that persons with reduced mobility have greater exposure in this area, i.e. the more vulnerable passengers currently sit in the less safe areas of the bus.

For seated passengers an issue with low backed seats was also identified, in terms of lack of head / neck support for rear facing seats and problems with restraint for some forward facing seats.

Assessment procedure

An assessment procedure was developed with the aim of minimising the main potential hazards identified above (handrails, restraint, general injurious features). Considering standing and seated passengers separately, the procedure developed uses a visual inspection to identify hazards, awards points for each one identified on the bus, with weighting applied to increase the number of points for hazards with greater injury causing potential and/or exposure. The aim for manufacturers is to have as few as possible potential hazards and therefore score the lowest number of points possible.

Based on the results of the CCTV analysis and bus examinations, the following potential design changes to improve safety were outlined, the second building on the first:

Solution level 1:

- Fit partitions in front of exposed seats behind wheelchair and middle door standing areas to provide better restraint for passengers in those seats
- Ensure that the partition fitted extends inboard far enough so that handrails associated with it are positioned far enough inwards so that they are not in alignment with a passenger sitting in the aisle seat to reduce likelihood of impact with it in an incident

Solution level 2:

- Solution level 1 plus:
- Reposition handrails that are not in the middle bus area, both vertical and horizontal
- Remove general hazards for standing and seated passengers
- Improve restraint for standing and seated passengers possibly with the use of high backed seats, for example:
- Improve the restraint of passengers standing in the middle door area by effectively increasing the height of the partition to the front of this area by the placement of high-backed seats in front of this partition
- Improve the restraint of passengers seated in the seats positioned above the rear wheels by placing high-backed seats in front of them
- Provide additional protection for rear-facing seats which have potential hazard behind. For example where there is a luggage rack or other hard structure behind an occupant's head

Work was also performed to investigate the specific issues of handrails and high / low backed seats. For handrails, modelling work considered the use of a compliant handaril mount to make it more impact friendly. Unfortunately, the work did not show a consistent reduction in head injury criterion values for the different initial conditions simulated, indeed for some conditions the values were higher. Therefore it was recommended that compliant mounts for handrails should not be implemented as part of the bus safety standard at this time, but TfL calls for further innovation in this area. For low / high backed seats test and modelling work indicated that safety improvements could be achieved through the use of high backed seats, although further work is required to address issues associated with them such as their increased mass. Again, TfL calls for further innovation in this area.

Cost-benefit

The cost-benefit analysis for implementation of the potential design solutions described above showed that the discounted payback period is within the year that the solutions are implemented because the total fleet costs (NPV) were calculated to reduce (i.e. changes in insurance claims costs were larger than all other costs combined). In other words, the potential occupant friendly interiors handrail and seat safety measures analysed would be likely to provide operators with a return on their investment within the year that they are implemented and continue to provide benefits for all years within the analysis period.

Table of Contents

1 Introduction to the Bus Safety Standard (BSS)

1.1 The BSS

In 2018 the Mayor of London, Sadiq Khan, set out a 'Vision Zero' approach to road casualties in his transport strategy (Transport for London (TfL), 2018). It aims for no one to be killed in, or by, a London bus by 2030 and for deaths and serious injuries from road collisions to be eliminated from London's streets by 2041.

Transport for London (TfL) commissioned the Transport Research Laboratory (TRL) to deliver a programme of research to develop a BSS as one part of its activities to reduce bus casualties. The goal of the BSS is to reduce casualties on London's buses in line with the Mayor of London's Vision Zero approach to road safety. The BSS is the standard for vehicle design and system performance with a focus on safety. The whole programme of work includes evaluation of solutions, test protocol development and peer-reviewed amendments of the Bus Vehicle Specification, including guidance notes for each of the safety measures proposed by TfL. In parallel to the detailed cycle of work for each measure, the roadmap was under continuous development alongside a detailed cost-benefit analysis and on-going industry engagement. The BSS programme is illustrated below in Figure 1-1.

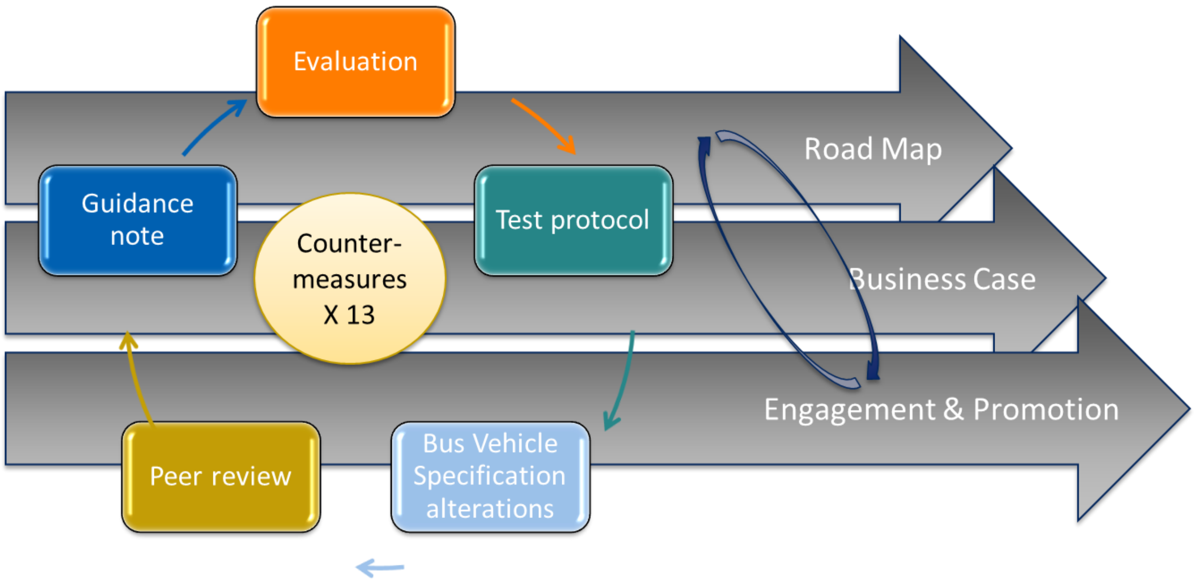


Figure 1-1: Summary of the BSS research programme

The exact methodology of the testing development depended upon each of the measures being developed. For AEB it included track testing and on-road driving, whereas for the occupant interior safety measures it involved computer simulation and seat tests. There was also a strong component of human factors in the tests e.g. human factors assessments by our team of experts. In addition, there were objective tests with volunteers to measure the effect of technologies on a representative sample of road users, including bus drivers and other groups as appropriate to the technology considered.

The test procedures developed were intended to produce a pass/fail and/or performance rating that can be used to inform how well any technology or vehicle performs according to the BSS requirements. The scenarios and/or injury mechanisms addressed were based on injury and collision data meaning it is an independent performance-based assessment.

A longer-term goal of the BSS is to become a more incentive-based scheme, rather than just a minimum requirement. The assessments should provide an independent indicator of the performance of the vehicle for each measure, and they will also be combined in an easily understood overall assessment.

It is important to ensure the money is spent wisely on the package of measures that will give the most cost-effective result. If zero fatalities can be achieved at a low cost, it remains better than achieving it at a higher cost. TRL has developed a cost-benefit model describing the value of implementing the safety measures, both in terms of casualties saved and the technology and operational costs of achieving that. Input from the bus industry has formed the backbone of all the research and the cost-benefit modelling. This modelling has helped inform the decisions of TfL's bus safety development team in terms of implementing the safety measures on new buses.

1.2 Bus Safety Measures

The measures selected for consideration in the BSS were wide ranging. Some will address the most frequent fatalities, which are the group of pedestrians and cyclists killed by buses, mostly whilst crossing the road in front of the bus. There are several measures that could address this problem, for example, Advanced Emergency Braking (AEB, which will apply the vehicle's brakes automatically if the driver is unresponsive to a collision threat with a pedestrian) or improved direct and indirection vision for the driver. These are both driver assis safety measures, which are designed to help the driver avoid or mitigate the severity of incidents. Intelligent Speed Assistance (ISA) is another example of driver assist, and TfL has already started rolling this out on their fleet. The last two driver assist measures are pedal application error (where the driver mistakenly presses the accelerator instead of the brake) and runaway bus prevention; both of which are very rare but carry a high risk of severe outcomes.

Visual and acoustic bus conspicuity are both partner assistance measures that are designed to help other road users, particularly pedestrians and cyclists, to avoid collisions. Partner protection is about better protection if a collision should occur. For this the work has started with Vulnerable Road User (VRU) front crashworthiness measures, including energy absorption, bus front end design, runover protection and wiper protection.

Passenger protection is focussed on protecting the passengers travelling on board the bus, both in heavy braking and collision incidents. This encompasses occupant friendly interiors inspections, improved seat and pole design, and slip protection for flooring. This group of measures that help to protect bus occupants are important because around 70% of injuries occur without the bus having a collision

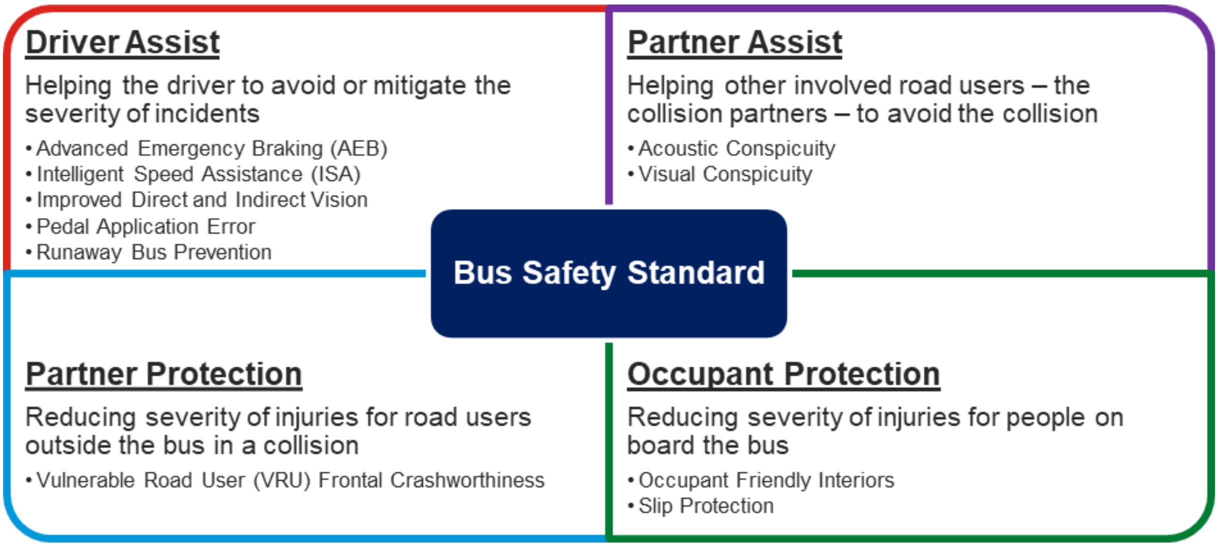


Figure 1-2: Bus Safety Measures

1.3 Occupant Friendly Interiors

The objective is to reduce the number of passenger casualties caused by impacts with the bus interior in collision and harsh manoeuvre incidents, such as emergency braking. A previous study, (Edwards *et al.*, 2017), recommended various safety measures based on detailed case analysis of 48 fatal files in combination with analysis of various databases of bus collisions; improving occupant interiors was one of the measures recommended. TfL further specified that the work should focus on head restraints (and seat backs), grab poles and bars (handrails), and visual inspection (as an assessment tool).

It should be noted that:

- A head restraint is usually incorporated as an integral part of the seat and therefore forms part of the seat back for passengers seated behind. The incorporation of a head restraint increases the height of the seat back. For passengers seated behind, this has a major effect on their constraint (and potential injury) in the event of frontal collisions and harsh braking. Indeed, because these events are much more frequent than rear impacts (see Section 2.2 below), interaction of passengers behind with the seat back in front is a larger issue than interaction of passengers in the seat with the head restraint. Rear facing seats are clearly an exception to this, but the current TfL bus specification discourages rear facing seats.
- The terminology for grab poles and bars in the UNECE and UK regulation is:
    - Grab pole: Handrail (vertical)
    - Grab bar: Handrail (horizontal)

  For these items, the regulatory terminology will be used in this section. This includes for reference to handholds which are sometimes referred to as grab handles.

- Head restraints, and grab poles and bars, are considered as countermeasures or items for which countermeasures should be developed. Visual inspection is somewhat different because it is an assessment tool. However, because it is related to occupant friendly interiors it is included in this section.

2 Defining the problem

This section is divided into four main sections, namely overall casualty priorities for TfL, then with a focus on the interiors: incident data analyses, literature review and a bus examination to identify interior features which may increase potential injury risk. A summary is given at the end of the section.

2.1 Casualty priorities for BSS

Transport for London's aim in implementing the Bus Safety Standard is to assist in achieving 'vision zero' on the principle that no loss of life is acceptable or inevitable. Thus, the largest focus is on incidents resulting in death or serious injury. However, they recognise the disruption and cost that minor collisions can have for bus operators and the travelling public alike. Thus, safety features that can reduce the high frequencies of incidents of damage only and/or minor injury are also included within the scope. The high-level matrix below in Table 2-1 categorises and prioritises the casualties based on past data for London derived from the GB National collision database.

Table 2-1 shows that over the past decade the highest priority casualty group in terms of death and serious injury from collisions involving buses in London has been pedestrians severely injured in collisions where the bus was coded as going ahead, without negotiating a bend, overtaking, starting or stopping, etc.

Table 2-1: Casualty prevention value attributed to different collision types;London STATS19 data from 2006-15 (%)

Casualty Type	Collision type	Fatal	Serious	Slight	KSI	Total
Bus Passenger	Injured in non-collision incidents - standing passenger	4.2%	17.1%	23.3%	11.9%	15.2%
	Injured in non-collision incidents - seated passenger	0.5%	6.4%	13.0%	4.0%	6.6%
	Injured in non-collision incidents - boarding/alighting/other	1.6%	7.6%	5.3%	5.2%	5.2%
	Injured in collision with a car	0.5%	4.6%	10.1%	2.9%	5.0%
	Injured in collision with another vehicle	0.0%	3.1%	5.0%	1.8%	2.8%
	Total	6.9%	38.7%	56.7%	25.9%	34.8%
Pedestrian	Injured in a collision while crossing the road with a bus travelling straight ahead	30.7%	20.0%	7.0%	24.3%	19.3%
	Injured in a collision, not while crossing the road, with a bus travelling straight ahead	10.6%	7.9%	4.6%	9.0%	7.7%
	Injured in a collision with a bus turning left or right	12.2%	3.1%	1.2%	6.8%	5.2%
	Injured in other collision with a bus	2.1%	1.4%	0.7%	1.7%	1.4%
	Total	55.6%	32.5%	13.6%	41.8%	33.6%
Car Occupant	Injured when front of bus hits front of car	6.3%	1.9%	0.9%	3.7%	2.9%
	Injured when front of bus hits rear of car	1.6%	0.8%	2.8%	1.1%	1.6%
	Injured when front of bus hits side of car	1.1%	1.1%	1.8%	1.1%	1.3%
	Injured in side impact collision with a bus	2.6%	1.9%	3.9%	2.2%	2.7%
	Injured in other collision with a bus	2.1%	1.0%	1.4%	1.5%	1.4%
	Total	13.8%	6.6%	10.8%	9.5%	9.9%
Cyclist	Injured in a collision with the front of a bus travelling straight ahead	2.1%	1.2%	0.9%	1.5%	1.4%
	Injured in a collision with another part of a bus travelling straight ahead	0.0%	2.6%	1.5%	1.6%	1.6%
	Injured in a collision with the nearside of a bus which is turning	1.6%	0.8%	0.4%	1.1%	0.9%
	Injured in other collision with a bus	0.5%	3.1%	2.1%	2.1%	2.1%

Casualty Type	Collision type	Fatal	Serious	Slight	KSI	Total
	Total	4.2%	7.8%	5.0%	6.4%	6.0%
Powered Two Wheeler (PTW)	Injured in a collision with a bus travelling straight ahead	2.6%	1.3%	0.7%	1.9%	1.5%
	Injured in a collision with a bus turning left or right	0.5%	1.0%	0.7%	0.8%	0.8%
	Injured in other collision with a bus	0.5%	1.0%	0.9%	0.8%	0.8%
	Total	3.7%	3.4%	2.3%	3.5%	3.2%
Bus Driver	Injured in collision with a car	0.0%	1.5%	2.5%	0.9%	1.4%
	Injured in non-collision incidents	0.0%	0.5%	0.5%	0.3%	0.4%
	Injured in collision with another vehicle	0.5%	1.2%	1.5%	1.0%	1.1%
	Total	0.5%	3.2%	4.5%	2.1%	2.8%
Other	**Total**	**15.3%**	**7.9%**	**7.1%**	**10.9%**	**9.8%**
Casualties Total		**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

2.2 Incident Data Analyses

This section is divided into three parts. The first two parts summarise findings from analyses of the STATS19 and IRIS databases, respectively. The analysis of the IRIS database was performed mainly to help confirm the target population for future cost-benefit analyses. The third part reports the results of an analysis of CCTV footage collected from incidents in buses operating in London, the aim of which was to determine how bus passengers are injured. The data was supplied by one operator (Operator A). This analysis was required because databases such as STATS19 and IRIS do not contain the detailed information necessary to determine injury mechanisms and this knowledge is critical to be able to provide evidence-based injury-mitigating solutions.

2.2.1 STATS19

Analysis of the STATS19 database shows that the number of killed and seriously injured (KSI) occupant casualties in buses/coaches in London has halved over the 2006 to 2015 period. However, the total number of casualties has remained approximately the same because of the fluctuation in the number of slight casualties (Figure 2-2).

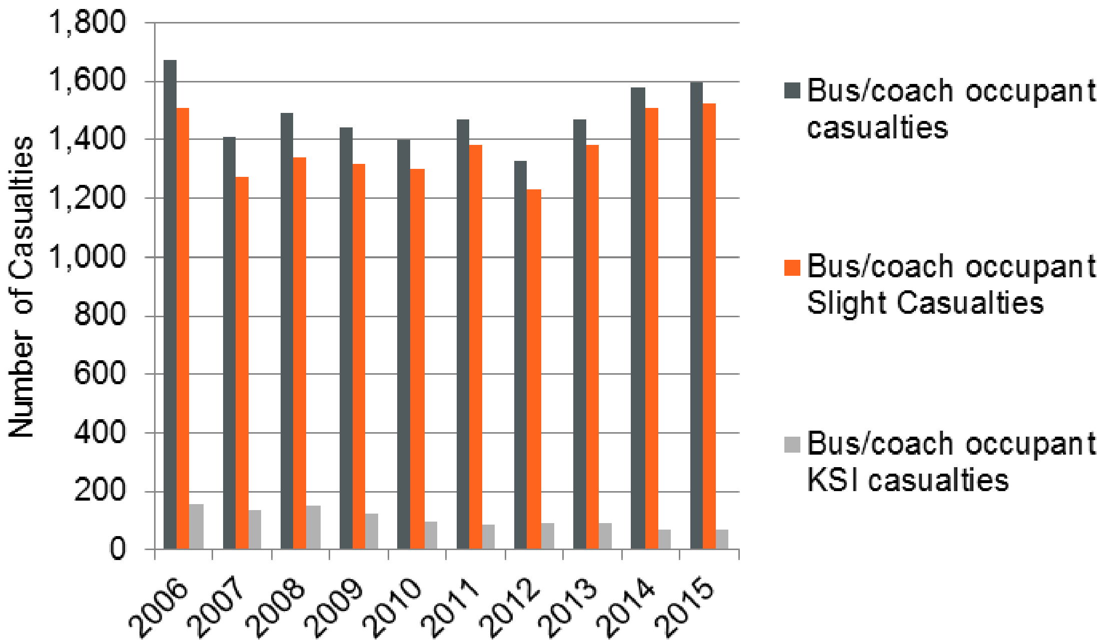


Figure 2-2: Variation in number of KSI and slight bus / coach occupant casualties in London 2006 to 2015

Table 2-3 below shows that three-quarters of all injured casualties occurred in incidents where there was no impact, with this proportion rising for serious and fatal injured casualties. This highlights that the majority of injuries on London buses/coaches occurred in incidents with no external collisions. The table also shows that the majority of the remaining casualties were in frontal impact collisions (13%). Most of the casualties were standing, 47% of all injured and 51% of seriously injured and a substantial proportion seated, 32% of all injured and 29% of seriously injured. The remainder were boarding or alighting. It is noted that care should be taken in the interpretation of the fatal casualty data for two reasons. The first is that the numbers are few and therefore distributions are not statistically significant. The second is that of the trend in boarding and alighting casualties found that all the fatal casualties occurred in the early years 2006 and 2007 when the old type of Routemaster buses with an open platform were operating and hence may relate to them.

Table 2-3: Distribution of bus / coach occupant casualties by casualty severity, occupant action and first point of impact for casualties in London 2006 to 2015

Casualty Severity	Bus (or Coach) Occupant Action	First point of impact					% of total
		Did Not Impact	Front	Back	Off-side	Near-side	
Fatal	Boarding	0	0	0	0	0	0.0
	Alighting	3	0	0	0	0	21.4
	Standing	9	0	0	0	0	64.3
	Seated	1	1	0	0	0	14.3
	% of total	92.9	7.1	0.0	0.0	0.0	100.0
Serious	Boarding	74	0	1	0	11	8.9
	Alighting	108	1	0	0	4	11.6
	Standing	451	27	2	8	6	50.9
	Seated	173	69	5	16	14	28.6
	% of total	83.1	10.0	0.8	2.5	3.6	100.0
Slight	Boarding	549	6	1	0	62	4.9
	Alighting	1736	108	20	44	44	15.5
	Standing	4842	626	120	210	158	47.2
	Seated	2418	911	214	343	215	32.5
	% of total	75.6	13.1	2.8	4.7	3.8	100.0
All	Boarding	623	6	2	0	73	5.2
	Alighting	1847	109	20	44	48	15.2
	Standing	5302	653	122	218	164	47.5
	Seated	2592	981	219	359	229	32.2
	% of total	76.1	12.8	2.7	4.6	3.8	100.0

Figure 2-4 shows the distribution of bus / coach occupant casualties of all severities by bus activity (i.e. stationary, slowing or stopping, etc.) and Figure 2-5 shows the same broken down for passenger activity (standing, seated, etc.). Incidents that occur with the bus accelerating or decelerating account for nearly two thirds of the injuries to standing passengers; this is perhaps unsurprising. More than a quarter of passengers are injured when the bus is ‘going ahead other’, and more are injured with a stationary bus than when cornering; 6% of injuries for standing passengers were when the bus was stationary. Injuries to passengers that are boarding and alighting buses are dominated by situations where the bus is stationary, but perhaps not to the extent expected. 21% of injuries while boarding involve a moving vehicle; which suggests that either people are boarding when the bus is pulling away, or that the bus is pulling away before all passengers are settled, though in this case the instructions for the completion of STATS19 data suggest the casualty should be recorded as a standing passenger not as boarding. Furthermore, 12% of the injuries whilst alighting are whilst the bus is going ahead other, which may also indicate that people are disembarking the bus when they shouldn’t, or that people are getting up to move to the exit while the bus is still moving have been classified as ‘alighting’ rather than as ‘standing’ passengers.

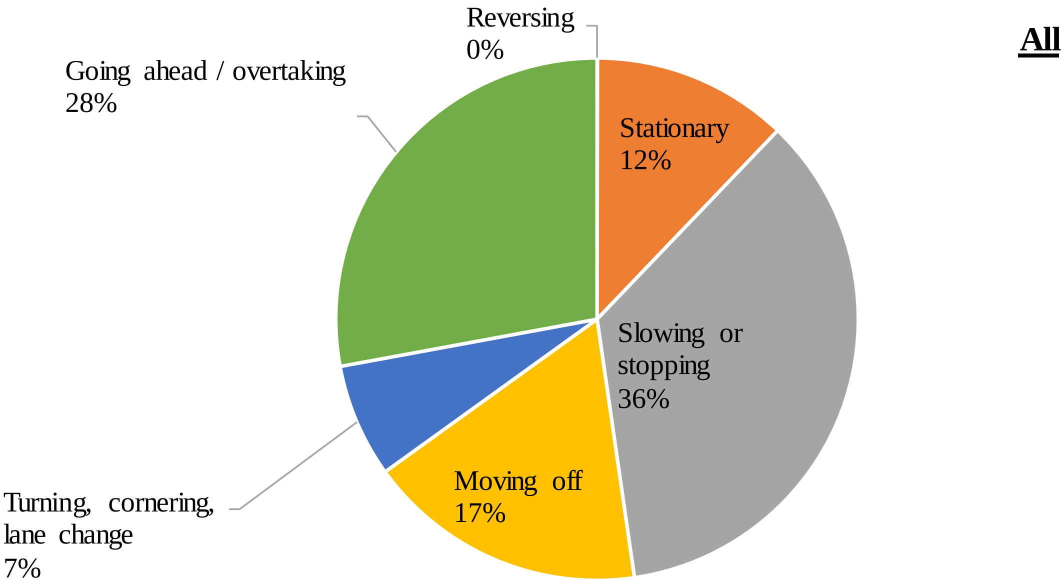


Figure 2-4: Distribution of bus / coach occupant casualties of all severities by bus activity

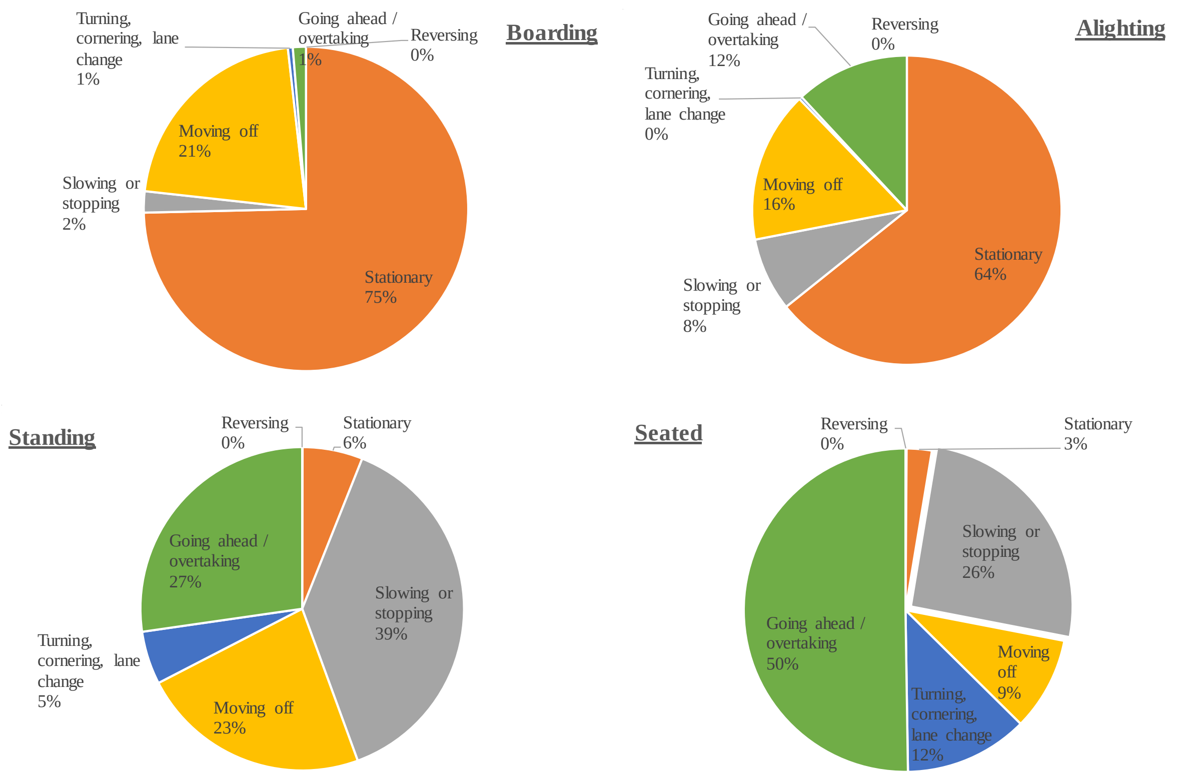


Figure 2-5: Distribution of bus / coach occupant casualties of all severities by bus activity for various occupant actions

An analysis of gender and age showed that older women (56 years and over) form about one third of all the KSI casualties and about a quarter of the slightly injured casualties (Figure 2-6 and Figure 2-7). This large proportion of older women has been observed previously (see Section 2.4 – literature survey) with likely explanations given as greater exposure of this group and their physiology, i.e. more likely to fall over and a lower injury tolerance. It is not possible to present this data in terms of risk because exposure data for gender and age is not readily available. Note that higher risk for this gender/age group is implied from the literature, but exposure (i.e. more of this group travelling on the bus) is also a major factor.

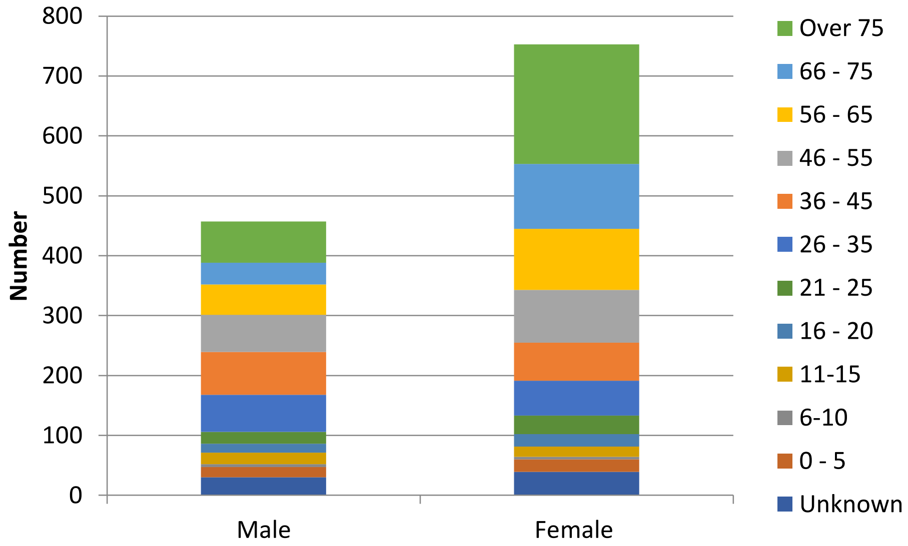


Figure 2-6: KSI bus / coach occupant casualties in London 2006 to 2015, by gender and age

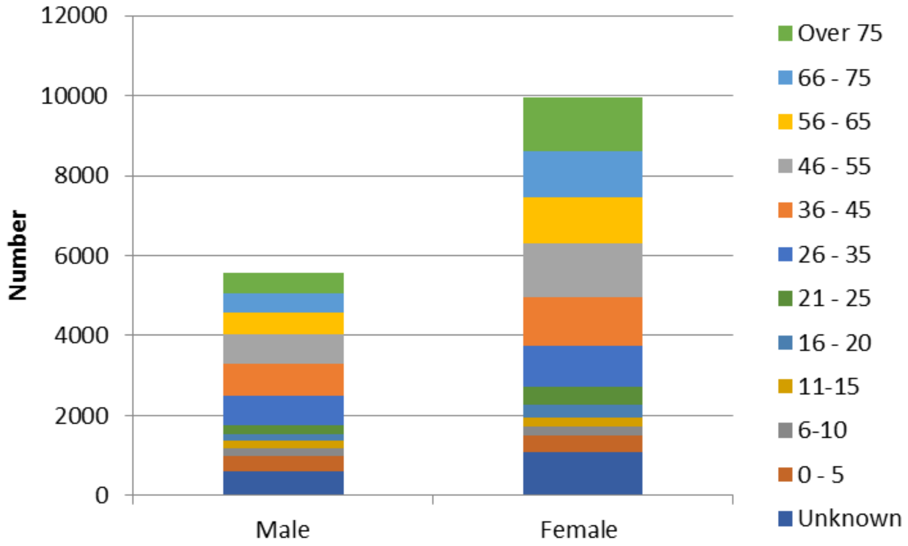


Figure 2-7: Slightly injured bus / coach occupant casualties in London 2006 to 2015, by gender and age

2.2.1.1 Summary of findings

In summary, the STATS19 data analysis described above indicates that on London buses/coaches the majority of the bus occupant casualty problem is associated with non-collision events and standing passengers, although a significant proportion of casualties are reported as being seated. The bus is often accelerating or braking at the time of the incident. A large proportion of casualties are older females aged over 56 years (about one third of all serious casualties).

2.2.2 IRIS

IRIS is TfL's incident management system, made up of bus incidents that are reported directly by bus operators. Bus companies are required to report incidents regardless of blame and severity. The logging system is intended to provide data for statistical reasons to support safety evaluations. Only limited information relating to the incidents is provided to TfL. Most of the detailed data (including the CCTV footage) are retained by the bus operating companies who also perform incident investigations.

(Edwards *et al.*, 2017) reported that, similar to the STATS19 data, the IRIS data shows that the vast majority of bus incident related casualties are bus occupants (79%), most of whom are only slightly injured, which is likely due to most of the injuries occurring on buses without a collision.

The IRIS data are held in two independent databases, the first containing data for passengers involved in slips, trips and falls type incidents, and the second containing data for collision type incidents. Injury classification for the IRIS data is different to the STATS19 data, which makes direct comparison of these data difficult.

The data for the three year period from April 2014 to March 2017 were analysed to help provide guidance to determine the target population for occupant friendly interior measures. To do this the injury levels of the casualties in the IRIS database needed to be classified according to STATS19.

The injury severity levels in STATS19 are defined as follows:

- Fatal: This includes only those cases where death occurs in fewer than 30 days as a result of the incident.
- Serious injury: Examples include broken neck or back; severe chest injury, any difficulty breathing; fracture; concussion; and severe general shock requiring hospital treatment.
- Slight injury: Examples include whiplash or neck pain; sprains and strains (not necessarily requiring medical treatment); and slight shock requiring roadside attention.

The injury severity categories for the IRIS data are not precisely defined and include injury mechanisms such as struck by / against object, injuries such as sprains, bruises, fracture and unconsciousness, and tertiary actions such as being taken to hospital.

The 'treatment type' field was used in an attempt to correlate the casualty injury level with the STATS19 defined injury severity levels as shown in Table 2-8. The reason the injury severity field was not used was because about 50% of the casualties had an injury severity categorisation of 'unknown' and it was difficult to align many of the injury severity categories with the STATS19 injury levels.

Table 2-8: Correlation of IRIS casualty data to STATS19 injury severity fields

IRIS treatment	Equivalent STATS19 injury severity level	IRIS (Slips, trips and falls data) Number of casualties	IRIS (Collisions data) Number of casualties
First aid provided at scene	Slight	976	305
No treatment provided / required	Non Injured	4,464	309
Refused treatment	Slight	557	260
Sought own treatment	Slight	55	
Taken to hospital	Serious	2,411	440
Unknown / other	Unknown	330	
Total		8,793	1,314

The resulting numbers of casualties per year from the IRIS database by STATS19 severity were compared with the STATS19 data for buses/coaches for the London area (Table 2-9). It is seen that the number of serious and slight casualties was quite different, which shows that the correlation attempted did not work. However, it is interesting to note that the total of serious and slight casualties compared reasonably well, 1668 with 1360, which indicates there is probably not much under-reporting of ‘serious and slight injuries as a total’ in STATS19 for the London area. Under-reporting of injuries within STATS19 has been well documented (Ward *et al.*, 2006).

Therefore, it was decided that the STATS19 values in Table 2-9 were representative of the target population for occupant friendly interiors.

Table 2-9: Comparison of number of casualties in IRIS and STATS19 databases by STATS19 injury severity

STATS19 injury severity	IRIS (Slips, Trips, Falls) Number of casualties	IRIS (Collision) Number of casualties	IRIS Total Average number of casualties per year	STATS19 Average number of casualties per year
Fatal	2	4	2	1.4
Serious	2,411	440	950	97
Slight	1,588	565	718	1,263
Non-injured	4,794	309	1,701	n/a
Unknown	330	-	110	n/a

2.2.3 Operator CCTV

2.2.3.1 Introduction

TfL require bus operators to collect CCTV footage of incidents which occur, in particular those in which persons are injured. Collision and non-collision CCTV data from one operator (Operator A) were analysed to develop a better understanding of how bus occupants are injured, i.e. to determine injury mechanisms.

2.2.3.2 Method

Introduction

192 incidents from recorded CCTV video files supplied by an operator from bus incidents spanning from January 2016 to October 2017 in London were selected in a representative manner using STATS19. From these incidents three types of data set were generated as follows, the incidents in each data set being a subset of the previous one:

1) Base general data:

   For all 192 incidents, passenger response and injury data. From observation of the CCTV footage, for passengers that moved substantially, the following parameters were estimated and recorded:

   - Passenger action – seated/standing/boarding/alighting
   - Location on bus
   - Bus part contacted by passenger and body part contacted
   - Injury severity estimate – contact/slight/moderate
   - When available accelerometer data recorded

2) Exposure data:

   For 70 incidents for which accelerometer data was available exposure data was collected, i.e. the total number of passengers in each area of the bus was recorded.

3) Detailed data:

   For about 10 incidents (which had higher severity and higher occupancy) the location and response of all passengers on the bus were recorded whether they moved substantially or not.

Following coding of the incidents, the base general data set was analysed to help understand injury mechanisms, the exposure data set was analysed to help understand how the risk of injury differed between different areas of the bus and the detailed data set was analysed to confirm findings related to injury mechanisms from the analyses of the general data set.

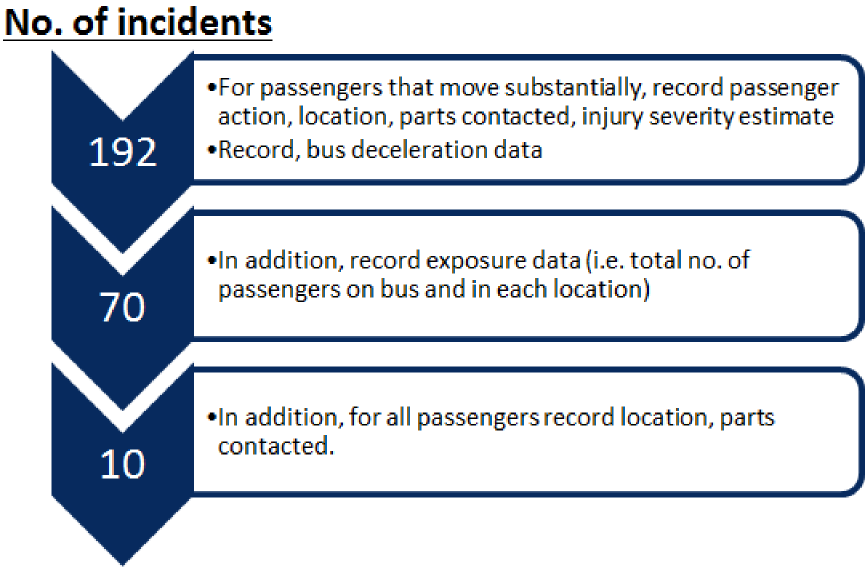


Figure 2-10: The three levels of data collected from CCTV footage analyses

Further details of how the base general data was derived are given below.

<u>Incident selection</u>

Relevant incidents, namely bus collision and non-collision incidents in which a bus passenger was injured and collision events in which a pedestrian or cyclist was hit, were identified using spreadsheet-based incident logs maintained by the operator. This removed cases not relevant to the study such as assaults and resulted in 31,537 incidents in the following three categories:

- Bus passenger injured, collision with e.g. a car
- Bus passenger injured, no collision, e.g. braking, manoeuvring
- VRU (pedestrian or cyclist) impact

The STATS19 data for London (2006-2015) was used to determine the proportion of these incident categories in all bus incidents: collision (17%), non-collision (48%), VRU (35%). 192 incidents were selected, in a random manner as close as possible to these proportions, to form a representative data set.

<u>Incident base analysis</u>

Each CCTV incident was analysed in the following manner and the results coded into a database.

1) An initial review of the data contained in the incident summary spreadsheet was performed to obtain an understanding of what to look for in the CCTV footage.
2) Using information from step 1, the appropriate cameras were selected and the relevant CCTV footage was viewed. The forward facing camera was always viewed to see the incident, and generally, multiple cameras were viewed simultaneously to enable passenger movement to be followed easily.

3) All passengers that were injured or moved substantially were identified. This was achieved by viewing the incident and identifying the relevant passengers. Once the passenger(s) were identified, they were observed just prior, during and after the incident.
4) From observations just prior and during the incident, the following parameters were entered into the database:
   - Passenger Action – Seated/Standing/Boarding/Alighting
   - Location on bus – Lower deck/On stairs/Upper deck
   - Specific location – dependent on a) and b) e.g. Standing in Middle door area on Lower deck
   - Object contacted by passenger and body part which made the contact.
     - One contact was recorded per passenger, namely the one identified as the first significant one. So, for example, where a passenger was standing holding a vertical handrail, the bus braked and the passenger fell into handrail with their head and chest, the analyst would identify the vertical handrail as the 'object contacted' and the body part they believed made the most significant contact (likely to be the head) and recorded just those, i.e. vertical handrail and head.

   Also, while analysing cases, analysts entered any other interesting observations into description fields to help capture as much relevant information as possible.
5) From observations after the incident, an estimation of each passenger's injury severity was made and divided into three categories (contact, slight, and moderate). This was done by viewing the passenger's reaction and actions following the incident, including whether they received first aid or, in some cases, left the scene in an ambulance. To categorise the injuries, an approach loosely based on the process used for STATS19 data, detailed in the STATS 20 manual, was used. The categories were defined as follows:
   - Non-injured (contact):
     - Passengers who showed no visible adverse effect and did not receive medical attention.
   - Slightly injured:
     - Passengers who showed visible signs of pain and did not receive medical attention, e.g. clutching shoulder, rubbing chest,
     - Passengers who were knocked to the floor and did not receive medical attention.
   - Moderately injured:
     - Passengers with symptoms as for slightly injured but who received professional medical attention at the scene and/or were taken to hospital.

- Operator notes record serious injury.

It should be noted that this injury classification process was subjective, so should be interpreted with that in mind.

6) When available, the peak acceleration / deceleration values for the bus, recorded and embedded in the video files, were entered into the database.

It should be noted that the quality and frame rate of the CCTV footage and the positioning of cameras caused some variation in the accuracy of the analysis, in particular the estimation of the passenger’s injury severity. For example, the newer London buses had high quality, high frame rate cameras, whilst some of the older vehicles had CCTV cameras which had a poor quality and slow frame rate, some of which were only one frame every two seconds.

Following coding of the database, it was then analysed in order to answer the research question.

2.2.3.3 Results – injury mechanisms

The base data set, containing 192 incidents, was analysed to help understand passenger injury mechanisms. The results are presented in the three sections below; the first reports results related to injury mechanisms for all passengers and the second and third give detailed results for the subsets of standing and seated passengers, respectively.

<u>All Passengers</u>

In the 192 incidents examined, 227 passengers were observed to have significant interactions with part of the bus interior or another passenger. For these passengers 17 were judged to have suffered moderate injury (where medical attention such as an ambulance arrived at the scene), 70 a slight injury, 112 no injury and 28 unknown, i.e. those for who it was not possible to estimate injury severity.

Figure 2-11 shows the frequency with which different parts of the bus interior were the first significant object that an occupant collided with. The vertical grab rails were hit most frequently, followed by the floor. Because many people fell off the seat onto the floor, approximately the same number of standing and seated occupants hit the floor, (17 standing, 14 seated) and 6 boarding and/or alighting the bus.

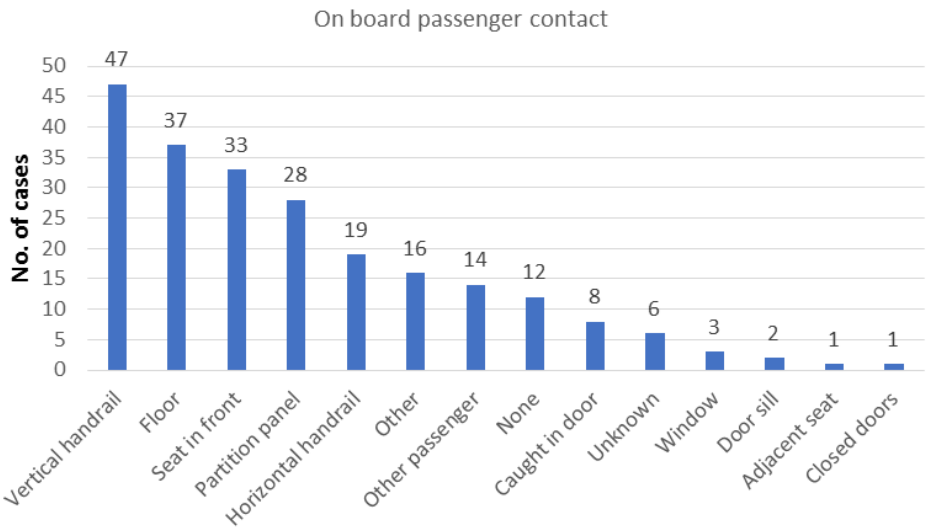


Figure 2-11: Bus interior part contacted (227 cases)

Figure 2-12 shows that the body part that makes the first significant contact most frequently with a part of the bus interior or other passengers is the head with 69 cases (30%), closely followed by the chest with 61 (27%).

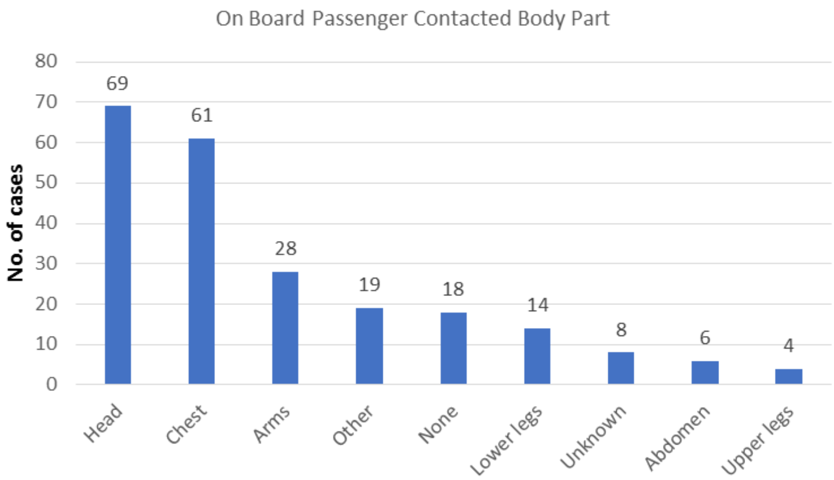


Figure 2-12 : Passenger body part contacted (227 cases)

Standing Passengers

Figure 2-13 shows the naming convention used for the identification of the locations of standing passengers within the bus.

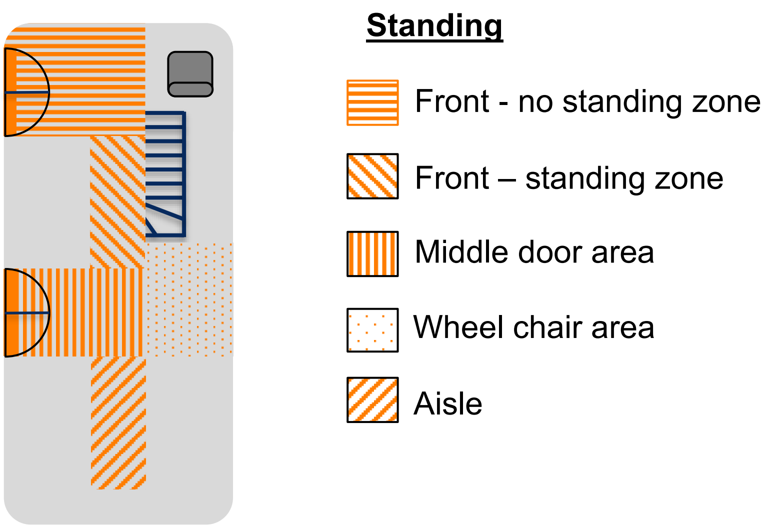


Figure 2-13: Naming convention for location of standing passengers - plan view

Table 2-14 shows the count of bus interior parts impacted by standing passengers who moved substantially and /or were injured by their initial location within the bus. It can be seen that the most frequently impacted part of the bus interior was the floor accounting for 20%, closely followed by vertical handrails with 19%, and partition panels with 16.5% of incidents. Further examination of the table shows that passengers standing in the middle door area accounted for the largest number of interactions (about a third) and a large proportion of them hit a vertical handrail.

There were only 4 cases where a passenger who was standing on the upper deck had a significant interaction with the bus interior. This low number was expected because passengers should not stand on the upper deck when the bus is moving, although some do stand, for example, to move towards the exit to be ready for their stop.

There were also 11 cases where a passenger was standing on the stairs and in 10 of these the bus was moving. Results of the injury severity analysis for these passengers showed five uninjured, three slightly injured (showing signs of pain but did not receive medical attention) and for three no injury severity assessment could be made. It was also observed that six out of 11 passengers were not holding onto the handrail at the time of the incident, this potentially being a contributory factor to their fall down the stairs.

This is very similar to a wider finding that 45% of standing passengers that suffered a significant movement/impact were holding on. Those that were holding on were using a handrail most of the time (89%). It was also found that in instances where a vertical handrail was being held, the most common object impacted was the vertical handrail itself.

Table 2-14: For standing passengers who moved substantially and/or were injured (85 cases), count of bus interior parts impacted by their initial location

Location	Location on Bus	Adjacent seat	Caught in door	Floor	Horizontal handrail	None	Other	Other passenger	Partition panel	Seat in front	Unknown	Vertical handrail	Window	Total
Lower Deck	Above rear axle	1	1	2			1					1		6
	Adjacent to luggage rack			4			2		4			2		12
	Aisle			3		3	1	2	1			2		12
	Frontal no standing zone		1						1					2
	Middle door area			6	1	2		6	2		2	9		28
	Priority/wheelchair zone				3	1	1	1	1	1		2		10
	Lower deck Total	**1.2%**	**2.4%**	**17.6%**	**4.7%**	**7.1%**	**5.9%**	**10.6%**	**10.6%**	**1.2%**	**2.4%**	**18.8%**	**0.0%**	**82.4%**
Stairs	On stairs			2			2	1	5		1			11
	On stairs Total	**0.0%**	**0.0%**	**2.4%**	**0.0%**	**0.0%**	**2.4%**	**1.2%**	**5.9%**	**0.0%**	**1.2%**	**0.0%**	**0.0%**	**12.9%**
Upper Deck	Above rear axle					1								1
	Aisle				1					1			1	3
	Upper deck Total	**0.0%**	**0.0%**	**0.0%**	**1.2%**	**1.2%**	**0.0%**	**0.0%**	**0.0%**	**1.2%**	**0.0%**	**0.0%**	**1.2%**	**4.7%**
	Total	**1.2%**	**2.4%**	**20.0%**	**5.9%**	**8.2%**	**8.2%**	**11.8%**	**16.5%**	**2.4%**	**3.5%**	**18.8%**	**1.2%**	**100.0%**

Table 2-15 shows the count of bus interior parts impacted by standing passengers who were injured by their initial location within the bus. As expected, a similar trend to Table 2-14 is observed with the floor, vertical handrail, and partition panel being the parts most frequently impacted.

Table 2-15: For standing passengers who were injured (36 cases), count of bus interior parts impacted by their initial location

Location	Location on Bus	Adjacent seat	Caught in door	Floor	Horizontal handrail	Other	Other passenger	Partition panel	Vertical handrail	Window	Total
Lower Deck	Above rear axle	1	1	1		1			1		5
	Adjacent to luggage rack			2		2		2			6
	Aisle			3		1	1		1		6
	Middle door area			4	1		2	1	3		11
	Priority/wheelchair zone				2	1		1			4
	Lower deck Total	**2.8%**	**2.8%**	**27.8%**	**8.3%**	**13.9%**	**8.3%**	**11.1%**	**13.9%**	**0.0%**	**88.9%**
Stairs	On stairs			1		1		1			3
	On stairs Total	**0.0%**	**0.0%**	**2.8%**	**0.0%**	**2.8%**	**0.0%**	**2.8%**	**0.0%**	**0.0%**	**8.3%**
Upper Deck	Aisle									1	1
	Upper deck Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**2.8%**	**2.8%**
	Total	**2.8%**	**2.8%**	**30.6%**	**8.3%**	**16.7%**	**8.3%**	**13.9%**	**13.9%**	**2.8%**	**100.0%**

Table 2-16 shows the count of bus interior parts impacted by standing passengers who were moderately injured by their initial location within the bus. It can be seen that there are only eight passengers injured at this level. However, the trends observed above are still apparent, i.e. the floor and vertical handrails are still impacted frequently. Interestingly, two cases of moderate injury were recorded for the horizontal handrail positioned at around head height on the bus side in the wheelchair zone. Although not statistically meaningful, this observation potentially indicates the injurious nature of this particular rail caused by its positioning at head height.

Table 2-16: For standing passengers who were moderately injured (8 cases), count of bus interior parts impacted by their initial location

Location	Location on Bus	Floor	Horizontal handrail	Other	Vertical handrail	Total
Lower Deck	Above rear axle	1		1		2
	Aisle			1		1
	Middle door area	2			1	3
	Priority/wheelchair zone		2			2
	Lower deck Total	**37.5%**	**25.0%**	**25.0%**	**12.5%**	**100.0%**
	Total	**37.5%**	**25.0%**	**25.0%**	**12.5%**	**100.0%**
		3	**2**	**2**	**1**	**8**
		37.5%	25.0%	25.0%	12.5%	100.0%

Table 2-17 shows the bus interior part impacted by standing passengers by body part. It is seen that the most frequently contacted body parts were the chest (31%) and head (28%), which is the same as for all passengers.

Table 2-17: For standing passengers who moved substantially and/or were injured (85 cases), count of bus interior parts impacted by body part

		Adjacent seat	Caught in door	Floor	Horizontal handrail	None	Other	Other passenger	Partition panel	Seat in front	Unknown	Vertical handrail	Window	Total
Contacted Body Part	Abdomen	1		2										3.5%
	Arms		1		1			1	1	1		5		11.8%
	Chest			7				7	5	1		6		30.6%
	Head			6	3		5		6			3	1	28.2%
	Lower legs		1				1							2.4%
	None					7								8.2%
	Other			2	1		1	1	1			1		8.2%
	Unknown							1			3			4.7%
	Upper legs								1			1		2.4%
	Total	**1.2%**	**2.4%**	**20.0%**	**5.9%**	**8.2%**	**8.2%**	**11.8%**	**16.5%**	**2.4%**	**3.5%**	**18.8%**	**1.2%**	**100.0%**

When considering the moderately injured standing passengers only (Table 2-18), the head accounts for the majority of the injuries (87.5%).

Table 2-18: For moderately injured standing passengers (8 cases), count of bus interior parts impacted by body part

		Floor	Horizontal handrail	Other	Vertical handrail	Total
Contacted Body Part	Head	3	2	2		87.5%
	Upper legs				1	12.5%
	Grand Total	**37.5%**	**25.0%**	**25.0%**	**12.5%**	**100.0%**

Whilst analysing the CCTV footage and entering the data into the database, the coders made the following observations:

- Passengers standing in the front of the bus generally remained standing in the majority of incidents because they were holding onto handrails. In the cases that they fell, it was usually because they were not holding on or they were impacted by passengers from behind them which caused them to lose their grip.
- Passengers standing in the middle area often leant against the panel in front of the door area. No cases of the passenger falling completely over this partition were observed.
- The pole for wheelchair lateral retention was not impacted often. In cases in which it was impacted, it was usually by passengers standing directly behind the pole, who were often holding on, or sometimes by passengers seated in alignment.
- Many passengers who fell were transitioning in or out of their seat. When transitioning out of the seat they often impacted the vertical handrail between the seat back and ceiling. A large proportion of the passengers that had this problem were elderly females. This is probably because they take longer to transition and are less stable. It was also noticed that if there were steps to reach the seats, this exacerbated the problem. Either it made the fall larger (fall down steps as well) or, if they were on the steps at the time of the incident, it appeared to make them less stable. It should be noted that priority seats do not have steps to access them; the seats in question were standard seats towards the rear of the bus.

  A potential solution to help mitigate this issue could be driver and/or passenger education related. For example, guidance could be given to drivers in their training to keep the bus stationary until passengers are seated, in particular vulnerable ones. Messages could be given to passengers to remain seated until the bus stops. Potential problems with these types of solutions are that they could likely lead to more time being spent at stops, which in turn may lead to timetable issues, and, without further research, it is uncertain how effective they may be.

2.2.3.4 Seated Passengers

Figure 2-19 shows the naming convention used for identification of locations of seated passengers within the bus.

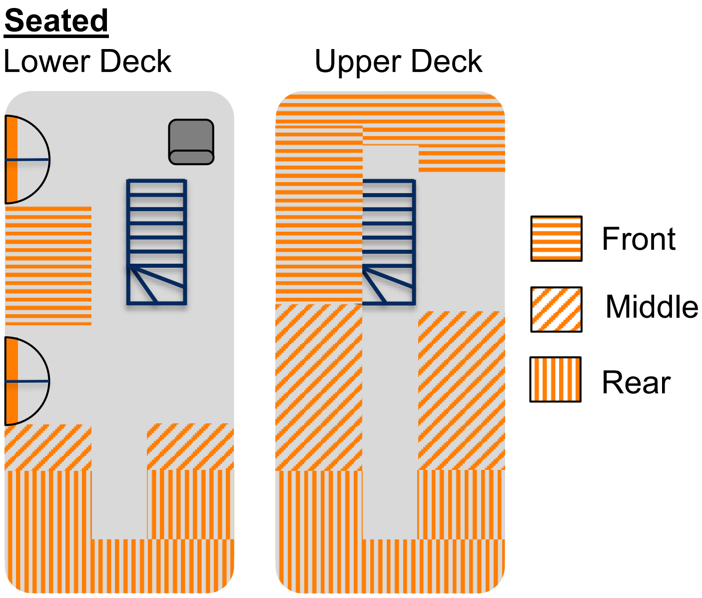


Figure 2-19: Naming convention for location of seated passengers – plan view

There were 114 cases of passenger interaction from a seated position during a bus event. Of these 114 passengers, 94 were sitting in the lower deck (85.1%), and 20 were sitting in the upper deck. Most passengers were sitting in forward facing seats (99), while 12 were sideways and 3 were rearward facing, which roughly reflects the relative numbers of these types of seats on the buses in the sample analysed.

Table 2-20 shows a count of bus interior parts impacted by seated passengers who moved substantially and/or were injured, by their initial location within the bus. Vertical handrails and the back of the seat in front were the most frequently impacted bus parts. The largest proportion of impacts on the lower deck occurred in the middle area (45.6%), near and around the middle doors and priority seats, with the main object impacted being a vertical handrail, many of which, the coders noted, were positioned directly in front of the seat.

Other points noted were:

- The lower deck also included 11 cases where a buggy was involved (about 10% of seated cases). In all 11 cases, the buggy had been positioned in a sideways position to the direction of travel, which under heavy braking, resulted in the buggy tipping over. This led to 6 children making contact with the floor, and 3 children making contact with a vertical handrail in the wheelchair zone. Of the children involved, 1 required hospital admission, while 3 recorded slight injuries.
- During harsh braking or collision events, passengers sitting in the middle seat on the rear row of seats on either the lower or upper deck were usually thrown

from their seats because they were not restrained at all. This resulted in them travelling a considerable distance down the bus, usually falling face forwards into the floor. Six cases in which this occurred were observed in the data set.

- Specific for defined areas of the bus
  - Seats behind wheelchair area
    - Restraint is often poor for these seats. This results in passengers been thrown from their seats into the wheelchair area and/or handrails in front of their seats or even the vertical handrail positioned to restrain a wheelchair.
  - Seats behind middle doors
    - The handrail in front of the aisle seat was impacted often because of its position towards the middle of the aisle seated occupant. Specifically, the interaction / outcome appeared to correlate somewhat with the magnitude of deceleration and reaction time of the passenger, for low deceleration pulse / quick reaction the passenger grabs pole and rotates around it sometimes falling onto the floor in middle area, for high deceleration pulse / slow reaction the passenger directly hits the pole in front of them, often with their head.
  - Bay seat arrangement
    - Many cases were observed in which passengers seated in the forward facing seats were thrown forwards with undesirable consequences, in particular for aisle seated passengers. These passengers often attempted to grab the vertical handrail positioned at top of opposite seat and if failed to do this, fell into aisle.
  - Upper deck
    - No specific problems were observed for the upper deck apart from children seated on the front row of seats. Often, they were observed to be thrown off the seat into the guard rail, whereas adults being larger would restrain themselves with their hands on the guard rail. It is interesting to note that for a substantial proportion of buses, this guard is padded in front of the passenger sitting position.

Table 2-20: For seated passengers who moved substantially and/or were injured (114 cases), count of bus interior parts impacted by their initial location

	Seating Location	Floor	Horizontal handrail	None	Other	Other passenger	Partition panel	Seat in front	Vertical handrail	Window	Total
Lower deck	Front	1		1			6	1	5		12.3%
	Middle	6	10	2	1	3	3	7	19	1	45.6%
	Rear	4	1	1	2	1		13	6		24.6%
	Lower deck Total	**9.6%**	**9.6%**	**3.5%**	**2.6%**	**3.5%**	**7.9%**	**18.4%**	**26.3%**	**0.9%**	**85.1%**
Upper deck	Front	2	1				1	1	1	1	6.1%
	Middle		1				1	3			4.4%
	Rear	1	1					6			7.0%
	Upper deck Total	**2.6%**	**2.6%**	**0.0%**	**0.0%**	**0.0%**	**1.8%**	**8.8%**	**0.9%**	**0.9%**	**17.5%**
	Total	**12.3%**	**12.3%**	**4.4%**	**4.4%**	**3.5%**	**9.6%**	**27.2%**	**27.2%**	**1.8%**	**100.0%**

Table 2-21 shows the count of bus interior parts impacted by injured seated passengers by their initial location within the bus. The parts of the bus hit most frequently were vertical handrails (31.4%) and horizontal handrails (19.6%), many of which the coders noted were positioned on the top of the seats in front. A comparison with Table 2-20 shows that the percentage of passengers who hit a vertical handrail is increased (27.2% to 31.4%), the percentage who hit a horizontal handrail is increased (12.3% to 19.6%) and the percentage who hit the seat in front is decreased (27.2% to 7.8%). This trend may indicate the injurious nature of an impact with a handrail and the less injurious nature of an impact with a seat back, although it must be noted that the results are not statistically significant. Note that horizontal handrails on the top of seat backs were identified separately to the seat back.

Table 2-21: For seated passengers who were injured (51 cases), count of bus interior parts by their initial location

	Seating Location	Floor	Horizontal handrail	Other	Other passenger	Partition panel	Seat in front	Vertical handrail	Window	Total
Lower deck	Front	1				5		3		17.6%
	Middle	2	8		3	3	1	9		51.0%
	Rear	3	1	2			2	4		23.5%
	Lower deck Total	**11.8%**	**17.6%**	**3.9%**	**5.9%**	**15.7%**	**5.9%**	**31.4%**	**0.0%**	**92.2%**
Upper deck	Front	1					1		1	5.9%
	Middle		1							2.0%
	Upper deck Total	**2.0%**	**2.0%**	**0.0%**	**0.0%**	**0.0%**	**2.0%**	**0.0%**	**2.0%**	**7.8%**
	Total	**13.7%**	**19.6%**	**3.9%**	**5.9%**	**15.7%**	**7.8%**	**31.4%**	**2.0%**	**100.0%**

Table 2-22 shows the distribution of injuries when considering moderately injured passengers only. It is seen that all of the moderate injuries occur on the lower deck, that a large percentage of these involve interaction with a vertical handrail (44.4%) and 3 out of 4 of these are in the middle area. This trend may indicate the injurious nature of vertical handrails in the middle bus area, although it must be noted that the results are not statistically significant and other factors, such that elderly people who are more prone to injury are more likely to sit in these seats, may confound the result.

Table 2-22: For seated passengers who were moderately injured (9 cases), count of bus interior parts impacted by their initial location

	Seating Location	Floor	Horizontal handrail	Other	Partition panel	Vertical handrail	Total
Lower deck	Front				1	1	22.2%
	Middle	1	1		1	3	66.7%
	Rear		1				11.1%
	Lower deck Total	**11.1%**	**22.2%**	**0.0%**	**22.2%**	**44.4%**	**100.0%**
	Total	**11.1%**	**22.2%**	**0.0%**	**22.2%**	**44.4%**	**100.0%**

Table 2-23 shows the bus interior part impacted by seated passengers by body part. It is seen that the most frequently contacted body parts were the head (35.1%) and chest (25.4%). The bus interior part impacted by the head most frequently was a vertical handrail.

Table 2-23: For seated passengers who moved substantially and/or were injured (85 cases), count of bus interior parts impacted by body part

Contacted Body Part	Floor	Horizontal handrail	None	Other	Other passenger	Partition panel	Seat in front	Vertical handrail	Window	Total
Abdomen	1									0.9%
Arms						3	10	4	1	15.8%
Chest	2	5			1		10	11		25.4%
Head	6	8		2	2	7	1	13	1	35.1%
Lower legs	1	1			1	1	1			4.4%
None			4				5	1		8.8%
Other	1			1			4	2		7.0%
Unknown	1									0.9%
Upper legs	2									1.8%
Total	**12.3%**	**12.3%**	**3.5%**	**2.6%**	**3.5%**	**9.6%**	**27.2%**	**27.2%**	**1.8%**	**100.0%**

Table 2-24 shows the bus interior part impacted by seated passengers who were moderately injured by body part. As for Table 2-23 above, the head to vertical handrail is the most frequent interaction, although not statistically significant.

Table 2-24: For seated passengers who were moderately injured (8 cases), count of bus interior parts impacted by body part

	Floor	Horizontal handrail	Partition panel	Vertical handrail	Total
Chest				1	11.1%
Head	1	2	2	3	88.9%
Total	**11.1%**	**22.2%**	**22.2%**	**44.4%**	**100.0%**

2.2.3.5 Summary of findings

<u>All passengers</u>

- About half of passengers who moved substantially and contacted part of the bus interior in an incident, were not obviously injured (i.e. there were no obvious signs of pain or impairment on the CCTV footage and they did not receive medical attention).
- The head and chest were the most frequently contacted parts of the body.
- Vertical handrails and the floor were the most frequently contacted parts of the bus.

<u>Standing Passengers</u>

- The parts of the bus that standing passengers who were injured hit most frequently were the floor (20%) and vertical handrails (19%), followed by partition panels (18.8%). The head and the chest were the body parts impacted most frequently, with the head receiving most (87.5%) of the moderate injuries. A number of moderately injured passengers standing in the wheelchair area impacted horizontal handrails positioned at head height.
- As many as 45% of the passengers who fall or who move substantially were holding on. For those passengers, some impacted the handrail that they were holding onto.
- Many passengers who fell were transitioning in or out of their seat. When transitioning out of the seat they often impacted the vertical handrail between the seat back and ceiling. A large proportion of the passengers that had this problem were older females. This is probably because they take longer to transition and are less stable than younger passengers. It was also noticed that if there were steps to reach the seats, this exacerbated the problem. Either it made the fall larger (fall down steps as well) or, if they were on the steps at the time of the incident, it appeared to make them more unstable. It should be noted that priority seats do not have steps to access them; the seats in question were standard seats towards the rear of the bus.
    - A potential solution to help mitigate this issue could be driver and/or passenger education. For example, guidance could be given to drivers in their training to keep the bus stationary until passengers are seated, in particular vulnerable ones, and messages could be given to passengers to remain seated until the bus stops.

Seated passengers

- The parts of the bus that seated occupants impacted most frequently were vertical handrails and the seat in front (both 27.2%). For injured seated occupants the parts of the bus hit most frequently were vertical handrails (31.4%) and horizontal handrails (19.6%) many of which the coders noted were positioned on the top of the seats in front.
- The largest proportion of impacts on the lower deck occurred in the middle area (45.6%), near and around the middle doors and priority seats, with the main object impacted being a vertical handrail, many of which, the coders noted, were positioned directly in front of the seat.
- The following issues were highlighted:
  - The positioning of buggies containing children in the wheelchair area. Eleven cases were observed where a buggy was involved. In all these cases the buggy was positioned sideways to the direction of travel, which under heavy braking, resulted in it tipping over, the child falling out and about a third of them been injured.
  - No restraint of passengers sitting in the middle seat on the rear row of seats. During harsh braking or collision events, these passengers were usually thrown from their seats and down the aisle in front of them.
  - Little restraint of passengers sitting in forward facing bay seats, in particular for aisle seated passengers. These passengers often fell into the aisle unless they managed to grab the vertical handrail positioned at the top of the opposite seat.

2.2.3.6 Results – injury risk

The data set with exposure data, containing 70 incidents, was analysed to help understand how the risk of injury differs for different areas of the bus. For each area of the bus the proportion of passengers injured was calculated. The results are shown in Figure 2-25 and Figure 2-26, for standing and seated passengers, respectively. Caution should be exercised in interpretation of these results because many differences will not be significant because of the small sample size.

The results show that a smaller proportion of seated passengers are injured (2%) compared to standing passengers (6%), indicating a smaller risk of injury for seated passengers. For seated passengers, the results show a smaller proportion of those seated on the upper deck are injured (0.3%) compared to those seated on the lower deck (1.5% to 6%), indicting a smaller risk of injury for passengers seated on the upper deck. It is likely that there are two main factors contributing to this, firstly that, generally, there are fewer features with injury causing potential on the upper deck (see Section 2.3 below), and secondly, person’s with reduced mobility (PRM), who are less injury tolerant, will usually sit on the lower deck because they find it difficult to climb the stairs to the upper deck.

Another notable observation is the high proportion of seated passengers injured in the area behind the middle doors (6%). This is discussed further in Section 2.3 below.

It is not known how many standing passengers had just stood up from being sat or how many were in the act of standing up. This would be recorded in further CCTV analysis work.

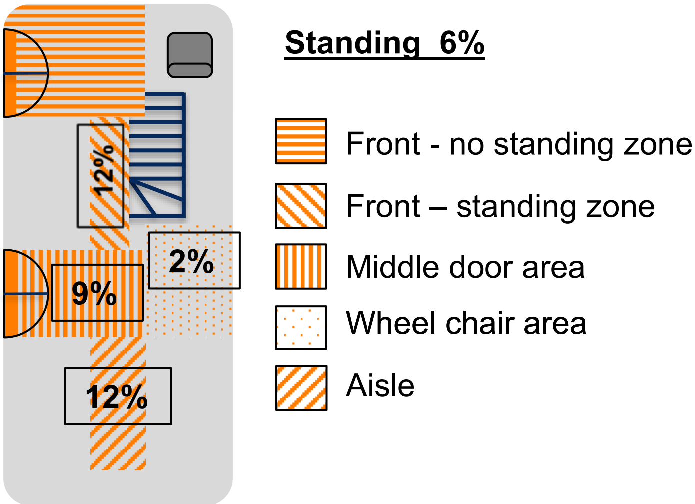


Figure 2-25: Proportion of standing passengers injured

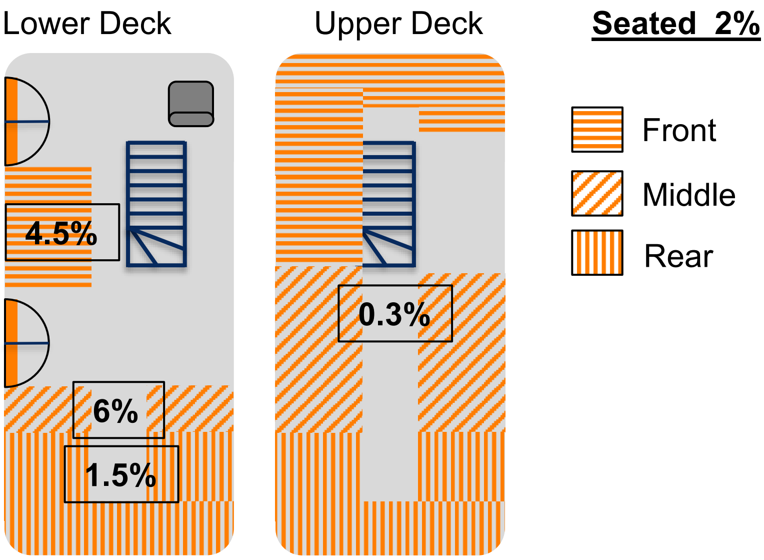


Figure 2-26: Proportion of seated passengers injured

2.3 TfL bus examination - interior

Buses were examined to identify potential injury causing items. It should be noted that handrails cause a dilemma in that they are required to help prevent passengers falling but if they fall they may cause an impact hazard, particularly if positioned poorly. The were a variety of issues noted.

2.3.1 Standing occupants

- Handrails in head impact zone, i.e. at the height of a standing passenger's head. These have been seen to be impacted in the CCTV incident analysis. Examples include horizontal and vertical handrails in the wheelchair area.

Figure 2-27: Vertical and horizontal handrails in head impact zone in wheelchair area

- Partitions which do not compartmentalise, i.e. half height partitions which a passenger can be propelled over during harsh braking or a collision.

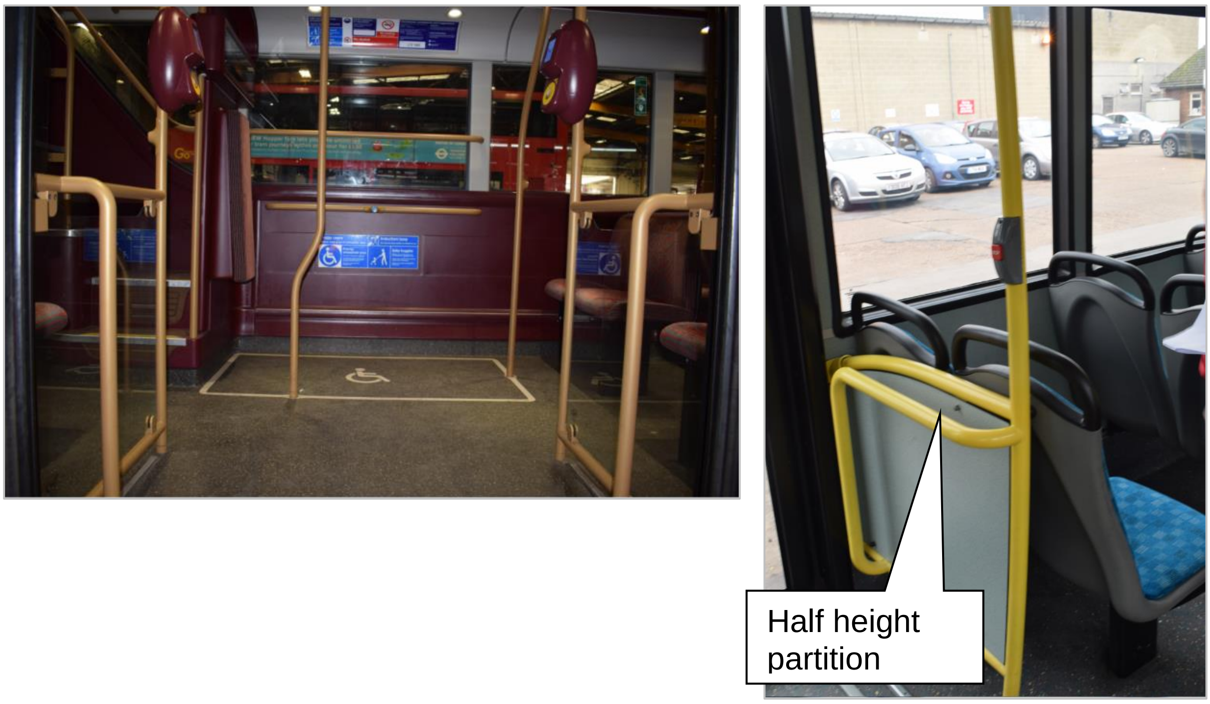


Figure 2-28: Half height partition to left of middle doors

- General impact hazards, i.e. protrusions, sharp edges and corners. Examples include steps and information displays. On some buses step corners are square as opposed to rounded and edges of steps on some buses are noticeably sharper than on other buses. Information displays sometimes have sharp corners in the head impact zone.

  Based on rail interior design guidance notes (Railway Group, 2011) GN95, it was proposed that the assessment procedure be developed to encourage removal of protrusions and that edges / corners of rigid features (i.e. those with with a shore hardness rating greater than 60) should have radii of circa 5 mm miniumum and higher (ideally 20 mm minimum) for head impact.

Figure 2-29: Sharp step corner (left); rounded step corner (right)

2.3.2 *Seated occupants*

- Handrails in alignment with likely trajectories of seated occupants, an example of a vertical handrail for aisle seat near middle doors is shown below.

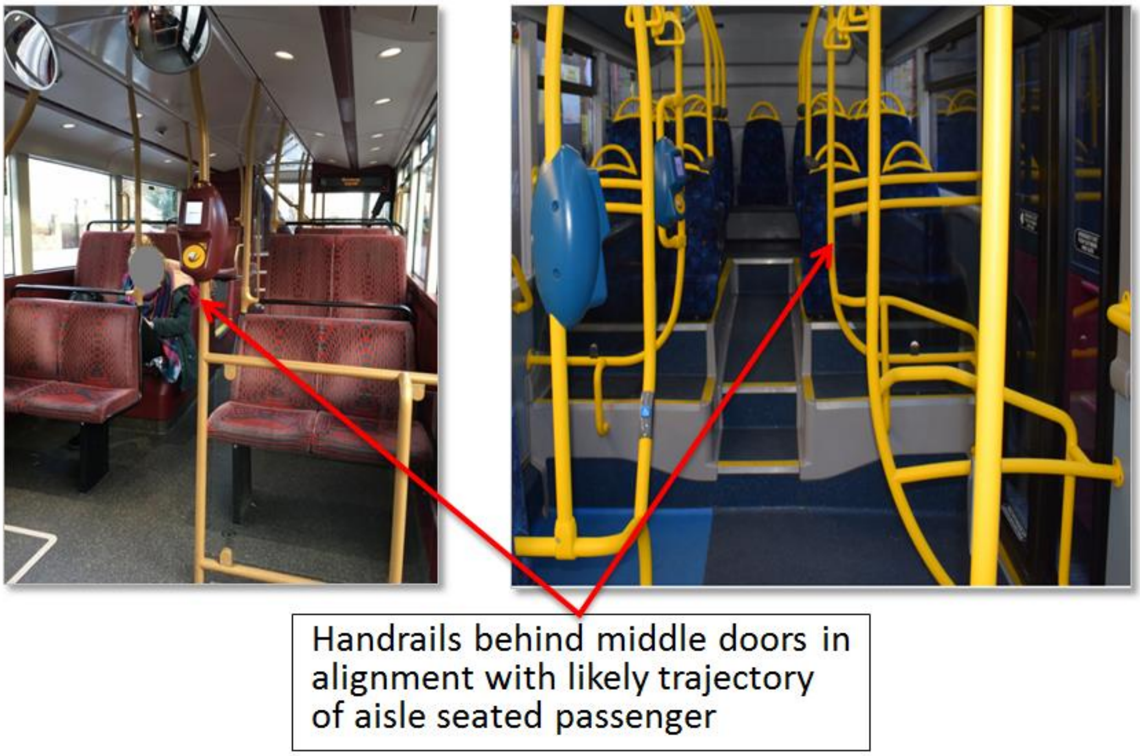


Figure 2-30: Vertical handrail in alignment with trajectory of passenger seated in aisle seat near middle doors

- Low backed seats with handrail on top. These can cause a number of issues:

- Handrail on top can be an impact hazard for passengers, especially shorter persons, e.g. children, seated behind because in alignment with likely trajectory of passenger.
- Rear facing low backed seats do not provide support for head and neck in frontal impact or harsh braking events.

Figure 2-31: Example of low backed seat, handrail on top can be impacted by passenger seated behind (left) and if rear facing provides no support for head/neck of passenger (right)

- Restraint – inadequate constraint of passengers on some seats, for example
    - No restraint of passengers on middle seats on back row.
    - Little / no restraint of passengers in some seats facing into wheelchair area.

- Inadequate restraint for higher seats (above rear wheels) because passenger positioned high above low backed seats in front of them

Figure 2-32: Little / no restraint of passengers on middle seat on back row (left) or seat facing into wheelchair area (right). Also, inadequate restraint for higher seats (above rear wheels) with inadequate restraint from low backed seats ahead of them

- General impact hazards, i.e. protrusions, sharp edges and corners. Examples are an external passenger information display by the priority seats and mirrors for the driver to see the middle door area at head impact height.

  As for standing passengers, it was proposed that the assessment procedure be developed to encourage removal of protrusions and that edges / corners of rigid features should have radii of circa 5 mm miniumum and higher (ideally 20 mm minimum) for head impact.

Figure 2-33: Sharp corners on passenger information display by priority seats

It is interesting to note that the seats positioned behind the wheelchair area and middle doors often have features associated with high injury potential, in particular inadequate restraint and handrails in alignment with passenger trajectories. This correlates with the area identified in the CCTV analysis as having the highest proportion of seated passengers who were injured (6%) - see Section 2.2.3.3 above, Figure 2-26. Confirmation of the problems in this area of the bus is shown below in Figure 2-34, Figure 2-35, and Figure 2-36.

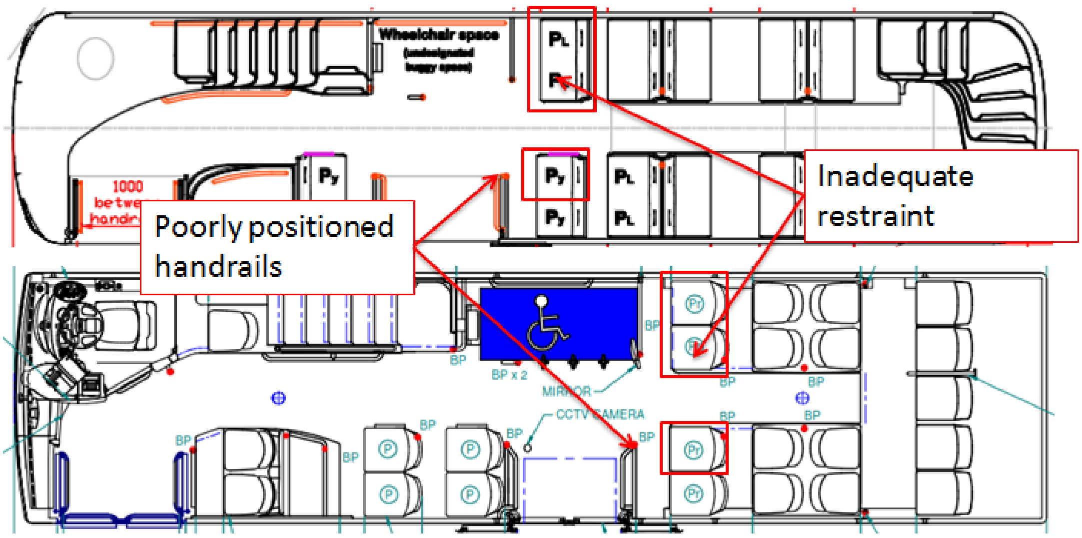


Figure 2-34: Poorly positioned handrails and inadequate restraint for seats behind middle doors and wheelchair area

Figure 2-35: Inadequate restraint of passengers on seats behind wheelchair area

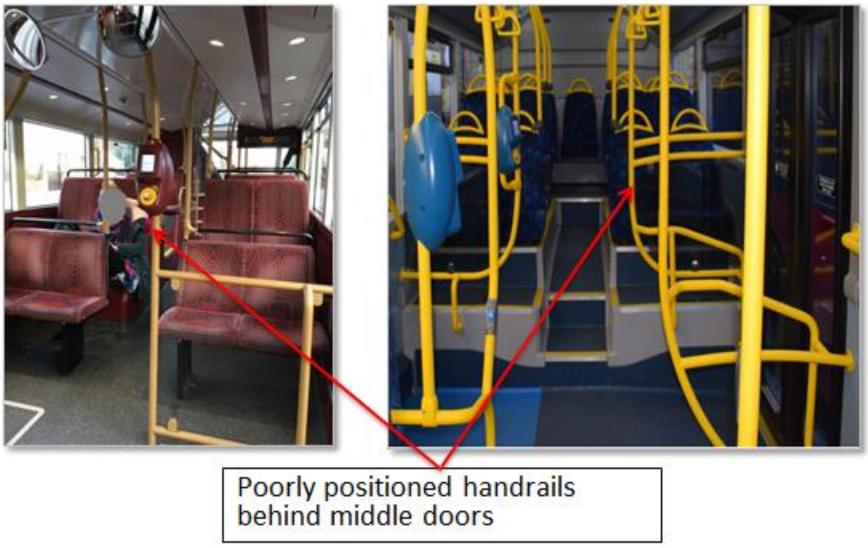


Figure 2-36: Poorly positioned handrails for seats behind middle doors

It should also be noted that the seats in these areas are often used by persons with reduced mobility (PRM) who are generally less injury tolerant, indeed they are often priority or preferential seats. This compounds the problem in that more vulnerable passengers are encouraged sit in seats, which often have a number of features associated with high injury potential.

It should be emphasized that not all the issues identified above were observed on all the buses examined. Indeed, many of the buses exhibited good features, although usually all buses exhibited at least one issue. Examples of good features seen included:

- Partition in front of exposed seat behind wheelchair area

Figure 2-37: Example of partition installed to improve passenger restraint for exposed seats behind wheelchair area

- Good restraint for seats over rear wheels enabled by raising floor level behind middle doors

Figure 2-38: Example of good restraint for sets over rear wheels

- Seat back to ceiling handrail positioned at outboard edge of seat which helps reduce risk of passenger impacting it in the event of harsh braking or a collision.

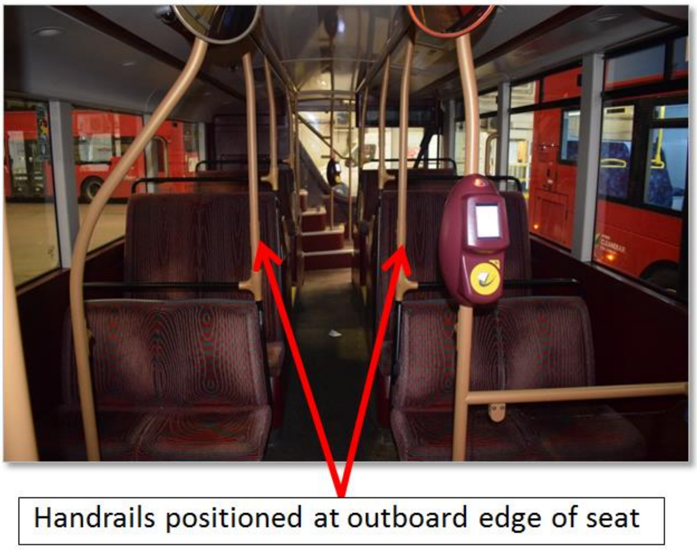


Figure 2-39: Example of handrails positioned at outboard edge of seat

2.3.3 Summary of findings

For both standing and seated passengers potential hazards were noted under the following categories:

- Handrails, mainly in relation to their position.
- Restraint – i.e. inadequate constraint of a passenger's movement in the event of a braking / collision incident. For seated passengers, low backed seats in front of seats positioned higher above the rear wheels, often do not provide adequate restraint.
- General impact hazards, i.e. protrusions, sharp corners and edges.

It was observed that seats behind the wheelchair area and middle doors often have features associated with high injury potential, in particular inadequate restraint and handrails in alignment with passenger trajectories. This correlates with the position for which a higher risk of injury was observed (6%) for seated passengers in the CCTV analysis.

Examples of good features which helped mitigate the issues noted above were observed on some buses.

2.5 TfL Bus examination – exterior

Buses were examined to identify potential injury causing items. The following points were noted:

2.5.1 General

Generally, the exterior of a bus presents flat surfaces with protrusions such as indicators well rounded. Items such as filler points are recessed and/or covered with a hinged flap (Figure 2-40). Vents for engine cooling present surfaces with no protrusions likely to cause injury, and are mounted on the offside or rear, so that hot air is not directed at passengers on the kerb who are about to embark or have just disembarked. So overall, the exterior of a bus presents no features that have a potential to cause injury to a embarking or disembarking passenger or passer-by. The exceptions to this statement are the wiper blade driver posts on some buses and the mirrors, some of which are mounted at a height at which they could strike a pedestrian. Further details are given in the bullet points below.

Figure 2-40: Views of bus exterior showing generally flat surfaces with no significant protrusions with the exception of mirrors and wiper driver posts on some buses

2.5.2 Wiper driver posts

On some buses, it was noted that wiper driver posts that protruded were positioned in the pedestrian impact zone and therefore present an increased injury potential risk. On some buses, this issue was solved by positioning the wiper driver posts above the top of the windscreen and above the pedestrian impact zone. This issue is being addressed as part of the work for the ‘VRU crashworthiness’ safety measure which considers counter-measures for impact protection, run-over protection and mirror strikes.

Figure 2-41: Protruding wiper driver posts positioned in pedestrian impact zone (left) and above pedestrian impact zone (right)

2.5.3 Filler points (fuel and Adblue)

Filler points for fuel and Adblue are recessed and sometimes covered with a hinged flap. It was noted that the flap could open easily. However, it was judged that this should not cause a significant problem because it was hinged on the right side which means that bus forward motion should help it close and the driver will be able to see if it is open in the mirror.

Figure 2-42: Filler points recessed (left) and covered with hinged flap (right)

2.5.4 Summary for bus exterior

In summary, the exterior of a bus presents no features that have a potential to cause injury to a embarking or disembarking passenger or passer-by. The exceptions to this statement are the wiper blade driver posts on some buses and the mirrors, some of which are mounted at a height at which they could strike a pedestrian. These issues are being addressed as part of the ‘VRU crashworthiness’ safety measure which considers counter-measures for impact protection, runover protection and mirror strikes. On this basis, it is recommended that there is no need for an exterior visual inspection of buses.

3 Literature survey

The literature generally supports the findings of the analyses of the incident data reported above, although no detailed information was found about passenger injury mechanisms.

Based on an analysis of STATS19 data from 1999 to 2001, (Kirk *et al.*, 2003) found that a high proportion of the killed and seriously injured bus passenger casualties (64.3%) in GB occurred when the vehicle was not involved in a collision. There was a high proportion of older females in this casualty group. Probable reasons given for this were a greater bus use by older females (evidenced by bus use data) and lower tolerance to injury (evidenced by KSI rate data). Based mainly on an observation that 94% of non-collision casualties occurred on 30 mph roads, Kirk stated that most non-collision casualties likely occurred on local service buses rather than coaches. A number of likely contributory factors were postulated. These included:

- Issues such as uneven floors, lack of visual clues and physiology in older people exacerbating slips, trips and falls.
- Bus manoeuvres such as acceleration of the vehicle before a passenger reaches a seat and in particular heavy braking, also exacerbating slips, trips and falls.
- Poor interior design, such as unprotected metal grab rails and items such as ticket machines which tend to have hard metal edges that will likely cause injury when hit by a falling passenger.

A similar non-collision injury problem has been observed in other countries. A study of injuries sustained by bus and coach occupants in Sweden found that injuries from non-collision incidents (54.2%) were more frequent than injuries from collision incidents (45.8%) [Bjornstig *et al.* 2005]. The EC 5th framework ECBOS project reported that approximately 55% of serious and slight injuries resulted from non-collision events with emergency braking being the main cause (95%) (TUG, 2003).

Much of the rest of the literature is focused on collision type incidents. (Olivares and Yadav, 2009) examined collision data from buses involved in fatal incidents in the US from 1999 to 2003 to define typical incident scenarios. They then used FE modelling to calculate compartment crash pulses for a transit bus for typical frontal, side and rear impacts. Following this, they performed sled tests to study occupant kinematics and identify injury mechanisms to seated bus passengers. The most common injury mechanisms were found to be head and neck injuries caused by body to seat structure contacts and body to body contact between unrestrained occupants. Specifically the injury mechanisms were found to be the following:

- For frontal impact conditions the mechanism was head to seatback contacts. It was noted that with the low seatback designs with a handrail on top it would be difficult to maintain a consistent injury level, because the interaction of the unbelted passenger with the seat yields either neck flexion or extension issues depending on the precise contact area. A compartmentalization approach, using a high back seat may be a potential design solution to provide head compliant surfaces for a wide range of passenger sizes.

- For rear impact conditions the neck extension is mainly due to the low back seat designs and the rearward rotational stiffness of seatbacks. Again, a high back seat may offer a potential design solution.

(Bjornstig *et al.*, 2005) analysed a ten year data set from the health sector which contained 284 injured bus and coach occupants from a well-defined catchment area around a hospital in Umea, Sweden. It found that:

- 54% of injuries occurred in non-collision incidents.
- The collision related injuries were mainly neck sprain / whiplash related (72%) in incidents caused by rear end impacts by other heavy vehicles.

It concluded that measures to reduce the high number of whiplash type injuries needs to be addressed further and the newly introduced law on compulsory seat belt use in long distance coaches may have a potential to reduce single vehicle crash and some collision injuries.

(Albertsson and Falkmer, 2005) performed a literature analysis with a special focus on injury causation and injury mechanisms in European bus and coach incidents. Their analysis focused on collisions, highlighted that rollovers occurred in almost all cases of severe coach crashes with ejection being a major issue. Seat belt fitment was recommended to address this with 3 point belts preferred to lap belts because they also provide protection against head and chest injuries in frontal impacts.

The most relevant papers found related to non-collision injuries and passenger injury mechanisms, were (Kendrick *et al.*, 2015) and (Barnes *et al.*, 2016).

(Kendrick *et al.*, 2015) performed a systematic review on the epidemiology of non-collision injuries occurring in older people during their use of public buses, to enable understanding of the size and nature of the problem of injuries, and to explore strategies for improving the safety of public transport for older people. From the small amount of published literature found, their findings were that older people and women were over-represented in terms of non-collision injuries. These most commonly occurred whilst passengers were standing and either moving around the bus, boarding, or alighting, and whilst the bus was accelerating or decelerating. Studies of Emergency Department (ED) attenders reported bruising to be the most common injury, but between 18% and 33% suffered fractures and or dislocations, with limbs being most commonly injured. Most injuries resulting in ED attendance were minor, but approximately 40% were moderate to severe.

(Barnes *et al.*, 2016) reported an analysis of a linked Hospital Episode Statistics (HES) and STATS19 data set for the period 1999 to 2009, focused on older (aged 60+) bus/coach passengers. As for previous studies it found that the majority of injuries occurred in non-collision type incidents. It also found that the main body regions injured were the head /neck (29.5%), upper extremities (22%) and lower extremities (30.5%) and ‘standing’ was associated with sustaining more injuries, closely followed by being seated. This is in agreement with previous studies, some of which have identified standing passengers to have higher incidences of injuries ((Nue Moller *et al.*, 1982), (Halpern *et al.*, 2005), (Albrektsen and Thomsen, 1983)) and some of which identified high incidence rates for ‘seated’ passengers (Kirk *et al.*, 2003).

It is interesting to compare the percentage of the body regions injured reported by Barnes with the results from the CCTV analysis (body part which makes first significant contact). It might be expected that the body regions injured reported by Barnes should correlate somewhat with the body part that makes first significant contact from the CCTV analysis (head (30%), arms / upper extremities (12%), lower extremities (8%)). It is seen that the correlation is poor, in particular for both the upper and lower extremities. A likely reason for the difference in the proportions of upper extremities is that the CCTV analysis coded shoulder contact with the chest[1] and AIS coding (which was used for the HES data in the Barnes paper) associated clavicle bone injuries to the upper extremities. This hypothesis is supported by the difference in the proportion of chest injuries 9% in Barnes paper compared to 27% in the CCTV analysis. Indeed if the difference in chest injuries (18%) is assumed to be related to shoulder injuries and added to the arm /upper extremity injuries, the comparison becomes very good. Possible reasons for the differences in the proportions of lower extremity injury are firstly; Barnes considers older passengers (60+) only, who are more likely to receive lower extremity injuries from falling than the population as a whole, and secondly; often the first significant contact may not be the cause of the principal injury.

Barnes also noted some discrepancies in passenger location and bus manoeuvres. The main example given was that it may be expected that alighting and boarding incidents would be associated with a ‘parked’ or ‘stationary’ vehicle but this was only recorded for 45% and 60% of these incidents, respectively. Barnes further postulated that the likely cause of this discrepancy was the classification of passengers who were moving through the bus after boarding or to get ready to alight. In summary, although this paper identifies the main body regions injured, it does not report any evidence for injury mechanisms. However, to do this it recommended improving the data collection processes for incidences on buses, especially for cases in which serious injury has occurred. It also recommended investigation of design factors such as the positioning of handrails for passengers moving around the bus whilst it is moving and the positioning of stop buttons noting that some passengers had to stand to push them, although the evidence to support these recommendations was not given in the paper.

A precursor study to this project, (Edwards *et al.*, 2017), was not able to identify large quantities of in-depth data in order to rigorously define the exact injury mechanisms involved. However, it did identify two case studies from the London fatality data, which combined with theory and available literature, suggested that injuries occurred when sharp manoeuvres caused people to fall either from standing or seating position and collide with the floor and/or other interior features, such as seats, hand rails, handholds and stairs. It also hypothesized that when buses suffered external collisions, mechanisms were similar, but with higher decelerations, resulting in higher injury severities.

As a result of the Sandilands Tram accident on 9th November 2016, TfL have identified the following actions to take forward, as a priority, within their main

[1] This was done because it was not easy to separate chest and shoulder contact consistently when examining the CCTV footage.

operational business areas, which includes TfL bus operations (TfL_Board_Paper, 2018):

- Strengthen the arrangements for monitoring and managing fatigue risk
- Review risk assessment processes and the effectiveness of controls to reflect the understanding of risk from the Sandilands incident and that they are capable of identifying and correctly assessing all significant risks
- Review whether the preferred glazing solution for trams is appropriate for other transport types to improve passenger containment
- Review mechanisms for promoting and embedding organisational learning.

The third bullet point related to glazing solutions to improve passenger containment is relevant to bus occupant friendly interiors.

3.1 Summary

The STATS19 data analysis shows that on London buses/coaches the majority of the bus occupant casualty problem is associated with non-collision events (83% of serious injuries) and standing passengers (51% of serious injuries), although a significant proportion of casualties are seated (29% of serious). The bus is often accelerating or braking at the time of the incident. The literature supports these conclusions. A large proportion of casualties are older females aged over 56 (about one third of all serious casualties). The literature suggests that this is probably due to the greater exposure of this gender / age group and their physiology, in particular their lower stability / reaction times and lower tolerance to injury.

The CCTV analysis identified that when passengers fell, vertical handrails and the floor were the bus interior features contacted most frequently and the head and chest were the most frequently contacted parts of the body (most significant first contact). Interestingly, the literature identified that for older people injuries occurred most frequently to the head, lower extremities and upper extremities. Possible reasons for this discrepancy could be that often the first significant contact may not be the cause of the injury and older people are more likely to receive lower extremity injuries from falling. Other issues identified from the CCTV analysis included:

- Standing passengers
    - The parts of the bus that standing passengers who were injured hit most frequently were the floor, vertical handrails and partition panels.
    - 45% of standing passengers who fell and /or moved substantially were holding on. Some passengers that were holding on impacted the handrail that they were holding on to.
    - A number of passengers received a head injury from impact with a horizontal handrail positioned at head height in the wheelchair area.
    - Many passengers who fell were transitioning in or out of their seat.
- Seated passengers
    - The parts of the bus that seated occupants impacted most frequently were vertical handrails and the seat in front. Many who were injured hit the horizontal handrail on top of the seat in front.
    - The largest proportion of impacts on the lower deck occurred in the middle area, near and around the middle doors and priority seats, with the main object impacted being a vertical handrail, many of which, the coders noted, were positioned directly in front of the seat.
    - No restraint of passengers sitting in the middle seat on the rear row of seats. During harsh braking or collision events, these passengers were usually thrown from their seats and down the aisle in front of them.
    - Little restraint of passengers sat in forward facing bay seats, in particular for aisle seated passengers. These passengers often fell into the aisle unless they managed to grab the vertical handrail positioned at the top of the opposite seat.
    - Inadequate restraint of passengers in seats, which are raised significantly above the seats in front, usually positioned above rear wheels.

- Other
    - The positioning of buggies containing children in the wheelchair area. Eleven cases were observed where the buggy was positioned in a sideways position to the direction of travel, and under heavy braking, resulted in it tipping over, the child falling out with a third of them being injured.

The CCTV analysis also calculated the proportion of passengers injured for the 70 incidents which exposure data was collected for. The results showed that a smaller proportion of seated passengers are injured (2%) compared to standing passengers (6%), indicating a smaller risk of injury for seated passengers. For seated passengers, the results show a smaller proportion of those seated on the upper deck are injured (0.3%) compared to those seated on the lower deck (1.5% to 6%), indicting a smaller risk of injury for passengers seated on the upper deck. These results indicate that it from a risk point of view it would be preferable for passengers to be sat on the upper deck compared to standing on the lower deck, although it should be remembered that these results will likely be somewhat confounded by persons with reduced mobility (PRM) being unlikely to occupy the upper deck.

In addition the analysis identified that a high proportion of passengers seated directly behind the middle doors and wheelchair area were injured. This indicates a high risk of injury for passengers seated in these positions. The bus examinations found that these seats often have features associated with high injury potential, in particular inadequate restraint and handrails in alignment with passenger trajectories.

The literature generally supported the findings of the analyses of the incident data reported above, however little detailed information was found about passenger injury mechanisms. Regarding TfL actions resulting from the Sandilands tram overturning, the action to review glazing solutions to improve passenger containment for other transport types is relevant to bus occupant friendly interiors safety measure.

For both standing and seated passengers the bus examination identified potential hazards under the following categories:

- Handrails mainly in relation to their position.
- Restraint – i.e. No or inadequate constraint of a passenger’s movement in the event of a braking / collision incident.
- General impact hazards, i.e. protrusions, sharp corners and edges.

For seated passengers an issue with low backed seats was also identified, in terms of lack of head / neck support for rear facing seats and problems with restraint for some forward facing seats.

4 Existing standards and test procedures and their suitability for buses.

This section is divided into two parts. The first part describes legislation for buses that is mandatory, i.e. the UN (ECE) regulations and the UK accessibility legislation. The second part describes other legislation and standards that could help provide a basis for a future rating system, i.e. the rail standards (GM/RT2100 and European TSIs, in particular the PRM TSIs), the American federal regulations (FMVSS) and the Australian standards.

4.1 Mandatory legislation for UK

This section is divided into two parts; the first describes the UN (ECE) regulations and the second the UK public service vehicle accessibility regulations (PSVAR).

The UNECE Consolidated Resolution on the Construction of Vehicles (R.E.3) defines buses (and coaches) as motor vehicles comprising more than eight seats (i.e. nine seats) in addition to the driver's seat. Buses (and coaches) are classified as M2 and M3 vehicles depending on their Gross Vehicle Mass (GVM) as follows:

- M2: GVM ≤ 5 tonnes
- M3: GVM > 5 tonnes

M2 and M3 vehicles are categorised further as follows:

- For vehicles having a capacity exceeding 22 passengers in addition to the driver, there are three classes of vehicles:
    - "Class I": Vehicles constructed with areas for standing passengers, to allow frequent passenger movement.
    - "Class II": Vehicles constructed principally for the carriage of seated passengers, and designed to allow the carriage of standing passengers in the gangway and/or in an area which does not exceed the space provided for two double seats.
    - "Class III": Vehicles constructed exclusively for the carriage of seated passengers.
- For vehicles having a capacity not exceeding 22 passengers in addition to the driver, there are three classes of vehicles:
    - "Class A": Vehicles designed to carry standing passengers; a vehicle of this class has seats and shall have provisions for standing passengers.
    - "Class B": Vehicles not designed to carry standing passengers; a vehicle of this class has no provision for standing passengers.

This further classification is summarised in Table 4-1 below.

Table 4-1: Classification of Buses (and Coaches) by capacity and passenger seated / standing

Class	Seated	Standing	Max passengers
I	✓	✓	>22
II	✓	Minimal	>22
III	✓	None	>22
A	✓	✓	<=22
B	✓	None	<=22

From communication with bus manufacturers, TRL were informed that the buses supplied to TfL are categorised as Class I. TRL were also informed that the buses supplied were often approved following the Small Series National Type Approval (SSNTA) option. This option restricts the number of buses, of a given type, that a manufacturer can supply per year within the UK to 250. Compared to the European Community Whole Vehicle Type Approval (ECWVTA) option, which does not restrict the number of vehicles supplied, technical requirements are reduced. These differences are highlighted when describing the requirements for the individual regulations in the relevant sections below.

The UN (ECE) regulations relevant to bus occupant friendly interiors, head restraints, grab poles and bars, and enhanced visual inspections are shown in Table 4-2. They were identified from examination of the Framework Directive (2007/46/EC) and the Resolution on the Construction of Vehicles (R.E.3).

Table 4-2: UN (ECE) Regulations relevant to bus occupant friendly interiors, head restraints, grab poles and bars, and enhanced visual inspections

Subject	UN (ECE) Regulation No	Description
Seat strength	17	Reg No. 17: Uniform provisions concerning the approval of vehicles with regard to the seats, their anchorages and any head restraints.
	80	Reg No. 80: Uniform provisions concerning the approval of seats of large passenger vehicles and of these vehicles with regard to the strength of the seats and their anchorages.
Safety glass	43	Reg No 43: Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles.
General Bus Construction	36	Reg No. 36: Uniform provisions concerning the approval of large passenger vehicles with regard to their general construction.
	52	Reg No 52: Uniform provisions concerning the approval of M2 and M3 small capacity vehicles with regard to their general construction.
	66	Reg No 66: Uniform provisions concerning the approval of large passenger vehicles with regard to the strength of their superstructure.
	107	Reg No 107: Uniform provisions concerning the approval of category M2 and M3 vehicles with regard to their general construction.

Seat Strength

Class I buses (which form the majority of TfL buses) are not within the scope of the regulations for seat strength (i.e. Regulations 80 and 17). This is mainly because seat belts are not required for buses of this class and therefore a minimum level of seat strength for mounting seat belts is not required. However, because these regulations contain requirements for seat backs, which are being considered in this project, a detailed description of them is included in the sections below.

Safety Gazing

The scope of Regulation No. 43 is safety glazing for vehicles of categories M, N and O. It includes requirements individually for the glazing permitted for the windscreen, driver's forward field of vision, driver's rearward vision, and other exterior (and interior) areas of M (passenger carrying) and N (goods carrying) vehicles. Interestingly it includes particular requirements for the front exterior forward-facing glazing of the upper deck of a double-deck vehicle, namely that it shall be laminated or a plastic pane suitable for forward facing exterior application. Regulation 43 was not reviewed further on the basis that consideration of changes to bus glazing for this part of the project were thought unlikely.

General Bus Construction

Regulation No. 66 contains requirements for the strength of the super structure of single deck class I, II and III buses. Regulation 66 was not reviewed further on the basis that consideration of changes to the bus superstructure for this part of the project were thought unlikely.

The transitional provisions of Regulation No. 107 state that: 'Contracting Parties applying this Regulation [107] shall no longer grant new approvals in accordance with Regulation No. 36 or Regulation No. 52', which effectively means that it supersedes these regulations. Therefore, only a detailed review of Regulation 107 is included in the sections below.

4.1.1 UN (ECE) Regulation No. 107

The scope of UN (ECE) Regulation No. 107 is all single-deck, double-deck, rigid or articulated vehicles of category M2 or M3, i.e. all buses (and coaches).

Regulation 107 contains technical requirements for:

- People with reduced mobility (Annex 8) – Note: requirement for class I only.
- Masses and dimensions (Annex 3, 7.2).
- Stability test (Annex 3, 7.4).
- Protection against fire risks (Annex 3, 7.5).
- Exits (including emergency), number, positioning, dimensions (Annex 3, 7.6).
- Interior arrangements (Annex 3, 7.7)
- Artificial interior lighting (Annex 3, 7.8)
- Articulated section of articulated vehicles (Annex 3, 7.9 & 7.10)
- Handrails and handholds (Annex 3, 7.11)
- Guarding of step wells and exposed seats (Annex 3, 7.12)
- Baggage racks and occupant protection (Annex 3, 7.13)
- Other, including trap doors, visual entertainment, trolley buses and passenger protection (Annex 3, 7.14 to 17)

The most recent version of this Regulation is revision 07. However, for approval following the Small Series National Type Approval (SSNTA) option, the requirements are different as given in Table 4-3 for the subject area (52) of buses and coaches[2].

[2] UK Road Vehicles (Construction and Use) Regulations No 25. Accessed Dec 2017 from VCA VISTA website: http://vcas.m-cloudapps.com/TroveStyle/WebserverVCA/VistaFrameset/VCAFrame.ASP?VDir=vcaeta&_LVDir=/VCAETA/&P2=1&w=1097&h=617&c=32&token=43080&HU=http:++www.dft.gov.uk+vca+legislation+vista-and-legstat.asp

Table 4-3: Requirements (and exemptions & modifications) for UK small series national type approval for buses & coaches relevant for Regulation 107

Requirement	Exemptions and modifications
All vehicles: The technical provisions of UNECE Regulation 107.02 excluding Annex 8.	1. Does not apply to N2, N3, or O category vehicles.
Vehicles of Class I: The technical provisions of UNECE Regulation 107.02, Annex 8.	2. Does not apply to vehicles for the secure transport of persons.
	3. Vehicles of Class I, II or III: As an alternative to UNECE Regulation 107.02, Annex 3, paragraph 7.6.1.14 the upper deck gangway shall be connected by one or more intercommunication staircases to the access passageway of a service door or to the lower deck gangway within 3m of a service door.
	4. Vehicles of Class I, as an alternative to column 1, paragraph 2, may comply with the Public Service Vehicles (Accessibility) Regulations 2000(4), Schedules 1 and 2, or the Public Service Vehicles (Accessibility) (Northern Ireland) Regulations 2003(5), Schedules 1 and 2.
	5. UNECE Regulation 107.02, Annex 3, paragraph 7.6.7.6. In the case of: (i) a manually operated sliding door fitted with a slam lock of the two stage type, the activation of the device may be by movement of the door itself; (ii) a nearside rear door forming part of a pair of doors fitted at the rear of the vehicle, the requirements do not apply if that door is capable of being held securely closed by the other door of that pair.

The main difference for approval following the SSNTA option is the reference to revision 02 of the Regulation rather than the most recent one, revision 07. Table 4-4 lists the changes made between the revisions 02 and 07. With the exception of the addition of a requirement related to ‘Guarding of step wells and exposed seats’, these are not relevant to the project current area of interest. The other main point to note is the exemption for the requirements of Annex 8, provided that requirements of the UK Public Service Vehicle Accessibility Regulations (PSVAR) are met.

Table 4-4: Regulation 107: summary of changes between revisions 02-07

Rev	Summary of changes
03	Addition of requirement (7.12.1) related to 'Guarding of step wells and exposed seats' "Where any seated passenger is likely to be thrown forward into a step well as a result of heavy braking, either a guard or, in the case of a vehicle of Class A or B, a safety-belt shall be fitted. Where fitted, the guard shall have a minimum height from the floor on which the passenger's feet rest of 800 mm and shall extend inwards from the wall of the vehicle at least as far as 100 mm beyond the longitudinal centre line of any seating position where the passenger is at risk or to the riser of the innermost step; whichever is the lesser dimension." Addition of requirements related to fire suppression for engine compartments located behind the driver compartment Addition of requirements related to driver's compartment and seat (7.7.13 and 7.7.14).
04	Amendments to the location of escape hatches and emergency exits (7.6.1.11, 7.6.1.12, 7.6.2.4)
05	Annex 3 , addition of requirements related to fire detection (7.5.6 to 7.5.6.3)
06	Addition of requirements related to fire detection and suppression (7.5.1.5.4. to 7.5.1.5.4.3) Addition of exemption for requirement related to Guarding of step wells and exposed seats "Paragraph 7.12.1. shall not apply to any sideways facing seat, a seat which has its centreline within the longitudinal projection of a gangway, a seat in front of which is existing vehicle structure (e.g. fixed table or luggage pen) offering comparable levels of protection as a guard meeting the requirements of paragraph 7.12.1. or transverse facing seats where the maximum distance between the front faces of the seat squabs of facing seats does not exceed 1,800 mm when measured in accordance with paragraph 7.7.8.4.3"
07	Space requirements for fire extinguisher on upper deck amended (7.5.4.1) Minimum dimensions for exits amended (annex 7, paragraph 1.1)

The requirements of main interest in Regulation 107.02 are listed in Table 4-5 below. In summary they include:

<u>Seats</u>

Passenger seating area is subject to free space requirements that mandate the amount of clearance required above the head of individual passengers. Class I buses have to comply with Annex 8 of the regulation also, which specifies requirements for passengers with reduced mobility. Class I buses have to provide a minimum of 4 priority seats. Tip-up seats may be provided within wheelchair spaces for the use of seated or standing passengers when not in use by a wheelchair passenger.

<u>Intercommunication staircases</u>

These staircases have to allow for free passage of one user as per the frame defined in Annex 4 of the regulation. To provide protection for passengers during a harsh braking scenario, manufacturers have to choose at least one of the following measures:

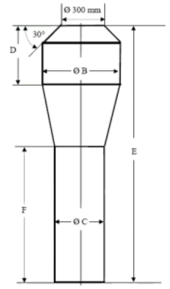
- non forward descending stairs,
- staircase equipped with guards,
- automatic device at upper part of staircase which prevents its use when vehicle in motion

Guards are required to be placed around the intercommunication staircase with a minimum height of 800 mm from the floor level. Paragraphs 7.11.5.1 and 7.11.5.2 specify that handrails are required to be provided for passengers on the staircase as well as around the access to the staircase at between 800mm to 1100mm above the floor height. These requirements can result in handrails in the head impact zone for passengers sitting in the seats adjacent to the intercommunication staircase, which may be undesirable, although issues related to this were not highlighted in the CCTV analysis.

Handrails and hand holds

Table 4-5 below contains the main relevant requirements from Regulation No 107.02, in particular for handrails and handholds.

Table 4-5: Regulation No. 107.02: some relevant requirements, in particular for handrails and handholds

Area	Reference	Requirement
Masses and dimensions: Area available for standing passengers	Annex 3, 7.2.2.2.8	To calculate area where standing allowed do not include any area of upper deck.
Interior arrangements: Gangways	Annex 3, 7.7.5	Designed and constructed as to permit the free passage of a gauging device consisting of two co-axial cylinders as shown, for with an inverted truncated cone interposed between them, the gauging device having dimensions class I B 550mm, C 450mm, D 500mm, E, F variable depending on single / double deck. Figure 6 GANGWAYS (see Annex 3, paragraph 7.7.5.)  The surface of gangways shall be slip resistant (7.7.5.9)
Interior arrangements: Slope of gangways / steps	Annex 3, 7.7.6/7	For Class I, II or A (i.e. those which carry standing passengers) slope shall not exceed 8% in longitudinal direction and 5% in transversal direction (7.7.6). Steps, dimensions, slip resistance surface, slope not exceed 5% in any direction (7.7.7)
Interior arrangements: Passenger seats	Annex 3, 7.7.8	Minimum dimensions including seat spacing which is 650 mm for class I buses.
Interior arrangements: Intercommunication staircases	Annex 3, 7.7.12	Designed such that during heavy braking no danger of passenger being projected downwards; fulfilled if one of following fulfilled; no part of staircase forward descending, staircase equipped with guards, automatic device at upper part of staircase which prevents its use when vehicle in motion
Handrails and hand holds: General requirements	Annex 3, 7.11	Shall be of adequate strength; be designed and installed as to present no risk of injury to passengers, Handrail at least 100 mm long, no dimension of section smaller than 20 mm or greater than 45 mm except for handrails on doors or seats, Clearance 40 mm minimum with exception of handrail on doors or seats, min 35 mm permitted

Area	Reference	Requirement
Handrails and hand holds: Additional requirements for standing passengers	Annex 3, 7.11	Handrails and/or handholds shall be provided in sufficient number in areas for standing passengers, it should be possible to reach at least two (which are mounted between 800 mm and 1950 mm above floor) with testing device and at least one not more than 1500 mm above floor level (with exception for area adjacent to door). The testing device has a maximum reach of 765 mm for an arm. Horizontal handrails shall be provided at a height between 800 mm and 1500 mm above the floor in areas where there are no seats to separate the standing passengers from the side or rear walls of the vehicle.
Handrails and hand holds: for intercommunication staircases	Annex 3, 7.11.5	Suitable handrails or handholds shall be provided at each side of all staircases at a height between 800 mm and 1100 mm above lower deck or above surface of each step For person standing on lower deck, not more than 400 mm inwards from outer edge of lower step For each step, not outwards from outer edge of step and not more than 600 mm inwards
Guarding of step wells and exposed seats	Annex 3, 7.12	Requirements for guarding of step wells and exposed steps; where any seated passenger likely to be thrown into a step well as a result of heavy braking a guard shall be fitted except for class A or B vehicles where a safety-belt should be fitted. Guard minimum height 800 mm. On upper deck, intercommunication staircase shall be protected by guard, minimum height 800 mm, lower edge maximum height 100 mm. Front windscreen ahead of passengers on upper deck protected by padded guard higher edge of which located between 800 mm and 900 mm above floor where passenger's feet rest.
Baggage racks and occupant protection	Annex 3, 7.13	Baggage racks, if fitted, need to be designed to prevent falling items of baggage in the event of a heavy cornering or sudden braking
Handrails and hand-holds for Passengers of Reduced Mobility (PRM) and wheelchair users	Annex 8, 3.4	Requirements for handrails from access door to priority seats and to facilitate entry and exit of seat. Handrail (between 800 mm and 900 mm height above floor level) shall be provided between priority seat and door. Break in rail is permitted where necessary to gain access to a wheelchair space, seat located at wheel arch, a staircase, access passage or gangway. Handrails or handholds to be placed adjacent to priority seats to facilitate entry and exit of seat and designed in such a way to allow the passenger to grasp them easily. Requirements for handrails for wheelchair user. A handrail or handhold shall be fitted to the side or wall of the vehicle or a partition in such a way to allow the wheelchair user to grasp it easily. This handrail or handhold shall not extend over the vertical projection of the wheelchair space, except by not more than 90 mm and only at a height not less than 850 mm above the floor of the wheelchair space A retractable handrail or any equivalent rigid device shall be fitted on the opposite side of the wheelchair space in order to restrict any lateral shift of the wheelchair and to allow the wheelchair user to grasp it easily

4.1.1.1 Regulation 107 amendment proposed by UK DfT

The UK DfT proposed the following amendment to Regulation 107 in October 2015, amended text highlighted in bold[3]:

Paragraph 7.12.1:

'*Where any seated passenger is likely to be thrown forward into a step well,* ***designated wheelchair space, buggy space or open area for standing passengers*** *as a result of heavy braking, either a guard or, in the case of a vehicle of Class A or B, a safety-belt shall be fitted. Where fitted, the guard shall have a minimum height from the floor on which the passenger's feet rest of 800 mm and shall extend inwards from the wall of the vehicle at least as far as 100 mm beyond the longitudinal centre line of any seating position where the passenger is at risk or,* ***in the case of a step well****, to the riser of the innermost step; whichever is the lesser dimension*.'

The justification given for this proposal was that, although it was recognised that bus and coach travel across Europe is statistically one of the safest forms of road transport, passengers still receive fatal serious injuries; in 2013 in Great Britain 7 passengers died and 250 received serious injuries. Incident reports confirmed that some of these related to occupants of exposed seats in buses who were thrown forward during heavy braking or vehicle impact conditions and sustained head injuries from contact with the vehicle floor or other hard structure. Seats particularly affected were those located to the rear of an open wheelchair or buggy space – these seats are often preferred by passengers of reduced mobility, irrespective of whether they are designated priority seats.

The aim of the proposal was to reduce this risk by extending existing requirements for a guard in front of exposed seats (without a safety belt fitted) adjacent to step wells, to apply to exposed seats in other areas, specifically behind a wheelchair space, buggy space or open area for standing passengers.

The amendment was adopted as part of the 06 series of amendments, supplement 5. For vehicles approved following EC whole vehicle type approval (ECWVTA), it is expected that these amendments will be mandatory circa 2020[4]. However, many UK buses are type approved following the National Small Series Approval (NSSA), which, generally, has fewer requirements and a different timeline compared to ECWVTA. Therefore, it is unclear exactly when this amendment will be made mandatory for approval following NSSA, although given that the UK DfT proposed

[3] Reference: https://www.unece.org/fileadmin/DAM/trans/doc/2015/wp29grsg/ECE-TRANS-WP29-GRSG-2015-34e.pdf

[4] Transitional provisions clause 10.11 state that: 'As from 48 months after the date of the 06 series of amendments, Contracting Parties applying this Regulation shall grant type-approvals only if the vehicle type to be approved meets the requirements of this Regulation as amended by the 06 series of amendments'. The date of entry into force of supplement 5, 06 series of amendments was 8 October 2016. Therefore, will become mandatory for ECWVTA 8th Oct 2020.

the amendment, it could be expected that the NSSA timeline may be the same as the ECWVTA one.

It should be noted that to allow fitment of these guards the length of the wheelchair area may need to be increased to allow sufficient space for wheelchair users to access it and meet the relevant requirements of the UK PSV Accessibility Regulations (PSVAR). Indeed, for a common bus design, currently in service in the TfL fleet, it would not be possible to retrofit these guards and also meet the PSVAR requirements, because the wheelchair area length is too short, circa 1.5 m. Consultation with bus manufacturers revealed that a wheelchair area length of about 1.7 m is the minimum length which would allow adequate space to manoeuvre a wheelchair into the wheelchair space and a guard to be fitted, which did not allow the wheelchair footrests to swing underneath it.

4.1.2 UN (ECE) Regulation No. 80

The scope of this regulation is M2 and M3 vehicles of classes II, III and B. It specifies requirements for forward facing passenger seats in regard of their anchorages and installation. The majority of TfL buses are currently classified as Class I and therefore are outside the scope for this regulation. However, a number of manufacturers have informed TRL that they fit Regulation 80 compliant passenger seats. Therefore, a description of Regulation 80 is given below.

The regulation specifies requirements for the testing and approval of seats and their anchorages.

Each type of seat shall be subject to the test requirements of either a dynamic (appendix 1) or static test (appendix 5) at the request of the manufacturer. The purpose of these tests is to determine that the occupant is correctly retained by the seat in front of him and/or by the seatbelt, i.e. forward motion restricted, and the anchorages have sufficient strength. Note that seatbelts are not considered further, because they are not fitted to Class I vehicles, which are being considered in this project.

The dynamic test consists of a sled test with the seat and a Hybrid III dummy. The deceleration / acceleration pulse corridors are shown in Figure 4-6. As well as fitting into these corridors, the pulse must meet the following criteria:

- A (sled) velocity change of between 30 and 32 km/h.
- An average deceleration of between 6.5 and 8.5g

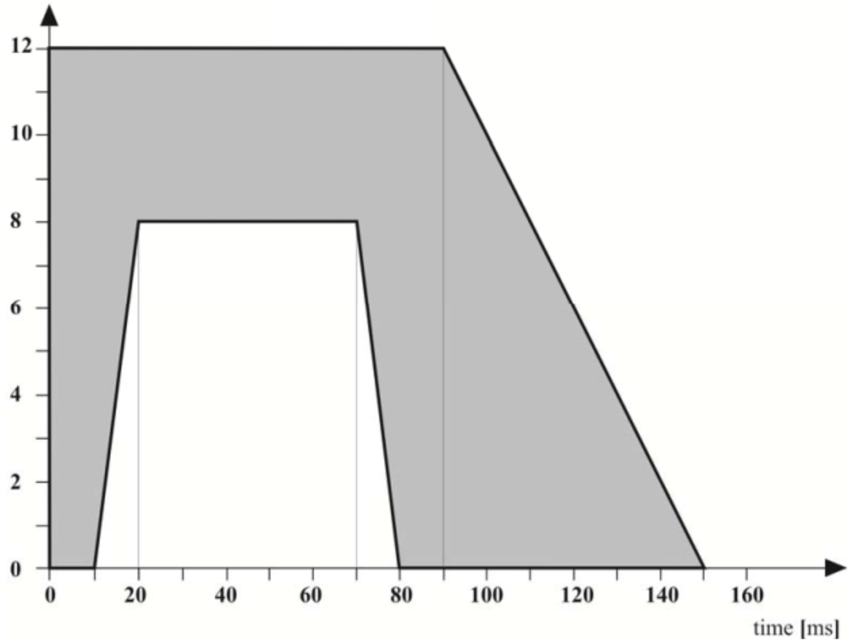


Figure 4-6: Regulation 80 dynamic test deceleration / acceleration pulse corridors

Acceptability criteria include dummy injury criteria (e.g. HIC < 500), dummy kinematics, and integrity of seat and its connections (anchorages).

The static test consists of placing a cylindrical surface to load the rear of the seat being tested (the curvature of the cylinder being 82 +/- 3 mm and a width being equal to the width of the seat back) and the application of forces at two points on this device (points H1 (0.70 to 0.80 m) and H2 (0.45 to 0.55 m) from a standard reference frame) for a period of 0.2 seconds. The force applied to the cylinder and its displacement, are measured. Acceptability criteria include minimum and maximum displacements of the cylinder at given loads to ensure the energy absorption capability and strength of the seat back, are sufficient to restrain the occupant without serious injury. Also, the seat should remain firmly held by its anchorages.

4.2 Public Service Vehicles Accessibility Regulations (PSVAR), 2000

The scope of the UK Public Service Vehicle Accessibility Regulations (PSVAR)[5] is all buses and coaches operating to a published timetable. Very small buses and coaches (with a capacity not exceeding 22 passengers) are excluded, as are vehicles used for holiday or touring services, day trips or private hire for example, to a theatre or theme park.

PSVAR Regulation 3 specifies requirements for wheelchair accessibility (Schedule 1) and general accessibility (Schedule 2) for buses. All full size single deck buses (with a GVM > 7.5 tonnes) are required to be fully accessible (i.e compliant to schedules 1 and 2) from 1st January 2016, and all double deck buses from 1st January 2017. New buses have been required to have wheelchair access from 1st January 2005.

The Department for Transport (DfT) provides the Driver and Vehicle Standards Agency (DVSA) with a specific fund to enforce the requirements outlined in the PSVAR. Non-compliance with PSVAR is a criminal offence (under Section 40(3) of the Disability Discrimination Act 1995) and carries a fine not exceeding Level 4 on the standard scale (currently £2,500).

Compliance with the PSVAR is usually checked as part of type approval. Alternatively, checks on individual buses can be made by a DVSA vehicle examiner and an ‘accessibility certificate’ issued.

It should be noted that the PSVAR do not deal with the carriage of mobility scooters. The DfT website[6] explains that this is because scooters are outdoor vehicles intended for use as an alternative to public transport for short trips. They are generally less manoeuvrable than wheelchairs and cannot be used as a seat on a vehicle because of their instability and difficulty in providing appropriate restraint systems for the both the scooter and the user.

4.2.1 PSVAR Regulation 3 – Schedule 1

Schedule 1 addresses wheelchair accessibility with sections describing requirements for:

- Wheelchair spaces – at least one shall be fitted
- Forward facing and rearward facing wheelchairs. Note that rearward is usually specified for Class I buses. This is because seatbelts are not fitted to Class I buses and to offer equivalent protection for wheelchair users a backrest only is used without a seatbelt or wheelchair tie-down restraints .
- Boarding lifts and ramps

[5] Public Service Vehicle Accessibility Regulations (PSVAR), 2000. Accessed Dec 2017: http://www.legislation.gov.uk/uksi/2000/1970/contents/made

[6] PSVAR and mobility scooters: https://www.gov.uk/government/publications/accessible-buses-and-coaches/bus-and-coach-accessibility-and-the-public-service-vehicle-accessibility-regulations-2000

- Entrances and exits
- Gangways
- Signs and markings
- Communication devices
- Lighting

4.2.1.1 Rearwards facing wheelchairs

Interesting points of note include:

- The wheelchair space shall be fitted with a backrest (note that wheelchair is positioned backed up to backrest when bus is travelling) which shall fulfill a range of requirements including:
    - Its position and dimensions – central at front-end of wheelchair space, height > 1300 mm, width between 350 mm and 480 mm.
    - a) Capable of bearing load of 2000 N for at least 2 sec.
- In the lateral plane of the wheelchair space, a clear space of not less than 750mm shall be maintained and, in order to restrict the lateral movement of a reference wheelchair, there shall be a distance not greater than 900mm (measured in the lateral plane of the wheelchair space) between any two of the following adjacent means of support fitted on each side of the wheelchair space:
    - a) a vertical stanchion situated to the rear of the front end of the wheelchair space and running continuously from the floor of the wheelchair space to a height of not less than 1500 mm, which shall comply with the following requirements:
    - i) the base of the stanchion shall be not less than 400 mm and not more than 560mm from the front end of the wheelchair space measured horizontally, and
    - ii) at heights exceeding 775 mm measured vertically from the floor of the wheelchair space, the stanchion shall be not less than 540 mm and not more than 560 mm from the front end of the wheelchair space measured horizontally; or
    - b) a retractable rail extending continuously from a point not more than 200mm from the front end of the wheelchair space to a point not less than 540mm from the front end of the wheelchair space measured horizontally and at a height of not less than 600 mm and not more than 800 mm measured vertically from the floor of the wheelchair space; or
    - c) a partition extending continuously from a point not more than 200 mm from the front end of the wheelchair space to a point not less than 540 mm from the front end of the wheelchair space measured horizontally and at a height of not less than 600 mm and not more than 800 mm measured vertically from the floor of the wheelchair space; or
    - d) the side wall, or equipment fitted to the side wall, of the vehicle extending continuously from a point not more than 200 mm from the front end of the wheelchair space to a point

not less than 540 mm from the front end of the wheelchair space measured horizontally and at a height of not less than 600mm and not more than 800 mm measured vertically from the floor of the wheelchair space.

- Entrances and exits and gangways:
  a) For access for wheelchair user entrance and exits shall have a clear unobstructed width of at least 800 mm.
  b) Gangway between wheelchair space and entrance / exit shall not be less than 750 mm wide and allow reference wheelchair to be moved from entrance /exit to wheelchair space

It should be noted that for these items the requirements of UN (ECE) Regulation 107 are similar, although not exactly the same in all cases, e.g. backrest loading PSVAR 2,000 N for 2 sec compared to Reg 107 2,500 N for 1.5 sec.

4.2.2 PSVAR Regulation 3 – Schedule 2

Schedule 2 addresses general accessibility requirements for single deck and double deck buses with sections describing requirements for:

- Floors and gangways
- Priority seats
- Steps
- Handrails and handholds
- Communication devices
- Kneeling systems
- Route and destination displays

The points of note are next discussed in further detail.

4.2.2.1 Floors and gangways

- The total floor area in the bus shall be slip resistant. The priority floor area shall:
  - Not contain steps
  - Have a slope not more than 3 degrees in any direction and not more than 5 degrees near the door ways (when vehicle unladen and on level surface).
    - Note that these requirements are more stringent than the requirements for the non-priority standing area in Regulation 107, 8% (4.5 degrees) in longitudinal direction, but similar in the transversal direction 5% (2.9 degrees).

4.2.2.2 Priority seats

- A PSV shall have not less than 4 priority seats as close as practicable to a priority entrance
- Requirements for seat and space around seat to allow access include minimum requirements for longitudinal space, and space above seats, e.g.
  - For seats facing same direction - distance between the front surface of the back of the priority seat and the back surface of the back of the seat in front (measured along an imaginary

horizontal line passing along the top surface of the cushion of the priority seat and through the centreline of the seating position of the priority seat) shall not be less than 650 mm, note minimum seat pitch defined in Reg 107 is 650 mm.

a) there shall be:
- (i) not less than 1300 mm of clear space above any point along the front edge of the top surface of a cushion of a priority seat measured vertically from the top surface of the cushion,
- (ii) not less than 900 mm of clear space above any point along the rear edge of the top surface of a cushion of a priority seat measured vertically from the top surface of the cushion, and
- (iii) clear space between any point on the top surface of a cushion of a priority seat and an imaginary plane connecting the maximum height of clear space specified in (i) above to the maximum height of clear space specified in (ii) above.

4.2.2.3 Handrails and handholds

- Shall be fitted:
  - a) along one or both sides of the gangway

(i) from a position level with the top of the back of a seat extending to the ceiling of the vehicle, or to a height of not less than 1500 mm measured vertically from the floor of the vehicle, at intervals of not more than 1050 mm measured in the longitudinal direction of the vehicle, or

(ii) in areas where there are no seats adjacent to a gangway, from the floor to the ceiling, or to a height of not less than 1500 mm measured vertically from the floor of the vehicle, at intervals of not more than 1050 mm measured in the longitudinal direction of the vehicle, and

(iii) where the gangway is adjacent to the internal walls of the vehicle, horizontally along the internal wall of the vehicle and parallel to those walls at a height of not less than 1200 mm and not more than 1500 mm measured vertically from the floor of the vehicle;

(iv) in seated areas from the seat backs, in standing areas adjacent to the vehicle wall and in any areas adjacent to where a passenger may stand, which are not marked for standing passengers such as intercommunication stairwells.

(v) They also need to be provided in areas near the doorways and priority entrances.

b) in any area where passengers may stand other than a gangway

(i) where the area is adjacent to the internal walls of the vehicle, horizontally along the internal walls of the vehicle and parallel to those walls at a height of not less than 1200 mm and not more than 1500 mm measured vertically from the floor of the vehicle, and

(ii) in any other area, from the floor to the ceiling, or to a height of not less than 1500 mm measured vertically from the floor of the vehicle, at intervals of not more than 1050 mm measured in the longitudinal direction of the vehicle;

    - (c) from the doorway area immediately adjacent to a priority entrance to not less than one of the priority seats at a height of not less than 800 mm and not more than 900 mm measured vertically from the floor of the vehicle or, where it is not practical to comply with those requirements, the handrail need not be continuous provided any gap does not exceed 1050 mm and a vertical handrail is provided on at least one side of the gap extending from a height of at least 1200 mm to a height of not less than 1500 mm measured vertically from the floor of the vehicle; and
    - (d) on both sides of the interior of an entrance or exit

- Shall comply with requirements which include:
    - For handrails - minimum diameter of 30 mm (max 35 mm),
    - For handholds - have a loop shape, or some other form, designed to prevent a hand from slipping from the handhold
      a) For handrails and handholds - positioned at a height between 800 mm and 1900 mm above the floor of the vehicle, a clear space not less than 45 mm around it, have a slip-resistant surface; be capable of being easily and firmly gripped by a passenger; and contrast with the parts of the vehicle adjacent to the handhold.

Compared to Regulation 107 requirements for handrails and handholds the UK PSVAR requirements are somewhat more stringent. Particular points of note are:

- The additional requirement in the UK PSVAR for handrails along the gangway from the level with the top of the back of the seat to the ceiling at intervals not more than 1050 mm.
- The more restrictive requirements for the dimensions of handrails in the UK PSVAR:
    - PSVAR circular cross-section diameter between 30 and 35 mm, Reg 107 circular / non-circular cross-section between 20 mm and 45 mm.
    a) PSVAR clearance minimum 45 mm, Reg 107 clearance minimum 40 mm

4.3 Other relevant legislation and standards

This section describes other relevant legislation and standards that could be useful to help develop a future rating system. Firstly relevant parts of the UK rail standards are described, namely GM/RT2100 and European Technical Standards for Inter-operability (TSIs), in particular the TSI for persons with reduced mobility. Secondly, bus standards in other parts of the world are described, namely the American federal regulations (FMVSS) and the Australian standards.

4.3.1 UK Rail Group Standards

4.3.1.1 Rail Group Standard; GM/RT2100

The rail group standard GM/RT2100 mandates requirements for the design and integrity of rail vehicle structures for both primary and secondary structures, including interior crashworthiness.

The document covers the rail vehicle structural requirements for the body, bogies & suspension, secondary structures, passenger and crew facing elements present within the interiors of vehicles, aerodynamic rail vehicle loads and mechanical coupling elements.

Part 6 of the standard contains requirements for the interiors and furniture in rail vehicles accessible to passengers and crew. The main aim of this section is to ensure that the interior elements are designed to help minimise occupant injury in the event of a crash when occupants impact them. Three types of crash and associated occupant trajectories are identified for assessment as follows:

- Frontal impact which could be with another train or object on level crossing (approx. 6g deceleration pulse), which will result in mainly longitudinal passenger trajectories with high impact velocities (circa 5 - 6 m/s considered).
- Dynamic rollover which could be a relatively high speed derailment with some longitudinal deceleration accompanied by lateral or roll motion of the vehicle which will result in passenger trajectories with longitudinal and lateral components, primary impact direction lateral / vertical with some longitudinal motion, impact velocity medium.
- Low speed rollover which could be a slow speed derailment where the main motion of the vehicle is a roll which will result in lateral passenger trajectories which may also be vertical relative to the vehicle; primary impact direction lateral / vertical, impact velocity low. Slow (static roll): The trajectory is aimed at low speed derailments due to track irregularities.

The requirements consist of:

- A Secondary Impact Assessment (SIA) in which areas of the vehicle accessible to passengers or traincrew shall be assessed using visual examination for potential injury due to secondary impact in the event of a collision or derailment (section 6.1.6).
- Loading strengths and dynamic testing requirements for seats (section 6.2), tables (section 6.3), and folding seat back tables (section 6.4).
- Loading strengths and other detailed requirements for interior door, glazing and partitions (section 6.5), grab handles, poles, rails and hand-holds (section 6.6), interior fixings and fittings (section 6.7) and luggage stowage (section 6.8).
    - Loading requirement for grab handles, poles and rails is 1.7kN perpendicularly without permanent deformation.

For the Secondary Impact Assessment (SIA) the areas assessed include:

a) Parts of seats, tables and drivers desks outside the scope of dynamic testing requirements (see 6.2, 6.3 and 6.9).

b) Panels and panel edges.

c) Controls, instruments, switches and indicators (for example driver's desks and guards panels).

d) Equipment cubicles or housings.

e) Passenger information displays, screens, loudspeakers.

f) Luggage racks and luggage stacks.

g) Minor items (for example coat hooks, poster frames, magazine racks, light-stick boxes, small equipment housings).

These areas are checked specifically for sharp points, sharp corners, protrusions or recesses, abrupt changes of contour and abrupt changes of stiffness (for example locally rigid areas on panelling). The assessment performed can take into account the probability of an impact occurring due to the location of an item, the likely occupancy of that part of the train where the item is located and functional requirements, for example statutory requirements for handrails.

Guidance notes associated to GM/RT2100 (GM/GN2687) and UNIFE (an endorsed technical report for interior passive safety in railway vehicles[7]) give some further guidelines for the secondary impact assessment. For example, GN95 from GM/GN2687 states that:

The injury potential of any given edge will depend very much on the part of the body making contact and the resilience of the object struck, making it difficult to propose generally applicable design rules. For rigid materials it is however suggested that edge or corner radii should be:

a) At least 20 mm where there is a risk of head injury.

b) At least 10 mm where there is a risk of arm or leg contact.

c) Not less than 5 mm elsewhere.

For potentially critical areas it is recommended that an assessment of the potential severity of injury if struck by a passenger in a collision is undertaken.

[7] Report prepared from the findings of the EU funded project 'SafeInteriors', approved by the European Rail Industry Association (UNIFE) and currently pending approval by the International Union of Railways (UIC). After this, it is intended that it will be published as a joint UNIFE-UIC TecRec (Technical Recommendation) http://www.unife.org/component/attachments/attachments.html?id=324&task=download .

4.3.1.2 European Technical Standards for Interoperability

The European technical standards for interoperability relating to accessibility of the rail system in the European Union for persons with disabilities and persons with reduced mobility are contained in Commission Regulation (EU) No. 1300/2014. For the rolling stock items covered include:

- Seats
- Wheelchair spaces
- Doors
- Lighting
- Toilets
- Clearways
- Customer information
- Height changes
- Handrails
- Step position for vehicles access and egress
- Boarding aids

It is interesting to compare the requirements for handrails with those for the UK PSVAR above. For the TSI (section 4.2.2.9) handrails are required to be circular with outside diameter between 30 mm and 40 mm and have a minimum of 45 mm clearance with any adjacent objects. Also, if the handrail is curved, the inside face of the curve shall be a minimum of 50 mm. For the UK PSVAR, requirements are circular with diameter between 30 mm and 35 mm, so more restrictive, but have a similar minimum 45 mm clearance with adjacent objects.

4.3.2 Other world standards

4.3.2.1 US standards: FMVSS 222 – School bus passenger seating and crash protection

The main US Federal Motor Vehicles Safety Standard (FMVSS) related to the crashworthiness of buses is FMVSS 222.

FMVSS 222 is specific to school buses in the US. The purpose of this standard is to reduce the number of deaths and the severity of injuries that result from the impact of school bus occupants against structures within the vehicle during crashes and sudden driving manoeuvers. It specifies requirements for large school buses (GVW > 10,000 lbs) and small school buses (GVW < 10,000 lbs).

Requirements include:

- Forward facing seats
- Seat back height minimum 610 mm above the seat reference point (note that this was increased from 510 mm in 2009).
- Seat performance forward – the seat back force deflection shall fall within the corridor shown in Figure 4-7 and not exceed 356 mm.
- Seat performance rearward – a test in which the force should not exceed a defined value (9,786 N), and deflection shall be limited whilst absorbing 316 Joules of energy.

- Fitment of seat-belts (three point) for small school buses and voluntary fitment of seat-belts (three point) for large school buses.
- Quasi-static test of compartmentalization and seat belt (three point) performance.

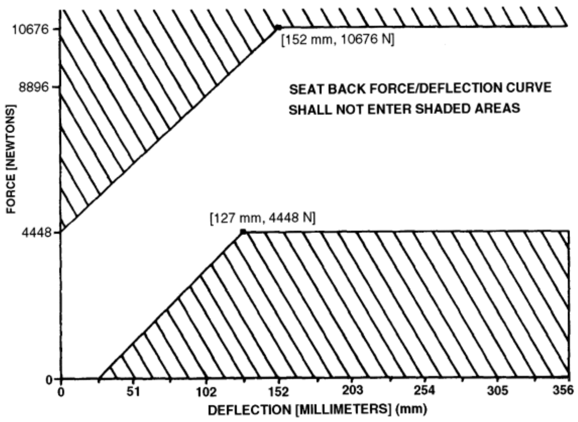


Figure 4-7: FMVSS 222: Seat performance forward force deflection corridor

The main point to note related to this standard is the upgrade in 2009 in which the minimum requirement for the seat back height was increased and procedures introduced to test lap / shoulder belts in small school buses and those fitted voluntarily in large school buses[8]. These upgrade measures were complementary to the principle of compartmentalisation (i.e. restraint of substantial movement in which large impact velocities can be achieved) on which the standard is based.

4.3.2.2 Australian Standards: Transport Operations (Passenger Transport) standard, Queensland

The legislation in Australia is similar to that in Europe (and the UK) because both areas are signatories to the UN (ECE) 1958 agreement concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations. In summary, for buses UN (ECE) Regulation 107 is mandatory in Australia, as in the UK.

However, it is interesting to note that Queensland has an additional standard for the safety of buses, the Transport Operations (Passenger Transport) Standard 2010. Schedule 1 part 3 of this standard contains requirements for padding to be fitted to

[8] Final Rule FMVSS 222 (NHTSA 2009). Accessed Dec 2017 from:

https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/fmvss/SchoolBusBeltsFinal_0.pdf each hard surface that is likely to be struck by the head of a seated passenger if the bus is involved in a frontal collision.

The areas that should be padded include tops of seats, handrails, partitions.

The padding must be semi-rigid moulded polyurethane, self-skinning rigid moulded polyurethane, closed-cell polyethylene foam or closed-cell EVA foam that:

(i) is at least 25mm, but not more than 30mm, thick; and

(ii) has a density of at least 270kg/m3, but not more than 300kg/m3;

OR

a material that gives at least the same level of protection.

It should be noted that fitment of padding of this nature to a handrail would effectively prevent it being used as a handrail because it would increase its diameter so that a person would not be able to grip it easily. However, padding of this nature could be fitted to a rail just intended to be a guard without negative consequences.

4.4 Summary

4.4.1 Seat backs / head restraints

UN(ECE) Regulation 80 contains requirements for seat backs for occupant protection for when an occupant impacts the seat from behind in a significant crash, i.e. 6 to 8g deceleration pulse; note that emergency braking is less than 1g. Class I buses are outside the scope of this Regulation. The majority of TfL buses are class I.

The GM/RT2100 rail standard contains requirements for seat backs for occupant protection somewhat similar to those to Regulation 80. The main requirement is a test in which an Anthropomorphic Test Dummy (ATD) is impacted into the seat back using a 6g deceleration pulse, i.e. slightly lower deceleration than for the dynamic (sled) test option for Regulation 80.

4.4.2 Grab poles / handles

The UK PSVAR and Regulation 107 constrain the positioning and size of handrails permitted on buses significantly. Examples are:

- The UK PSVAR mandates vertical handrails from level with the top of the back of a seat to ceiling level at intervals of not more than 1050 mm.
- Regulation 107 mandates that, in standing areas, sufficient handrails / handholds shall be provided that it is possible to reach two with the testing device (which effectively represents the reach of a human), with an exception for the area adjacent to door.
- The UK PSVAR mandates that handrails should be circular with 30-35 mm diameter and have a clear space of 45 mm around them.

Neither the PSVAR nor Regulation 107 contains specific strength or load requirements for handrails or handholds. However, Regulation 107 states that handrails and hand holds shall be of adequate strength and be designed and installed in a manner such as to present no risk of injury to passengers. The GM/RT2100 rail standard contains load requirements for handrails, namely a 1.7 kN load applied perpendicularly.

Regulation 107 has been amended to require a guard (effectively a partition) in front of exposed seats to the rear of a wheelchair space, pram space or open area, to prevent passengers in those seats been thrown forward in braking or impact events and sustaining injuries. The UK DfT proposed this amendment in 2015. It is expected to become mandatory circa 2020 (for ECWVTA).

4.4.3 Visual inspection

The GM/RT2100 rail standard contains requirements for visual inspection of the train interior for items which may cause injury due to secondary impact in the event of a collision or derailment. The type of approach used for this inspection could be used for buses.

5 Initial solutions proposed and their development

To address the problems identified in Section 1 above, namely:

- Handrails mainly in relation to their position, but also their high injury potential if hit
- Restraint – i.e. No or inadequate constraint of a passenger's movement in the event of a braking / collision incident.
- General impact hazards, i.e. protrusions, sharp corners and edges.
- High risk of injury for passengers seated behind the middle doors and wheelchair area.

Following discussion with TfL, it was decided to investigate and develop the following solutions further:

- A visual inspection based assessment system to encourage better positioning of handrails, better restraint of a passenger's movement, and minimisation of general hazards.
- The UK DfT has proposed an amendment to Regulation 107 to improve restraint of passengers, (often persons with reduced mobility (PRM)), seated behind wheelchair / push-chair area. It is expected that this amendment will become mandatory for European whole vehicle type approval (ECWVTA) circa 2020.
    - The solution proposed is to effectively apply this amendment early, by enforcement of it with a minimum requirement
- Potential design solutions for specific issues to be enforced with a minimum requirement or possibly encouraged with the rating system. Specific issues were:
    - Replacement of low backed seats with high backed seats – note that high backed seats can be used to improve restraint of passengers seated behind them, especially for those seated higher on seats positioned above the rear wheels.
    - Use of special mounts for handrails to increase their compliance and hence reduce their injury risk potential if impacted.

5.1 Visual inspection based assessment system

5.1.1 Introduction

The aim of the visual inspection-based assessment system was to address selected key issues / hazards identified in Section 1 ‘Defining the problem’ for both standing and seated passengers, namely:

- Handrails
- Restraint, i.e. inadequate constraint of movement
- General, for example protrusions, sharp corners and edges which are likely to be impacted by a passenger and are likely to cause injury if impacted

5.1.2 General approach

The aim of the assessment system was to address the key problems identified in the research and be applicable to different bus designs whilst allowing manufacturers design freedom.

The approach proposed for the assessment system entailed the identification and assessment of bus interior potential hazards (i.e. features that have injury causing potential) present in three categories, handrail, restraint and general, for standing and seated passengers, as shown diagrammatically in Figure 5-1 below. The approach was to award points for each potential hazard identified on the bus, with weighting applied to increase the number of points for hazards with greater injury causing potential and/or exposure. The aim is to encourage manufacturers to have as few as possible potential hazards and therefore score the lowest number of points possible.

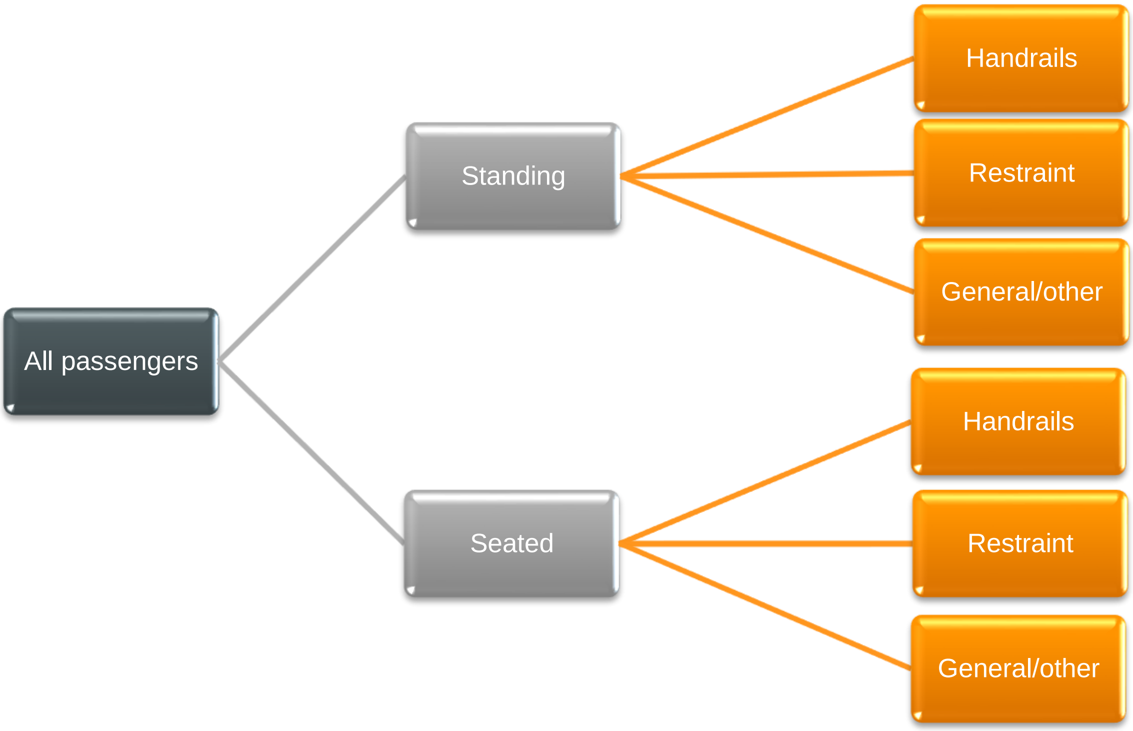


Figure 5-1: Hierarchy of visual inspection based rating system

One potential problem was identified for this approach, related to the assessment of handrails. The problem was that the approach may encourage bus manufacturers to remove some critical handrails needed to help prevent passengers falling, to obtain a better lower score, with a resulting detrimental effect on safety overall. However, good enforcement of the regulations (UNECE Regulation 107 and the UK PSV accessibility regulations) and the TfL bus specification should ensure that this does not occur. The regulations mandate requirements such as the approximate position of handrails and the relative distances between them – see Section 4.1. Also the TfL bus specification contains requirements for fitment of handrails. A summary of relevant regulatory and TfL requirements are given in Table 5-2 below.

Table 5-2: Summary of relevant regulatory and TfL requirements for handrails

Item	Requirement		
	PSVAR2000	Regulation 107	TfL Specification
Wheelchair vertical handrail (for lateral stability)	Schedule 1; 4(3a): Base 400-560mm from front of w/c area, above 775mm, 540-560mm; 750-900 mm from other lateral support, load 1000N <50mm deflection (elastic).	Annex 8, 3.8.4.1.5: Retractable handrail or equivalent rigid device shall be fitted to restrict any lateral shift of the wheelchair and to allow wheelchair user to grasp easily.	2.6, Wheelchair position and access: A manual or automatic security arm replacing the floor to ceiling handrail is not permitted. (i.e. a vertical handrail must be fitted).
Handrails (gangway positions)	Schedule 2, 5(1a) Along gangways: top of back of seat to ceiling (or height >1500mm) at intervals <1050mm longitudinally; no seats floor to ceiling; gangway adjacent to internal wall horizontal rail height 1200-1500mm	Annex 3, 7.11.2.1: Handrails and/or handholds shall be provided in sufficient number in areas for standing passengers, it should be possible to reach at least two (which are mounted between 800 mm and 1950 mm above floor) with testing device and at least one not more than 1500 mm above floor level (with exception for area adjacent to door). Notes: 1. The testing device has a maximum reach of 765 mm for an arm, so max distance of 1530 mm between handrails in standing area (if at height of shoulder 1375 mm). 2. Requirement will not apply to upper deck.	2.11 Handrails: Seat back to ceiling handrails (with bell push) are required at all forward facing seats on lower saloon and alternate seats on upper saloon
Handrails (other standing positions)	Schedule 2, 5(1b): Adjacent to internal walls, horizontal rail height 1200-1500mm; not adj walls, vertical floor to ceiling (or height >1500mm) at intervals < 1050mm longitudinally.		
Handrails (door to priority seats)	Schedule 2, 5(1c): horizontal rail height 800-900mm, if not possible gap < 1050mm and vertical handrail at least one side of gap 1200 to 1500mm at least.	3.4.1 horizontal rail height 800-900mm, if not possible gap < 1050mm and vertical handrail at least one side of gap	A longitudinal waist height handrail is required, to provide a continuous passenger waist height hand grip support from the entrance / cab area to the beginning of the seated area or staircase steps
Handrails (dimensions)	Schedule 2, 4(3): circular cross-section 30-35 mm diameter OR oval max 30-35mm, min 20 mm	Annex 3, 7.11.1.3: section dimension 20-45mm, except for doors and seats min dimension 15mm if other dimension >25mm	2.11, Handrails: 30-35mm diameter
Handrails, clearance	Schedule 2, 4(4): >45mm	Annex 3, 7.11.1.4: >40mm with exception for doors and seats of >35 mm.	No requirement

It can be seen that, generally, the PSVAR requirements are more stringent than those in Regulation 107, e.g. PSVAR has a specific requirement for handrails on upper deck gangways whereas Regulation 107 does not, the PSVAR requirements are more stringent for handrail cross-section dimensions and clearance. This is important because PSVAR compliance can be achieved by compliance with relevant sections of Regulation 107. Hypothetically, this could allow a bus manufacturer to obtain a better rating by reducing the number of handrails, for example by not fitting seatback to ceiling handrails on the upper deck. However, this issue is prevented by the TfL bus specification, for the specific example given the TfL specification requires seat to ceiling handrails to be fitted on alternate seats for the upper deck. It is interesting to note that the TfL specification would not prevent a manufacturer to have smaller handrail clearances than required by PSVAR; however, this parameter is not influenced by the assessment procedure.

Therefore, on this basis, it is expected that the assessment approach should encourage the better positioning of handrails to reduce their injury potential, as opposed to their removal because the regulation and TfL bus specification will ensure that an adequate number of handrails are fitted.

The following assessment steps were developed:

1) Identify and count potential hazards in each category for standing and seated passengers.
2) Scale individual potential hazards identified according to passenger exposure. This step is also used to avoid discontinuities in the assessment system. To help understanding of this step, an example of the scaling for horizontal handrails (for standing passengers) is given below in italics.
3) Further weight the points for each potential hazard identified in each of the six categories (handrail, restraint and general for standing and seated passengers) and add them to give overall point scores for the lower deck and upper deck (if appropriate). Weightings are applied to reflect the following:
    a) The injury potential of the hazard, e.g. if the hazard is likely to cause a head injury as opposed to a lower limb injury, a higher weighting is given.
    b) Exposure of the hazard, e.g. if the hazard is in an area of the bus with a higher occupancy rate, a higher weighting is given. Also, additional weighting is applied to hazards to which persons with reduced mobility (PRM) are likely to be exposed. This is because, generally, PRM have slower reaction times and are less tolerant to injury, which can increase the likelihood of impacting a hazard and being injured, respectively.

Horizontal handrails can be positioned where they may be hit by a standing passenger’s head, when that passenger falls. The likelihood of this occurring depends on the position height of the rail. The more the rail is in alignment with a passenger’s head, the more likely it is that it will be hit. To account for this and to avoid discontinuities, a sliding scale scoring system has been developed that gives a score ranging from 0 to 1. This results in red, grey and safe zones as described below and illustrated in Figure 5-3.

- The red zone is positioned between 1420 mm (height of chin of 5th percentile female) and 1755 mm (height of top of head of 50th percentile male). The head height of a substantial proportion of the population will be in this zone. Therefore a passenger is likely to hit their head on a rail positioned at this height. Hence, a score of 1 (per unit length) is given for a horizontal rail positioned within this zone. The unit length chosen was 500 mm on the basis that this is approximately the space taken up by one passenger stood or leaning against the side of the bus.
- The grey zones are positioned above and below the red zone. The top grey zone is positioned between 1755 mm (height of top of head of 50th percentile male) and 1870 mm (height of top of head of 95th percentile male). The head height of a large proportion of the population will be in this zone, with the proportion reducing to about 5% as the height becomes closer to 1870 mm. Hence, a score linearly reducing from 1 to 0 (per unit length) is given for a rail positioned in this zone depending on the precise height of its top edge. For example a rail with a top edge height of 1800 mm would be scored (1870 – 1800)/(1870 -1755) = 0.61 per unit length. The bottom grey zone is positioned between 1420 mm (height of chin of 5th percentile female) and 1130 mm (height of chin of 5th percentile 11 year old child). A similar argument applies and approach is taken for this zone as for the top grey zone.
- The safe zones are positioned above and below the grey zones. These zones are above 1870 mm (top safe zone) and below 1130 mm (bottom safe zone). The head height of a small proportion of the population will be in these zones. Therefore a score of zero is given for rails positioned in these zones.

Note: It can be seen that if a manufacturer decides to change the height of a horizontal handrail by a small amount, say 10 mm, then the score will change a small amount to reflect this, i.e. there are no discontinuities in the assessment system with the sliding scale approach.

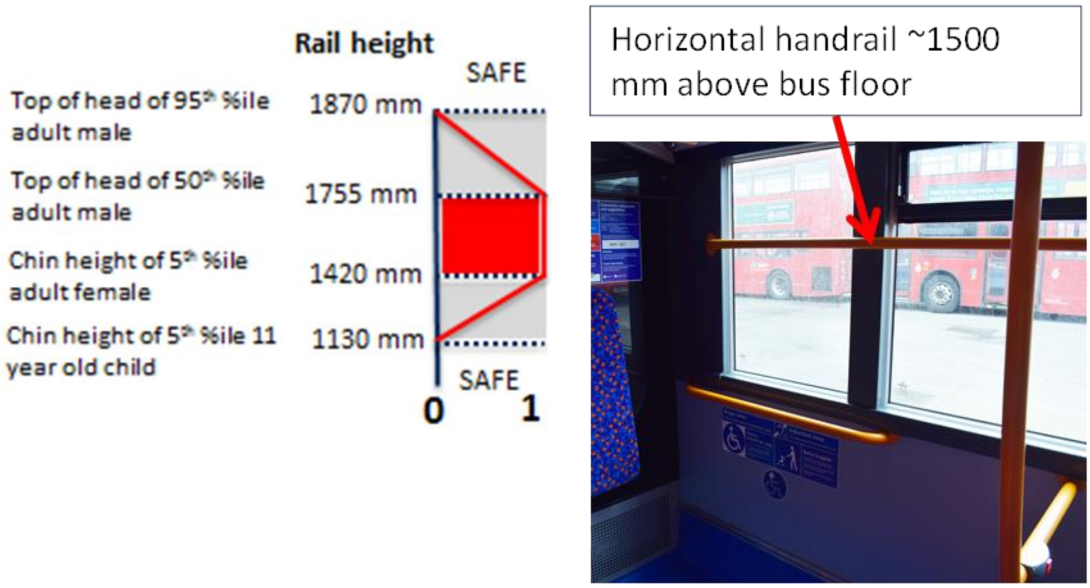


Figure 5-3: Illustration of concept. Top rail in picture is about 1500 mm above the bus floor and in the red zone (and scores 1) whereas bottom rail is about 1000 mm above the bus floor and in the safe zone (and scores 0). Grey zones, in which the score is scaled linearly from 1 to zero depending on the height of the rail above the bus floor, are positioned between the red and safe zones

Based on these concepts the assessment system and target scores were developed iteratively by application to a number of current buses and 'modified buses' in which design improvements were hypothetically implemented.

The anthropometric data shown in Table 5-4 and the regulatory requirement for a minimum guard height of 800 mm (UN Regulation 107, Annex 3, clause 7.12.2) were used to develop the sliding scales for the assessment system.

Table 5-4: Anthropometric data used to develop sliding scales for assessment system

(mm)	5th percentile 11 year old	5th percentile adult female	50th percentile adult male	95th percentile adult male
Height	1310		1755	1870
Chin height	1130	1420		
Centre of gravity height	770			1060
Head width				180

5.1.3 Brief description of assessment system.

The full protocol for performing a bus interior safety inspection and assessment can be found in the 'Bus interior safety inspection and assessment protocol' document. In this section a brief description of the objectives, methodology and evidence for each of the six components/categories of the rating system (i.e. handrails, restraint and general for both standing and seated passengers,) is given. Also, the weighting applied for each of the components/categories is described briefly.

5.1.3.1 Standing passengers

	Objective	Methodology	Evidence
Handrails	Minimise number of poorly positioned handrails with a focus on braking and frontal collision events	Vertical handrails: Identify vertical handrails that could be impacted and weight by the likelihood that they will be impacted. Horizontal handrails: Identify horizontal handrails in head impact zone and weight by likelihood that they will be impacted, i.e. their height above the bus floor and their length.	CCTV Analysis: The parts of the bus that standing passengers who were injured hit most frequently were the floor (20%) and vertical handrails (19%), followed by partition panels (18.8%). The head and the chest were the body parts impacted most frequently, with the head receiving most (87.5%) of the moderate injuries. A number of moderately injured passengers standing in the wheelchair area impacted horizontal handrails positioned at head height.
Restraint	Ensure partitions are high enough, so that standing passengers are not thrown or pivot over them in the event of harsh braking or a collision	Identify partitions that standing passengers may be propelled over as a result of harsh braking or a collision and weight by their height and length	CCTV Analysis: Some passengers were observed pivoting over partitions, but evidence that it is a substantial problem was low
General / Other	Minimise the number of sharp corners / edges and protrusions that a standing passenger may hit (in particular with their heads) if they stumble and / or fall, often in the event of a harsh braking or collision event	Identify objects with protrusions, sharp corners and edges that may be impacted, e.g. step corners and mirrors for driver view of middle door observed on a buses examined	CCTV analysis: The floor was identified as the bus part most frequently impacted by standing passengers who were injured. However, no specific instances of an injured passenger impacting potential hazards identified in the bus inspections (see Section 2.3), such as step corners or mirrors, were observed

The following further weighting was determined, mainly on the basis of expert judgement, to encourage focus on the categories of potential hazards with higher injury potential:

- Handrails: multiply by 5
- Restraint: multiply by 4
- General: multiply by 3

5.1.3.2 Seated passengers

	Objective	Methodology	Evidence
Handrails	Move handrails out of head impact zone for seated passenger, e.g. ensure handrail from seat back top to ceiling is sufficiently inboard that seated occupant will not hit it	Identify handrails in alignment with trajectory of seated occupant and weight by how much aligned, (i.e. likelihood that will be impacted)	CCTV analysis: Identified the part of the bus hit most frequently by seated occupants who were injured was vertical handrails (31.4%)
Restraint	Reduce number of seats which do not have adequate restraint for passengers seated in them, .e.g. seats with nothing in front of them (middle seats in rows at back of bus and some seats facing into wheelchair or standing areas), seats positioned high with low backed seat in front (seats above rear wheel arch), bay seats in particular aisle seat facing forward	Identify seating positions where passenger movement not adequately restrained and weight by degree of lack of restraint	CCTV analysis: Highlighted the issue of restraint for passengers seated in the middle seat on the rear row (usually thrown from seat and down aisle in front of them) and in forward facing bay seats, in particular for aisle seated passengers (often fell into aisle)
General / Other	Minimise number of sharp corners / edges and protrusions that a seated passenger may hit (in particular with their heads) when they are thrown, often in the event of a harsh braking or collision event	Identify objects with protrusions, sharp corners and edges that may be impacted by seated passengers. Weight each seating position by number of hazards and weight further if head impact hazard	Bus inspections (see Section 2.2) identified potential hazards such as bolt heads and corners of passenger information systems. CCTV analysis identified examples of head injuries to seated passengers caused by some of these potential hazards.

Further weighting

- The following weighting was determined, mainly on the basis of expert judgement, to encourage focus on the categories of potential hazards with higher injury potential:
    - Handrails: multiply by 5
    - Restraint: multiply by 4
    - General: multiply by 4
- For seats with much greater exposure (i.e. those close to the doors which have much higher occupancy rates) and that persons with reduced mobility (PRM) use, on the basis of the increased exposure and the reduced tolerance to injury of PRM, the weighting applied to these seats was increased to:
    - Handrails: multiply by 10
    - Restraint: multiply by 8
    - General: multiply by 8

5.1.4 Possible design solutions to improve bus interior safety

In this section two possible design solutions to improve bus interior safety are proposed and their potential dis-benefits discussed. The solutions build upon one another with solution 2 adding to solution 1. Solution 1 has two parts A and B which are proposed to be combined, i.e. implemented simultaneously.

Solution level 1:

Level 1A

The first part of solution 1 proposed is the fitment of guards (partitions) in front of exposed seats behind wheelchair and middle door standing areas to provide better restraint for passengers in those seats and meet future regulatory requirements (see Section 3.1.1.1 – Regulation 107 amendment proposed by the UK Department for Transport). For a majority of buses this will involve the addition of a guard (partition) for the seats behind the wheelchair area because most buses already have a partition (guard) in front of the seats behind the middle door standing area. It should be noted that:

- To allow fitment of these guards the length of the wheelchair area may need to be increased to allow sufficient space for wheelchair users to access it and meet the relevant requirements of the UK PSV Accessibility Regulations (PSVAR).
- The amendment proposed by UK DfT specifies that the guard shall extend inwards 100 mm beyond the longitudinal centre line of any seating position. The may result in a handrail positioned somewhat in alignment with a passenger sat in the aisle seat, who may impact it in a harsh braking or collision incident.

Level 1B:

The second part of solution 1 is to extend the guard so that handrails associated with it are positioned far enough inboard so that they are not in alignment with a passenger sat in the aisle seat. This should help ensure that they are not likely to be impacted in an incident.

Solution level 2:

Solution level 2 is solution level 1(A+B) plus further modifications:

- To reposition handrails not in the middle bus area, both vertical and horizontal.
- To remove general hazards for standing and seated passengers.
- To improve restraint for standing and seated passengers possibly with the use of high backed seats, for example:
    - The restraint of passengers standing in the middle door area could be improved by effectively increasing the height of the partition to the front of this area by the placement of high backed seats in front of this partition.
    - The restraint of passengers seated in the seats positioned higher above the rear wheels could be improved by placing high backed seats in front of them.

Figure 5-5: Exposed seats behind wheelchair area. Solution level 1 proposes to fit guard (partition) in front of these seats. Solution level 2 proposes to extend guard and move handrails further into aisle

The main potential dis-benefit to the possible design solutions is a possible increase in the weight of the design caused by the additional items (guards and extension of them) and the replacement of some low backed seats with higher backed seats, which weigh more. However, this may not be the case and, if it is, it may be possible to manage it. For example, for solution level 1A the wheelchair area will likely need to be longer. In this case, the weight of the additional guard (partition) may be offset by a reduced seating capacity on the lower deck, if it is assumed that the length of the bus does not change.

Other potential dis-benefits related to 'human factors' include:

- Disruption of passenger flow by guards

  Because they restrict the width of the aisle, the additional guards, in particular when extended inboard as for solution level 1B, could disrupt and cause a slight delay to the passenger flow, especially for passengers entering the middle door and moving towards the back of the bus. Similarly, the guards could also disrupt passengers disembarking from the back of the bus through the middle door. Passengers tend to gather at the middle exit door prior to disembarking. The added guard length will reduce this area size, resulting in fewer people being able to gather by the exit. This is expected to have a minimal impact on passenger flow and would likely enhance safety as exiting passengers will be more dispersed and have a greater access to hand rails or partitions.

- Access to seats behind guards

  The guards, in particular when extended as for solution level 1B, could make it more difficult for passengers, in particular those with reduced mobility (PRM), to access the seats behind the guards.

- Access to seats behind those with higher backs

  Increasing the backrest height may reduce a passenger's ability to access the seats on the bus, especially for the seats situated closest to the window. Bus seats backs are typically positioned at a backwards angle, so that increasing the height of the back of seats, will reduce the access space between seat rows. This may slightly delay passengers in accessing or egressing from their seats, and may lead to passenger dissatisfaction, particularly for passengers with restricted mobility.

  The normal backrest height and backwards angle of a low backed seat is 435 mm and 5°, respectively. Based on these numbers, a 200 mm and 300 mm increase in backrest height will result in 17.50 mm and 26.24 mm less space between rows, respectively (Figure 5-6). This does not appear to be a significant reduction in space. However, this small reduction could make a significant impact, if row width is already confined.

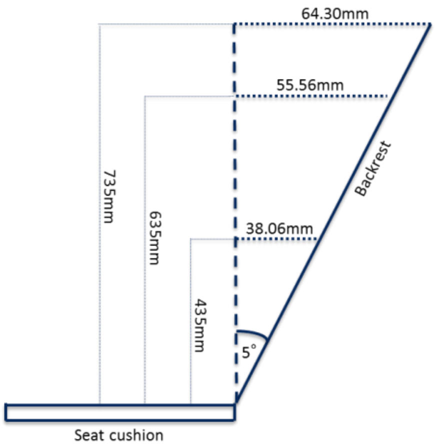


Figure 5-6: Estimated bus seat dimensions for three backrest heights

Without performing usability testing of the higher backed seat it is difficult to determine whether passenger accessibility will be affected. Accessibility is dependent on the current row width and the angle of the high backed seat, which varies amongst buses. As a guidance, the minimum dimensions for a passageway for passengers walking straight is 630 mm (Pheasant, 2003)

Additional work to quantify these potential dis-benefits is recommended. This work would likely need to be a trial based comparative study using bus mock-ups and volunteers.

5.1.5 Application of assessment system to current buses and development of target scores

The assessment system and target scores were developed iteratively by application to a number of current buses and 'modified buses' in which design improvements were hypothetically implemented. The application of final system to these buses to derive the target scores is described below.

The assessment system was applied to a variety of five current buses, two single decker (SD) and three double decker (DD), which included two of the more popular makes / models. The results show a range of scores (Table 5-7), with Bus E scoring the worst overall because of its poor score for handrails on the upper deck. It is also seen that the lower deck has a much larger score than the upper deck, even when just seated passengers are considered. This indicates that the majority of the potential hazards are located on the lower deck. This is in alignment with a key result from the analysis of the CCTV data, which shows a much higher proportion of passengers on the lower deck are injured, i.e. a higher risk of injury for the lower deck, although a contributory factor to this observation is that more passengers that are less injury tolerant travel on the lower deck, i.e. Persons with Reduced Mobility (PRM).

Table 5-7: Scores for application of assessment system to five current buses

Bus Decks	Bus A Single	Bus B Single	Bus C Double	Bus D Double	Bus E Double
Lower Deck					
Standing Handrail	33.19	28.50	41.26	32.02	28.04
Standing Restraint	0.00	4.55	1.93	2.34	0.00
Standing General	3.00	0.00	3.00	6.00	9.00
Seated Handrail	40.00	20.00	27.14	2.50	40.71
Seated Restraint	4.00	4.00	18.00	22.00	10.00
Seated General	0.00	0.00	0.00	16.00	0.00
Total – lower deck	80.19	57.05	91.34	80.87	87.76
Upper Deck					
Seated Handrail			3.00	0.00	45.00
Seated Restraint			4.00	0.00	4.00
Seated General			0.00	0.00	0.00
Total – upper deck			7.00	0.00	49.00
Grand Total	80.19	57.05	98.34	80.87	136.76

Design improvements were hypothetically implemented for two of the more popular makes / models of buses to investigate how these improvements changed the scores and to help set target scores. The improvements made were:

- Modification 1A:

  The addition of guards (partitions) for exposed seats behind wheelchair and middle door standing areas to meet future regulatory requirements (see Section 3.1.1.1 – Regulation 107 amendment proposed by DfT).

- Modification 1B:

  Modification 1, plus repositioning of handrails in front of these exposed seats (far enough out into the aisle) in order that they do not present a hazard.

- Modification 2

  Modification 1(A+B) plus further modifications to reposition handrails not in middle bus area, improve restraint for standing and seated passengers possibly with the use of high backed seats, and remove potential general hazards.

Assessment of these 'modified' buses showed large improvements (reductions) in the scores, which demonstrates that the assessment system has the potential to drive improvements in safety to bus interiors. Hypothetically a score of zero should be possible. However, the scores for the modified buses illustrate that in reality it will be difficult to achieve a score much less than 20.

Table 5-8: Scores for application of assessment system to modified buses

Bus	Bus C DD	Bus C DD Mod 1A	Bus C DD Mod 1B	Bus C DD Mod 2	Bus D DD	Bus D DD Mod 1A	Bus D DD Mod 1B	Bus D DD Mod 2
Lower Deck								
Standing Handrail	41.26	41.15	41.15	20.35	32.02	32.02	32.02	23.51
Standing Restraint	1.93	1.93	1.93	0.00	2.34	2.34	2.34	0.00
Standing General	3.00	3.00	3.00	0.00	6.00	6.00	6.00	0.00
Seated Handrail	27.14	27.14	27.14	0.00	2.50	2.50	2.50	0.00
Seated Restraint	18.00	12.18	10.00	4.00	22.00	8.18	6.00	0.00
Seated General	0.00	0.00	0.00	0.00	16.00	16.00	16.00	0.00
Total – lower deck	91.34	85.41	83.23	24.35	80.87	67.05	64.87	23.51
Upper Deck								
Seated Handrail	3.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00
Seated Restraint	4.00	4.00	4.00	4.00	0.00	0.00	0.00	0.00
Seated General	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total – upper deck	7.00	7.00	7.00	4.00	0.00	0.00	0.00	0.00
Grand Total	98.34	92.41	90.23	28.35	80.87	67.05	64.87	23.51

Where DD = Double deck

From the assessments of the current and modified buses target scores are proposed (Table 5-9). To apply the assessment to single deck and double deck buses in a straight forward manner, the proposal is to base the rating on the lower deck score and with the proviso for double deck buses that a minimum score for the upper deck has to be achieved for this lower deck rating to be applicable. In the case that this minimum score is not met, the rating should be reduced by one level.

Table 5-9: Proposed target scores (and star rating) for assessment system

Target Scores		Buses qualifying	Proposed star rating
Lower Deck	Upper Deck		
<20	<4	No current / modified buses	*****
20-30	<4	Bus C DD Mod 2, Bus D DD Mod 2	****
30-60	0-10	Bus B SD, Bus D DD Mod 1A & Mod 1B	***
60-90	10-40	Bus A SD, Bus D DD, Bus C DD Mod 1A & Mod 1B	**
90-120	40-100	Bus E DD, Bus C DD	*
>120	>100	No current / modified buses	Zero

5.1.6 Discussion and recommendations

On the basis of evidence from bus incident CCTV analysis and bus examinations, a system to assess and rate the interior safety of a bus has been developed which focuses on:

- Better positioning of handrails
- Improved passenger restraint
- Minimisation of general hazards which a passenger may impact such as protrusions, sharp corners and edges.

The following stages for improvement of the interior safety of a bus can be envisaged:

1A) Improvement of restraint for seats on lower deck, by the addition of guards (partitions) for exposed seats behind wheelchair and middle door standing areas to meet future regulatory requirements (see Section 3.1.1.1 – Regulation 107 amendment proposed by DfT).

1B) In addition, the repositioning of handrails in front of these exposed seats (far enough out into the aisle) in order that they do not present a hazard.

2) In addition, repositioning of handrails not in middle bus area, improve restraint for standing and seated passengers possibly with the use of higher backed seats, and remove potential general hazards.

The assessment of ‘hypothetical’ buses has shown that the assessment system could be used to drive these improvements.

Stage 1(A+B) could possibly be achieved circa 2021 (2/3 star rating) and stage 2 circa 2024 (4 star rating) assuming the use of high backed seats in a limited number of positions to improve restraint of standing and seated passengers is achievable within the bus’s weight budget.

It is recommended that the assessment system and proposed target scores are strongly considered for introduction to encourage interior safety improvements, specifically:

- Better positioning of handrails
- Improved passenger restraint
- Minimisation of general hazards such as protrusions, sharp corners and edges.

It is also recommended that following its introduction, the assessment system is reviewed periodically (and is updated if appropriate) to ensure that it still continues to encourage new bus interiors to be safer in a cost effective manner. These reviews may need to be more frequent around its introduction as stakeholders become more aware of its implications on other aspects of the bus design.

5.2 Potential design solutions for specific issues – high / low backed seats

5.2.1 Introduction

The objective was to illustrate and help provide data to estimate reduction in injury that could be achieved by the fitment of high-backed seats in place of current low-backed seats.

The potential advantages of high backed seats are:

- High backed seats should help improve restraint of passengers seated on seats behind, in particular for seats behind that are at a higher level, for example those above the rear wheels with seats at a lower level in front of them.
- High backed seats should help reduce neck whiplash type injuries for passengers in rear facing seats in collision type and possibly braking type incidents. However, research suggests that whiplash should not be a major issue for braking type incidents because the decelerations in these incidents (less than 1 g) are substantially below a threshold of circa 2 g, below which whiplash injuries are not expected to occur. This guidance was derived based results of rear impact tests that TRL have performed with volunteers (Hynd *et al.*, 2007). In these tests a 2 g deceleration pulse was used. Clearly, the aim was that no volunteers should be injured and the results showed that this was the case.

The main disadvantage of high backed seats compared to lower backed ones is their increased weight. Although the TfL bus technical specification does not set any specific requirements on the heights of seat backs, it encourages weight saving strategies because weight has a relationship to fuel economy. The specification states that buses should be designed to maximise their fuel economy. To some extent, this encourages lower backed seats.

Another disadvantage is that high backed seats usually have a larger seat back angle (recline) for comfort reasons (7 degrees compared to 5 degrees). This makes it more difficult to get in and out of these seats unless the seat pitch is made larger to compensate. In addition high backed seats are generally more expensive.

5.2.2 Method

Examination of typical bus seats revealed that seats called ‘high backed’ did not have a back high enough to support the head fully in the event of a collision in which the occupant is propelled into their own seat (i.e. forward facing seat in a rear impact, or rear facing seat in a frontal impact). On this basis, from now on, these seats are referred to as ‘medium backed’.

Therefore, a seat which does have a high enough seat back to support the head fully, a coach seat, was also included in the simulation matrix.

Figure 5-10: 50th percentile Hybrid III dummy sat in bus seat with 'high back' showing that seat back is not high enough to support head fully if occupant propelled into their own seat

Table 5-11: Typical bus seat back heights and angles

Seat (back) type	Total seat height (mm)	Seat back height / angle (mm) / (deg)
Low (Bus standard)	885	435 / 5
Medium / (Bus high)	1110	660 / 5
Medium (Inter-urban)	1130	680 / 5-7
High (Coach)	1200	750 / 7

To investigate the potential reduction in injury that could be realised by the fitment of high-backed seats instead of the current low backed ones, simulations as shown in Table 5-12 below, were performed. The simulation models of the seats were built using drawing (CAD) and material data supplied by a seat manufacturer. The Hybrid III Rail Safety dummy was used for the simulations in which the dummy was propelled forward into the seat back in front. The rail safety dummy was used because its kinematics are more biofidelic than a standard Hybrid III dummy, mainly because it has a different pelvis which enables it to stand up. For simulations in which the dummy was propelled backwards into his own seat, both the H3 RS and BioRID II dummies were used. The BioRID II is specifically designed for rear impact, and the assessment of whiplash type injuries, hence the reason why it was used.

Two deceleration pulses were used for the simulations to cover the wide range of decelerations that may be seen in bus incidents. These were a high deceleration pulse representing a collision, specifically the pulse used for testing the crashworthiness of seats in Regulation 80; and a low deceleration pulse representing emergency braking, specifically a pulse recorded from a test with Advanced Emergency Braking (AEB). The test pulses are shown Figure 5-13 and Figure 5-14 respectively.

Table 5-12: Simulation matrix to investigate low / medium / high backed seats

Deceleration pulse and direction	Dummy propelled forwards into seat back in front		Dummy propelled rearwards into own seat			
	High decel pulse (Collision)	Low decel pulse (Emergency braking)	High decel pulse (Collision)		Low decel pulse (Emergency braking)	
Dummy type	H3 RS	H3 RS	H3 RS	BioRID II	H3 RS	BioRID II
Seat type						
Low back	X	X	X	X	X	X
Medium back	X	X	X	X	X	X
High back (coach)	X	X	X	X	X	X
High back (coach) with modified head restraint foam			X	X		

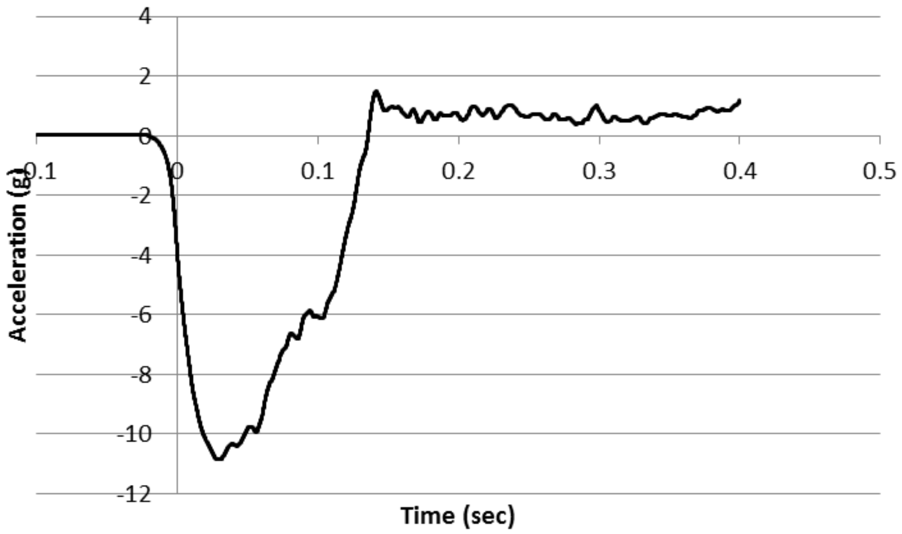


Figure 5-13: Collision (Regulation 80) deceleration pulse, initial speed 34 km/h

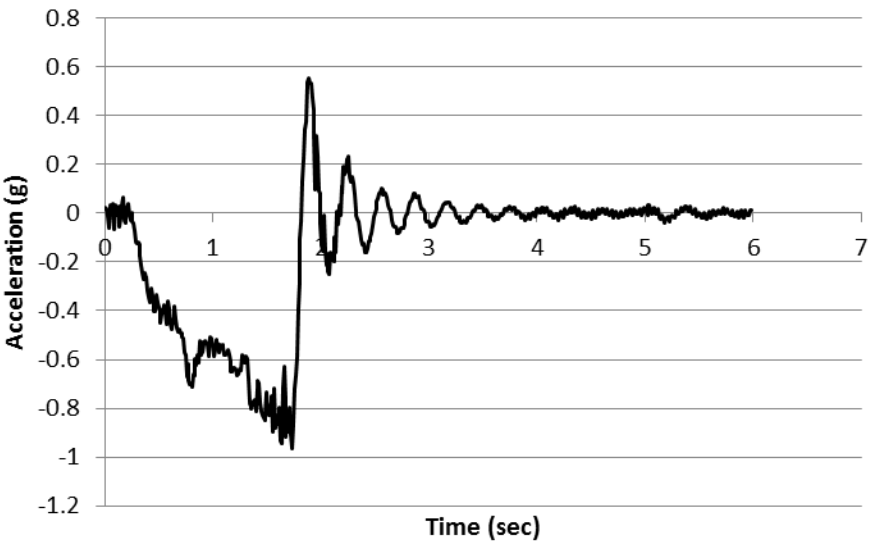


Figure 5-14: Emergency braking deceleration pulse from AEB test, initial speed 30 km/h

Also, a limited number of tests were performed, as shown in Table 5-15 below, to validate the simulation results focused on assessment of injury performance and assess the structural performance of the seats. The tests to assess the structural performance of the seats were performed using 95th percentile Hybrid III dummies to apply a load equivalent to the maximum likely to be experienced in the real world. This is similar to the approach used for testing of passenger seats in trains (see Section 4.3.1.1).

Table 5-15: Test matrix for validation of high / low backed seats simulations

Deceleration pulse and direction	Dummy propelled forwards into seat back in front		Dummy propelled rearwards into own seat
Test type	Injury	Structural	Injury
Dummy type	1 x 50th %ile H3 RS	2 x 95th %ile H3	1 x 50th %ile H3 RS
Seat type			
Low back (standard)	X	X	X
Medium back	X	X	
High back (coach)	X	X	X

5.2.3 Results and discussion

5.2.3.1 Injury Assessment (Forward)

Dummy (H3 RS) propelled forwards into seat back in front

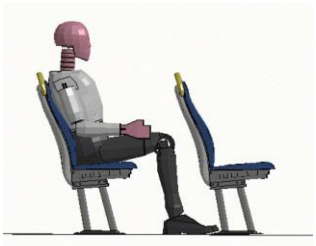
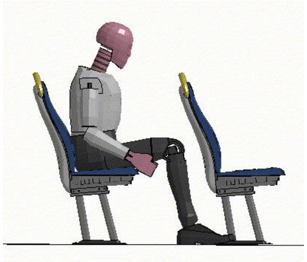
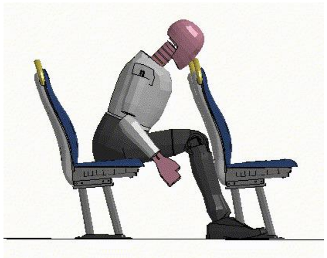
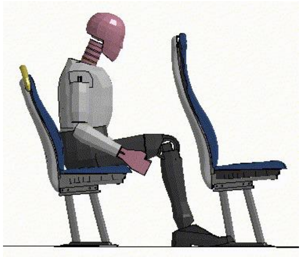
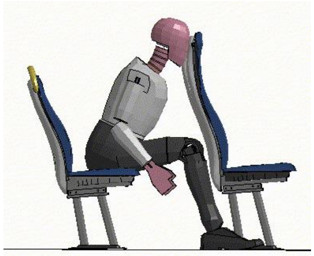
The differences in kinematics for the braking pulse are shown in Table 5-16 for low, medium and high backed seats. It is seen that for all seats the dummy's head contacts the back of the seat in front. For the low backed seat the dummy's head contacts the seat back handle on top of the seat, which is a stiff part of the seat structure. In contrast, for the medium and high backed seats the dummy's head contacts the upper part of the seat back which is generally not a particularly stiff part of the seat back.

However, it should be noted that these simulations do not account for human muscle reaction and therefore the results may not be representative of human behaviour. Generally, humans brace themselves in a low deceleration incident. In the CCTV analysis many instances were observed of a person's head not contacting the seat in front at all or going over the top of the seat in front.

Also, it should be noted that the HIC values related to the contacts are extremely low (see Table 5-18 braking deceleration pulse columns), which indicates a low risk of a serious head injury, although this does not include injuries such as cuts, bruises, broken noses, teeth etc.

It is interesting to note that compared to the low and medium backed seats, the coach seat has a larger seat back angle (7 degrees compared to 5 degrees) and the seat squab cushion is angled back more. This results in the dummy sliding off the seat less when subjected to the braking pulse.

Table 5-16: Comparison of kinematics of dummy propelled into seat in front for low, medium and high backed seats – braking pulse, simulation only

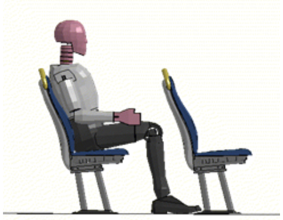
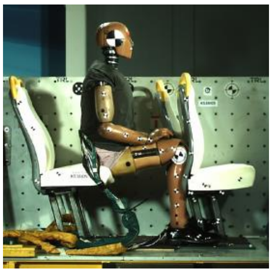
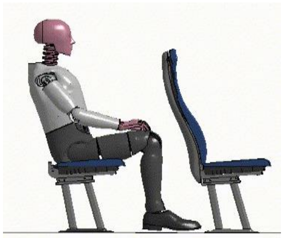
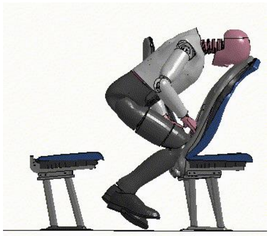
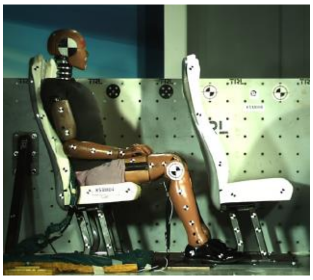
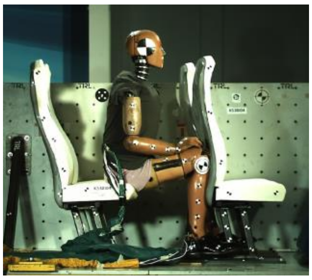
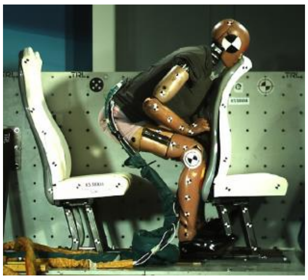
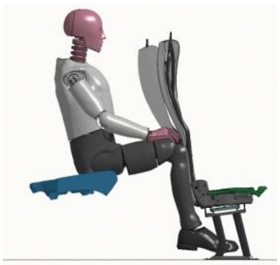
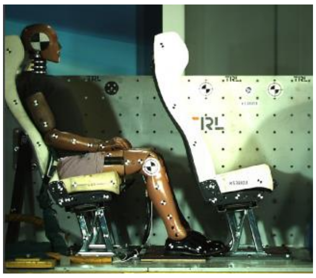
Seat type	0 sec	0.5 sec	0.94 sec
Low backed (sim)			
Medium backed (sim)			
High backed (sim)			

The differences in kinematics for the collision pulse are shown in Table 5-17 below for low, medium and high backed seats, for the simulations and the physical sled tests. For all the seats, the seat back bends substantially to absorb the energy of the impact to help protect the passenger from injury.

Some injury assessment reference values for the legs, used in GM/RT2100 for the assessment of rail seats, were exceeded for the low and medium backed seats in the simulations but not in the physical sled tests (Table 5-18). Detailed examination of the results showed that this discrepancy was caused by a problem in the simulations related to the interaction of the dummy's feet with the floor in the simulations at about 100 msec. Unfortunately, this problem could not be solved in the timeframe available, thus the simulation results for the legs after this point in time were deemed unreliable and the test results were used instead.

In the real-world, the deceleration pulses for incidents / collisions which occur will vary substantially, but are likely to be somewhere between the two pulses modelled. Bearing this in mind, a likely outcome of a potential change from current low backed seats to higher backed ones could be a greater number of head impacts on the back of the seat in front. However, this could be mitigated by making the back of the seat in the area likely to be impacted benign with the addition of padding.

Table 5-17: Comparison of kinematics of dummy propelled into seat in front for low, medium and high backed seats – crash (R80) pulse, simulation and test

Seat type	0 msec	100 msec	200 msec
Low backed (sim)			
Low backed (test)			
Medium backed (sim)			
Medium backed (test)			
High backed (sim)			
High backed (test)			

Table

Table 5-18: Comparison of injury criteria values for dummy propelled into seat in front for low, medium and high backed seats for braking and crash deceleration pulses. Note: simulation crash results (leg) for low and medium backed seats unreliable, so not shown

Body region	Criterion	Performance Limit		Low Backed Seat			Medium backed Seat			High backed Seat		
		Regulation 80	GM/RT2100	Braking (sim)	Crash (sim)	Crash (test)	Braking (sim)	Crash (sim)	Crash (test)	Braking (sim)	Crash (sim)	Crash (test)
Head	Head Injury Criterion (HIC15)	≤ 500	≤ 500	9.3	64	72	3	44	55	7.7	111	305
Neck	Bending moment in flexion (My)		≤ 310 Nm	44	74	28	11	52	63	7.7	65	77
	Bending moment in extension (My)		≤ 135 Nm	0.9	68	64	4	64	27	7.5	41	27
	Peak tensile force (Fz)		≤ 4.170 kN	0.5	1.954	2.44	0.5	1.606	1.04	0.04	1.01	1.39
	Neck Injury Criterion (Nij)		≤ 1.0	v low	0.55	0.63	v low	0.54	0.28	v low		0.37
Thorax	3 ms resultant chest acceleration	< 30g	≤ 60g	7	19.6	24.6	5	17	15	9.1	10.8	15.3
	Deflection (Dmax)		≤ 63 mm	0.9	1	6.5	0.7	1	6.9	0.6	1.1	4.6
	Viscous criterion (V*C)		≤ 1.0 m/s	0	0.04	0.02	v low	0.1	0.01	v low	0.007	0.01
Leg	Femur compressive force	< 10 kN, < 8 kN 20 msec exceedance	≤ 4.3 kN, 5.7 kN with caveat on TI	0.076	-	3.5	0.056	-	3.5	0.18	2.7	5.21
	Knee slider displacement		≤ 16 mm	v low	-	11.1	v low	-	9.6	v low	10.3	15.5
	Tibial compressive force		≤ 8 kN	0.65	-	1.2	0.65	-	1.3	0.19	1.9	1.7
	Tibial Index		≤ 1.3	v low	-	0.64	v low	-	0.6	v low	0.2	0.8

5.2.3.2 Structural Assessment (Forwards)

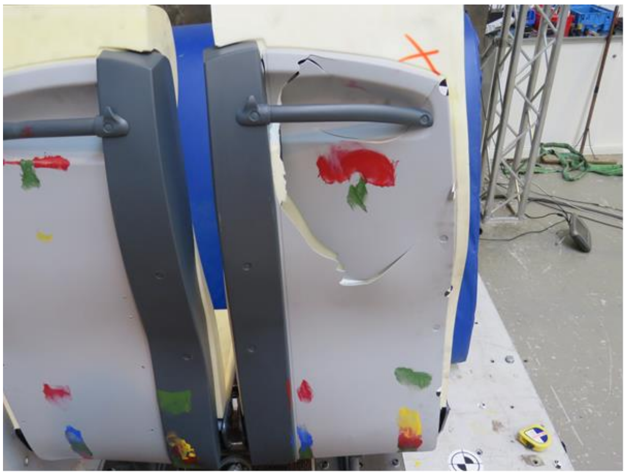
Dummies (2 x Hybrid III 95th percentile) propelled forward into seats in front

A comparison of kinematics of the dummies and the restraint offered for low and high backed seats is shown in Table 5-20 for the crash (regulation 80) deceleration pulse. It is seen that the high backed seats provided much better restraint than the low backed ones. Part of the reason for this was the structural failure of the low backed seat between the seat structure and the supporting pedestal legs, which could have prevented containment of passengers in a crash. However, in typical bus a bodyside connection is usually used, which would have likely prevented this structural failure.

Failure (splitting) of rear panel occurred for both the low and high backed seats (see Figure 5-19). However, edges formed were not particularly sharp.

Low backed seat: splitting of rear panel in area where dummy legs impacted

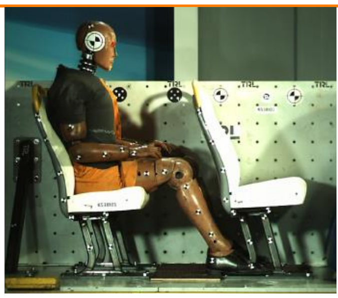
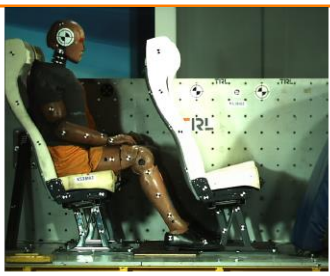
Low backed seat: failure causing detachment from pedestal legs



High backed seat: failure (splitting) of rear panel in area where dummy head impacted

Figure 5-19: Damage sustained to low and high backed seats in tests to assess structural performance

Table 5-20: Comparison of dummy kinematics and restraint for low and high backed seats in tests to assess seat structural performance, for crash deceleration pulse

Low backed (test)			
	0 msec	100 msec	200 msec
			
	300 msec	400 msec	500 msec
High backed (test)			
	0 msec	100 msec	200 msec
			
	300 msec	400 msec	500 msec

5.2.3.3 *Injury Assessment (Rearwards)*

<u>Dummy (Hybrid III 50th percentile RS) propelled rearwards into own seat</u>

The differences in kinematics for the braking pulse are shown in Table 5-21 below for low, medium and high backed seats. For this pulse there the neck deflection is negligible for all seats although the dummy is pressed a little into the seat back and in the animations (not shown) can be seen to rebound forward slightly after the end of the pulse.

Table 5-21: Comparison of kinematics of H3 dummy propelled rearwards into own seat in front for low, medium and high backed seats – braking pulse

Seat type	0 sec	0.5 sec	0.94 sec
Low backed (sim)			
Medium backed (sim)			
High backed (sim)			

The differences in kinematics for the collision pulse (for simulations and tests) are shown in Table 5-22 below for the low, medium and high backed seats. For all the seats, to prevent the seat back collapsing and the occupant sliding backwards out of the seat, a bar was positioned behind the seat back to represent a supporting structure such as a partition or another seat. The reason the seat backs bend without support is that they are designed to bend when impacted from behind to absorb energy and help mitigate occupant injury for collisions in which the occupants are propelled forwards. Substantial neck extension (rearward motion) is seen for all the seats, even for the high backed coach seat. This is because the high backed coach seat has a recess behind the head to allow a passenger to rest their head and sleep (Figure 5-23). To investigate the effect of supplying better support for the head, simulations were performed with the head restraint part of the seat modified with this recess filled in (Figure 5-24). With this modification much less neck extension was seen (Table 5-22).

The dummy injury criteria values predicted are all substantially below the injury assessment reference values used for rail seat testing in the GM/RT2100 standard (Table 5-25). Ostensibly, this indicates a low risk of AIS[9] 2+ injuries, such as vertebral body burst fractures or fractures involving spinal cord injuries. To some extent this is surprising, considering the degree of neck extension. Note that whilst whiplash injury is often referred to as a minor injury or classified as an AIS 1 injury, it can actually include more severe injuries according to the modified WAD scale. The injury criteria values for the high backed (coach) seat with the modified head restraint are substantially lower than for the standard coach seat, illustrating that a high backed seat that supports the head has the potential to reduce neck injury.

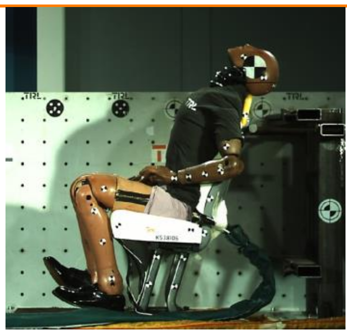
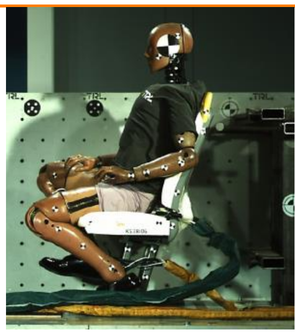
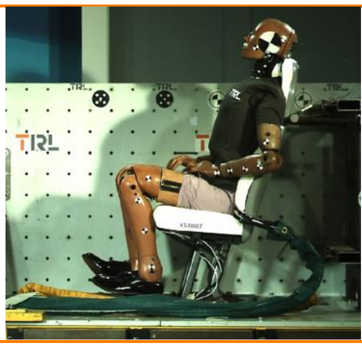
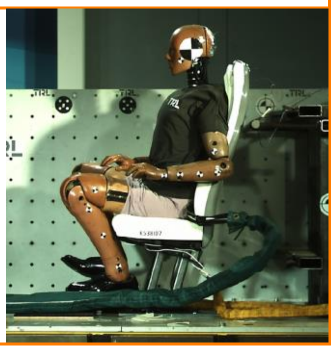
Agreement between test and simulation is reasonable but with some differences. The most notable of these is that for the simulations the dummy tends to ride up the seat back more than for the tests[10].

[9] AIS: Abbreviated Injury Scale created by the Association for the Advancement of Automotive Medicine (AAAM) to classify and describe the severity of injuries. It represents the threat to life associated with the injury rather than the comprehensive assessment of the severity of the injury

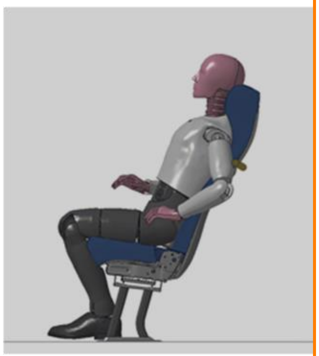
[10] Sterling M. (2004). A proposed new classification system for whiplash associated disorders-implications for assessment and management. Man Ther., 9(2), pp. 60-70.

The Quebec Task Force was a task force sponsored by a public insurer in Canada. This Task Force developed recommendations regarding the classification and treatment of Whiplash Associated Disorder (WAD), which were used to develop a guide for managing whiplash in 1995. An updated report was published in 2001. Each of the QTFC grades corresponds to a specific treatment recommendation.

Table 5-22: Comparison of kinematics of H3 dummy propelled rearwards into own seat in front for low, medium, and (standard and modified) high backed seats – crash (R80) pulse

Seat type	0 msec	100 msec	200 msec
Low backed (sim)			
Low backed (test)			
Medium backed (sim)			
Medium backed (test)			

(cont…)

Seat type	0 msec	100 msec	200 msec
High backed (coach) (sim)			
High backed (coach) (test)			
High backed (coach) with modified head restraint foam (sim)			

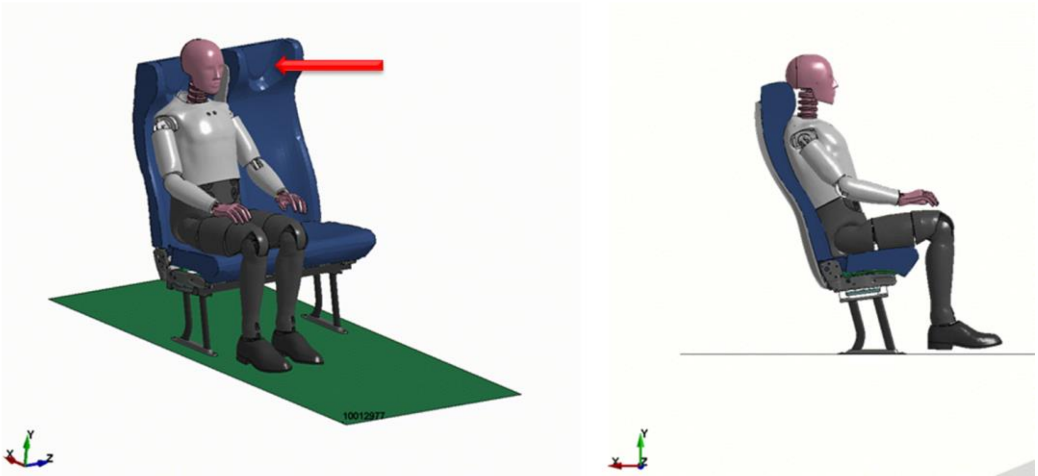


Figure 5-23: Iso and side views of H3 dummy in high backed (coach) seat showing recess to allow passenger to rest head (indicated with arrow). Also, note that dummy is settled into seat foam under gravity loading before deceleration pulse applied, so seat back only just high enough to supply support for head rearward motion

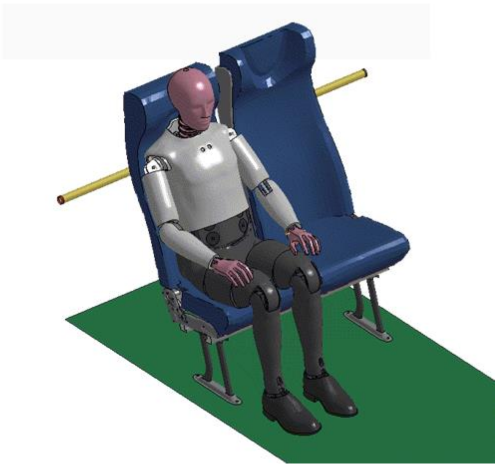


Figure 5-24: Iso view of H3 dummy in high backed (coach) seat with modified head restraint foam (recess filled in) to improve support for head rearward motion

Table 5-25: Comparison of injury criteria values for H3 dummy propelled into own seat for low, medium and high backed seats for braking and crash deceleration pulses

Body region	Criterion	Performance limit		Low Backed Seat			Medium backed Seat			High backed Seat			
		Reg 80	GM/RT2100	Braking (sim)	Crash (sim)	Crash (test)	Braking (sim)	Crash (sim)	Crash (test)	Braking (sim)	Crash (sim)	Crash (test)	Modified head restraint foam Crash (sim)
Head	Head Injury Criterion (HIC15)	≤ 500	≤ 500	0.5	125	61	8	126	124	8	83	273	38
Neck	Bending moment in flexion (My) (forwards)		≤ 310 Nm	4	24	31	7	35	40	8	23	45	13
	Bending moment in extension (My)		≤ 135 Nm	3	35	54	5	24	7	3	72	25	13
	Peak tensile force (Fz)		≤ 4.170 kN	0.1	2.49	1.15	31	2.49	2.12	0.02	1.58	2.27	0.87
	Neck Injury Criterion (Nij)*		≤ 1.0	v low	0.45	0.54	v low	0.45	0.36	v low	0.58	0.36	0.16

*Highest value of Nij for four possible loading conditions, tension-extension (Nte), tension-flexion (Ntf), compression-extension (Nce) and compression-flexion (Ncf).

5.2.3.4 Dummy (BioRID II) propelled rearwards into own seat

The BioRID II dummy and associated injury criteria are designed to assess the protection seats offer against whiplash type injury in rear impacts. The injury assessment reference values (IARVs) used for this study were taken from Euro NCAP and are for the assessment of the protection offered against whiplash injury for car seats in response to a high severity deceleration pulse. This pulse is somewhat similar to the Regulation 80 pulse, although it is a little less severe; a delta V of 24.5 km/h compared to 32 km/h for Regulation 80. Euro NCAP specifies upper and lower limits and a capping limit. Below the lower limit maximum points are awarded tailing off to zero points at the upper limit. If the capping limit is exceeded for any criteria, no points are awarded at all for the whole test, even if other criteria values are below the upper limit.

Table 5-27 shows the injury criteria values predicted from the application of braking and crash (Regulation 80) pulses for the low, medium and (standard and modified) high backed seats. Comparison of these values with the Injury Assessment Reference Values (IARVs)[11] used by Euro NCAP indicates that, for the crash pulse, no seat offers good protection against whiplash. Indeed, capping limits are exceeded for all criteria for all seats, with the exception of the high backed (coach) seat with the modified head restraint foam, which exceeds the capping limit for just the Neck Injury Criterion (NIC). The much better performance of this modified seat, which provides much better support for the head, indicates that, most likely, a high back bus seat that provides good protection against whiplash injuries in a bus crash with a Regulation 80 type deceleration pulse, could be developed in the future.

[11] Euro NCAP assessment protocol – Adult occupant protection. https://cdn.euroncap.com/media/57827/euro-ncap-assessment-protocol-aop-v911.pdf

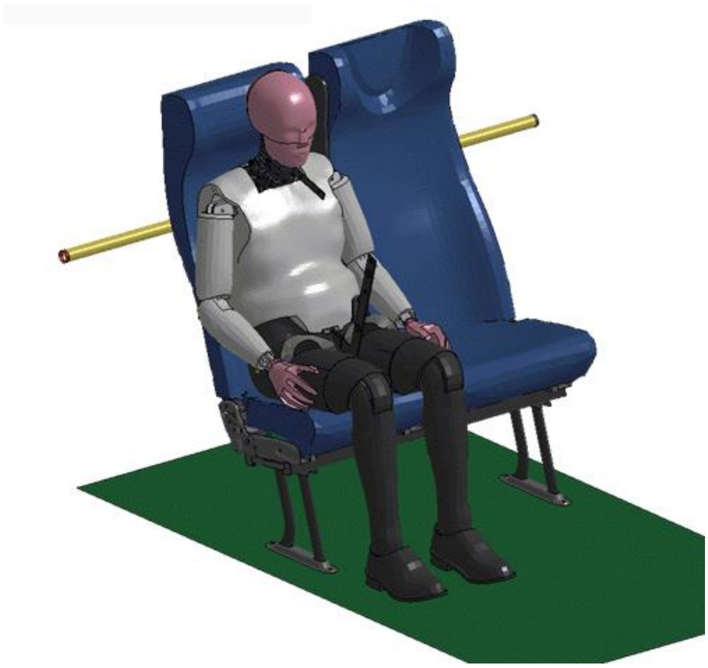


Figure 5-26: Iso view of BioRID II dummy in high backed (coach) seat with modified head restraint foam (recess filled in) to improve support for head rearward motion

Body region	Injury Criterion	EuroNCAP performance limits for high severity			Low Backed Seat		Medium backed Seat		High backed Seat		
		Capping	Lower limit	Upper limit	Braking	Crash	Braking	Crash	Braking	Crash	head restraint foam
Neck	Nkm	0.78	0.47	0.22	0.16	2.02	0.28	2.73	0.2	1.42	0.7
	NIC	25.5	23	13	6	80.6	>3.2	92.3	>39.1	101	103
	Upper Neck Tension Fz (N)	1024	770	470	0	1850	0	2160	0	2010	900
	Upper Neck Shear Fx (N)	364	210	30	51	770	90	1100	49	410	200
	Thoracic T1 Acceleration (g)	17.8	15.9	12.5	0.91	29.4	0.7	33.9	0.88	25.8	15.8

Table 5-27: Comparison of injury criterion values with IARVs used by Euro NCAP for BioRID II dummy propelled into own seat for low, medium and high backed seats for braking and crash deceleration pulses[12]

[12] Nkm is a neck protection criteria https://www.tandfonline.com/doi/pdf/10.1080/15389580212002?needAccess=true

5.2.4 Discussion and recommendations

There are two possible reasons to fit high backed seats on bus. The first is to provide additional protection for passengers seated in rear facing seats, in particular for neck and whiplash type injuries. The second is to provide better restraint for passengers seated behind the seat, in particular for passengers on seats positioned higher than the one in front, e.g. for seats above the rear wheels.

Fitment of high backed rear facing seats

The IRIS data for the three year period from April 2014 to March 2017 were analysed to investigate neck injury. The IRIS data are held in two independent databases, the first containing data for passengers involved in slips, trips and falls type incidents, and the second containing data for collision type incidents.

The collision database contained 3,530 casualties, 1,737 of whom were travelling on the bus (selected using ‘Victim casualty category’ field). Of these 98 (5.5%) recorded an injury related to the neck (selected using the injury result and narrative fields). Interestingly, 52 of these injuries were related to bus drivers, i.e. only 46 passengers recorded an injury related to the neck.

The slips, trips and falls database contained 8,949 casualties. Of these 43 recorded an injury related to the neck (selected using the injury result and narrative fields).

Therefore overall less than 1% of casualties recorded an injury related to the neck, rising to about 3% for collision type incidents. This illustrates clearly that neck injury is not a major issue.

However, it should be noted that in the CCTV analysis, for a frontal collision an instance was observed where passengers seated in rear facing seats impacted their heads on an obstacle behind the seats. A higher backed seat could have prevented this.

The simulation and test work above shows that it should be possible to develop a high backed bus seat for use in rear facing seating positions that could provide protection against whiplash injury, although they are not currently available. Suggested criteria for such a seat are:

- Minimum height of seat back to ensure back high enough to provide support to the head.

  The rail industry use a criterion that requires that the top of the seat structure should be at least 20 mm above the level of the centre of gravity of the head of a 95th percentile male when seated on a compressed seat cushion (see Section 4.3.1.1, GM/RT2100). Typically, a 95th percentile Hybrid III male dummy is used to make this measurement. The car industry use a criterion that requires that the top of the seat structure should be at least 800 mm above the seat R point as defined in the diagram below (see GTR 7[13]):

[13] GTR 7: Global Technical Regulation 7: https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a7e.pdf

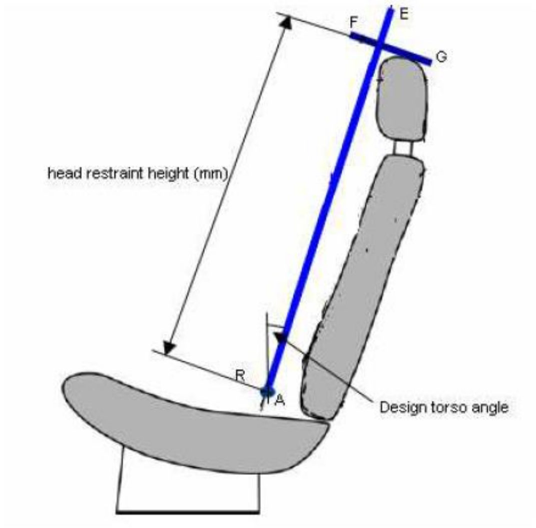


Figure 5-28: Definition of measurement of seat back height from GTR 7

- Static geometry assessment to ensure that head restraint part of seat back provides adequate support of head, e.g. there is no recess to rest the head.

  The car industry use a head restraint back-set measurement which can be made with either the H-point method using the 3D H-point machine and the Head Restraint Measuring Device (HRMD), or the R-point method using a geometric assessment (e.g. by co-ordinate measuring machine). The back-set requirement is different for each method, not more than 55 mm for the method with the H-point method and not more than 45 mm for the R-point method.

On the basis that neck injury is not a major issue and that high backed seats for buses that provide protection against whiplash injury are not available currently, mandatory fitment of high backed seats for rear facing seating positions is not recommended at this time. However, it should be noted that removal of head impact hazards behind rear facing seats is encouraged by the visual inspection based assessment system and one way to achieve this is to fit high backed seat. For the longer term it is recommended that further consideration is given to the fitment of high backed seats for rear facing seating positions to help mitigate head / neck injuries, in particular whiplash.

Fitment of high backed forward facing seats

Overall, the results of the simulation and tests reported above, show that high backed seats provide better restraint for passengers. However, they also show that for a seat with a higher back a passenger is more likely to hit their head on the back of the seat in front. This should not affect injury levels, provided that the zone which the head may impact is made suitably benign with appropriate padding. A potential method to ensure this could be to require that the seat backs comply with the pendulum head impact test contained in Appendix 6 of UN ECE Regulation 80, ideally with a test area of the full width of the seat back, not just 400 mm as defined in Regulation 80.

The CCTV analysis (see Section 2.2.3) showed an issue of poor restraint for low backed seats for passengers seated in seats positioned higher than those in front, e.g. the seats over the rear wheels in some buses, but generally did not show an issue for seats positioned at the same floor level.

A further advantage of high backed seats is that they are generally more comfortable than low backed ones mainly because they offer more support to the spine.

However, high backed seats also have some disadvantages, the main one being their additional weight – the high backed coach seat tested was about 40 percent heavier than the low backed one, although the medium backed seat was only about 10 percent heavier. Also, assuming seat pitch remained the same, high backed seats would likely make it more difficult to enter and egress the seat because the higher seat back intrudes more into the space behind because of its greater height and seat back angle required for reasons of comfort. However, higher backed seats generally have handholds placed on their sides rather than a handrail along their top as for low backed seats. It has been learnt from stakeholders that people generally prefer handholds compared to a rail across the seat back mainly because they are less likely to grab a passenger's hair with a handhold. However, it is not known how handholds compare to a handrail in terms of vertical assist for a person with reduced mobility entering or egressing a seat.

On the basis of the above, mainly that poor restraint is not a major issue and high backed seats have a substantial weight penalty, mandatory fitment of high backed seats for forward facing seating positions is not recommended at this time. However, it should be noted that better restraint of passengers seated in seats positioned higher than the ones in front, e.g. the seats above the rear wheels, is encouraged by the visual inspection based assessment system and one way to achieve this is to fit high backed seats in front of these specific seating positions. For the longer term it is recommended that further consideration is given to the fitment of high backed seats for forward facing seating positions to help improve passenger restraint and also passenger comfort.

5.3 Potential design solutions for specific issues - compliant handrail mounts

5.3.1 Introduction

The objective was to perform investigations to determine if it is possible to design handrails which are more compliant and hence reduce injury for head impacts.

No literature was found which indicated that the compliance of hand rails could be improved by covering them with a softer (i.e. less stiff) material. From private communication with experts from the rail industry who have researched this issue, the authors believe that this is most likely because this would be detrimental to the functionality of the handrail (i.e. it would be more difficult to hold) and its robustness (a soft material would be less durable and more likely to be vandalised). However, past research (Payne and Patel, 2001) has indicated that it may be possible to improve the effective compliance of handrails, in particular grab poles, by making their attachment points compliant, and hence reduce injury for head impacts. The potential of this solution was investigated using FE modelling.

5.3.2 Method

Two FE models were built of a standard floor to ceiling pole in the wheelchair area, one with a fixed mount and the other with a compliant mount (Figure 5-29). Drawings (CAD) and material data for the typical pole were obtained from a bus manufacturer. A Hybrid III Rail Safety dummy model was stood at fixed distances from the pole, typical braking and collision deceleration pulses applied (same pulses used as for seat simulations in previous section) and head injury criteria compared for the fixed and compliant mounts to investigate if, and what, potential injury reductions could be achieved.

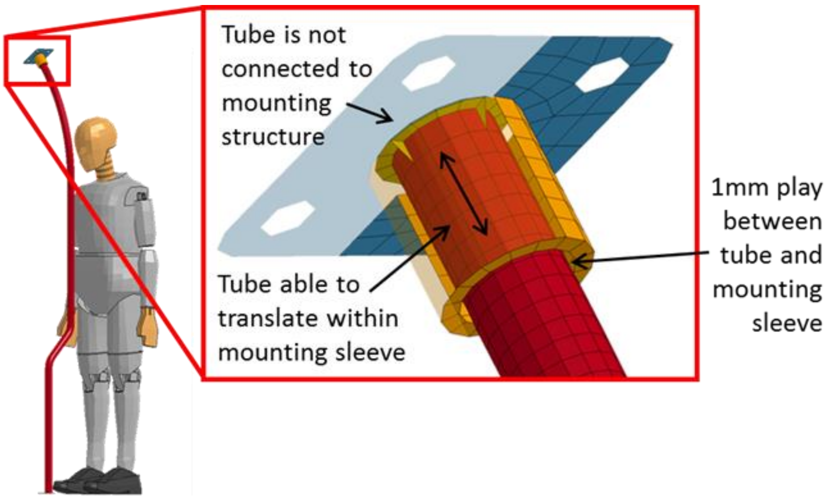


Figure 5-29: FE model of dummy and pole showing compliant mount

Initial model runs found problems with confounding factors, namely:

- Proximity of dummy to pole (262 mm and 362 mm) – one position chosen with a H point distance of 262 mm resulted in such low impact velocities that injury criteria values indicated a very low likelihood of any injury. This was resolved by positioning the dummy further from the pole (362 mm and 662 mm).
- Unrealistic interaction of dummy feet with floor – the friction with the floor had to be modelled differently to resolve this problem.
- Interaction of dummy body with pole – sometimes this interaction changed the head injury criteria values. This was resolved by performing modelling runs with full contact and just dummy head/ neck contact.

The matrix of simulations shown below was performed.

Table 5-30: Matrix of simulations performed

	High decel pulse (collision)				Low decel pulse (emergency braking)			
Dummy position	Distance occupant to pole – close		Distance occupant to pole – medium		Distance occupant to pole – close		Distance occupant to pole – medium	
Dummy pole contact	Full	Head	Full	Head	Full	Head	Full	Head
Standard pole	X	X	X	X	X	X	X	X
Long stroke compliant pole	X	X	X	X	X	X	X	X

5.3.3 Results

5.3.3.1 Braking deceleration pulse

Head injury criteria values estimated from simulations with the braking pulse are shown below.

Table 5-31: Head injury criteria values from simulations with braking pulse

Distance of dummy H-point from pole 362 mm				
	Full Contact		Head Contact Only	
	Baseline	Compliant	Baseline	Compliant
HIC_{15} (≤ 500)	31.1	14.7	31.1	14.7
Peak G	35.1	29.0	35.1	29.0
3ms Clip (≤ 80g)	28.7	18.2	28.7	18.2
Distance of dummy H-point from pole 662 mm				
	Full Contact		Head Contact Only	
	Baseline	Compliant	Baseline	Compliant
HIC_{15} (≤ 500)	38.1	44.0	38.1	44.0
Peak G	40.5	39.0	40.5	39.0
3ms Clip (≤ 80g)	38.1	20.6	28.1	20.6

Overall, the injury criteria values indicate a low risk of any injury for both the standard pole and the one with a compliant mount. (Prasad, 1999) reports injury risk functions used in the automotive industry that predict a 5% risk of skull fracture for HIC_{15} of 700. (Somers *et al.*, 2011) developed injury assessment reference values for the space industry (re-entry capsules), specifically 5% risk of mild concussion equates to HIC_{15} of 98.5 or a translational acceleration of 40g.

It is seen that, with the larger stand-off distance (662 mm), the compliant pole gives an increase in HIC even though translational accelerations (peak g and 3ms clip) are reduced. The explanation for this observation is that the compliant pole increases the contact time of the head with the pole, which in turn increases HIC, because HIC is based on an integral of acceleration over time.

5.3.3.2 Collision deceleration pulse

Head injury criteria values estimated from simulations with the collision pulse are shown below.

Table 5-32: Head injury criteria values from simulations with collision pulse

Distance of dummy H-point from pole 362 mm				
	Full Contact		Head Contact Only	
	Baseline	Compliant	Baseline	Compliant
HIC 15	201.3	214.8	229.9	267.6
Peak G	85.6	71.7	85.7	74.6
3ms Clip	50.2	53.4	50.0	52.9
Distance of dummy H-point from pole 662 mm				
	Full Contact		Head Contact Only*	
	Baseline	Compliant	Baseline	Compliant
HIC 15	331.4	199.8	1490	2119
Peak G	95.4	84.5	107.4	131.7
3ms Clip	49.9	45.7	102	122.6

* Note: Injury criteria values high because of secondary contact of head with pole, which does not occur when full dummy contact is simulated.

For the stand-off distance of 362 mm, a similar effect is seen as for the braking pulse; that the compliant pole gives an increase in HIC even though translational accelerations (peak g) are reduced. However, for the larger stand-off distance of 662 mm, the compliant pole gives a reduction in all the head injury parameters for full dummy contact. Note that for the head contact only simulations, there was a secondary contact of the head with the pole which gave different results, which were not comparable. However, they do illustrate the unpredictable nature of how an occupant may fall against a pole and how much this can affect the magnitude of their injury.

5.3.4 Discussion and recommendations

For the braking pulse the injury criteria values estimated indicated low risk of any injury, even though the compliant handrail sometimes gave higher HIC values. For the collision pulse, results were variable with the compliant handrail giving lower injury criteria values for the larger stand-off distance but some larger ones for the shorter stand-off distance.

On the basis that a consistent reduction in injury criteria values was not seen for the different initial conditions simulated, it is recommended that compliant mounts for handrails are not implemented as part of the bus safety standard.

In the author's opinion, further work in this area would probably not be fruitful because similar investigations for the rail industry have not produced any viable solutions.

6 Cost-Benefit Analysis

The Occupant Friendly Interiors safety measure focuses on grab poles and bars (handrails), seats (head restraint and seat backs), and slip protection. All the work related to slip prevention measures, including the cost-benefit analysis, is contained in a separate report. For the handrails and seats measures, issues have been identified such as poorly positioned handrails and inadequate restraint of passengers in some seating positions (see Section 1). It is proposed to reduce the number and severity of bus occupant injuries related to these issues through the introduction of minimum requirements and an assessment system based on visual inspection (see Sections 4 and 5). For implementation of this proposal, two main solution levels were envisaged as follows:

LEVEL 1:

- Improvement of restraint for exposed seats behind the wheelchair and middle door standing areas on the lower deck, by the addition of guards (partitions). This could be achieved through the introduction of the amendment to Regulation 107 proposed by the UK DfT, as a minimum requirement.
- In addition, the repositioning of handrails in front of these exposed seats (far enough out into the aisle) in order that they do not present a hazard. This could be achieved through the introduction of a visual inspection and assessment rating system with appropriate incentives.

LEVEL 2:

- In addition to LEVEL 1 changes, repositioning of handrails not in middle bus area, improve restraint for standing and seated passengers possibly with the use of higher backed seats, and remove potential general hazards. As for the second part of LEVEL 1, this could be achieved through the introduction of a visual inspection and assessment rating system with appropriate incentives.

The benefit-cost-analysis was performed for each of these proposed steps, with further information on the general approach adopted by the cost-benefit analysis to be found in Appendix A.

6.1 Approach

The approach used to perform the benefit analysis was based on the results of the CCTV analysis (see Section 2.2.3.6) and the assumptions detailed below. The CCTV analysis estimated the proportion of standing and seated passengers injured by bus area (Figure 6-1). These proportions are indicative of the risk of sustaining injury in a braking or collision incident for a standing or seated passenger travelling in that bus area.

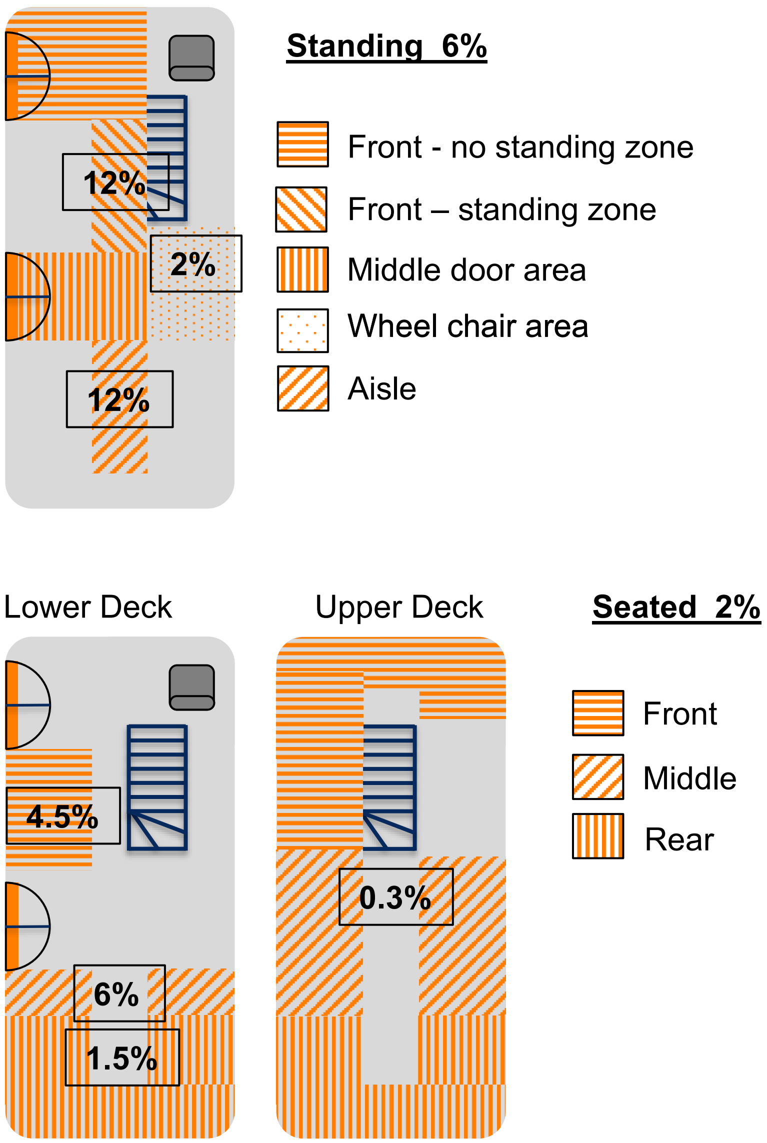


Figure 6-1: Proportion of standing and seated passengers injured by bus area in braking and collision incidents

For each of the proposed LEVELS the following assumptions were made to perform the benefit analysis:

LEVEL 1:

- Design changes make the risk of injury for all able bodied passengers seated in the lower deck middle area the same as for the upper deck – note assumption somewhat optimistic.
- Assume no benefit for impaired passengers seated in the lower deck middle area, i.e. Aged 65+ and Persons with Reduced Mobility – note assumption somewhat pessimistic.

LEVEL 2:

- Design changes make the risk of injury for all able bodied passengers on the lower deck the same as for the upper deck – note assumption somewhat optimistic.
- Assume no benefit for impaired passengers on the lower deck, i.e. Aged 65+ and Persons with Reduced Mobility – note assumption somewhat pessimistic.

It was hoped that the combination of somewhat optimistic and somewhat pessimistic assumptions should balance themselves out to give a reasonable 'middle' (neither optimistic or pessimistic) benefit estimate.

6.2 Target population

The annual target population was estimated for all injury severities (fatal, serious and slight) using the UK STATS 19 road safety database and the CCTV analysis results. The total annual target population for seated and standing passengers was determined from an average of all injured bus occupants in London for the years 2006 to 2015 (see Section 2.2.1). Passengers who were boarding or alighting were not included in the target population. Checks that these data were consistent with IRIS data were made (see Section 2.2.2).

The proportions of the total target population expected to benefit from the proposed changes (termed the relevant target population) were calculated using the CCTV analysis results in which passengers were identified if they were impaired. Impaired passengers were defined as those seen to signs of reduced mobility and / or seen to be elderly (i.e. greater than 65 years old).

LEVEL 1:

- *Relevant target population description:* Able bodied (i.e. not impaired) seated in middle area.
- *Seated:* Fatal 0%, Serious 36%, Slight 67%.
- *Standing:* 0% for all injury severities (because design changes aimed to improve safety for seated passengers only)

LEVEL 2:

- *Relevant target population description:* Able bodied seated and standing on lower deck
- *Seated:* Fatal 0%, Serious / Slight 73%
- *Standing:* Fatal 0%, Serious / Slight 67%

Given the CCTV analysis used a sample of cases, it was recognised that there was also an element of uncertainty regarding the generalisation of these proportions to the entire population. Thus, these target population proportions were given a range of ±5% to reflect these lower levels of confidence. Also, because there were no fatalities in the CCTV sample of cases, it was not possible to calculate a proportion for the fatal relevant population. An assumption was made that it was zero, i.e. the safety measures proposed would not save any fatally injured passengers.

Table 6-2: Estimated average annual target population in 2018 for the Occupant Friendly Interiors [OCC] handrail and seat safety measure solutions

Safety Measure Solution	Bus Occupant Type	Injury Severity		
		Fatal Casualties	Serious Casualties	Slight Casualties
LEVEL 2	Seated	0	18.8-21.5	277.7-318.8
	Standing	0	30.5-35.4	367.3-426.8
	Totals	0	49.2-56.9	645.0-745.6
LEVEL 1	Seated	0	8.7-11.5	252.9-293.9
	Standing	0	0	0
	Totals	0	8.7-11.5	252.9-293.9

6.3 Estimates of effectiveness

The effectiveness of implementation of the proposed design changes for each of the levels was estimated as explained in Section 6.1 above using the results from the CCTV analysis. The relative reduction in risk was calculated based on the assumptions for each level listed below and +/- 10% confidence intervals applied to provide a range.

LEVEL 1:

- Design changes make the risk of injury for all able bodied passengers seated in the lower deck middle area the same as for the upper deck.
- Calculation:
    - Risk of injury for passengers seated in lower deck middle area 6%
    - Risk of injury for passengers seated on upper deck 0.3%
    - Relative reduction in risk of injury = (6%-0.3%)/6% = 95%

LEVEL 2:

- Design changes make the risk of injury for all able bodied passengers on the lower deck the same as for the upper deck.

Table 6-3: Estimated overall effectiveness ranges for casualties prevented for the Occupant Friendly Interiors [OCC] handrail and seat safety measure solutions

Safety Measure Solution	Bus Occupant Type	Casualties Prevented		
		Fatal Casualties	Serious Casualties	Slight Casualties
LEVEL 2	Seated	0%	80-100%	80-100%
	Standing	0%	4-24%	4-24%
LEVEL 1	Seated	0%	80-100%	80-100%
	Standing	0%	4-24%	4-24%

6.4 Fleet fitment and implementation timescales

The proportion of the current fleet fitted with the LEVEL 1 and LEVEL 2 solutions were estimated with the help of stakeholder consultation (Table 6-4).

Implementation timescales were determined for both the LEVEL 1 and 2 handrail and seat solutions proposed to develop fleet fitment and policy implementation roadmaps for each solution (Table 6-4) for the new build option. A retrofit option was not considered feasible, because the solutions envisaged usually involve changing the design of the much of the bus interior. For example, the introduction of guards (partitions) in front of exposed seats behind the wheelchair area for the LEVEL 1 solution can entail lengthening the wheelchair area, which in turn can entail re-arrangement of all the seats on the lower deck of the bus. The timescales were determined based on stakeholder consultations with bus manufacturers, for first-to-market timescales, and TfL, for the proposed timescales for policy implementation. Bus operators and suppliers contributed to establishing the estimates for current levels fleet fitment and expected years to full fleet fitment after implementation for each solution. Please see associated stakeholder consultation report which covers all measures for further information on stakeholder feedback on fleet fitment and policy implementation timescales.

Table 6-4: Fleet fitment and policy implementation timescales for Occupant Friendly Interiors [OCC] safety handrail and seat measure solutions

Safety Measure Solution	First to Market	Date Policy Implemented	Current Fleet Fitment	Full Fleet Adoption (yrs)	
				Retrofit	New Build
LEVEL 2	2020	2024	0%	N/A	12
LEVEL 1	2019	2021	15%	N/A	11

6.5 Casualty benefits

Table 6-5 below summarises the estimated total change in the number of casualties expected in London during the period 2019-2031 by specifying the performance of new build buses to the proposed LEVEL 1 and 2 handrail and seat safety measure solutions. Outcomes are then monetised to estimate the total value of these casualty reductions to society.

Table 6-5: Estimated total change in number and value (NPV) of casualties over the 12-year analysis period (2019-2031) for the Occupant Friendly Interiors [OCC] safety handrail and seat measure solutions

Safety Measure Solution	Bus Occupant Type	Injury Severity			Total Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	
LEVEL 2	Seated	0	70-101	1,043-1,497	31.1-44.6
	Standing	0	6-40	69-481	2.27-15.9
	Totals	**0**	**76-141**	**1,112-1,978**	**33.4-60.5**
LEVEL 1	Seated	0	42-70	1,229-1,785	28.3-42.8
	Standing	0	0	0	0
	Totals	**0**	**42-70**	**1,229-1,785**	**28.3-42.8**

6.6 Cost implications

The costs of the LEVEL 1 and LEVEL 2 handrail and seat solutions as part of the bus safety standard can be divided into five key cost categories based on:

1) Differences in technology development, manufacturing and certification costs
2) Differences in implementation and installation costs
3) Differences in ongoing operational costs
4) Differences in insurance claims costs
5) Differences in environmental and infrastructure costs

The LEVEL 1 and LEVEL 2 solutions entail changes to the bus interior layout at the new build stage only. Therefore, there are potential differences to the technology costs, (i.e. development, manufacturing and certification costs), but no changes to implementation and installation costs or ongoing operational costs.

The main design change envisaged for the LEVEL 1 solution was the addition of a partition in front of seats behind the wheelchair area and an associated longer wheelchair area. This design change was estimated to be cost neutral (i.e. no additional cost) on the basis that the development and certification would be part of the normal design cycle and the cost of the partition would often be offset by a lower number of seats on the lower deck because of the need of a longer wheelchair area to allow the fitment of the partition (required to give enough space for a wheelchair occupant to manoeuvre into the wheelchair area).

The main design changes envisaged for the LEVEL 2 solution were the repositioning of handrails and the incorporation of a small number of seats with higher backs to improve the restraint of occupants sat behind them on seats positioned higher above the floor, e.g. seats above the rear wheels. The repositioning of the handrails was estimated to be cost neutral. Incorporating a small number of seats (4) with higher backs was estimated to cost an additional £300 +/- £260 per bus at 2018 prices.

These costs were confirmed and agreed by bus manufacturers and their suppliers as part of a stakeholder consultation.

The annual reductions in the number of bus occupant casualties was used to estimate the changes in insurance claims that may be expected by regulating the performance of buses for each occupant friendly interiors handrail and seat safety measure solution. Changes in the costs of insurance claims are highlighted below in Table 6-6.

Cost differentials resulting from environmental or infrastructure costs were not considered within the scope of this safety measure. Please see the associated overall benefit cost analysis report which covers all measures for further information on both development and operational cost calculations.

Table 6-6: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the Occupant Friendly Interiors [OCC] handrail and seat safety measure solutions (cost reductions are shown in (parentheses))

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NPV) (£M)
LEVEL 2	Change in Technology Costs	37-523	0.3-4.2
	Change in Implementation Costs	0	0
	Change in Operational Costs	0	0
	Change in Insurance Claims Costs	(1,682)-(729)	(13.5)-(5.8)
	Totals	(1,645)-(206)	(13.2)-(1.6)
LEVEL 1	Change in Technology Costs	0	0
	Change in Implementation Costs	0	0
	Change in Operational Costs	0	0
	Change in Insurance Claims Costs	(1,062)-(549)	(11.4)-(5.9)
	Totals	(1,062)-(549)	(11.4)-(5.9)

6.7 Benefit-cost analysis outcomes

Table 6-7 provides estimates for the break-even costs, discounted payback period and benefit-cost ratios associated with specifying the performances of new build buses for each occupant friendly interiors handrail and seats safety measure solution. The discounted payback period is within the year that the solutions are implemented because the total fleet costs (NPV) were calculated to reduce (i.e. changes in insurance claims costs were larger than all other costs combined). The benefit-cost ratio is shown as 'Return on Investment' (**RoI)** to indicate that the occupant friendly interiors handrail and seat safety measures are likely to provide operators with a return on their investment within the year that they are implemented and continue to provide benefits for all years within the analysis period.

Table 6-7: Estimated 12-year analysis period (2019-2031) break-even costs per vehicle (NPV), discounted payback periods and benefit-cost ratios (NPV) for the Occupant Friendly Interiors [OCC] handrail and seat safety measure solutions

Safety Measure Solution	Break-Even Costs (NPV) (£)	Discounted Payback Period	Benefit-Cost (NPV) Ratio
LEVEL 2	4,173-7,562	2020-2020	RoI
LEVEL 1	2,644-4,000	2019-2019	RoI

7 Summary of recommendations and way forward

7.1 Recommendations

The main recommendations are:

1) To introduce the amendment to Regulation 107 proposed by the UK DfT to improve the restraint of passengers seated behind the wheelchair / buggy area as part of the TfL London Bus Technical Specification.

- The amendment requires that guards for (exposed) seats shall be fitted as per the performance requirements where any seated passenger is likely to be thrown forward into a designated wheelchair space, buggy (pram) space, or open area for standing passengers as a result of heavy braking.
- The guards shall have a minimum height from the floor on which the passenger's feet rest of 800 mm and shall extend inwards from the wall of the vehicle at least as far as 100 mm beyond the longitudinal centre line of any seating position where the passenger is at risk.
- This amendment was adopted as part of the 06 series of amendments, supplement 5. For vehicles approved following EC whole vehicle type approval (ECWVTA), it is expected that these amendments will be mandatory circa 2020.
- It should be noted that to fit guards as required and allow wheelchair users sufficient space to manoeuvre into the wheelchair space, the length of the wheelchair area will need to be greater than the minimum length of 1300 mm specified in Regulation 107. Consultation with bus manufacturers revealed that a wheelchair area length of about 1.7 m is the minimum length which would allow adequate space to manoeuvre a wheelchair into the wheelchair space and a guard to be fitted, which did not allow the wheelchair footrests to swing underneath it. The minimum wheelchair area length specified in the current TfL London Bus Technical Specification is 2000 mm, which will be sufficient.

2) To introduce an interior visual inspection and assessment for occupant safety to encourage better positioning of handrails, improved restraint of passengers and minimisation of general hazards such as protrusions, sharp corners and edges.

- One way to implement it would be to require that given ratings should be achieved by all buses by given dates, with incentives for achieving those ratings before the given dates. At present the following solution levels are recommended:
    - Solution level 1 circa end 2021, rating of ~80 points: Main design changes anticipated are:
        a) Improvement of restraint for seats on lower deck, by the addition of guards (partitions) for exposed seats behind wheelchair and middle door standing areas to meet future regulatory requirements.

b) In addition, the repositioning of handrails in front of these exposed seats (far enough out into the aisle) in order that they do not present a hazard.

- Solution level 2 circa 2024, rating of ~30 points: Main design changes anticipated are:

3) In addition to design changes for level 1 (A+B), repositioning of handrails not in middle bus area, improve restraint for standing and seated passengers possibly with the use of higher backed seats, and remove potential general hazards.

- A benefit-cost analysis was performed for each of these recommended solution levels. The analysis showed that for both solutions the discounted payback period is within the year that the solutions are implemented because the total fleet costs were calculated to reduce (i.e. reductions in insurance claims costs were larger than all other costs combined). This means that the operator would receive a Return on their Investment for the implementation of either or both of these safety measures.
- It is recommended that following its introduction, the inspection and assessment system is reviewed periodically (and is updated if appropriate) to ensure that it still continues to encourage new bus interiors to be safer in a cost effective manner. These reviews may need to be more frequent around its introduction as stakeholders become more aware of its implications on other aspects of the bus design.
- It is recommended that further work is performed, in the form of human factor usability trials, to investigate the human factors aspects of the main design changes anticipated, in particular:
- The effect of lengthened guards (partitions) in front of exposed seats behind the wheelchair and middle door standing areas, anticipated for design change 1B, on access to the window seat for persons with reduced mobility.
- The effect of these lengthened guards (partitions), which effectively narrows the aisle in the middle part of the bus, on passenger access and egress to the bus in general.

Other recommendations are:

- Handrails:
    - Simulation-based investigations were performed to determine if it is possible to design handrails with compliant mounts and hence reduce injury for head impacts against these handrails in harsh braking and collision events. For braking events the head injury criteria values estimated indicated low risk of any injury, even though the compliant mounted handrail sometimes gave higher HIC_{15} values. For the collision events, results were variable with the compliant mounted handrail giving lower injury criteria values for the larger stand-off distance but some larger ones for the shorter stand-off distance.

    - On the basis that a consistent reduction in injury criteria values was not seen for the different initial conditions simulated, it is recommended that compliant mounts for handrails are not implemented as part of the bus safety standard.
- High backed seats
    - There are two possible reasons to fit high backed seats on bus. The first is to provide additional protection for passengers seated in rear facing seats, in particular for neck and whiplash type injuries. The second is to provide better restraint for passengers seated behind the seat, in particular for passengers on seats positioned higher than the one in front, e.g. for seats above the rear wheels.
    - Fitment of high backed rearward facing seats:
    - On the basis that neck injury is not a major issue and that high backed seats for buses that provide protection against whiplash injury are not available currently, mandatory fitment of high backed seats for rear facing seating positions is not recommended at this time. However, it should be noted that removal of head impact hazards behind rear facing seats is encouraged by the visual inspection based assessment system and one way to achieve this is to fit high backed seat. For the longer term it is recommended that further consideration is given to the fitment of high backed seats for rear facing seating positions to help mitigate head / neck injuries, in particular whiplash.
    - Fitment of high backed forward facing seats:
    - On the basis that poor restraint is not a major issue and high backed seats have a substantial weight penalty, mandatory fitment of high backed seats for forward facing seating positions is not recommended at this time. However, it should be noted that better restraint of passengers seated in seats positioned higher than the ones in front, e.g. the seats above the rear wheels, is encouraged by the visual inspection based assessment system and one way to achieve this is to fit high backed seats in front of these specific seating positions. For the longer term it is recommended that further consideration is given to the fitment of high backed seats for forward facing seating positions to help improve passenger restraint and also passenger comfort.
- Bus exterior inspections
    - The exterior of a bus presents no features that have a potential to cause injury to a embarking or disembarking passenger or passer-by. The exceptions to this statement are the wiper blade driver posts on some buses and the mirrors, some of which are mounted at a height at which they could strike a pedestrian. These issues are being addressed as part of the 'VRU crashworthiness' safety measure which considers counter-measures for impact protection, run-over protection and mirror

strikes. On this basis it is recommended that there is no need for an exterior visual inspection of buses.

This research was completed in 2018. The detailed specification, assessment procedures and guidance notes have been incorporated into the Transport for London specification for buses, which is a continuously updated document to keep pace with the latest technological and research developments. This report is not the specification for a bus and should not be used as such. Bus operators, manufacturers, and their supply chain should consult with TfL for the specification.

7.2 Way forward – further work

Further work should be considered to address the following issues noted during the course of this project:

1) Buggies (push-chairs) on buses

- In CCTV analysis substantial proportion of cases recorded where buggy involved (10% of all seated cases).
    - Buggy positioned sideways to direction of travel, in incident tips over and child falls out; 4 from 11 children injured.

2) Mobility scooters on buses

- Class 2 mobility scooters are permitted on London buses provided they are not wiser than 600 mm, longer than 100 mm and have a turning radius less than 1200 mm. When using a bus they should position themselves in the wheelchair area in alignment with the longitudinal axis of the bus.

  At the time the main bulk of the work for this project was performed (July 2017 to October 2018), the rules regarding mobility scooters were not clearly understood and / or enforced. This likely contributed to an observation by TRL, confirmed by bus operators, that substantial numbers of unsuitable scooters used TFL buses.

  With this in mind, it is recommended that further work, in particular CCTV analysis, is performed to better understand the safety of mobility scooters on buses.

3) Further incident (CCTV) analysis

- The analysis performed for this project has a limited sample size, 192 incidents for general analysis and 70 incidents with exposure data. Larger sample sizes could give more confidence in the results.
    - It is recommended that further CCTV analysis is performed to gather a larger sample size, ideally using data from a different operator.

4) Review of BCI bus performance in service with operator, including analysis of CCTV incident footage, to investigate effect of novel features introduced on this bus, such as higher backed seats.

- Base on CCTV analysis, investigate changes in:
    - Proportion injured (overall and distribution)
    - Injury mechanisms

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Appendix A General cost-benefit analysis approach

The following Appendix summarises the general approach taken to perform the cost-benefit analysis (CBA) for each safety measure and its proposed solutions over the 12-year analysis period (2019-2031). Using the research presented in previous sections, a number of key CBA outcomes can be determined for each safety measure solution. These outcomes include values for the target populations, effectiveness, fleet fitment timeframes, casualty reduction benefits, costs per vehicle, total fleet costs, monetised casualty benefits, break-even costs and benefit-cost ratios associated with each solution. The theory behind calculating these values is covered in the following paragraphs.

The target population represents the total number of casualties and/or incidents that a particular safety measure solution has been designed to prevent or mitigate each year. Target populations may be calculated for each relevant casualty type (pedestrians, cyclists, powered two wheelers, car occupants, HGV/LGV occupants and bus occupants) and collision severity level (fatalities, serious injury, slight injury, major damage-only incident and minor damage-only incident) using a range of sources. These may be either directly calculated using casualty numbers from the STATS19 database or through the combination of top-level STATS19 data with an indication of the proportion of relevant casualties from other sources (Equation 1). Further information on what approach was adopted is provided in the relevant following section.

$$Target\ Population = Total\ No.of\ Casualties \times Proportion\ of\ Relevant\ Casualties$$

(Equation 1)

The effectiveness of a safety measure solution is determined by an estimate of how well the particular solution works for the specific target population. Estimates of effectiveness may be calculated based on the percentage of relevant target population casualties or incidents that could have been prevented, or severity mitigated, should the particular safety measure be implemented. Overall effectiveness values may therefore be calculated through several different approaches, including values taken directly from testing performed as part of the BSS project and from those abstracted from the literature. Overall effectiveness may also be indirectly calculated by combining technology effectiveness values from studies with similar scenarios or target populations with percentage based correction factors, such as driver reaction factors (Equation 2). Further information on the approach adopted is provided in the relevant following section.

$$Overall\ Effectiveness = Technology\ Effectiveness\ \times Driver\ Reaction\ Factor \times \cdots$$

(Equation 2)

Fleet fitment and implementation timescales were determined for each safety measure solution based on a stakeholder consultation with the bus industry. This was used to include the temporal aspects of the penetration of each safety measure solution in to the TfL fleet, which can then be used for better determining the changes in costs and benefits over time. The ‘first-to-market’ timescales were established based on bus manufacturer feedback and represent the earliest point in time that the leading manufacturer will be able to bring the particular solution to market. The timescales for 'policy implementation' were proposed by TfL based on bus manufacturer feedback on when series production would be possible for at least three different manufacturers. Current levels of fleet fitment for each solution were established based on bus operator feedback, whilst the estimated period of time that it would take to fit the entire TfL fleet with the solution was determined for new build buses (12 years), solutions fitted during refurbishment (7 years) and retrofit solutions (timeframes based on supplier feedback). This gave a year-on-year fleet penetration value, based on the proportion of the fleet fitted with the particular solution, for each solution and each year of the analysis period.

Total casualty reduction benefits were then calculated by multiplying the target population and overall effectiveness values together with fleet penetration for each year of the analysis period (Equation 3). To correct for changes in the modal share in London, target population values were adjusted according to the forecasted growth in the number of trips made by each transport mode within London, whilst the bus fleet size was adjusted by the forecasted growth in the population of London (based on TfL forecasts (Transport for London, 2015)). These values were then aggregated to provide the total casualty reduction values associated with each target population and severity level over the total analysis period.

$$Casualty\ Reduction\ = Target\ Population \times Overall\ Effectiveness \times Fleet\ Penetration$$

(Equation 3)

These values were then monetised to provide an estimate of the societal benefits of the casualty reductions to TfL using 2016 average casualty costs calculated by the Department for Transport (DfT) for each relevant severity level (Department for Transport, 2018). For the purposes of this report, fatal casualties were assigned a value of £1,841,315, seriously injured casualties assigned a value of £206,912, slightly injured casualties assigned a value of £15,951 and major damage-only collisions assigned a value of £4,609 based on these DfT estimates, whilst minor damage-only collisions were assigned a value of £1,000 based on a reasonable estimate for such collisions. Net present values (NPV) for the monetised casualty saving benefits for each solution were then calculated for the analysis period. A discounting factor of 3.5% and interest rates that reflect forecasted annual changes in the retail pricing index (RPI), as defined by the WebTAG databook (v1.11) (Department for Transport, 2018), were applied.

When considering the cost based outcomes, both the costs per vehicle and total fleet costs were calculated for each solution. These were based on estimated increases in costs related to the development, certification, implementation and operation of the proposed solution and included operational cost reductions due to a reduction of claims costs associated with the reduction in casualties. The baseline costs per vehicle were adopted from information abstracted from the literature and manufacturer/supplier websites, before aggregating and confirming the estimated cost ranges through stakeholder consultation. Fleet costs were then calculated by multiplying the baseline costs per vehicle and fleet penetration values together for each year of the analysis period (Equation 4).

Claims costs reductions for each year of the analysis period were calculated by combining average insurance claim costs (calculated from operator provided data), with the expected annual changes in incidents for each outcome severity (Equation

4). For the purposes of this report, claims reductions for fatalities was assigned a range of £35,000-45,000, seriously injured casualties assigned a range of £60,000-70,000, slightly injured casualties assigned a range of £6,000-8,000, major damage-only collisions assigned a range of £4,000-5,000 and minor damage-only collisions assigned a range of £1,000-2,000.

Changes in baseline and claims costs were then aggregated to provide the net present value of the total fleet costs over the total analysis period. The net present values of the costs per vehicle were then calculated by dividing the total costs by the total number of fitted vehicles in the fleet. A discounting factor of 3.5% and interest rates that reflect forecasted annual changes in RPI were again applied.

$$Total\ Cost = (Baseline\ Cost \times Fleet\ Penetration) - (Claim\ Cost \times Casualty\ Reduction)$$
(Equation 4)

The break-even costs, discounted payback periods and benefit-cost ratios were calculated for the analysis period by combining values from the net present values for both the costs and monetised benefits. The 12-year analysis period was selected based on a combination of stakeholder and industry expert opinion to ensure the one-off and ongoing costs for each vehicle were combined with the casualty reduction benefits over the estimated operational lifetime of the vehicle. Break-even costs describe the highest tolerable costs per vehicle for the fitment of a safety measure solution to remain cost-effective for society. These were calculated by normalising the monetised casualty reduction benefits by the total number of fitted vehicles in the fleet (Equation 5). This value may be a useful indicator when no cost estimates are available, or there is low confidence in the cost inputs, with higher break-even costs indicating a greater potential for cost-effectiveness.

$$Break\ Even\ Cost = Monetised\ Casualty\ Reduction / Total\ Number\ of\ Buses\ Fitted$$
(Equation 5)

Benefit-cost ratios (BCR) describe the ratio of expected benefits to society (arising from the prevented casualties) to the expected costs (arising from fitment to vehicles) (Equation 6). This was calculated by taking the ratio of the net present value of the total casualty benefits to the net present value of the total costs. As ranges of estimated benefits and costs have been calculated, the greatest possible benefit-cost ratio range was estimated by comparing maximum costs against minimum benefits, and vice versa. Benefit-cost ratios greater than one indicate that the value of the benefits would exceed the costs and so the measure may be cost-effective, with higher benefit-cost ratios indicating higher cost-effectiveness. Should the total costs of implementing the safety measure solution reduce, then the benefit-cost ratio will be shown as a 'Return on Investment' (RoI) to indicate that the safety measure solution is likely to provide operators with a return on their investment within the analysis period.

$$Benefit - Cost\ Ratio = \ Monetised\ Casualty\ Reduction / Total\ Cost$$
(Equation 6)

Finally, the discounted payback period (DPP) was established based on calculations for the benefit-cost ratio ranges for each year of the analysis period. To establish the DPP range, the year where each boundary of the benefit-cost ratio first exceeded the value of 1 was calculated. This gives a range for the expected period in time where the societal benefits of implementing the safety measure solution would outweigh the costs of doing so. Should any boundary of the DPP be greater than 2031 (i.e. a BCR value boundary of <1 over the analysis period), then the DPP boundary was assigned a date of 2031+.

The Transport for London (TfL) Bus Safety Standard: Occupant Friendly Interiors

The Bus Safety Standard (BSS) is focussed on vehicle design and safety system performance and their contribution to the Mayor of London's Transport Strategy. This sets targets to for deaths and serious injuries from road collisions to be eliminated from London's streets by 2041 and to achieve zero deaths in incidents involving buses in London by 2030.All TfL buses conform to regulatory requirements. TfL already uses a more demanding specification when contracting services and this requires higher standards in areas including environmental and noise emissions, accessibility, construction, operational requirements, and more. Many safety aspects are covered in the specification such as fire suppression systems, door and fittings safety, handrails, day time running lights, and others. However, the new BSS goes further with a range of additional requirements, developed by TRL and their partners and peer-reviewed by independent safety experts.

The occupant-friendly interiors measure has been particularly challenging. Current regulations heavily constrain designs for reasons of accessibility, so making safety improvements without conflicting with regulations and other priorities such as passenger flow and comfort is difficult. Nevertheless, beneficial changes have been identified. The process has been to examine CCTV footage to help understand how passengers are injured in harsh manoeuvre (e.g. emergency braking) and collision events. Following this, existing bus designs were reviewed to identify potentially injurious features and how they could be redesigned to reduce the risk of injury, e.g. move the handrail to reduce risk of a head strike. An assessment scheme for occupant-friendly interiors has been developed to allow bus manufacturers to incorporate safety considerations alongside the existing constraints from regulation, accessibility, flow etc. It is hoped that this will give the manufacturers a guide for producing the best compromise, without being too design prescriptive.

Other titles from this subject area

PPR872 Bus Safety Standard: Executive Summary. TfL & TRL. 2018

PPR819 Analysis of bus collisions and identification of countermeasures. Edwards et al. 2018

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