THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR819

Analysis of bus collisions and identification of countermeasures

Alix Edwards, Adam Barrow, Siobhan O'Connell, Varun Krishnamurthy, Rahul Khatry, Nicola Hylands, Mike McCarthy, Shaun Helman and Iain Knight

Report details

Report prepared for:	TfL		
Project/customer reference:	tfl_scp_001142_co036		
Copyright:	© TRL Limited		
Report date:	18/02/2018		
Report status/version:	1.1		
Quality approval:			
Anna George (Project Manager)		Mike McCarthy (Technical Reviewer)	

Disclaimer

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	24/10/2017	Published version agreed with TRL	Alix Edwards	Mike McCarthy
1.1	18/02/2018	Minor edits to Appendix D	Alix Edwards	Mike McCarthy
1.2	10/10/2018	ISSN & Abstract added	Alix Edwards	Mike McCarthy

Document last saved on:	10/10/2018 10:40
Document last saved by:	Alix Edwards

Table of Contents

List of Abbreviations and Terminology

Abbreviated Injury Score **(AIS)**
Advanced Driver Assistance Systems **(ADAS)**
Advanced Emergency Braking **(AEB)**
AfterMarket **(AM)**
Automated Emergency Steering **(AES)**
Closed Circuit TeleVision **(CCTV)**
Collision Avoidance System **(CAS)**
Collision Investigator **(CI)**
Emergency Braking System **(EBS)**
Front Underrun Protection **(FUP)**
Heavy Goods Vehicle **(HGV)**
Heavy Vehicle Crash Injury Study **(HVCIS)**
Intelligent Speed Assistance **(ISA)**
Large Passenger Vehicle **(LPV)**
LIght Detection And Ranging **(LIDAR)**
Metropolitan Police Service **(MPS)**
Nearside = left/passenger/kerb- side in the UK
Offside = right/driver/road- side in the UK
On The Spot **(OTS)**
Original Equipment Manufacturer **(OEM)**
Road Accident In Depth Studies **(RAIDS)**
Transport for London **(TfL)**
TRL Limited **(TRL)**
Truck Crash Injury Study **(TCIS)**
Vehicle and Operator Services Agency **(VOSA)**
Vehicle Restraint System **(VRS)**
Vulnerable Road Users **(VRUs)**

1 Executive Summary

Transport for London (TfL) is working through a programme of research designed to develop a Bus Safety Standard (BSS) with the objective of reducing the frequency of collisions involving buses in London and the associated bus casualties. This report is the first phase of that research and is focussed on examining casualties involving buses and their potential countermeasures in detail.

Data from Stats19, the Police Fatal Archive (police fatal files) the Road Accident In Depth Studies (RAIDS), and the Heavy Vehicle Crash Injury Study (HVCIS), plus research and evidence from literature, stakeholders, and experts in the field, have all been combined to examine bus collisions. The first step was to analyse the distributions of bus collisions, their configurations, circumstances, and the associated casualties. According to Stats19, around two-thirds of injuries occur on buses without a collision; for example from slips, trips and falls. Bus operator data supplied to TfL indicates this is even higher at 76%. Whilst the focus of this work is on the casualties occurring from collisions, the countermeasures proposed for the BSS do overlap. In collisions involving buses, bus occupants are the most frequently injured. However, in bus collisions, pedestrians account for the greatest share of fatalities and serious injuries. The pedestrians involved are mainly crossing the road from the nearside, leaving only a very short time available for the bus driver to react. Overall, collisions involving buses show a declining trend in frequency, both at UK and European levels, and the Bus Safety Standard will help to continue this reduction in collisions and casualties.

The second step was to then use the in-depth collision details to assign, using engineering judgement, countermeasures that might help to avoid or mitigate the severity of each collision. The approach was based on the Haddon matrix and assigned countermeasures in the pre-crash and crash phases. Causation factors and Countermeasures were classified as related either to the vehicle, human or environment. The causation factors were mainly human or environmental, because vehicle based causes such as defects or blind spots were rare. However, the countermeasures assigned were mainly vehicle based. There are a number of reasons for this but it is at least in part because where human error was involved in the cause of the collision, it was most frequently on the part of a pedestrian or other road user rather than the bus driver. Thus, any behavioural countermeasure applied to that group must effectively be applied to the whole population and would be difficult to target specifically at the bus problem (i.e. pedestrians also walk out in front of other vehicle types too). It would normally be expected that ‘human’ countermeasures would be targeted at the bus driver. However in these most common pedestrian situations, there was little extra the bus driver could reasonably be expected to do to avoid the collision.

Finally, the countermeasures that had been assigned were then analysed to quantify the number of fatalities that they might prevent and to develop a prioritised list of countermeasures to be considered as part of the Bus Safety Standard.

The countermeasure with the greatest count of relevant cases was Advanced Emergency Braking System (AEBS). It is important to note that the full list included detailed notes about potential countermeasure effectiveness, and where any countermeasures should be implemented in combination with others. For example, it was proposed that AEBS should be implemented alongside improved interior design of the buses, in order to provide the best protection for any standing occupants that might be at risk of injury during pre-crash braking. Also, AEBS should be implemented in combination with pedestrian friendly front end structures, particularly on the front corners of the buses, such that should the AEBS fail to detect a pedestrian in time to avoid a collision, then protection could be provided to help mitigate the severity of any injuries. It is also important that any AEBS should be designed to minimise false activations, and to control/minimise any repair and calibration costs.

The priority list represents the top ten bus coumtermeasures recommended for the BSS, and is summarised below. These were prioritised on the basis of: numbers of fatalities (combined from a range of sources), system effectiveness and system applicability, with the final list ordered by the frequency count for the police fatal files becasue this was judged most relevant for the BSS. The arrows on the priority list below indicate combined/complementary countermeasures that address the same collisions, or in the case of bus interior design and AEB, those that might be considered as part of the risk migation straetgy for standing passengers. In addition, if changes are made for the sake of bus conspicuity, then front end design might be affected, so these two measures are also combined. ISA is relatively low on the list because there were few cases where excess speed showed up in the small sample of 48 police fatal files; however, it has been mandated on the basis of trials showing that it is effective in reducing speeding.

1. Advanced Emergency Braking System (AEBS) for pedestrians and cyclists
2. Bus conspicuity
3. Pedestrian Friendly Front End
4. Improved front/side design (to prevent pedestrian, cyclist and motorcyclist underrun)
5. Camera/sensor systems for detection of pedestrians, cyclists and motorcyclists
6. Improve Direct Vision (front and side)
7. Advaned Emergency Braking System (AEBS) to other vehicle rear
8. Bus interior design
9. Intelligent Speed Assistance (ISA)
10. Energy-absorbing Front Underrun Protection System (FUPS)

Combined/complementary countermeasures

In terms of reducing fatalities in London the prioritised list indicates that AEBS, improved bus conspicuity, and improved pedestrian friendly front end design are the top three measures. The next phase of the BSS by TfL is a program of work to develop the test procedures required to assess the measures, to alter the Bus Vehicle Specification text and produce relevant guidance notes, and to develop the business cases and a road map for implementation of the measures. The BSS is an extensive program of work to be implemented by TfL and will require collaborative engagement and support from the bus manufacturers and operators as changes are made to buses in order to reduce fatalities on London’s roads.

2 Introduction

Transport for London (TfL) has decided to implement a Bus Safety Standard as part of their strategy to reduce collisions involving buses and to mitigate the severity of injuries. This will control parts of the design and specification of the vehicles, including elements of primary, secondary and tertiary safety. Primary safety is concerned with preventing a collision from occurring (or reducing its severity); for example by reducing speed, braking or steering to avoid a collision. Secondary safety is focused on preventing or reducing the severity of injuries in a collision; for example with improved restraint design, or softened structures. Finally, tertiary safety is concerned with getting help to injured parties as quickly as possible in order to improve injury outcomes.

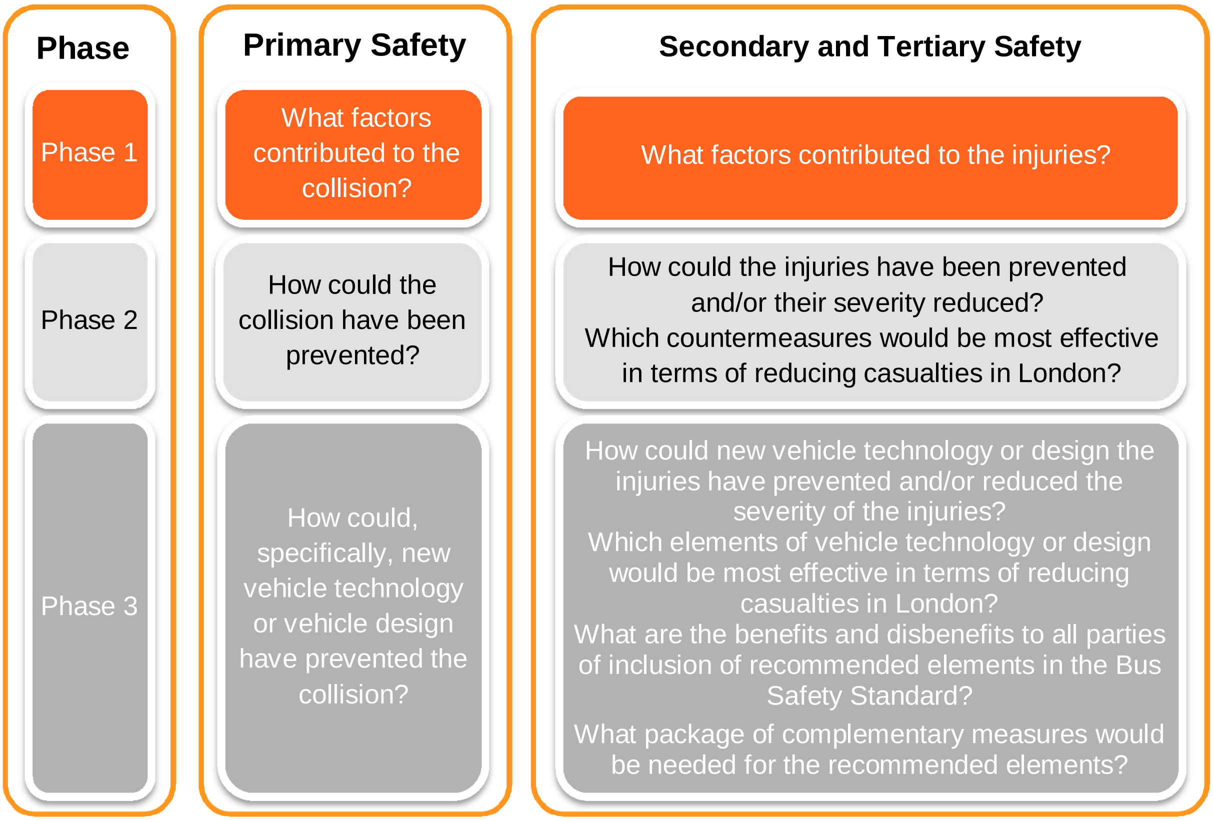
This report sets out the evidence being used to inform the first stage of TfL's work to develop a new Bus Safety Standard (BSS). The report provides the evidence base for robust recommendations to define the vehicle safety interventions that will be integrated into new buses in order to improve bus safety. The BSS is planned for implementation from December 2018 so that all new buses introduced after that date will meet or exceed the Standard.

Where feasible, the data considered injuries of all severities, including slight injuries. However, due to the nature of the datasets available (e.g. police fatal files), the findings were focussed on the fatalities associated with bus collisions. The data was analysed to understand how the accidents and casualties could be most effectively avoided or mitigated. This was achieved by examining the frequencies of countermeasures applied to the collision sample.

2.1 Work Plan

The research into bus collisions and the relevant countermeasures was split into three phases. The first phase was concerned with defining the factors that could have contributed to the collisions. The second phase examined how the collision might have been prevented or mitigated by primary safety countermeasures, or how the injuries might have been prevented or reduced by secondary safety countermeasures; and which of these countermeasures would be most effective in London. The third phase was concerned with vehicle design and technology countermeasures and which of these might have prevented or reduced collisions and injuries. The phased research is described below in Figure 1.

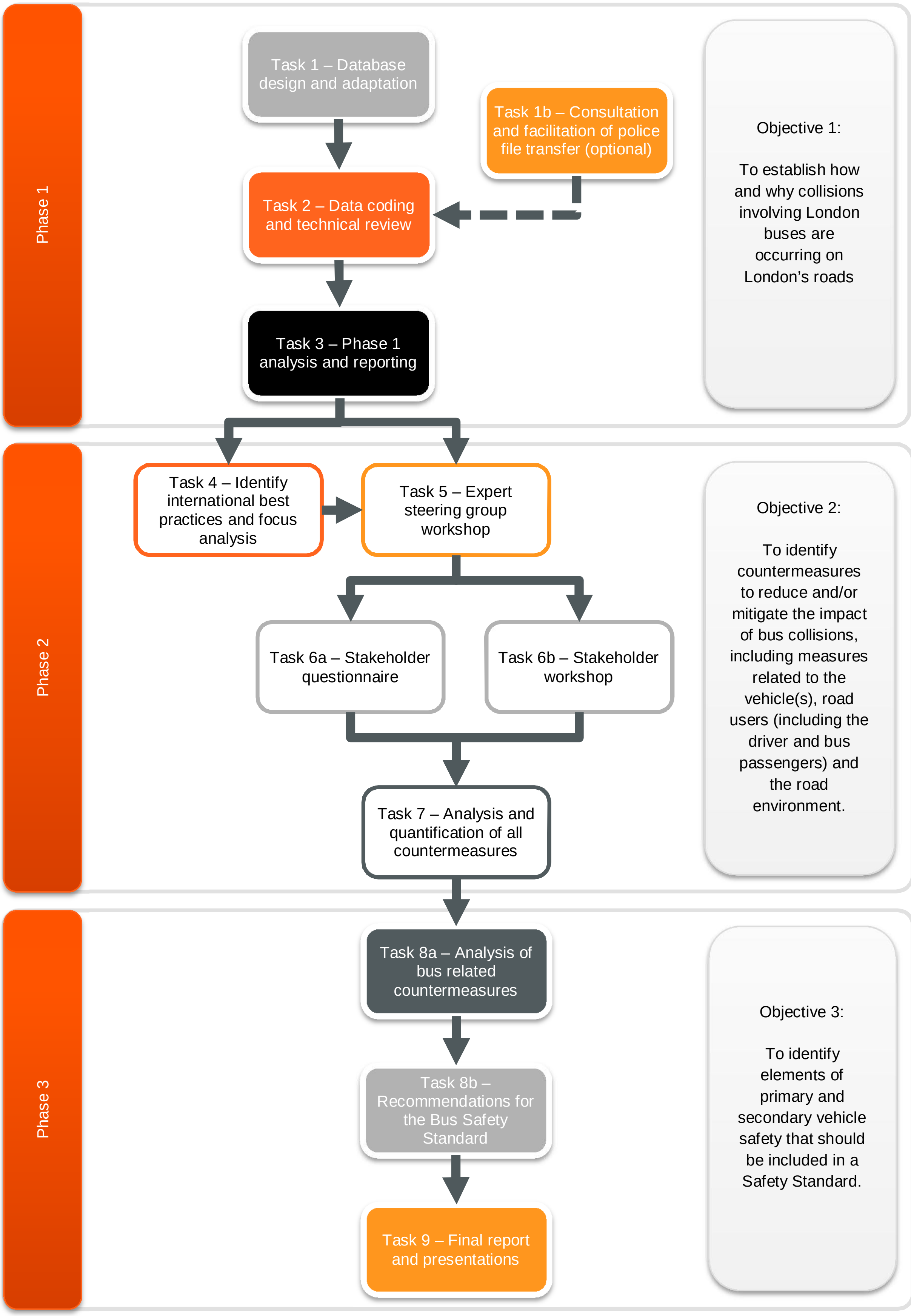
Figure 1: Three phases of research into bus collisions and casualties, and the relevant countermeasures for buses in London.



The methodology is based on the successful delivery of research performed in previous projects for TfL examining pedestrian collisions (Knowles *et al.*, 2012) and motorcyclist collisions (Smith *et al.*, 2013) and has proven to be appropriate and robust. However, buses are unique vehicles in terms of their primary and secondary safety risks. For example, they almost exclusively operate on set routes in generally urban environments in London, making frequent stops at designated points on the route and are exposed to a different combination of risk factors compared to other road users. Furthermore, their secondary safety risks are unique as they can have high numbers of unrestrained and standing occupants; plus other features such as stairs, which are a feature rarely found on other vehicles.

As a result, the causation factors for these collisions occurring in London are very different to other collision and vehicle types and the primary and secondary safety countermeasures are likely to be highly specialised and unique to buses. In previous and ongoing in-depth collision studies, TRL has investigated in excess of several hundred buses and coaches involved in fatal collisions as a part of Road Accident In Depth Studies (RAIDS), the On The Spot (OTS) study, and the Heavy Vehicle Crash Injury Study (HVCIS). Using the experience from these previous studies and incorporating TRL's in-depth collision research expertise has provided an improved methodology to address the added complexities of buses with respect to vehicle design, potential countermeasures and collision dynamics. Specifically, Figure 2 presents the methodology applied:

Figure 2: Project task breakdown.



3 Phase 1: Collision Analysis

City buses have distinctive characteristics which distinguish them from other vehicle types. These characteristics include their size, routes, travel speed, schedules and frequency of stops (Chimba *et al.*, 2010). Buses are large, often have stairs, often have standing passengers, and often travel near and around pedestrians; that is their purpose in serving customers. However all of these features can contribute to the types of collisions that they are involved in and the injury outcomes. The focus of phase one of this research was to examine the bus casualty and collision data, in order to describe the types of injuries and collisions that buses are involved with in London and GB nationally.

3.1 Methodology

The purpose of this research was to establish what factors contributed to the collision and injuries; phase one of the research. The approach is broadly based on Haddon's matrix (described more fully in section 4.1) which considers the vehicle, human, and environmental countermeasures that can be used in the different phases of a collision to improve the outcome. The approach is broad in order that the countermeasures are not limited to just those applicable to the vehicle or technology solutions.

The process of determining which countermeasures will be effective begins with a full understanding of how a collision occurred. This can be broken down by considering the risks posed by the people, vehicles, and roads. To identify the collision and injury trends for buses there were various datasets available for analysis; these are described in more detail as in Figure 3 and the following sections.

Figure 3: Comparative summary of data sources: Police fatal files, HVCIS, OTS & RAIDS, Stats19.

Police Fatal Files

- **Metropolitan Police**

- Sample details:
- 48 bus cases
- 55 bus casualties
- 48 bus fatalities
- 48 with countermeasures
- 2009 to 2014
- London

HVCIS

- **Heavy Vehicle Crash Injury Study**

- Sample details:
- 340 bus cases
- 350 bus fatalities
- 244 bus or coach fatalities with full details
- 169 with countermeasures
- 1999 to 2008
- Urban only

OTS & RAIDS

- **On-The-Spot & Road Accident In Depth Studies**

- Sample details:
- 35 bus cases
- 3 bus fatalities
- 35 with countermeasures
- 2000 to 2015
- Urban only

Stats19

- **GB police reported accidents involving injury**

- Sample details:
- 71,282 bus or coach cases
- 99,096 casualties
- 855 bus or coach fatalities
- (no countermeasures)
- 2006 to 2015
- national, or was restricted to London only

3.1.1 National Data Sources

Stats19 is Great Britain's database that records police reported traffic accidents[1] (collisions) that result in injury to at least one person (Department for Transport, 2009-2014). The police collect details of all incidents which they attend or become aware of within 30 days which occur on the highway, in which one or more person is killed or injured, and involving one or more vehicles. The database primarily records information on where the collision took place, when the collision occurred, the conditions at the time and location of the collision, details of the vehicles involved, and information about the casualties. Approximately 50 pieces of information are collected for each collision (Department for Transport 2007). Data from 2006-2015 was analysed.

It is important to note that because the collisions are police-reported, the database is likely to be biased toward the more severe collisions. Stats19 does not include the bumps and shunts that occur frequently between vehicles and are only reported to insurers, if at all, and therefore suffers from some under-reporting issues; i.e. Stats 19 does not cover damage only collisions, only personal injury. However, since this analysis is concerned with buses, the under-reporting is likely to be minimal (although very difficult to actually quantify), because the police are more likely to be called when public transport is involved (unless for a very minor collision such as a wing mirror clipping a pedestrian), and because a bus collision is more likely to require the police to assist with traffic management at the scene.

The DfT Transport Statistics GB (2006-2015) is another source of data relating to bus travel. This was used in combination with the Stats19 data to calculate bus collision rates.

3.1.2 Fatal Files

If a fatality or a life-changing serious injury occurs as the result of a road collision, police carry out a detailed investigation. Police road collision files for Greater London are held by the Metropolitan Police Service (MPS). This project involved specific analysis of files held by the Metropolitan Police about fatalities that had occurred in collisions involving buses. There were 48 fatal collision files that were analysed for the period 2009 to 2014 inclusive, which represents the total available. The Collision Investigator (CI) report, scene plans, photographs, witness statements, and Closed Circuit TeleVision (CCTV) evidence were all examined and interpreted. There were 30 post mortems that were also reviewed for investigation.

The evidence from the fatal files was coded into a database by the TRL expert investigators. The database was hierarchical in nature, covering the sections described in Figure 4, noting that the fields described are examples and the list is not exhaustive. The database only recorded anonymous information and no information that identified an individual. Only the factors relevant to describing the collision and

[1] Stats19 specifically uses the terminology 'accidents', however the term 'collision' has been used throughout this report.

subsequent injuries were included. Abbreviated Injury Score (AIS) coding was also used to code the injuries described in the post mortems in a standardised manner by using the internationally recognised 7 digit code to describe the location of injury, type of injury and injury severity. Any countermeasures that could be identified during investigation of the fatal file as being relevant to the case were also noted, along with a confidence in their effect.

Figure 4: Fatal files database structure; example fields.

Environment	• Description, weather, location, road surface etc
Bus Details	• Bus driver, bus description, seating etc
Other Road Users	• Other road user type, description etc
Fatalities	• Injury description, location etc
Contributory Factors	• Contributory factors and indication of the likelihood of relevance etc
Phase	• Pre impact through to collision, vehicle interactions and movements, lines of sight etc
Injury Evidence	• Description of evidence, location
AIS Injuries	• 7 digit code describing location, type and severity of injury
Countermeasures	• Selection of relevant countermeasures for human, vehicle, environment and other factors, likelihood of effect etc

The police fatal files database was then analysed. This database is only a small sample of 48 cases, so it is difficult to draw statistically significant conclusions. However, the database does provide considerably more detail on what actually occurred during the collisions, what factors contributed to the causes, and what measures might have had the potential to prevent the collisions or reduce the severity of the consequences. This data has been used both in this section for analysis of bus collisions, and to feed into the countermeasures lists in section 5.1.

3.1.3 HVCIS

The Heavy Vehicle Crash Injury Study (HVCIS), collected detailed information on collisions involving heavy goods vehicles, light commercial vehicles, large passenger vehicles, minibuses, agricultural vehicles and ‘other motor vehicles’ (OMVs). The project consisted of two main elements:

- Retrospective analysis of police fatal files (HVCIS fatal files) for collisions involving vehicles of interest. The researchers used the detailed information collected by the police to determine potential countermeasures which could have avoided or reduced the severity of the collision.
- The Truck Crash Injury Study (TCIS) which collected detailed information from investigations undertaken by the Vehicle and Operator Services Agency (VOSA) for both injury and non-injury collisions in 15 areas covering England, Scotland and Wales.

The HVCIS bus collision data represented a larger sample than the police fatal files. However it consisted of data relating to older buses, and could only be limited to ‘urban’ collisions with no mechanism to limit it to London only. This data has been used both in this analysis of bus collisions, and also to feed into the countermeasures lists in section 5.1.

3.1.4 OTS & RAIDS

The On The Spot (OTS) study collected crash data at the scene, enabling data to be collected as soon as possible after the crash had occurred and before vital evidence had been removed. Data was collected for all vehicle types and collision severities (2000 to 2010).

The Road Collision In-Depth Studies (RAIDS) brings together different types of investigation from earlier studies into a single programme, combining existing data with new in a common and comprehensive database. The study began in 2012 and captures data in two types of investigation:

- On-scene investigations are done at the time of the collision while the emergency services are still present - these focus on the vehicle, the road user and the highway issues and can include non-injury crashes and those with relatively minor vehicle damage.
- Retrospective investigations examine vehicles that have been recovered from the crash site having suffered more serious damage and where the occupants have attended hospital due to their injuries.

There were 35 OTS and RAIDS cases involving bus collisions, and with sufficient detail to allow analysis. These have been used to generate the case summaries in section 4.4 to allow a greater understanding of the types of bus collisions occurring and their countermeasures. This data has also been used to feed into the countermeasures lists in section 5.1.

3.1.5 IRIS data

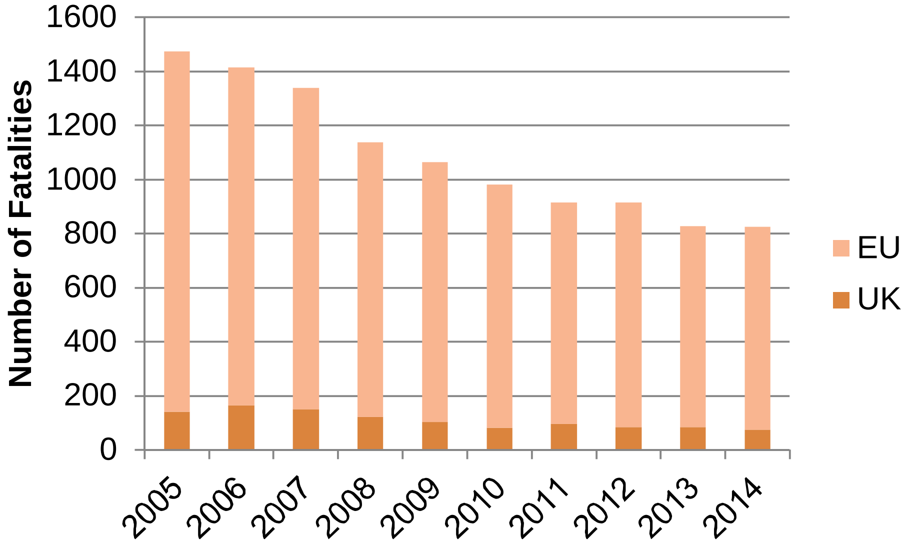
IRIS is TfL's incident management system, made up of bus incidents that are reported directly by bus operators. It covers all incidents, including 'damage only' (where the only damage which occurs is to the bus itself or surrounding objects). The data is published on the TfL website every quarter. All data is gathered from London Bus operating companies using an in-house data logging system which every London bus operating company has access to. 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 evaluation. Only initial information relating to incidents is provided to TfL by bus operating companies on a prima facie[2] basis. Incident investigations are carried out by the operating companies involved who retain resultant information. The IRIS dataset combines slips, trips and falls and other personal injury events such as knocks against objects to create separate category called "Onboard Injuries". Data for the year 2016 was referenced from the Bus Safety Data release (Transport for London, 2017); no further analysis or investigation of the data was possible for this dataset.

[2] prima facie = based on the first impression; accepted as correct until proved otherwise

3.2 Bus Collisions in a European Context

Over the ten year period from 2005 to 2014 the number of fatalities involving buses or coaches in both the EU and the UK fell by almost 50% (ERSO, 2016), as shown in Figure 5. This is good progress with respect to the reduction of bus fatalities and the Bus Safety Standard is aimed at continuing this trend.

Figure 5: Number of fatalities in collisions involving buses or coaches. Source: CARE database, data available in May 2016.

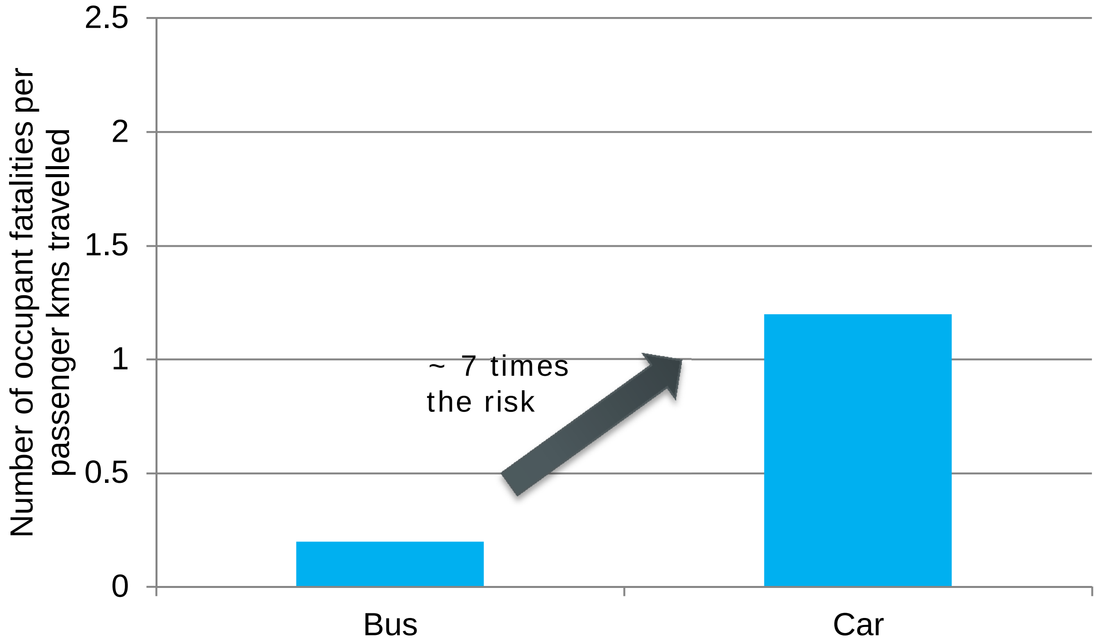


3.3 Bus Collision Rates

An important part of the analysis is to put bus safety into context at a national level by carrying out a risk comparison of buses against other forms of transport. Public transportation is considered to be safer than other motorised modes of transport (Chimba *et al.*, 2010); it is often stated that buses are the safest form of road passenger transport. However the following discussion highlights that using this is perhaps not the case, depending on what measure is used.

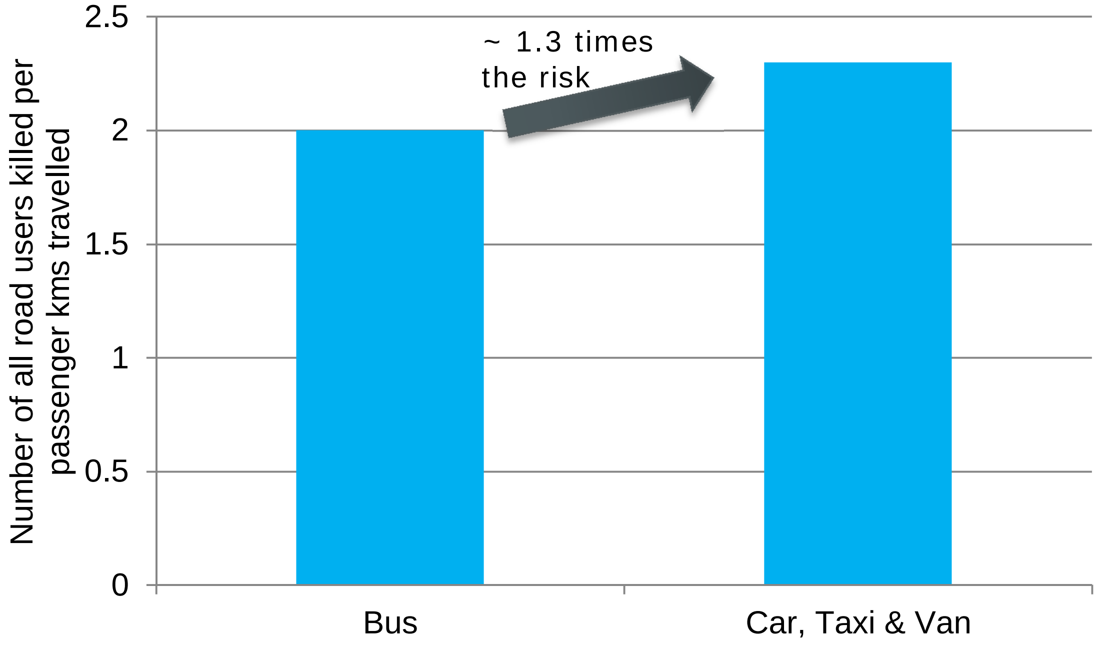
By comparing the number of bus occupant fatalities per passenger kilometres travelled for buses and cars, it is shown in Figure 6 that car occupants have a risk approximately seven times greater (per km) than bus occupants. However, it should be reiterated that the above figures relate only to the deaths of the occupants of the specific vehicle considered.

Figure 6: Occupant fatalities per passenger kilometres travelled (expressed in terms of fatalities per passenger kilometre for that vehicle group). Source data: Stats19 (2006-2015) and transport statistics GB (2006-2015).



If the fatalities in the entire collision are considered for each vehicle of interest, then the difference between car and bus travel is much smaller, because it accounts for casualties outside the bus. Considering all fatalities involved in the collision in terms of road user fatalities per passenger kilometres travelled, car, taxi & van collisions have approximately 1.3 times the risk of collisions compared to collisions involving buses. It is important to note here that the data used in Figure 6 and Figure 7 is not directly comparable. This is because Figure 6 is from collision rate data directly published by DfT, whereas Figure 7 (for all road users) is data published on passenger travel combined with analysis of Stats19. The passenger data is only presented as a combined category of car, van and taxi, so the collision statistics were grouped in the same manner. Therefore, part of the 1.3 times increase in risk is actually due to the inclusion of vans and taxis within the grouping of cars.

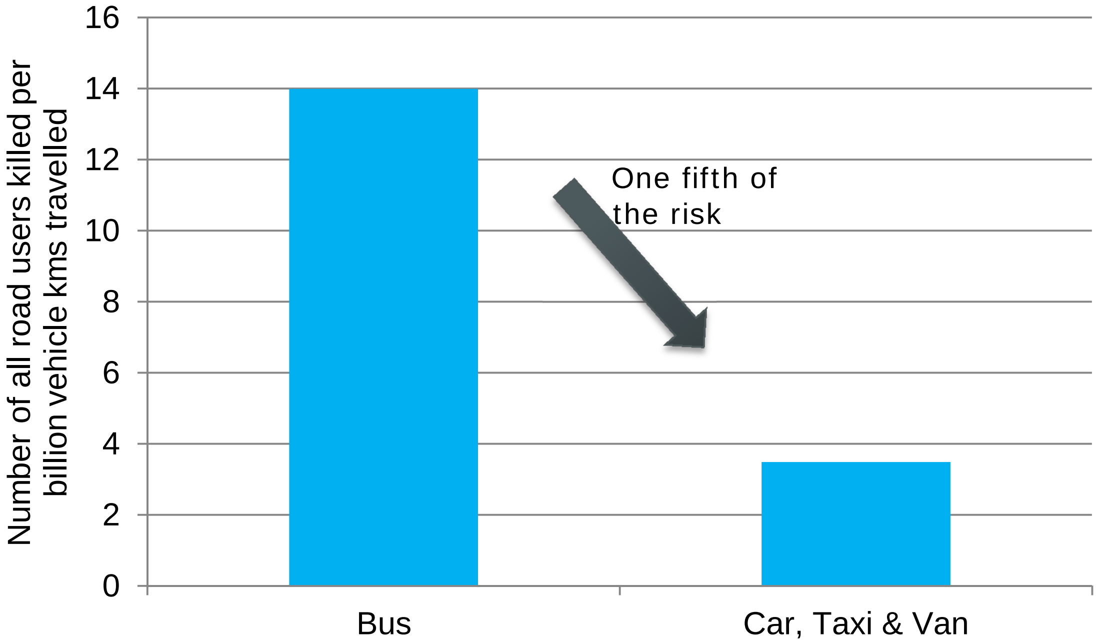
Figure 7: All road user fatalities in collisions involving the vehicle group indicated (expressed in terms of fatalities per passenger kilometre for that vehicle group). Source data: Stats19 (2006-2015) and transport statistics GB (2006-2015).



However, when considering the vehicle kilometres travelled (rather than passenger kilometres), the transport statistics reveal that bus collisions have a greater fatality rate, as shown in Figure 8. As before, this is a combination of the transport statistics with Stats19 collision analysis. The car, taxi and van group have approximately one-fifth of the risk in comparison to buses. Part of the reason that buses have more fatal crashes per kilometre travelled is probably due to factors related to usage/exposure. City buses are all in urban areas at low speeds doing relatively low mileage, yet regularly negotiating complex junctions and interacting with pedestrians, cyclists and motorcyclists. Coaches travel long distances on motorways, but there are relatively small numbers of them on the road, so this motorway use is likely to have a relatively small influence on the overall fatality rate. Part of the reason will also be that buses have more passengers; however analysis of casualty type in Appendix A.2 shows that they are infrequently killed so this is only a small factor.

Viola et al. (2010) showed that the association of buses and pedestrian casualties, although statistically measurable, was entirely a result of exposure to risk. This is because buses tend to operate in environments with the greatest density of pedestrian traffic and operate in bus lanes next to the footway, where pedestrians will step out from; it is this that explains the higher numbers of pedestrian casualties on bus routes.

Figure 8: All road user fatalities per billion vehicle kilometres travelled. Source data: Stats19 (2006-2015) and transport statistics GB (2006-2015).



In a specific London analysis, the Cycle Safety Action plan from TfL indicates that buses have a disproportionate share of the fatal and serious injuries in London, with a ratio of 2.3. Where the ratio is above one, these modes are overrepresented in casualty statistics. This means that they are involved in a large number of collisions resulting in a cyclist KSI relative to their traffic share - although it may be that they are involved in a small number of collisions overall (Mayor of London & Transport for London, n.d.).

3.4 Collision and Casualty Analysis

Appendix A provides the full details of the analysis of collisions and casualties in London; this section provides a brief overview of the findings.

On a national level, statistics for GB show that casualties from bus collisions are reducing. Considering only bus fatalities, this group are reducing only fractionally less in London than nationally. Making a similar comparison between London and GB, the reduction in casualties from collisions involving buses is much lower (13%) than for the national equivalent (38%); mainly due to a substantially smaller reduction in slight injuries which represent the bulk of the injuries occurring.

Both nationally in GB and in London, when bus collisions occur they most frequently result in injured bus occupants. However, when considering the fatalities only, pedestrians are the most frequently killed in bus collisions. Pedestrians account for around two-thirds of the fatalities in bus collisions in London.

When pedestrians are killed in collisions with buses, detailed analysis of accident reconstruction databases reveals that they are most often killed when crossing the road. In the majority of cases the pedestrian collides with the front of the bus, when crossing from the nearside[3]. The expert accident investigators were able to reconstruct the collisions (where sufficient data was available) to enable and understanding of the precise timing of the collision. For a vehicle the speed and distance are the most important factors; but because a pedestrian can change direction and move off from stationary very suddenly, the reaction time is the most important factor for whether a system might be effective. The time to collision is often very low (less than a second), for example in the case when a pedestrian steps out from the kerb. However, in about 40% of the police fatal files, the pedestrian became visible more than 1 second before impact; which is potentially within the operational scope of Advanced Emergency Braking (AEB); more information on AEB is given in section 4.2.1.1.

After pedestrian fatalities, the car occupants are the next largest fatality group in bus collisions. Car occupants are also most often killed in impacts with the front of the bus. From the sample of detailed accident cases that were reconstructed, belt usage by the car occupant is an important factor for these crashes.

It is also very important to note that, according to Stats19, over half the injuries on GB buses occur without a collision. For London this is even higher, with over two-thirds of injuries on buses occurring without a collision. The IRIS data from TfL shows an even higher proportion of injuries occurring without a collision, at 76%. The Stats19 data revealed bus occupants were recorded as either standing, seated, alighting or boarding at the time of their injury, and in London the majority were standing at the time of their injury.

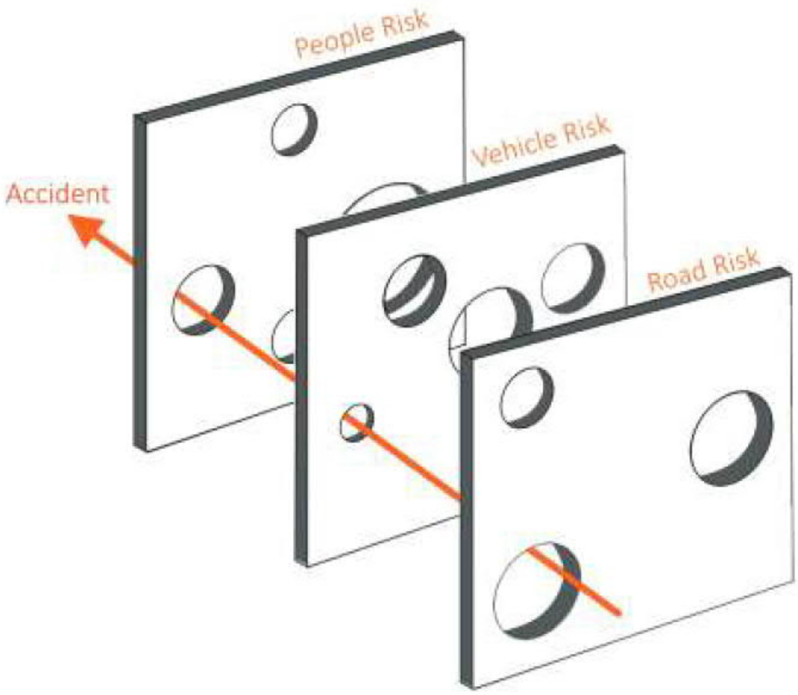
[3] **Nearside** = left/passenger/kerb- side in the UK

3.5 Collision Causation

Collision causation is a complex topic; there are typically many factors that contribute to the occurrence and severity of a collision. The particular combinations of circumstances combine in time and space to cause a collision. Without any one of the contributing factors, the collision would not happen. Indeed, most drivers have experienced first-hand, circumstances that have not led to a collision, but could have done so had the situation been only slightly different.

Another way to visualise this issue is by considering the ‘Swiss cheese model’ of hazards first proposed by Reason (1990), as shown in Figure 9. This model proposes that failures (in this case collisions) occur only when all specific risks align to result in a collision. If one aspect is not conducive to the occurrence of the collision, it is prevented.

Figure 9: Swiss cheese model of collision causation. Adapted from (Reason, 1990)

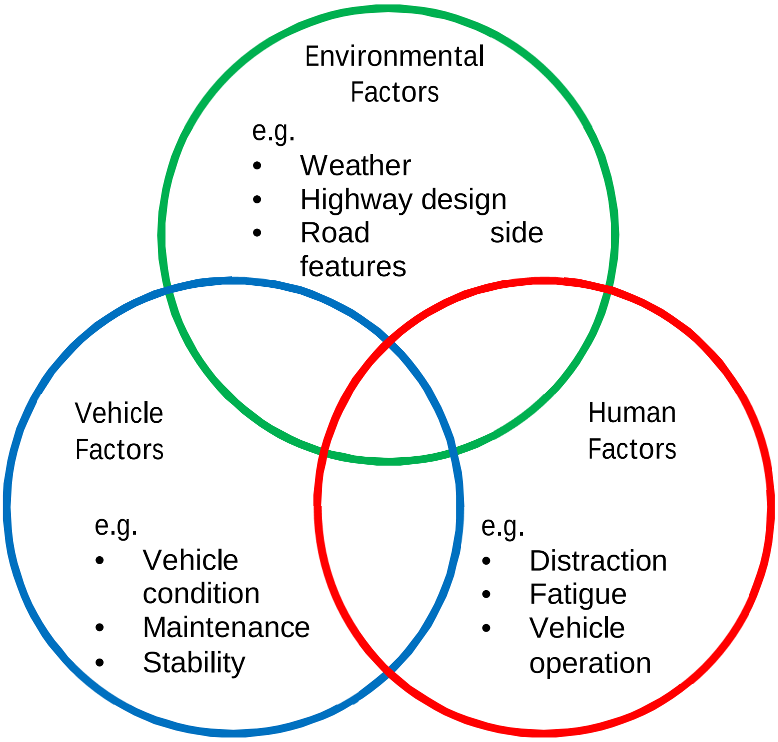


The majority of collisions have multiple causation factors. These causation factors can be grouped according to whether they relate to the human (driver), vehicle or road environment as displayed in Figure 10 and the factors may also be overlapping. These causation factors provide a useful way to analyse the high-level causation factors associated with a collision.

Road users are continually subjected to a combination of these people, vehicle or road factors. A collision occurs when a factor, or combination of factors in any category, influence a road user (or group of users) with the result that a collision occurs. The occurrence of a collision and the severity and outcome of that collision can be influenced by any number of factors at any stage during the collision. Therefore, changing any element of the collision circumstances, or the factors influencing the road users, can completely change the outcome of a collision and even prevent it from occurring.

For example, consider a collision in which a fatigued driver drifts across the centre-line and into the adjacent lane, striking an oncoming vehicle and resulting in a fatal collision. If identical circumstances occur but there was no oncoming vehicle before the driver corrected the lane departure, the collision would not occur. If the vehicle was equipped with a lane departure warning system, the collision may have been prevented despite the oncoming car, or the severity of the contact reduced as the driver reacted to the warning.

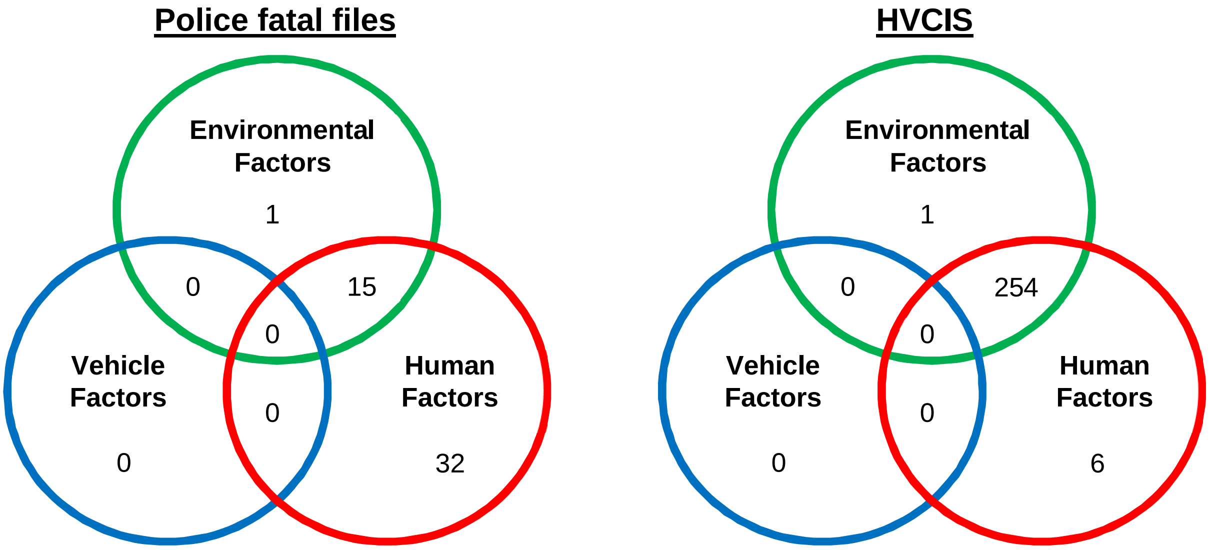
Figure 10: Fatal bus collision causation factors.



The distribution of the frequency of these factors is given for the police fatal files (left) and HVCIS (right) in Figure 11. In both cases there were no vehicle causation factors. For the police fatal files the most frequent causation group was human factors, whereas in HVCIS it was human and environmental combined.

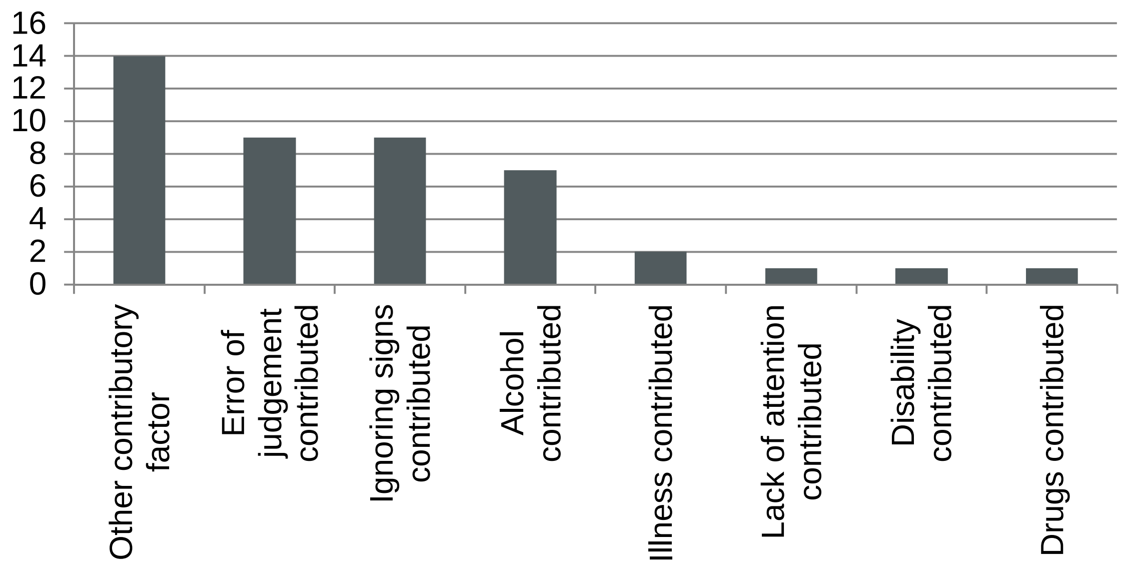
The majority of causation factors for the police fatal files were human factors, with another large group that were human and environmental. There were no vehicle factors contributing to the fatal collisions. The one environmental factor was for an incomplete case with limited information compared to the other files. The factor was low sun and the driver over shot a junction. The human causation factor was coded as unknown, due to lack of information. There were eight cases with the bus driver coded as vision obscured. In three cases this was due to vehicle geometry, three by parked vehicles, two by other objects, and one by sunlight.

Figure 11: Venn diagram classification of causation factors. Source data: Police fatal files (left) and HVCIS (right).



The HVCIS data records 'contributory' factors for a collision. These may be multiple factors that have contributed to the collision, and are similar to the causation factors; however the limitation is that they are given in isolation without links to any evidence or explanation. The analysis of HVCIS data reveals a range of causation factors that were recorded for the bus collisions, as shown in Figure 12 for the human factors only. The 'other' factors were the largest group, but due to lack of information it is difficult to use it to inform the assignment of countermeasures. The 'error of judgement' and 'ignoring signs' groups were the next most frequently assigned groups of human contributory factors.

Figure 12: Human contributory factors. Source data: HVCIS.



The in-depth reconstruction of the fatal files also allows analysis of the precipitating factors leading up to the collision, as well as the causation factors. The precipitating factor is the main failing that led to the collision, whereas the causation factors may be multiple factors that contributed to why that failing happened. For example, the precipitating factor could be driver distraction, and the causation factor could be that the vehicle drifted out of lane.

3.5.1 Bus drivers

The precipitating factors are described in Figure 13 and for the majority 33 of the 48 police fatal files there were 'none'; i.e. there was no precipitating factor on the part of the bus driver. In fact, for 22 of those 33 cases the pedestrian entered the carriageway without due care. For example, in one case the driver was quickly checking his rear-view mirror, and then when turning back was confronted by a pedestrian stepping into the carriageway from behind an advertising sign on the footway, so the driver had no time to react.

For the remaining 15 cases there was some precipitating factors for the bus drivers, although six of them were 'other'. Failing to avoid a pedestrian/vehicle, and failed to stop were the more frequent of the remaining factors as shown in Figure 13.

Figure 13: Precipitating factors for bus drivers. Source data: Police fatal files.

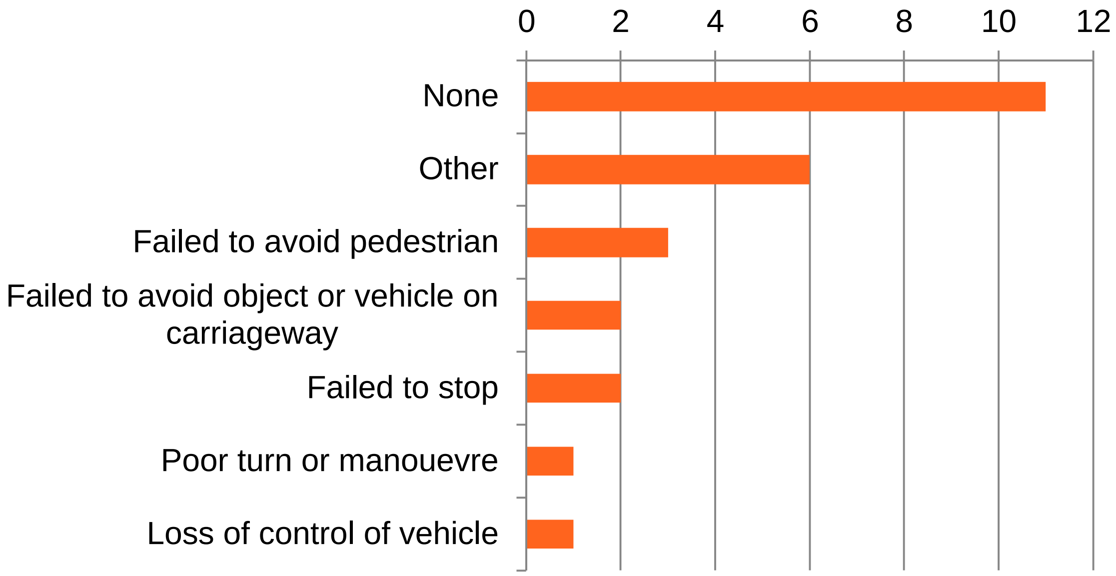


Figure 14: Causation factors for bus drivers. Source data: Police fatal files.

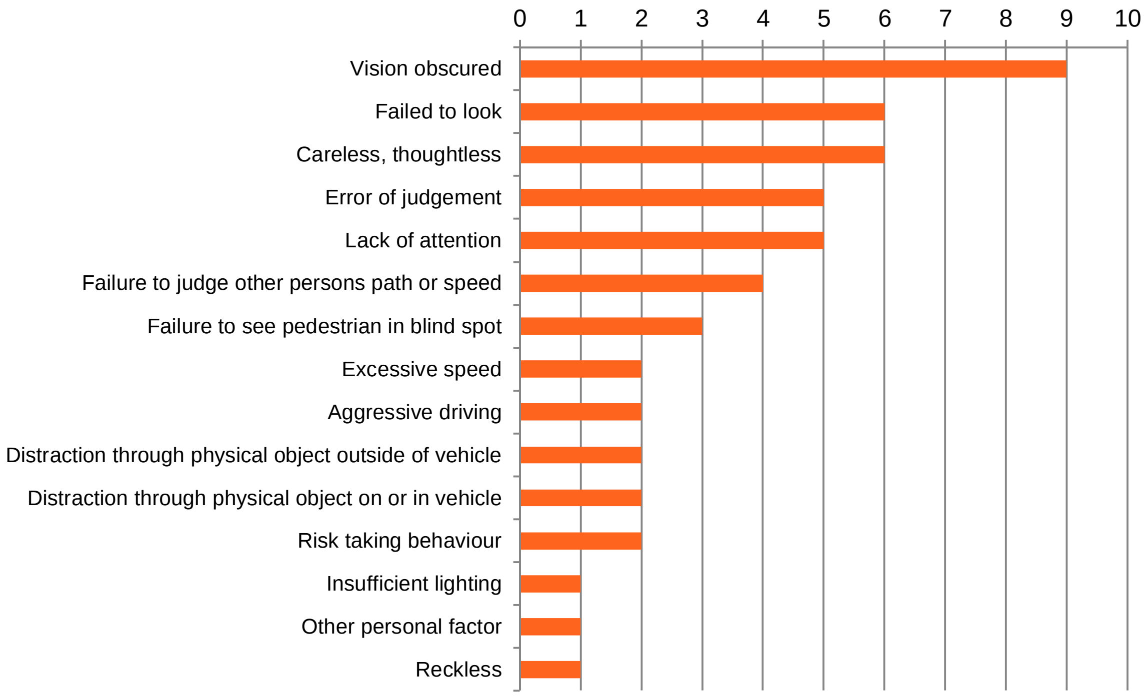


Figure 14 describes the distribution of the specific causation factors where the bus drivers were found to have contributed to the collision for the police fatal files. The most frequent causation factor was obscured vision, with vehicle geometry and parked vehicles being the most frequent cause as previously described. It would appear that an AEB system would be a beneficial countermeasure in addressing the top six of these causation factors, perhaps indicating the importance of AEB as a countermeasure.

3.5.2 Other road users

For the police fatal files, in the majority of the other road user cases the pedestrian entered the carriageway without due care (28 cases) as shown in Figure 15. There were an additional four cases with no precipitating factor as the fault of the driver.

For the causation factors shown in Figure 16 for the police fatal files the majority were concerned with poor judgement in some form by the driver: carelessness, error of judgement, risk taking, lack of attention, failed to look, reckless, alcohol; all these have a frequency greater than 10. Obscured vision is much lower down the list for other road users then for bus drivers, and consists of obscuration by parked vehicles (two cases), other features (two cases) and the vehicle in front (one case).

These cases and their causation factors are more challenging for the Bus Safety Standard to address, because that Standard can only address the buses, and not the other road users.

Figure 15: Precipitating factors for other road users. Source data: Police fatal files.

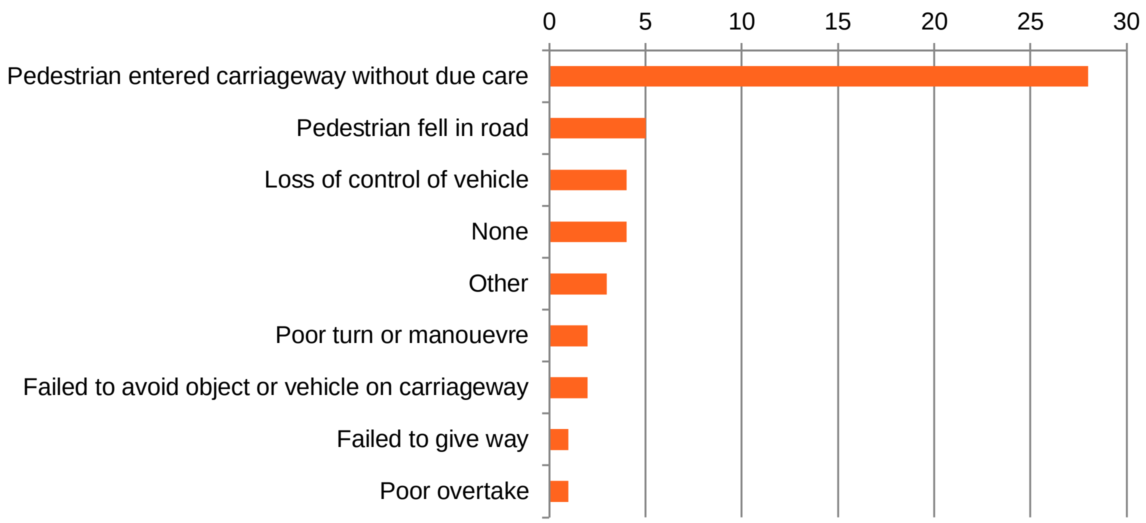
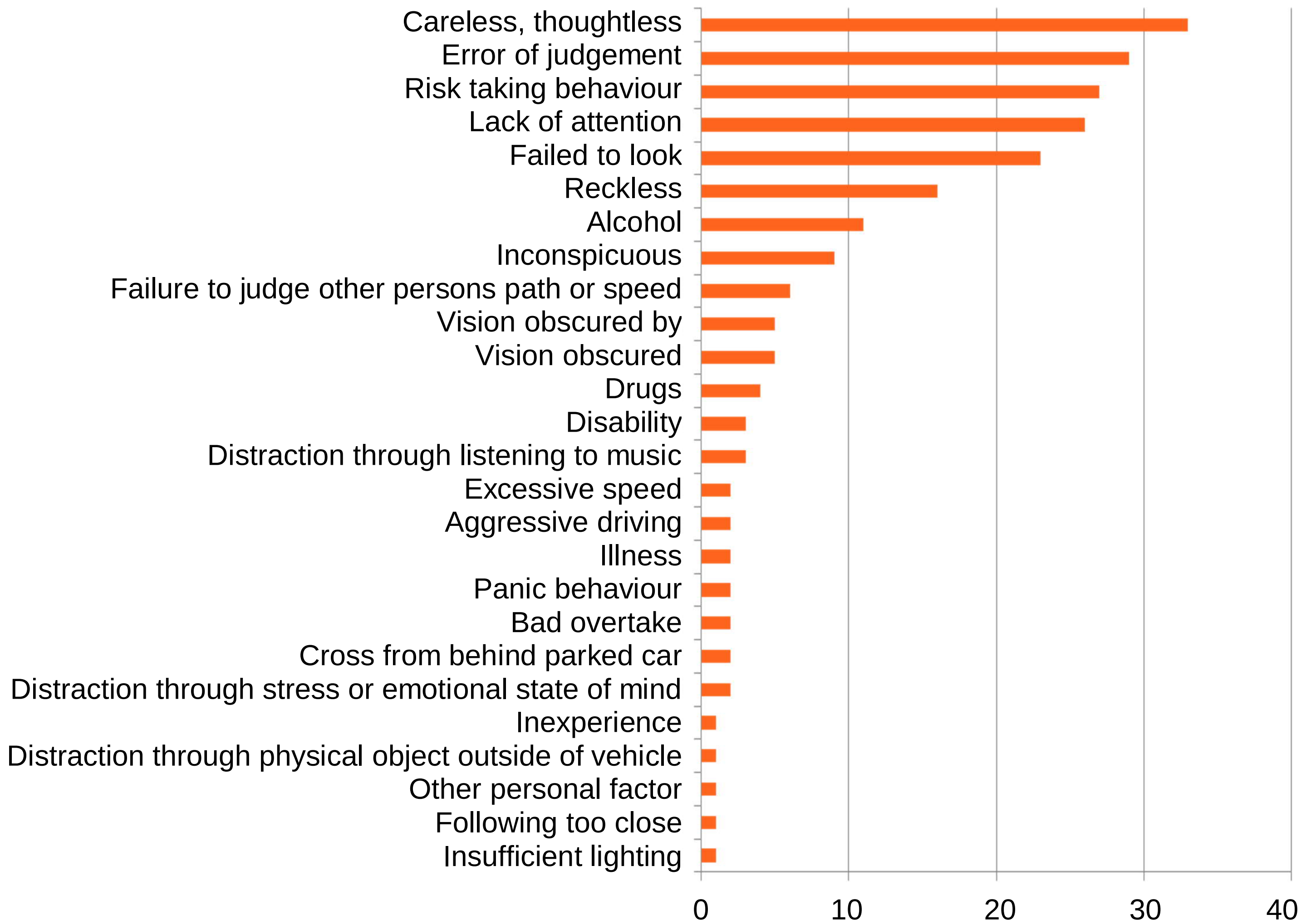


Figure 16: Causation factors for other road users. Source data: Police fatal files.



3.6 Stakeholder Input on Collision Data

A questionnaire was shared with attendees at the Stakeholder workshop in November 2016. The stakeholders included bus manufacturers and operators. They were given a presentation about the findings in section 3 on bus collisions nationally, and the in-depth investigation of fatal files, alongside some initial work on countermeasures. The questionnaire text was as given in Appendix A. Responses were received from 6 organisations; four bus operators and two bus manufacturers. Half the respondents were prepared for their responses to be published, half were not. Thus, results have not been attributed to any individual respondent and in the presentation of summaries of results; efforts have been made to avoid presenting information that would allow the response to be attributed to a particular stakeholder.

Three of the four operators regarded collisions involving bus occupant injury to be the highest priority for them. Two of the four contributors considered car occupants to be the second highest priority. The explanatory comments showed that this was partly because the respondents were basing their view on the frequency of collisions rather than severity; the ranking provided by stakeholders and described above would be broadly consistent with the objective data for collisions of all severity. However, some responses highlighted the corporate fact that bus passengers were their core business and should be their highest priority. One bus manufacturer followed a similar approach. One bus operator and one manufacturer ranked the problems in line with the frequency of fatalities, with pedestrians most important.

Four respondents cited pedal cyclists as another important group mainly because of their high media profile, complaints from them about bus driving and potential implications for future contracts, rather than the frequency or severity of collisions.

The respondents views on the relative safety of buses and other vehicles and on bus operations in London and the rest of the UK was very mixed and covered the full range. Some thought buses safer than other vehicles; others thought them the same or worse. London was generally viewed as a more demanding environment for buses than most other places but whether this resulted in worse safety, the same, or even better safety was mixed.

Reasons considered for differences in the observed reductions in slight injury collisions in London and the rest of GB were highly varied, including both more or less ‘claims culture’ and/or claims fraud, higher levels of collision reporting in London or other regions, slower speeds in London etc.

In terms of injuries to bus occupants where the bus itself suffered no external impact, respondents generally thought the most important cause was braking in order to avoid a collision, and one respondent broke this down to list the following sub-cases in order of priority:

- Vehicle pulling into the path of a bus
- Pedestrian deliberately stepping in front of a bus to cross
- A pedestrian stepping off the kerb to walk around street furniture
- Cyclists weaving in and out of traffic

In addition to this, the following were also noted as mechanisms

- Bus moving off while occupant was moving to seat/climbing stairs
- Problems when opening or closing doors, getting limbs caught, and tripping up steps
- General slips & trips over steps or wet floors
- Passengers not holding on, or climbing the stairs when the vehicle was in motion

3.7 Summary of Bus Collisions Analysis

This section of the report has examined the bus collision evidence and the following are the key findings:

1) In a European context, bus collisions have reduced by almost 50% in the period 2005 to 2014.
2) Comparing fatalities per billion vehicle kilometres travelled, the group comprising cars, taxis and vans have one-fifth of the risk compared to buses; however exposure and usage differences are likely to be important factors in this difference.
3) GB statistics show that casualties from bus collisions are reducing; fatality reduction on London’s buses is only fractionally less than nationally. When only London is considered, the reduction in casualties from collisions involving buses is much less (13%) than for the national equivalent (38%).
4) In bus collisions, occupants of the bus are the most frequently injured casualties.
5) According to Stats 19 over two-thirds of the injuries on buses occur without a collision. IRIS data from TfL indicates that 76% of injuries are onboard injuries.
6) Pedestrians are the most frequent bus fatalities accounting for around two thirds of the fatalities in London.
7) Pedestrians are most often killed by buses when crossing the road, and most often in collisions with the front of the bus crossing from the nearside. The time to collision is often very low (less than a second), but in about 40% of the police fatal files the pedestrian became visible more than 1 second before impact; potentially within scope of AEB.
8) Car occupants are also most often killed in impacts at the front of the bus; belt usage by the car occupant is an important factor for these crashes.
9) Human and environmental factors were the most frequent causation factors.
10) In over half the police fatal files assessed, the bus driver was not assigned a precipitating factor because the pedestrian entered the carriageway without due care. However in other cases the drivers failed to avoid a pedestrian/object/vehicle or failed to stop.
11) Loss of control of the vehicle was the biggest precipitating factor for the car occupant fatalities in the police fatal files.

4 Phase 2: Identification of Countermeasures

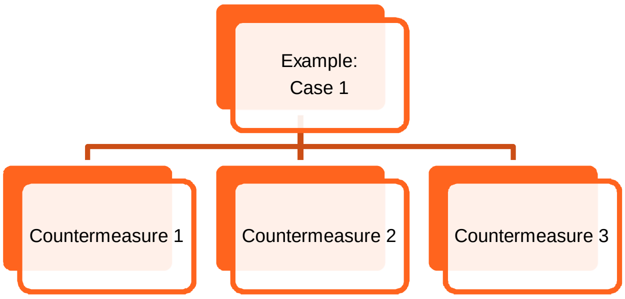
4.1 Methodology for assignment of countermeasures

The process of determining what countermeasures will be effective begins with a full understanding of how a collision occurred. This can be broken down by considering the risks posed by the people, vehicles, and roads. A risk from any of these areas can allow a collision to happen, so reducing the risk involves identification of countermeasures that will address those specific aspects of the collision.

Haddon's Matrix is the most frequently used concept in the injury prevention domain, and it is summarised in Table 1 below. This considers the vehicle, human, and environmental countermeasures that can be used in the different phases of a collision to improve the outcome. The approach is broad in order that the countermeasures are not limited to just the vehicle or technology solutions. The countermeasures were based on existing and near-future technologies and strategies. Investigators assigned countermeasures to each case based on their ability to avoid the entire collision, and/or to reduce the severity of the collision. A key point is that the assignment of countermeasures was an indicator of potential effect in describing a maximum count of relevant cases; it was not designed to represent the precise expected performance of a given system. For example, there are many different AEB solutions available with different performance capabilities such that the counts do not represent these precise systems and their individual expected effects; instead the counts represent a 'flag' that an idealised AEB system had the potential to improve the outcome of the collision.

Table 1: Haddon's matrix approach to assignment of countermeasures in a road collision.

	Human	Vehicle	Environment
Pre-Crash	Improved driver training Driver awareness	Better maintenance Primary safety (e.g. AEBS, ESC, Alco-lock)	Improved road surface Improved highway layout/design
Crash	Use of safety systems (e.g. helmet or seat belt)	Secondary safety Presence & performance of safety systems	Road side hazards Barrier performance
Post-Crash	Incident response eCall systems (e.g. Vauxhall OnStar)	Fuel system Safety pyrotechnics Vehicle design standards	Infrastructure performance (e.g. access for emergency services)



It is also important to note that there can be multiple countermeasures assigned per case, and these may be from the same or different categories (human, vehicle, and environment) too. There may also be more than one injured person per case that might benefit from the implementation of a countermeasure.

4.1.1 Experts Steering Group

In order to examine the relevant countermeasures (phase two of the research), an Experts Steering Group was established. The Experts' role was:

- to review the countermeasures used in other countries and with other similar vehicle types such as Heavy Goods Vehicles (HGVs)
- to review the countermeasure analysis performed in Phase 1
- to make recommendations of cross-domain countermeasures that could be applied to the types of collision that were identified from Phase 1
- to review any other countermeasures based on our experts' knowledge of the effectiveness of various countermeasures
- to highlight areas of understanding that are missing in the evidence provided

Safety interventions have been considered for buses, other vehicles (including pedal cycles) and surrounding infrastructure through reading appropriate literature, discussions of the Experts Steering Group, and analysis of the cases. The following section considers countermeasures that are technologically ready now and also those that could be feasible in the future.

There are several stages before a collision occurs where different safety systems can intervene. In Table 2 examples of vehicle safety interventions for both buses and other vehicles have been categorised according to what time in a collision sequence they prevent the occurrence or mitigate the damage of a collision. These examples and more have been described in further detail in the following section.

Table 2: Safety Systems in a collision sequence. Source: adapted from Flodström and Strömberg (2011)

Phase:	**Preventative**	**Dynamic**	**Avoidance**	**Mitigation**	**Impact**	**Post Crash**
Sequence:	Normal Driving	Danger phase	Collision Imminent	Collision Unavoidable	Collision	Post-collision
Activity:	State of driver and situation	Driver can avoid	Vehicle can avoid	Minimise severity	Minimise damage/injury	Rescue and save
Countermeasures:	Alco-lock Driver alertness/ drowsiness monitoring Improved direct and indirect vision Night vision Intelligent Speed Assistance **(ISA)** Passenger seatbelts Softer internal bus structures Advanced Driver training Improvement of bus stops Improvement to junctions	Pedestrian warning Vehicle collision warning Bridge collision warning	Advanced Emergency Braking (AEB) AEB for pedestrians and cyclists	AEB Pedestrian and cyclist AEB	Airbag Belt tension Softer front end Nosecone structure Underrun airbags	E-call Bus raising system Improved injury awareness

4.2 Vehicle Countermeasures

The vehicle countermeasures identified in this research are from a range of sources including:

- Literature review – with evidence included where possible;
- Expert Steering Group – with experience and expert opinion described;
- Experience from other vehicles – e.g. experience of a system on cars or HGVs that can be learnt from; and
- ‘blue sky thinking’ – ideas for the future that are perhaps not yet implemented, but that could be considered for BSS in later phases.

4.2.1 Vehicle Countermeasures in the Pre-Crash Phase

4.2.1.1 Advanced Driver Assistance Systems (ADAS)

Collision Warning Systems

Collision warning systems use camera or radar technologies to alert the driver to a potential collision with a pedestrian, cyclist or other vehicle with the intention that the driver reacts and avoids the collision.

TRL carried out a study into the detection of pedestrians and cyclists near buses and evaluated two detection systems. The first utilised both radar and camera technologies in order to detect cyclists undertaking the rear quarter of the bus. The second system used cameras and image processing algorithms to detect both pedestrian and cyclists and had a wider detection area, covering both the nearside and front of the bus. TFL is in the process of developing a test procedure to categorise similar systems fitted to HGVs and to rate their performance; the conclusions would likely be relevant to buses too, however the work is as yet unpublished.

As part of the Active Safety Collision Warning Project, Washington State recently equipped 38 transit buses with the ROSCO-Mobileye Shield+ System to help drivers avoid and mitigate imminent collisions and protect pedestrians and cyclists. This Collision Avoidance System (CAS) offers a variety of features including pedestrian and cyclist collision warning, forward collision warning, headway monitoring warning, lane departure warning and a speed limit indicator. Dashboard alarms flash when pedestrians enter into the driver’s blind spots. The project will involve comprehensive examination of the total costs of the most severe and costly types of collisions and will evaluate potential for CAS to reduce the frequency and severity of these types of collisions, and reduce the associated casualty and liability expenses. Preliminary analysis has shown that the potential exists for the cost of equipping an entire bus fleet with collision avoidance technology (CAS+AEB) to be recovered by preventing one pedestrian or bicycle collision (Lutin, 2016). Alternatively, if the system were to reduce the risk of collisions by 35%, the cost of it would be recovered in one year (Washington State Transit Insurance Pool, 2015). Data from the five-month trial period is currently being analysed by the Smart Transportation Applications and Research Laboratory at Washington University.

Mobileye technology is currently being used on trucks in Ealing Council as part of the Cycle Safety Shield System. During trials the Safety Shield System was found to have potentially stopped 15 serious collisions happening between a HGV and pedestrians and cyclists (Slobodova, 2016). Ealing Council has since rolled out the collision avoidance system across its whole contractor fleet (Ealing Council, 2016). The system is also being successfully used on a number of other UK fleets, including the Amey Group's vehicles and Sainsbury's supermarket delivery trucks. As part of the European Road Safety Pilot Project Richmond Council and Ealing Council have partnered with Cycle Safety Shield to trial incident prevention software. The preliminary results of this project have been released in the form of safety score graphs which have shown an improvement across all vehicle types, however, there is no information at this time on how this score is calculated or what raw data it is formed of (SafetyShieldSystems, 2017).

The majority of collision warning systems alert only the driver to a potential collision. A team from the University of Pennsylvania are developing a system that also alerts pedestrians that they are in danger of being hit by a bus. The system is comprised of a directional speaker, projecting an audio warning from the bus towards the pedestrian (Burka *et al.*, 2014). It activates automatically and is not driver activated or on all the time.

Bridgeclear offer an integrated bridge warning system for buses which utilises the driver's CCTV monitor to display warnings of low bridges. To ensure the driver is not distracted by unnecessary warning the system will only display bridges which are lower than the height of the bus (BridgeClear, n.d.).

Collision Avoidance Systems

Signals from the collision warning systems can be used to trigger systems such as Advanced Emergency Braking (AEB) or Automated Emergency Steering (AES) to allow the vehicle to automatically avoid a collision event.

AEB systems utilise radar, camera and/or LIght Detection And Ranging (LIDAR) based technology to avoid collisions or to mitigate the impact by detecting imminent collisions and applying the brakes automatically. As yet AEBS is not available on buses; it is mainly fitted on cars and some vans, and AEBS is just entering the HGV market too. The first implementation on cars was for RADAR based systems, and these typically have a long range (e.g. 120m-200m) meaning that they can operate over a wide range of speeds up to 75mph or 120km/h. On cars, the LIDAR systems have a shorter forward range so these systems are only operational in lower speeds (e.g. up to 31mph or 50km/h). More advanced systems include pedestrian and sometimes cyclist detection, and these typically use cameras on cars in order to identify a pedestrian. The cameras may be used in isolation or used in 'sensor fusion' with a RADAR for example. RADARS are typically mounted in the front of the car, behind the grille or bumper cover; whereas a LIDAR or camera system is mounted in the cars front windscreen near the rear view mirror. The fitment of these sensor does incur some additional repair costs, which may be a factor to consider for bus operators. If the sensor is damaged in a crash situation where AEB is not relevant (e.g. during parking when AEBS is typically not active under 3mph or 5km/h), then the additional cost of repair and calibration is incurred. Similarly, if a stone chip means that the windscreen has to be replaced then there must be a suitable process to ensure the correct operation of the AEBS with the new screen. Experience with cars indicates that these sensors can increase costs, but for buses the emphasis should be on implementation of systems and processes designed to minimise and control these costs from the outset.

However the effectiveness of AEB is highly dependent on the situation. Pedestrians and cyclists crossing situations are characterised by much shorter times between the moment when a threat can first be identified and the moment of impact; a pedestrian for example can change direction or move off from standing much more rapidly than a vehicle can. Although slow driver reactions and inattentiveness can be a factor in some crashes, using the system to reduce the reaction time compared to even an alert human driver is one of the main benefits. Thus, it is considered appropriate for an AEB system to react differently to a crossing pedestrian compared with a stopping vehicle ahead. As such, sensors need to be capable of a much greater degree of object classification than is required for front to rear crashes only. Effects will be much smaller where pedestrians are running fast than where walking. Effects will be smaller where obstructions (e.g. emerging from between parked cars) limit the ability of the system to track the pedestrian.

EU regulation 347/2012 (EU, 2013) sets out the requirements for vehicles to have AEB systems installed (although note this is vehicle to vehicle AEB rather than pedestrian AEB). In the past, cost benefit analysis demonstrated that the mandatory application of AEB effective only in vehicle front to rear collisions would generate more costs than benefits on M_3 Class A, Class I and Class II[4], and articulated buses of category M_3 of Class A, Class I and Class II. As a result, buses of over 5 tonnes with 22 or more seated/standing passengers are currently exempt from the obligatory installation of AEB systems.

Bus specific emergency braking systems are emerging as both Original Equipment Manufacturer (OEM) and AfterMarket (AM) solutions. DCS Technologies has developed a Pedestrian Avoidance Safety System (PASS) which is an active safety system that decelerates a vehicle automatically in a potential pedestrian collision event. DCS Technologies claim that the PASS technology will react up to 20 times faster than a human. It is stated that the system can be retrofitted to existing fleets or applied to new purchases. However, they are a US company and the regulatory situation is different in the US. In Europe, applying an AEB system as a retrofit would involve changing a type approved system (the brakes) which would be a notifiable alteration to the vehicle and would require regulatory approval. Effectively, it would have to show that it complied with type approval regulations. It is not known if the system would comply and the process can be burdensome for aftermarket manufacturers.

[4] M3 = Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes. For further detail see Annex II of http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007L0046.

An example of an OEM product, an Emergency Braking System (EBS) is currently under development by Alexander Dennis. The system has already undergone testing and basic level calibration in an Enviro200 MMC and is expected to go into production by the end of 2017. The system utilises a forward-facing cyclist, motorcyclist, pedestrian and vehicle detector that applies the vehicle brakes automatically (Deakin, 2016).

Some stakeholders have suggested that while AEB has the potential to decrease the frequency and severity of collisions with other vehicles and pedestrians outside of the bus, it may cause added injury risk to bus occupants, particularly those standing at the time of the automated braking activation. From the collision files it has been noted that in one case the driver actively decided to brake conservatively to protect standing bus occupants. Operators say they are apprehensive about adopting AEBS because if passengers are hurt as a result of harsh braking from the system they fear that they, the operator, may be held liable. However, the benefit of the system is in a reduced reaction time between the pedestrian becoming an identifiable hazard and full braking being applied. The system does not increase the maximum level of braking the vehicle can achieve; a driver initiated emergency stop will be just as harsh as the quickest AEB stop. The system is designed to give only the deceleration needed to avoid the collision, so if in an identical situation a human driver applied less braking in order to protect occupants it would result in a collision. Depending on the collision object, this may well be much worse for the occupant than slightly heavier braking. Furthermore if the collision avoidance system can react faster than a human, there is a potential that less harsh braking will be required to avoid a collision. The only unarguable additional risk from AEBS in this context is the risk of occupant injury if the AEBS is falsely deployed; i.e. the bus would not otherwise have been braking at all. If the AEB activates where there is no imminent threat of a collision, then any injuries to occupants will have been directly caused by that false activation. Any risk associated with braking could be mitigated if the bus interior was adapted to further protect the occupants or standing is prohibited. Implementation of the AEBS must focus on minimising the risk of false activations. AEBS is quite mature now on cars, and experience from the Expert Steering Group indicates that false braking activations are very rare, although false warnings occur a little more often. The aftermarket warning only systems on buses for identifying pedestrians and cyclists in blind spots are perhaps showing more evidence of false warnings; however an implementation of AEBS would be required to be more robust and to minimise false activations.

Given that AEBS is not yet implemented on buses on the roads, it would be difficult to make it mandatory on the short term. However a suggestion from the Experts with experience of design and delivery of test and ratings systems is that the BSS might be used to encourage fitment in the short term as an incentive; AEBS could be made mandatory in the longer term.

Adaptive Cruise Control (ACC)

Whilst AEBS is designed to activate in emergency situations, ACC is designed for normal driving. The system regulates the speed of the vehicle to maintain a safe distance from the vehicle ahead, by using acceleration up to a maximum speed limit, combined with braking at low levels. ACC was not coded as a countermeasure by the collision investigators, so it has not been possible to include it in the countermeasures analysis. ACC is often combined with AEBS on cars where is now quite widely available. On cars ACC typically uses a RADAR mounted in the front grille, and as such is also subject to the repair and calibration cost concerns described for AEBS.

ACC on cars typically has at least three distance settings for the distance to the vehicle ahead. Experience from the Expert Steering Group, although not quantified, is that ACC might be beneficial in training drivers to keep a safer distance from the vehicle ahead, and to reduce tailgating behaviour. A further suggestion was that a system could be implement with algorithms tuned to provide a tailgating warning. Further research would be needed to verify the potential effectiveness of ACC for such driver training purposes.

Automated Emergency Steering (AES)

In the future, Automated Emergency Steering (AES) systems could help to mitigate the near side pedestrian impacts that pedestrian AEB might not be able to by adjusting the steering to avoid the pedestrian. Mercedes currently offer an Evasive Steering Assist system which activates when the driver initiates an evasive steering manoeuvre. The system adjusts the steering torque to guide the driver away from danger in a controlled manner whilst also facilitating the straightening up of the vehicle (Mercedes-Benz, 2016). Nissan have developed a future concept of combining AEB with AES to provide an autonomous system that can make the most effective choice between steering and braking to avoid or mitigate the risk of a collision (Nissan, 2016). These types of systems could offer some benefit for collisions at the corners of buses, where there is little time for an AEB system to react, and only a small steering input is required. However, they were not on the countermeasures list for coding, since they are in the very early stages of development, none are available on buses yet and vehicle manufacturer stakeholders have indicated that the lead time for their application to buses would be substantial; therefore they were not included in the priority list (although AES could perhaps be considered in a second phase of the Bus Safety Standard). This technology may benefit from wider lanes on roads to allow the bus more room to steer clear of a pedestrian. However, people do tend to utilise available space, so the risk is that pedestrians might just start walking in the road and using the space that is designed for buses; thereby eroding the benefit.

Intelligent Speed Assistance (ISA)

ISA systems detect the speed limit and either warn the driver when they are driving faster than the speed limit (supportive ISA) or actively aid the driver to abide by the speed limit (intervening ISA). TRL carried out a trial of intervening ISA on two London bus routes at the beginning of 2016 (Greenshields *et al.*), and the driver could not turn the ISA off. The ISA system was supplied by Zeta Automotive Ltd. and utilised GPS data matched against an on-board map and speed-limit database and electronically intervened to prevent further accelerator input when the speed limit was reached or exceeded. The system was not connected to the vehicle brakes. Results from the trial showed that compliance with the speed limit improved after buses were equipped with ISA and only a marginal increase in journey time was recorded.

Current ISA systems limit vehicle speeds to the maximum speed limits on roads; however this speed may not be suitable for the given conditions. In the future, ISA systems are anticipated to be able to assume or detect the risk on a particular road and then limit the speed of the vehicle accordingly.

4.2.1.2 Improved Field of View

Direct Vision

In some cases, safety features such as thick A-pillars and side mirrors can create blind spots that limit the driver's view; particularly of pedestrians, as shown in Figure 17. The use of smaller mirrors or adjustments to the placement of the mirrors can improve the driver's direct vision.

Figure 17: A bus driver's view of a pedestrian crossing with three different mirror configurations: inverted mount (left); medium mount (centre); high mount (right) (Leverette, 2013).

According to EU regulations buses must be equipped with mirrors but in the future the replacement of mirrors with a camera and display system could further reduce the issue of mirrors creating blind spots.

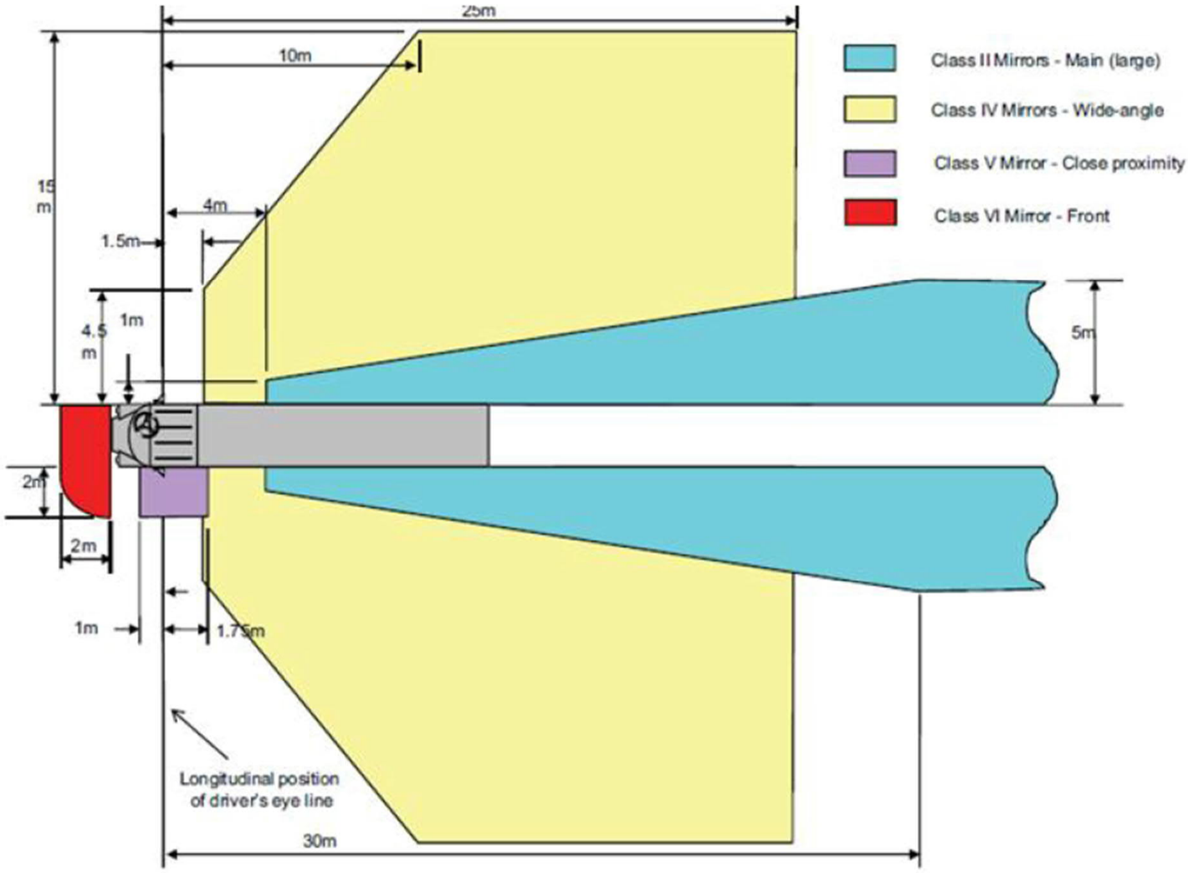
Assault screens may cause reduced direct vision to drivers. There are currently two main types of assault screen design, one which meets to the centre of the windscreen and one which meets the A-pillar. Often the Perspex assault screens become scratched and restrict the driver's direct vision. Redesign of the assault screens, more regular replacement of the Perspex or the elimination of the screens may help to increase the driver's vision. A specification for assault screens could be included in the new Bus Safety Standard.

Indirect Vision

According to EU Directive 2003/97/EC Class M3 vehicle (exceeding 5 tonnes and comprising more than 8 seats including the driver) only require Class II mirrors; one on the driver's side and one on the passenger's side. The installation of wide angle Class IV, V and/or VI mirrors has the potential to greatly reduce the blind spot areas surrounding the bus. Figure 18 shows the field of vision supplied by the different classes of mirrors on a HGV. However the introduction of extra mirrors has the potential to increase the driver's workload and may lead to attention being taken away from direct vision. This issue of increased driver workload had been raised in several studies into improved vision for HGVs. The mean glance time for a single mirror has shown to be just over a second and the time to travel between mirrors is approximately 0.32- 0.34 seconds, resulting in a total time of 4 to 6 seconds to check all mirrors in a HGV (Woolsgrove, 2014). Summerskill *et al.* (2015) noted that by the time a driver has examined all the mirrors and then made observations through the windows the road situation may have changed. They suggest further research should be carried out to establish the best combination of mirrors which enable optimal visibility and workload.

An alternative approach to improving the driver's field of vision is to implement cameras around the vehicle to provide the driver with a wide angled view of each side of the bus. The images from each camera can be blended and stitched together to provide a 360° bird's eye view around the bus in real time on a dash mounted monitor. When the driver uses the indicator to change lanes or turn the monitor will automatically display the appropriate view, from the front view, to the left or right side view. It would turn off at speeds over 10mph for example, in order to minimise drive distraction; and it should turn on by default in reverse gear too. Cameras mounted on the top of buses may need image recognition algorithms adapted due to difference in appearance of pedestrians from the high angle view. The field of view of the camera systems will also need to be assessed to reduce blind spots to a minimum. The introduction of an extra screen to monitor may also increase the driver's workload, however there is no need to have multiple screens for multiple cameras because the images can be integrated into one view using suitable algorithms. Summerskill *et al.* (2015) proposed that additional research should take place to investigate if and how additional technologies should be added to a vehicle in a manner which does not increase the workload upon the driver.

Figure 18: Field of Vision Requirements (2003/97/EC)



Night Vision

Collision data collected in Canada has shown that many pedestrian fatalities and injuries occur at night or under low-light conditions. The authors suggest implementing adaptive headlights that orientate light in the direction the vehicle is turning as well as better illumination of bus stops (Canadian Council of Motor Transport Administration, 2013)[5].

Nambisan *et al.* (2010) conducted a study on automatic pedestrian detection devices and found that smart lighting proved to be effective in increasing pedestrian safety on dimly lit roadways. The smart lighting system formed part of the road infrastructure rather than a device fitted to a vehicle or worn by a pedestrian. The

[5] Note that Stats19 data reported by the Metropolitan and City of London Police forces suggests approximately 67% of pedestrian fatalities, 68% of serious pedestrian injuries and 71% of slight pedestrian injuries from collisions involving buses occur during daylight. This suggests that there is a slightly increased severity of bus pedestrian collision at night time. Whether there is an increased risk of any type of collision depends on the split of bus mileage by daylight and darkness, which is unknown.

device detects pedestrians stepping out into the road and shines a light on them so they are easily seen by other vehicles. The device was shown to increase the pedestrians' operational behaviour as well as the vehicles' likelihood of yielding to the pedestrians.

The Blaze Laserlight is a bicycle mounted light that alerts vehicle drivers to the presence of a cyclist. TRL carried out a study to test the visibility of the Blaze Laserlight in low light and after dark around a bus and found that the blind-spot areas around the vehicles were significantly reduced and the percentage of maximum visibility at night improved from 72.4% with just the existing LED lights to 96.2% with the Blaze Laserlight (Greenshields *et al.*, 2016).

4.2.2 Vehicle Countermeasures in the Crash Phase

4.2.2.1 Crashworthiness

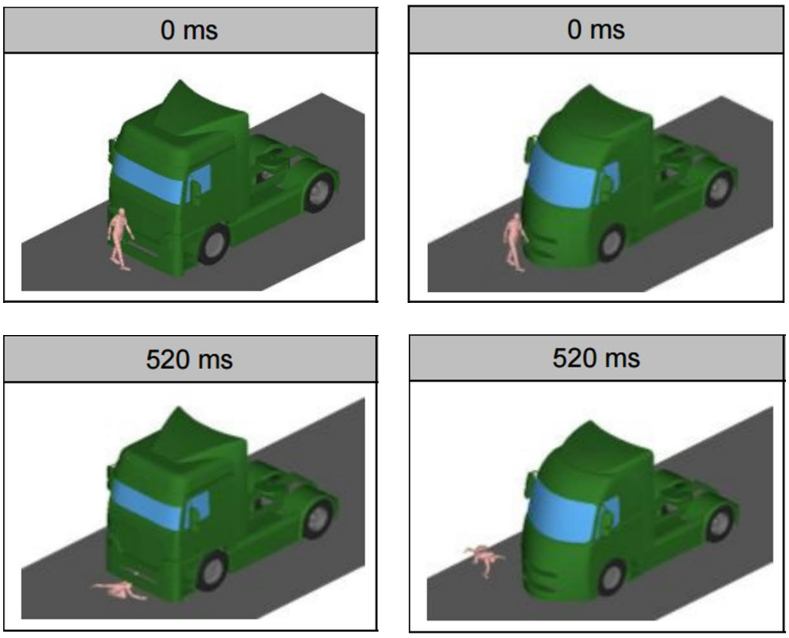
Pedestrian-Friendly Frontal Structures

During pedestrian collisions, the initial pedestrian contact with the vehicle obviously creates a significant risk of injury. The centre of the force applied by flat-fronted bus structures is usually above the centre of gravity of the pedestrian causing them to be rotated around their feet towards the ground, potentially with quite high forces depending on the exact geometry. This adds a significant risk of injury from the secondary contact with the ground. When the collision occurs, the pedestrian will be accelerated almost instantly to the speed of the bus. Once lying on the ground, they will decelerate again at a rate dependent on the coefficient of friction between the pedestrian's clothes and the ground. If the bus is not braking hard at this point, there is a high chance that the pedestrian will be run over by the bus, with the obvious potential for catastrophic injury.

A frontal structure more like a car bonnet provides an initial impact point lower than the pedestrian's centre of gravity so the pedestrian is rotated around their centre of gravity with the head moving towards the windscreen of the vehicle rather than directly towards the road. Depending on the exact geometry of the person and vehicle this can make the initial contact with the vehicle more severe. However, this can be mitigated by making sure that the part of the vehicle involved is sufficiently soft to minimise the chance of injury. Once full contact has been made with the vehicle and the pedestrian has been accelerated to the same speed as the vehicle they will fall down to the floor under the effects of gravity only, reducing the potential for secondary injury in contact with the ground. If the vehicle does not brake, it will stay underneath the pedestrian. If it does brake the pedestrian will slide forward on the bonnet and fall to the ground ahead of the braking vehicle. In either case, the probability of being run-over by the vehicle is relatively low.

A nosecone is a tapered front end structure that is intended to help protect pedestrians in exactly this way. The concept was first developed for HGVs in the Advanced PROtection SYStems (APROSYS) project (Feist *et al.*, 2008) and further developed by Welfers *et al.* (2011) to optimise the aerodynamics and safety performance and is shown in Figure 19.

Figure 19: Simulation of a 50th percentile male collision with a reference tractor unit (left) and the optimised tractor unit (right). Source: Adapted from Welfers *et al.*, (2011)



It can be seen that the pedestrian is overrun by the flat fronted tractor (left) but is deflected off to the side by the optimised tractor (right), preventing overrun.

A study commissioned by the DfT examined the effect of length of HGV nosecones on the potential number of lives saved. A 1m nosecone was estimated save 10 pedestrian fatalities per year in GB and 2 pedal cyclists (DfT, 2010). The number of bus related fatalities is less than HGV related fatalities[6] but the application of nosecone structures on buses would still be expected to reduce the number of fatalities.

The nosecone structure may also provide the driver with better protection from frontal impacts. The maximum permissible length of a 2 axle bus according to Annex 1 of EU Council Directive 96/53/EC is 13.5m (EU, 1996). TfL buses range in length from 11.2m for the new route master style buses to 12.6m for Alexander Dennis Enviro 300 single deck buses (TfL, 2016c) (Alexander-Dennis, 2012). In theory, this leaves approximately 1m of length for a nosecone front end structure without encroaching on the passenger space, but analysis would be required to confirm what constraints the manoeuvrability criteria also contained in Directive 96/53/EC might place on the amount of additional length that can be put ahead of the front axle.

[6] Stats19 records 408 pedestrian fatalities in 2015, of which 55 occurred in collisions involving an HGV and 30 in collisions involving a bus or coach.

There might also be operational issues with longer buses, e.g. bus garage parking capacity, routing and turning profiles.

A nosecone structure would also adjust the driver's position as they would be further away from the front of the bus. This may affect the driver's direct vision and change the blind spot areas. As such, any 'nosecone' structure would best be implemented as an integrated frontal structure on new models of buses and would be difficult to retrofit.

Another type of front end structure is a safety bar fixture. This is an alternative to the above in that it can be retro-fitted to a vehicle rather than built in during the design stages. For example, it could be a steel and foam safety bar, added to the front of the vehicle. A steel and foam safety-bar concept was developed for HGVs by the APROSYS project and was regarded to have no significant effects on manoeuvrability and was estimated to save around 4 lives per year in Great Britain. The safety bar concept was shown to reduce primary impact loads and injury risks, but does not provide the lateral deflection of the pedestrian as the nosecone does (Feist and Gugler, 2009). Robinson and Chislett (2010) suggested a similar concept of applying an energy absorbing front to the large passenger vehicles (LPVs). The authors describe that by fitting an energy absorbing front to the LPV, the distance over which a pedestrian can be decelerated is increased which allows the pedestrian to be protected at higher impact speeds. This would be more effective in combination with a measure to reduce the probability of a runover. For example, AEBS has the potential to achieve this because even if the system was unable to avoid a pedestrian, then it should help to ensure the vehicle is braking at the moment of impact such that the pedestrian would be less likely to be run over.

Through UK based cost benefit analysis, Robinson and Chislett (2010) was found that a safer front for LPVs was one of the countermeasures most likely to provide a positive return on investment and also had the potential to reduce the number of LPV related fatalities annually by 15 (based on casualty levels recorded in2006-8) and the number of serious injuries by annually 134, with an annual KSI cost saving of £45.7 million. By comparing these figures to the average annual total number of UK fatalities and injuries between 2006 and 2008 caused due to a collision with the front of a LPV, this equates to a reduction of approximately 23.8% of fatalities and 44.9% of serious injuries.

Another form of pedestrian friendly end is to implement softer structures. By using softer materials then a greater energy could be absorbed, and so help to mitigiate the injury severity. Bus A-pillars, wiper points and toughened windscreen are all high stiffness components that can contribute to increased risk and severity of head injury. Softer frontal structures can help to decelerate pedestrians over a longer time period and reduce injury risk. The inclusion of pedestrian airbags could help to shield these stiff structures and further increase the deceleration period of the pedestrian. Airbags need approximately 10ms to inflate so the bonnet would have to be designed in such a way to allow sufficient inflation time. A simpler countermeasure would be to use top hung windscreen wipers, instead of bottom mounted ones; although this might cause maintenance problems in an operational sense.

4.2.2.2 Occupant Safety

A study into Enhanced Coach and Bus Occupant Safety (ECBOS) performed parametric computer modelling of frontal city bus crashes. A baseline scenario of an M2 vehicle impacting a mature tree at approximately 45km/h was created and then further models were made with one parameter varied at a time. When the seat back padding stiffness was decreased by 33% significantly lower head injuries occurred (HIC decreased by 62%) meaning potential serious or fatal head injuries could be avoided. When a lap belt was added into the simulation the HIC valued decreased by 19% and the femur and pelvis loading were significantly reduced (TUG, 2004).

Palacio *et al.*, (2008) used a Madymo human model to simulate a standing passenger in an accelerating bus. It was found that horizontal metal seat handles were particularly hazardous and should be replaced with vertical ones hung from the roof of the bus. It was recommended that passengers should not stand in the bus aisles, but in a padded, designated standing area where there is no hazardous bus furniture items such as rows of seats which may increase this risk of injury. Palacio *et al.*, (2008) also suggest that lower stiffness rubber flooring should be used to minimise injuries such as knee fractures which are commonly associated with impacts with the bus floor.

From discussions at the Experts' Steering Group it was established that configuration of the interior of buses is specified by TfL. This means it may be feasible to drastically change the interior if clear benefits to bus occupants are identified; however any interior changes must be balanced with capacity needs. Many potential modifications were considered for example, increasing the diameter of handrails and poles could help to spread the impact with a passengers head, for instance, over a larger area which may help to reduce injury severity. Frangible[7] poles could also reduce injury risk as their stiffness would be much lower than traditional metal poles.

To help prevent falls on stairs of double decker buses a gate could be installed at top and bottom of the stairs that only opens when the bus is stationary. To help reduce injuries caused by falls down stairs the edge of the steps could be rounded and the stairwell could have added padding. There is also potential for the stairs to be turned around by 180 degrees, although it is unclear if this would provide any benefits.

The use of seatbelts could help to reduce injuries caused by braking situations. The introduction of rear facing seats could also assist passengers in staying in their seats during braking situations. To prevent whiplash type injuries rail style high backed seats should be used, however, passengers may be opposed to facing backwards. There might also be practical implementation concerns for operators, if a mix of front- and rear-facing seats reduced seating capacity.

Compartments for standing passengers could be implemented to minimise the distance travelled by the passenger during harsh braking. The compartments would need to be constructed with low stiffness, softer materials. Considerations would

[7] Frangible mean easily broken into frangments

need to be made to ensure good accessibility and visibility into/through the compartment so passengers feel safe and comfortable to use them. Using compartments on the buses might affect passenger flow on the vehicle, and operators have operational concerns about using this approach, so it is not recommended at this time.

4.2.3 Vehicle Countermeasures in the Post-Crash Phase

The most obvious countermeasure in the post-crash phase is eCall, which is an automatic emergency call system for motor vehicles. It dramatically shortens the time it takes for emergency services to arrive. Carmakers will have to install the technology in all new car and van models from 31 March 2018 onwards according to EC regulation 758 (EU, 2015). Buses are not currently required to fit the system, although a review is required by March 2021 to describe the achievements of eCall fitted to cars and vans, and to report on whether the legislation should be extended to heavy goods vehicles, buses and coaches, powered two-wheelers, and agricultural tractors. According to some estimates, eCall could speed emergency response times by 40 percent in urban areas and by 50 percent in rural areas (ERTICO, n.d.). However eCall was not assigned as a countermeasure in any of the cases.

4.3 Human Countermeasures

There are also a range of human countermeasures that might help to avoid, and/or to mitigate the severity of injuries. These human countermeasures are outlined below, starting with the pre-crash phase.

4.3.1 Human Countermeasures in the Pre-Crash Phase

4.3.1.1 Training in vehicle systems and use

In almost all areas of road safety, better training and education are suggested as central pillars in the fight to reduce injury. There is one respect in which this is uncontroversially true; users of vehicles should be trained how to use them and the technologies they contain. In this sense, road transport is no different to other, more heavily regulated modes such as air travel, and a single example from this domain will serve to illustrate the point.

In 1989, on the 8th January, a Boeing 737-400 crashed on the M1 motorway, just short of the runway at which it was attempting to make an emergency landing at East Midlands Airport (the so-called ‘Kegworth air disaster’). The aircraft had experienced a fault in its left engine. The pilots subsequently shut down the still functioning right hand engine, rather than the damaged left engine, and this ultimately led to the crash. The decision to shut down the right engine arose from a number of factors, one of which was that the pilots had not received any training in the 400 series of the Boeing 737 aircraft in relation to managing engine malfunctions; their knowledge of how to handle such malfunctions in the previous series of the aircraft led them to take the incorrect action, due to several changes introduced by the manufacturer. One of the recommendations of the ensuing accident investigation was that the Civil Aviation Authority should require that pilot training on engine malfunctions should be updated (Air Accidents Investigation Branch, 1989).

For reasons illustrated by this case study (albeit in a different domain) it is self-evident that with all new safety features implemented in buses in London, there should be sufficient training in place to ensure that drivers feel comfortable and confident in using them, and, crucially, actually know how to use them. The precise form that this training should take will depend on the systems used, their complexity, and the extent to which they require active driver input. It has been apparent in previous projects involving applying safety systems such as ISA and collision avoidance systems that at first drivers can be reluctant to embrace the technology, but after a short while they become familiarised with it and can see the benefits (Greenshields et al., 2016).

4.3.1.2 Training and Education for Drivers in Safer Driving

In contrast to the self-evident need for training in the use of bus safety systems for drivers, the case for wider training and education for bus drivers, focused on safer driving, is not as clear.

One reason for this is that the evidence for the effectiveness of training interventions, specifically for bus drivers is scarce. Thus it is not clear what form such training should take if it is to be effective (although see Section 5.1.3 for a discussion of hazard perception training – an area that would benefit from more detailed research as to what should be included in any approach).

Another reason is that the wider literature on driver training is equivocal at best in terms of its support for the effectiveness of training as a safety intervention. When systematic reviews of training and education for young and novice drivers are considered, a good deal of evidence suggests that it is ineffective (Vernick *et al.*, 1999); see (Helman *et al.*, 2010) for a recent review). A Cochrane systematic review also concluded the same for advanced and remedial post-licence driver education (Ker *et al.*, 2003).

When considering the work-related road safety literature, (Grayson and Helman, 2011) concluded that only a handful of training and education interventions had been properly evaluated; a later update of this review by (Helman *et al.*, 2014) concluded that nothing had changed. Aside from the obvious need for good management of work-related road risk, see (Health & Safety Executive, 2014) and the CLOCS inititiave in London, based on the work of (Delmonte *et al.*, 2013); those working in the area seem to lack any agreed approaches to improve safety.

In short, any approach to training bus drivers in 'safer driving' should proceed under modest expectations of effectiveness at best, until specific interventions have been shown to deliver specific benefits in good quality evaluations. A recent review of the literature to identify the most promising candidates may be a useful first step.

4.3.1.3 Training and Education Relating to Pedestrians

The most commonly assigned countermeasure assigned in a study of pedestrian fatalities in London between 2006 and 2010 was 'improved pedestrian awareness of other road users'. In pedestrian collisions involving buses/coaches specifically the most common contributory factor was found to the 'failed to look correctly' and so therefore the authors suggested the implementation of education/publicity measures highlighting the importance to looking properly in particular. Pedestrian training could also include the dangers of being impaired by drugs and alcohol, developing strategies to minimise the risk of being involved in a collision and increasing general road safety knowledge (Knowles et al., 2012).

From discussions at the Experts' Steering Group it was highlighted that training pedestrians and other roads users was lacking in direct evidence that it can reduce the frequency and severity of collisions. Thus the same issue exists with this group of road users as is the case in the the driver training and education literature. Thus we would recommend that any training interventions considered are done so on the basis of evidence, or are evaluated. One promising line of enquiry might be training and educating pedestrians regarding their lack of conspicuity and visibility at night; for example (Tyrrell *et al.*, 2004) showed that this is something pedestrians overestimate, and something that shows promise in terms of training interventions to overcome this misunderstanding.

Another option suggested by the Experts' Steering Group (and echoed in the Human Factors and Behaviour Change Workshop – see Section 5.1.3) is that to deal with pedestrian risk, a safe systems approach should be adopted and the focus of countermeasures should be on vehicle/environmental interventions. For example, the implementation of high visibility strips, extra lights on the front of buses or the replacement of the upper windscreen on double decker buses with a more visible material may help pedestrians to see the bus and reduce the likelihood of them stepping out in front of a bus. Again, research may be needed to understand the best way to achieve this.

4.3.2 Human Countermeasures in the Crash Phase

The point made in Section 4.3.1.1 regarding appropriate training on vehicle safety systems applies to the crash phase, should any such systems designed to reduce crash severity be in use. Obvious examples include things such as seat belts and air bag systems.

The importance of using such systems should be clarified through communication and appropriate health and safety policies focused on driver safety. As with wider training and education, any interventions used to try and encourage uptake of such systems as seat belts should be based on evidence where possible, and evaluated properly to ensure that levels of effectiveness are known.

4.4 Environment Countermeasures

4.4.1 Bus stops

Stopped buses can create line of sight hazards for both pedestrians and other road users. The Canadian Council of Motor Transport Administrators advise that bus stops are best located away from crossings to deter pedestrians from crossing right in front of or behind a bus (Canadian Council of Motor Transport Administration, 2013).

The CCMTA also recommend that fencing is installed between the road and pavement to help guide the pedestrians away from crossing near the bus stop and towards a safer crossing location (2013). However in the London road environment extensive guardrailing is not practical, and the workshop revealed mixed opinion on this option; so guardrailing is not recommended at this stage.

Bus stops also pose a risk to cyclists as the buses and cyclists often end up crossing paths as the bus pulls in and out of the stops. Bus stop bypass cycle lanes reroute the bicycle around the nearside of the bus in a separate cycle lane and could reduce the potential for cyclists and buses crossing paths (Talbot *et al.*, 2014).

4.4.2 Junctions

A study into pedestrian related bus collisions in Philadelphia suggested that at junctions the installation of left- or right-turn protected signal phases at busy junctions could reduce collision frequency (Park and Trieu, 2014). Furthermore the installation of pedestrian protected crossing phases and longer time to cross could also reduce collision frequency. With regard to cyclists, the addition of advanced stop lines at junctions allow cyclists to get ahead of other vehicles to a safer location, however this can result in the cyclist undertaking other vehicles to reach the advance stop line or can place the cyclists in the blind spots of large vehicles. The combination of advanced stop lines with technologies such as the BlazeLight could work effectively together to improve cyclist visibility as well as road location (Talbot *et al.*, 2014).

4.5 RAIDS & OTS Case Studies

Case study reviews of urban bus collisions are summarised for all the cases included in OTS and RAIDS phase 1 databases. Cases are summarised by analysing the circumstances, collision scenario, physical conditions and contributing factors. Based on these inputs, countermeasures are assigned to each case that might help to prevent or to reduce the severity of each collision, based on the specific circumstances of that collision. The master bus countermeasures list, from which the countermeasures were selected, is provided in Appendix C.

4.5.1 Case selection criteria:

Cases summarised were selected based on a case selection criteria explained below:

Table 3: Case selection criteria for the OTS & RAIDS case summaries.

Area	Bus collisions in urban areas only
Vehicles involved	All collisions involved at least one bus (Coaches were excluded)
Injuries	At least one slight, serious or fatally injured road user (includes pedestrians, cyclists and motorcyclists)

Using the case selection criteria, the case search resulted in a total of 47 cases (41 OTS and 6 Raids). Out of these 47, 35 cases were selected for further analysis based on more relevant scenarios, collision configuration and causation factors.

4.5.2 Creation of case summaries

Each case was examined in detailed by an expert investigator reading through the case files. The case was summarised on a one page format with a focus on explaining the key details as described in Figure 20:

Figure 20: Key details used in the OTS & RAIDS case summaries.

Case ID	• A written case ID was generated to convey case information rather than just a numeric id. The Case ID defines: • the selected case number (1-35), • study from where the case was chosen from (OTS/Raids), • Max Severity in the collision and Collision classification (interaction between the two vehicles or vehicle and road user).
Conditions	• Physical conditions that can influence the collision and severity of the collision such as weather, lighting, visibility, type of road and road surface are considered.
Collision Partners	• Vehicles or road users involved in the collision.
Scene	• Pictorial representation of the scene and collision including the position of objects and the movement of vehicles that contributed to the collision. These are illustrative only and are not to scale.
Scenario	• Brief explanation of the collision with reference to the scene for the ease of understanding.
Causation Factors	• Applying the Haddon Matrix, all the causation factors that led to collision are classified against: • Human • Vehicle • Environment
Countermeasures	• Countermeasures are assigned to each causation factor that could have avoided the collision or reduced the severity of the injuries. Counter measures are classified against: • Human • Vehicle • Environment

4.5.3 Case Summaries

The legend for the case summaries is given first in Figure 21, thereafter followed by an example of a completed case summary, Figure 22. The full set of 35 case summaries is provided in Appendix C.

Figure 21: Legend for OTS & RAIDS case summaries.

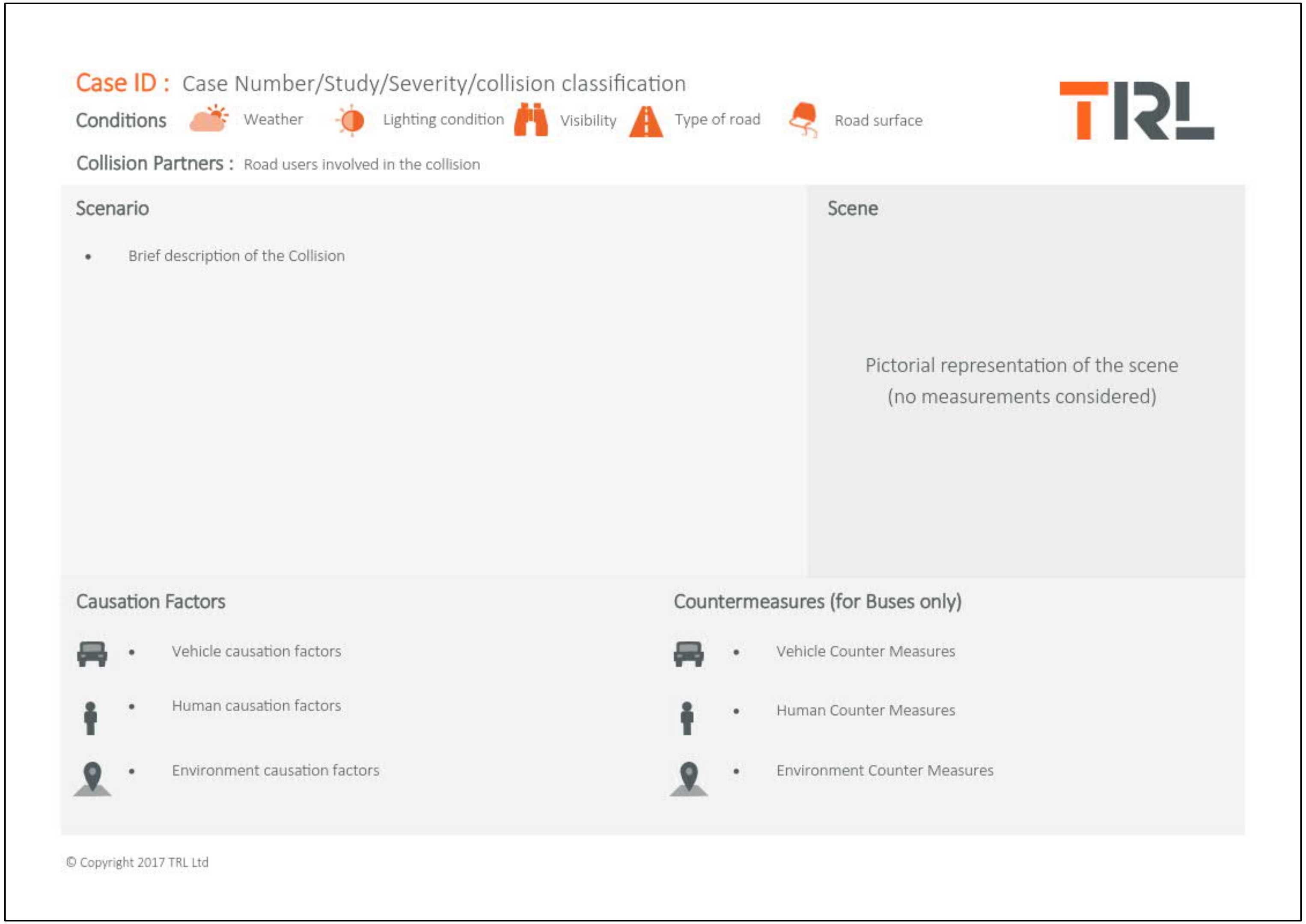
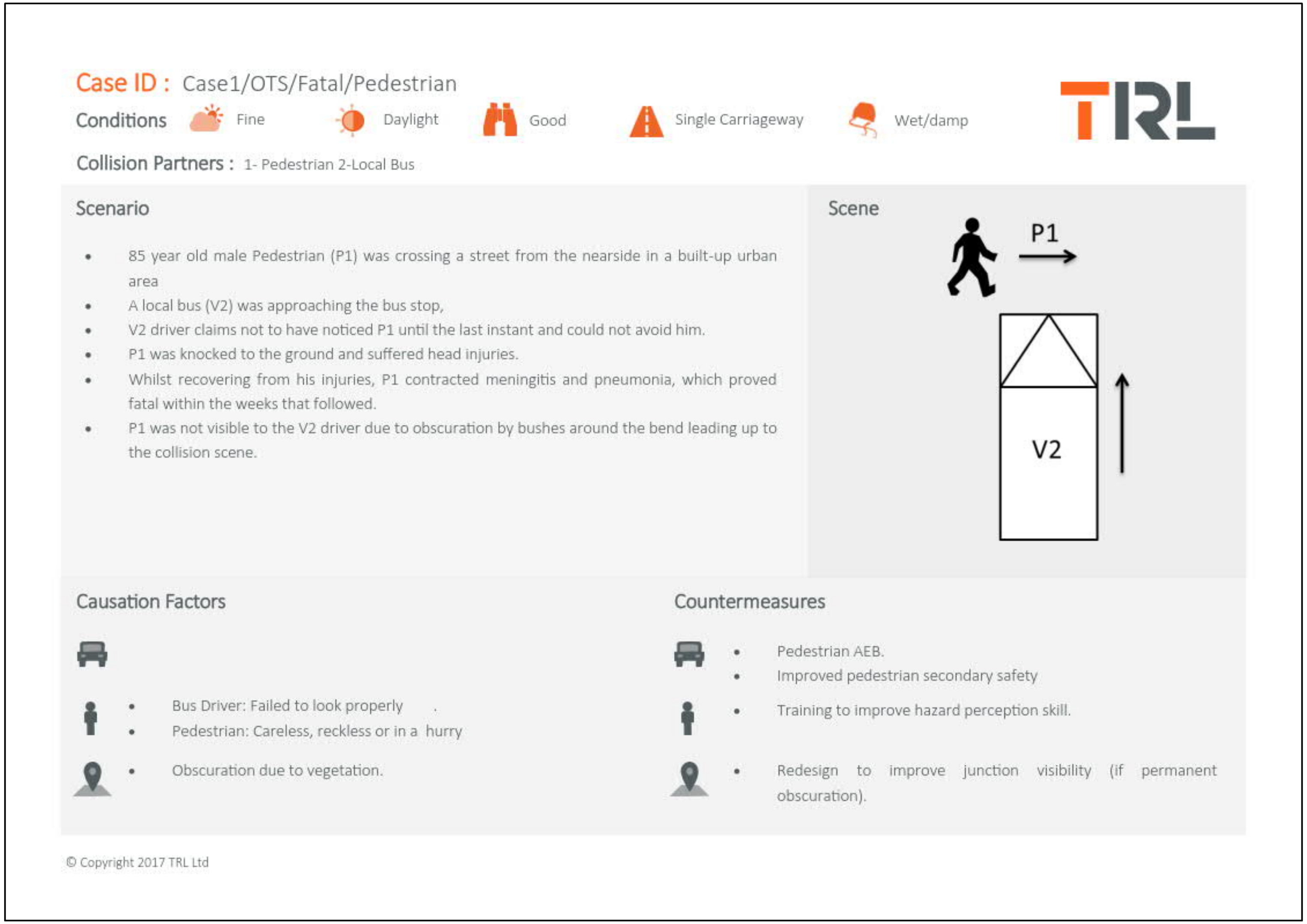


Figure 22: Example Case Summary (Case 1).



4.6 Summary of identification of countermeasures

There are a variety of countermeasures designed to help avoid or to mitigate the severity of injury in bus collisions. Countermeasures can include countermeasures designed to address the pre-crash and crash phases. Some examples include:

- Advanced Driver Assistance Systems (ADAS)
- Pedestrian-friendly frontal structures
- Improved field of view
- Occupant safety
- Human factors
- Environment factors

The effectiveness of the countermeasures varies depending on the specific situations and site locations. Combinations of countermeasures applied together may prove more effective than isolated countermeasures.

5 Phase 3: Countermeasures Analysis

The investigators have assigned countermeasures that might help to either prevent or to reduce the severity of the collisions, based on the specific circumstances of each collision. It is important to note that multiple countermeasures may be assigned to each case.

5.1 Stakeholder Input on Countermeasures

5.1.1 Stakeholder questionnaire

A questionnaire was shared with attendees at the Stakeholder workshop in December 2016. The stakeholders included bus manufacturers and operators. They were given a presentation about the findings on bus collisions nationally, and the in-depth investigation of fatal files, alongside some initial work on countermeasures (Section 3 Phase 1: Collision Analysis). The questionnaire text was as given in Appendix A. Responses were received from six organisations; four bus operators and two bus manufacturers. Half the respondents were prepared for their responses to be published, half were not. Thus, results have not been attributed to any individual respondent and in the presentation of summaries of results; efforts have been made to avoid presenting information that would allow the response to be attributed to a particular stakeholder.

There was general agreement that CCTV, telematics and driver monitoring would have been significant influences on safety improvements in recent years. These were sometimes recorded as vehicle improvements and sometimes as driver improvements. There was also a general consensus that bus driver training had improved and that this would have been a positive influence. Other measures were less consistently referred to; several respondents cited better brakes on the bus and one or two to improved vehicle layout, seat design, interlocks and acceleration limiting. When it came to bus operation the only factors cited by more than 1 operator were improved route risk assessment and allocating specific buses to specific routes. Others getting a single mention included staff at stands, radio contact with driver, improved maintenance and more realistic schedules. However, in the case of the latter, another respondent suggested evidence with respect to schedule changes was mixed.

The results in relation to infrastructure measures were also mixed. Improvements to siting/accessibility of bus stops was cited twice as was an increase in bus lanes, though one respondent made an exception of contra-flow bus lanes which they considered an increase in risk. In general, it was considered car and HGV safety had improved but that motorcycle safety hadn't and, with the exception of cycle lanes, nor had cyclist safety.

When considering the potential new countermeasures listed in the questionnaire, the response provided was numeric (5 best, 1 worst) with text justification. It was apparent that there were differences in response between manufacturers and operators; responses from operators were likely opinion-led rather than evidence-led. All respondents tended to have a preference either for measures that aimed to avoid the collision (active), but might interfere in normal driving; or those that didn't intervene at all in normal driving, could not avoid collisions but could reduce the severity of injuries received (passive protection). The responses are summarised in Table 4.

Table 4: Summary of survey responses for estimated countermeasure effectiveness.

Countermeasure	Average effectiveness		
	Operator	Manufacturer	All
Blind spot warning	3	4	3.33
Advanced Emergency Braking (AEB); Bus to Vehicle Rear	4.5	4	4.33
AEB for pedestrians and cyclists	3.25	4	3.50
AEB Left turn	2.75	3	2.83
Automated Emergency Steering (AES)	2.5	2	2.33
Pedestrian friendly front	3	2.5	2.83
Runover prevention structure	3	2	2.67
Direct vision	3.75	3	3.50
Interior design	3	2.5	2.83
Average Active	3.27	3.4	3.27
Average Passive	3.19	2.5	2.96

Broadly, the respondents considered that AEB for vehicle to vehicle collisions and pedestrian frontal collisions would be quite effective, as would blind spot warnings. However, AEB for left turns was considered less effective. One operator suggested a fatigue monitoring/warning system as an addition to the list that they considered would be highly effective. The bus manufacturers tended to prefer the active safety measures to the passive measures, whereas overall the operators were more even. However, it should be noted that one of the four operators thought that all except vehicle to vehicle AEB would be highly ineffective rating all active measures apart from this as one and all of the passive countermeasures as five. In the absence of this result, the remaining operators would have favoured active measures in a similar proportion to the bus manufacturers.

A variety of subjective explanations for the scoring were received. For active systems they were generally thought to have much potential but concerns were expressed about the number of false positives, the potential for warnings to be distracting, and how drivers would feel about control taken away. The left turn problem was considered less frequent than frontal and ‘more for trucks’. In relation to the passive measures, the comments were varied. Some thought them highly effective, capable of preventing lots of KSIs. Others were more sceptical, suggesting the benefits might be limited because performance was already good, avoidance was preferable to injury mitigation and integrating into design and operation could be complex.

All but one bus operator considered that the feasibility of countermeasures was a matter for manufacturers and did not respond. The two vehicle manufacturers resulted in the following range of results for when they considered each system would be in full production. Where the two responses disagreed they have been presented as a range:

- Blind spot warning: 2020
- AEB Bus to Vehicle Rear: 2018
- AEB for pedestrians and cyclists: 2020-2026
- AEB Left turn: 2020-2022
- Automated Emergency Steering (AES): 2024-2026
- Pedestrian friendly front: 2020 - 2026
- Runover prevention structure: 2022-2026
- Direct vision: 2020
- Interior design: 2020

The vehicle manufacturers also identified the following barriers to introduction, as described in Table 5:

Table 5: Barriers to introduction of countermeasures based on survey responses from Bus manufacturers and operators.

Measure	Barriers and constraints
Blind spot warning	Systems available with complex integration
Advanced Emergency Braking (AEB); bus to vehicle rear	Liability if a passenger gets injured in the occurrence of a false positive, or even in a true positive where a collision is prevented (how to prove this was the case)
AEB for pedestrians and cyclists	Complex and difficult to perfect and integrate and liability issues as for AEB BVR
AEB left turn	Integration can be complex. Must have blind spot detection as AEB already fitted. Safety ratings of blind spot detection must be considered to enable AEB, especially with pedestrian and cyclist detection
Automated Emergency Steering (AES)	Steering system availability as well as development and integration cost and complexity
Pedestrian friendly front	Limitations based on legislative requirements (e.g. manoeuvrability), while maintaining a usable vehicle for London routes
Runover prevention structure	Very difficult, never considered before, full concept development required
Direct vision	Already very good, some minor improvements possible
Interior design	Already very good. Further research, design and simulations must be completed first to validate that any changes really provide a safety benefit

One vehicle manufacturer provided an estimate of costs but did not wish for this information to be published. In the absence of information from any other source with which to merge and anonymise the data in wider ranges or averages, no information on the costs can be presented. It was noted that the degree of difficulty in integration would provide the best indicator of possible magnitudes of cost as this early stage.

5.1.2 Bus Collisions Workshop

A workshop was held on 5th December 2016 for bus manufacturers and operators. The purpose of this was to review the collision data and identify how to fill any gaps in knowledge and to understand the countermeasures currently implemented. Another discussion topic for the workshop was to review the countermeasures identified by the analysis of bus collisions, specifically by considering these questions:

- What other countermeasures do participants foresee?
- What barriers are there to implementation?
- When might solutions be technically feasible?
- How would they affect operations?
- Are there any synergies from grouping of measures?

This workshop raised some questions, and gathered some feedback, all of which has been integrated into the previous sections of the report in section 3 and 4, and into the following analysis of countermeasures in section 5, so will not be discussed in further detail in the this section.

5.1.3 Human Factors & Behaviour Change Workshop

On 13th February 2017 a Human Countermeasures workshop was held at TfL with the aim of informing stakeholders about the human factors and behaviour change elements that need to be considered when thinking about the implementation of bus countermeasures. The stakeholders in attendance included bus manufacturers and operators. The workshop began with an introduction to the topic, and the slides are in Appendix E. The key topics covered were:

- Introduction to human factors
- Training, campaigning, and behaviour change
    - Can’t we just train people to behave differently
    - Campaign examples
    - Behaviour change models and research examples

Two interactive sessions were then held. These invited participants to consider some of the countermeasures that had been suggested in the wider project from a human factors perspective, and for the stakeholders in attendance to consider:

1) What are the barriers and enablers?
2) Pick one ‘quick win’, one medium and one long term countermeasure

There is a long list of countermeasures and it was not feasible to discuss them all, but a handful of them were considered and the discussions are summarised in Table 6 for the vehicle countermeasures and in Table 7 for the human countermeasures.

Table 6: Summary of barriers and enablers identified by stakeholders at workshop for selection of vehicle countermeasures.

Category	Crash Phase	Group	Countermeasure	Enablers/Opportunities	Open Questions	Barriers/Blockers
Vehicle	Pre-Crash	ADAS	**Advanced Emergency Braking**	Fewer fatalities	How sensitive is it/should it be? Would pedestrians walking on the edge of the footpath trigger it?	People could 'bully' a bus
				Easier to respond to customer complaints about braking because the system would provide a log	How should it be calibrated?	Injury to standing passengers from harsh braking
				Prevents pedal confusion	How will this change driver performance and behaviours?	False alarms will reduce trust – cry wolf, disuse
				Phased implementation would help with driver buy-in	How will liability work?	Possibility of overtrust – rely on bus to brake
				Could reduce driver stress	How will unions react?	
				Involve drivers in developing/deploying the technology		
				Improve reputation		
				Culture shift in the public to recognise that it is important to help keep the bus network moving		
Vehicle	Pre-Crash	ADAS	**Mandatory Intelligent Speed Adaptation (ISA)**	Lower speeds = lower risk = fewer collisions	How can the driver turn it off?	Cost
				Driver doesn't have to think about the speed limit	Is it easy to maintain for the engineers? i.e. how reliable will it be?	Speed limit be to too high for safety driving in some conditions
				Could help with headways/regulation	Training would have to change	Lack of driver responsibility
				Improve reputation – buses can't break speed limit	Who sets the speed limit? Are they variable under different road and weather conditions or fixed to the legal speed limit?	May be stressful for drivers falling behind schedule who cannot increase speed to catch up
				Help contractors – no speeding incidents to be monitored	Is the equipment not working a reason to take a bus off the road?	Pressure from passengers to drive faster
				Safety Culture – zero tolerance of speeding	How sensitive would the system be?	Might create a risk of overtaking by other road users in some conditions
					How would it feel for the driver and how would this affect their driving performance and behaviour?	Probably not 100% effective across the geographical network (reception blackspots)
						Overtrust in the system

Category	Crash Phase	Group	Countermeasure	Enablers/Opportunities	Open Questions	Barriers/Blockers
Vehicle	Pre-Crash	ADAS	**Fatigue monitoring**	Reduction in KSIs	How accurate would it be?	Driver perception – big brother
				Could enable better fatigue management policies by providing data on actual levels of fatigue	How would it account for individual differences?	Cost of implementation
				Health benefits		Cost of dealing with reported fatigue
				Improvement in driver engagement		False positives
				Reduced driver turnover		Ability to understand variances
Vehicle	Pre-Crash	Vision	**Mirrors & cameras**	A standard 'drill' for mirrorwork		Task – driving close to the kerb (passenger access)
				Raising awareness in pedestrians and cyclists		Too many things to look at – attention
				Overconfidence in current visibility (show people this) Dispelling myths – drivers 'Exchange places' training - passengers		Cognitive overload
				Improved/easier visibility – makes it easier to 'sell' to drivers		Small size, cheap mirrors, assault screen – perceptual degradation
						Where does camera output go?
						Training needs
						Difficult to set up mirrors in a bus
						Conflicting goals seeing a lot of bus in the mirror and avoid hitting buses
						Assault screen
Vehicle	Crash	Occupant Safety	**Internal design**	Drivers/customer education for 'extra time' to get off bus		Pressure to maintain occupancy – pressure for production
				Better signage re: stairs		Operational – competing needs (e.g. cleanable, hard-wearing seats)
				Empowering bus drivers re: pressure for production		Safety Culture
Vehicle	Crash	Occupant Safety	**Seat belt use**	Raising awareness of other safety features (e.g. airbag) that do not appear in buses		Physically uncomfortable
				Social norming? Everyone wears one in a car		Evidence of effectiveness - to change safety culture
				Penalties for non-use (TfL)		Culture/social norm
						Task incompatibility? Twisting in seat to deal with clients – ergonomics
						Task incompatibility – PA system

Table 7: Summary of barriers and enablers identified by stakeholders at workshop for selection of human countermeasures.

Category	Crash Phase	Group	Countermeasure	Enablers/Opportunities	Open Questions	Barriers/Blockers
Human	Pre-Crash	Improve driver skills/behaviour	Training to improve driver behaviour	Increasing number of controllers during peak times – to lower cognitive workload		Road environment contributing to HF issues
				Technical solution – in-cab blocking of comms with controller (with override?)		Perceived punishment (e.g. losing breaks)
				Replace dedicated training with 'toolbox talks' – regular is important		Safety culture!!
				Telematics, if accepted		Drivers job is safety, controllers job is efficiency
				Monitoring and feedback on basis of incidents – for controllers		If technical solutions can be over-ridden, again this can lead to pressure for production
				Starting the training with what drivers perceive as risks		Speeding – perception that drivers are picking up time
				Bus industry is very good and getting people on training courses – this can help with delivery		People don't accept behaviour training
						Time available for training makes it difficult to fit it in
						Telematics if not accepted – big brother
						Perception of need for training
						Pressure for controllers and drivers to communicate even when driving
Human	Pre-Crash	Improve driver skills/behaviour	Hazard perception training	The idea that 'bus drivers should be the best drivers on the road'	What would the training look like?	Driver may become overly cautious
				Makes driving a more desirable job	What should the outcome be?	Time intensive for drivers
				Tailor training to the bus driver task	How often would it need to be delivered?	
				Could cover impact of hazards on passengers		

Category	Crash Phase	Group	Countermeasure	Enablers/Opportunities	Open Questions	Barriers/Blockers
Human	Pre-Crash	Improve driver skills/behaviour	Better licensing (medical/health related)	Random checks (drugs and drink) leads to fear of detection		Experience overcomes need for change – drivers resist change
				Unions – could be a useful conversation opener		Pressure for production!
				Leadership buy-in		Random checks could be more frequent
				Incentives for medical tests (vision, etc.)		Fatigue – understanding, fear, LAW
						Legal requirements become the standard
						Fear of declaration (fear of losing job)
						Unions – could resist
Human	Pre-Crash	Improve driver skills/behaviour	Public training & education	Highlight good/bad behaviour	Is it just a box tick exercise?	Really difficult to do well
				One key message		Really expensive
				Explain reasons behind bus operations		Doesn't change behaviour
Human	Pre-Crash	Improve driver skills/behaviour	System design to reduce distraction from in-vehicle devices	Find less distracting alternatives (e.g. automation – automate lights on buses)	Include the distracting devices on training buses so drivers can get used to them while training?	Legislation might mandate the devices
				Increases safety		Pressure from GLA to use them
				Better integration of displays		Cost
				A review of the devices in buses and analysis of what is still beneficial		Many different types of buses
				Involve drivers		

The workshop concluded with a summary of the top things that stakeholders would take away as knowledge, and these were:

- Hazard perception training shows promise
- Involve the drivers and unions in the development and implementation of any behaviour changes
- There is no register for PSV drivers and no qualifications for learning how to drive a bus. Bus safety interventions need to consider human factors
- Organisational factors influence the success of behavioural change programmes and should also be considered.

This list can essentially be reduced to the statement that when implementing bus safety measures, individual and organisational human factors need to be considered if effecitveness is to be maximised. The one specific recommendation on the list relates to hazard perception training, and this is expanded below.

5.1.3.1 Hazard perception skill and its importantance as a trainable skill

(Horswill and McKenna, 2004), among others, point out that hazard perception skill (broadly, the skill of anticipating potentially dangerous traffic situations) is the only driving-related skill that has been shown to be related to colliosion risk across multiple studies. The actual term has come to be used by many working in road safety more generally, without attention being paid to the specifics of the definition above. Hazard perception (as defined in the literature on its effectiveness) is not ‘general risk awareness’ or ‘ability to control a vehicle’ in hazardous situations. It is not ‘risk aversion’, and nor is it ‘driving style’.

As pointed out by (Helman *et al.*, 2010) although the measure of interest in indicating the degree of hazard perception skill tends to be ‘time-critical responding’, it is the ability to anticipate hazards that is important – not the possession of fast ‘reactions’; for example in early work on the topic at TRL in the 1970s and 1980s, it was apparent that hazards which gave no clue as to their development (for example, a pedestrian suddenly ‘appearing from nowhere’) do not seem to differentiate between people with greater or lesser levels of hazard perception skill (Grayson and Sexton, 2002). Instead the presence of anticipatory cues is required; for example a pedestrian seen approaching the roadside while distracted or looking in another direction might suggest a potential hazard.

The majority of work on the skill of hazard perception has been concerned with young and novice drivers, who lack this important skill as they begin their driving. Work in the UK has led the world in this regard, and the UK hazard perception test, delivered since November 2002 as part of the driving theory test, has been shown to have reduced some novice driver accidents by as much as 11% (Wells *et al.*, 2008).

The programme of work on which the hazard perception test was based showed that the skill of hazard perception possessed three critical features. Firstly that it can be measured reliably, see (Grayson and Sexton, 2002) for a summary of this work. Secondly that it is related to collision risk (McKenna and Horswill, 1999), (Hull and Christie, 1993), (Quimby *et al.*, 1986); and thirdly that it is trainable (Sexton, Development of hazard perception testing), (McKenna and Crick, 1993), (Crick and McKenna, 1991).

The purpose of the test in GB has so far been to ensure that people only pass their theory test if they possess sufficient hazard perception skill to pass the hazard perception component, but work with young and novice drivers worldwide is now moving to focus on how the skill can best be trained. The ‘missing link’ in hazard perception research is data showing that people actually trained in the skill have fewer accidents as a result. Some preliminary data from the US has shown such an effect for young male drivers, but much remains to be done to establish a full understanding of the skill, and how it can best be trained, even in the user group about which most is known (young and novice drivers).

5.1.3.2 Developing hazard perception training for bus drivers

With the latter point in Section 5.1.3.1 in mind, the development of any bus driver hazard perception training intervention should proceed on the assumption that bespoke research is required, along with the development of bespoke testing and training materials. It is certainly not the case that there is an ‘off the shelf’ training package which has been shown to improve safety in any kind of scientific trial for this road user group.

A number of specific features of bus hazard perception suggest themselves for consideration in any work to research and develop materials.

1) Buses are large, and may require a greater awareness of ‘blind spot’ monitoring to adequately anticipate future hazards than is the case for cars.

2) Drivers will tend to be more experienced than the most-studied group in hazard perception research (young drivers). Although some literature exists on older drivers, this specific group has not, to the authors’ current knowledge, been studied in detail.

3) Passengers on the bus will form part of the hazard space. Because the actions of bus drivers responding to hazards outside the vehicle will impact on standing and seated passengers inside the bus, there will almost certainly be a need to cover this in training and testing materials.

Because of these specific issues, and because of the unique position of hazard perception as a driving-related skill that is actually related to collision risk, it will be important that any attempt to introduce hazard perception training into bus driving training is undertaken with sound research, beginning with a formal literature review which can underpin future development of tests and training materials.

5.2 Aggregated Countermeasures List

The countermeasures for the HVCIS data, police fatal files, and OTS & RAIDS cases have been aggregated into tables. These tables are based on the Haddon matrix, so they cover pre-crash, crash and post-crash groups of countermeasures. In addition some sub-categories are provided for the countermeasures, in order to aid understanding. The countermeasures are also grouped as being for the vehicle (& equipment), human or environment.

The aggregated tables sum up the numbers of cases per countermeasure, which represents the pool of relevant collisions. This is given for the police fatal files, HVCIS and the OTS & RAIDS cases separately. The total cases are then summed if the countermeasure is related to a bus because this is the focus of the Bus Safety Standard. The numbers for vehicles other than buses are also provided for information, but are not included in the total because they are not the focus of this research.

Within those collisions, each countermeasure will have its own effectiveness; i.e. if there are 24 cases for a given countermeasure, that countermeasure may be only 50% effective and so 12 cases might be effected rather than the full 24. The effectiveness of each countermeasure will depend upon many factors. For example, AEB system effectiveness will depend upon the type of sensor used and its performance parameters; if the potential collision with another vehicle is at too great an angle or offset then the AEB system might not be able to detect the threat, or might detect it late, resulting in a reduced effectiveness. Furthermore, the AEB system effect might be limited by human interaction with it. If the driver gives a large steering, braking or acceleration input then the system will not activate; the driver takes priority over operation of the vehicle. However it may be that the driver has a panic response to an AEB warning, and perhaps they might take an inappropriate action (accelerating instead of braking); in that case the AEB system, even though it’s fitted, cannot be effective. So these are simple examples of both system and human reasons why a countermeasure is not likely to be 100% effective. We cannot know the realistic effectiveness without years’ worth of data after a countermeasure has been implemented, and that is not available for most, particularly because many are new to market. The effectiveness indicator given in the aggregated tables therefore provides an estimated effect based on TRL expert opinion, by providing an estimate in bands:

- High (75% or greater)
- Medium (25%-75%)
- Low (less than 25%)

The tables of aggregated countermeasures also provide an average of the effectiveness estimate for some countermeasures based on the feedback received from manufacturers and operators in the questionnaire. Unfortunately the response numbers were very small (four from manufacturers and two from operators). However, it may still be used as an indicator for the purpose of prioritisation for the Bus Safety Standard. Not all countermeasures were included in the questionnaire, so this field is only completed where a response was received (blank indicates lack of information, not a zero effect).

Estimated timescales are provided for each countermeasure, as either in current availability, or for an estimated period in the future. These timescales are a compilation of the responses from the questionnaire from manufacturers (noting that there were only 2), or are an estimate for TRL experts.

Finally a description or definition is provided for all the bus and human countermeasures. This definition should help to provide additional detail for understanding of the purpose and implementation of the countermeasure.

It is worth noting that there were three 'other' countermeasures applied to the police fatal files in addition; however these have been excluded from the aggregated tables that follow because there was no 'other' category in the HVCIS or OTS & RAIDS cases.

(intentionally blank, see next pages for tables of aggregated countermeasures)

Table 8: Vehicle - Pre-Crash phase - ADAS Countermeasures.

There may be multiple countermeasures per case. There may be multiple injured occupants associated with each case.			Count represents one case. Sample is 169 cases with fatality and countermeasure applied for 1999-2008.		Count represents one fatal case. Sample is 48 cases of bus fatality 2009-2014.		Count represents one case. Sample is 35 cases of bus injuries (all severities) 2000-2015.			Bus fatalities count: HVCIS + police fatals files + OTS & RAIDS fatals	High = 75% + / Medium = 25-75% / Low = <25% / TRL Estimate	Effectiveness rating from 1/lowest) to 5/highest based on stakeholder input. Figure is the average of received responses. (blanks were not requested; blanks do not mean zero effect)		Estimated timescale as either current or future.		Timescales, effectiveness indicators, and definitions provided only for bus countermeasures.
			HVCIS		Fatal Files		OTS & RAIDS			TOTAL	Effectiveness Indicator (within target population)*	Effectiveness* (bus manufacturer; 4 responses)	Effectiveness* (bus operator; 2 responses)	Timescale*		
Category	Crash Phase	Countermeasure	Buses	Others	Buses	Others	Buses	Buses (fatal)	Others	Total Fatals		Score out of 5	Score out of 5	Manufacturer responses	TRL Estimate	Definition
Advanced Driver Assistance (ADAS) – both warning and intervention	Pre-Crash	Advanced Emergency Braking System (AEBS)	6	4	1	1	4		2	7	High	4.50	4.00	2018	2018	AEBS combines sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid a collision. The level of automatic braking varies, but may be up to full ABS braking capability. A City system is designed to function in low speed traffic. An Inter-Urban system is designed to work at higher speeds. A pedestrian/cyclist system is capable of responding to pedestrians and cyclists as well as vehicles. Most AEBS work in longitudinal traffic, but the Cross-traffic AEBS can respond to crossing traffic.
		Advanced Emergency Braking System (AEBS) (city/low speed)				1	1			0	High				2018	
		Advanced Emergency Braking System (AEBS) (Pedestrian/cyclist)			24	1	7	2		26	High	3.25	4.00	2020-2026	2018-2020	
		Cross traffic Advanced Emergency Braking System (AEBS)			1	1	11		1	1	High					
		AEBS - Left turn					2			0	Medium	2.75	3.00	2020-2022	2020	AEB system capable of identifying a collision between a bus turning left and pedestrians and cyclists moving along the inside of the vehicle.
		Forward Collision Warning (FCW) (motorcycles only)				1			1	0						If the driver is unresponsive and an imminent collision is detected the system automatically provides a warning to try to bring the driver back into the loop. Note: AEB systems will typically pick up motorcycles in the same situations as cars e.g. mainly front to rear.
		Driver alert for approaching permanent hazard (sharp bend, steep decline)				1				0						Uncertain, not existing now but possible with enhanced GPS maps. Better with live feed to cloud mapping as likely to be available for automated vehicles.
		Anti-lock Brakes (ABS)	4	10					3	4	Low				current	Anti-lock braking system (ABS) uses electronics to detect and prevent wheel lock up. This helps a driver maintain control of a vehicle and prevent skidding, because a car's steering will still work when ABS is engaged. Most vehicles in service will have ABS, coded in older HVCIS data because many vehicles in study were not equipped.
		Electronically controlled Brakes (EBS)	1	9						1	Medium				current	Adds electronic control over the basic pneumatic braking system. Always incorporates ABD and can improve brake response time and the distribution of braking amongst the axles improving stopping distance
		Post impact braking system			1					1	Medium				2018	Post impact braking system uses sensors to identify an impact and then applies the brakes automatically so that the vehicle does not roll or deflect into another collision.
		Electronic Stability Control (ESC) system	1	11		2			4	1	High				2018	Electronic Stability Control (ESC) compares the heading of the vehicle against the steering input and if an oversteer (spin) or understeer is detected then it applies braking to individual wheels to help correct the steering and maintain control.
		Lane Departure Warning (LDW)		4		1			1	0						LDW monitors the position of the vehicle with respect to the lane boundary and issues a warning, when a lane departure is about to occur or when a vehicle has just crossed the lane boundary
		Lane Keep Assist (LKA)	1	12		1				1	Medium				2020	LKA monitors the position of the vehicle with respect to the lane boundary and applies a torque to the steering wheel, or pressure to the brakes, when a lane departure is about to occur to keep the vehicle in the lane.
		Improve Tyre Adhesion		1						0						A range of tyres with different adhesions are available so it would be possible for some increase by effectively banning the bottom end of existing range. However, more substantial changes might require significant development and acceptance that other properties might suffer (e.g. wear or rolling resistance)
		Turning Indicators		2						0						Turning indicators.
		Intelligent Speed Adaptation (ISA) (mandatory)	4	38	1	2				5	High				current	Intelligent Speed Adaptation (ISA) describes a range of technologies designed to aid drivers in observing the appropriate speed for the road environment. ISA can be voluntary the driver is given a warning when their speed is too great but no action taken, or it can be mandatory where the driver's speed selection is physically limited by an ISA system that cannot be switched off.
		Intelligent Speed Adaptation (ISA) (voluntary)			1					1	Low				current	
		Speed-limiter (70mph)	1							1	High				current	System prevents the vehicle from travelling at speed over 70mph.
		System preventing harsh acceleration			1					1	Medium				current	A system preventing harsh acceleration or deceleration would help to reduce this risk of standing occupants falling over.
		System preventing harsh deceleration			2					2	Medium				2022-24	
		Alco-lock	1	12		1				1	High				current	Prevents ignition if driver over limit. Sensed in vehicle compartment or specific device that driver must blow into before starting car.
		Driver Alertness Warning	2	7						2	Medium				current	System either uses camera system to examine blink rate/eyes in general or monitors steering wheel inputs. Warns driver if distraction detected. Future systems are likely to become more sophisticated and effective.
		Fatigue monitoring					1		1	0	Medium				current	
		Traffic Sign Recognition (TSR) (warning only)			1					1	Low				current	Traffic Sign Recognition (TSR) uses a camera in the vehicle to identify road signs such as speed limits, and displays them to the driver to the driver on-board the vehicle.
		Reverse Alarm	2							2	Low				current	An audible warning is issued to other road users, particularly pedestrians and cyclists, when the vehicle is reversing.
		Door Interlock	3							3	Medium				current	Door interlocks ensure that doors cannot open whilst the bus is in motion and may require the brakes to be applied or gear to be in park.

1.1 * For Buses only

Table 9: Vehicle - Pre-Crash phase - Vehicle Condition & Vision Countermeasures.

There may be multiple countermeasures per case. There may be multiple injured occupants associated with each case.	**Count represents one case. Sample is 169 cases with fatality and countermeasure applied for 1999-2008.**	**Count represents one fatal case. Sample is 48 cases of bus fatality 2009-2014.**	**Count represents one case. Sample is 35 cases of bus injuries (all severities) 2000-2015.**	**Bus fatalities count: HVCIS + police fatals files + OTS & RAIDS fatals**	High = 75% + Medium = 25-75% Low = <25% TRL Estimate	**Effectiveness rating from 1/lowest) to 5/highest based on stakeholder input. Figure is the average of received responses. (blanks were not requested; blanks do not mean zero effect)**	**Estimated timescale as either current or future.**	**Timescales, effectiveness indicators, and definitions provided only for bus countermeasures.**

Category	Crash Phase	Countermeasure	HVCIS Buses	HVCIS Others	Fatal Files Buses	Fatal Files Others	OTS & RAIDS Buses	OTS & RAIDS Buses (fatal)	OTS & RAIDS Others	TOTAL Total Fatals	Effectiveness Indicator (within target population)*	Effectiveness* (bus manufacturer; 4 responses) Score out of 5	Effectiveness* (bus operator; 2 responses) Score out of 5	Timescale* Manufacturer responses	Timescale* TRL Estimate	Definition
Vehicle Condition	Pre-Crash	Prohibit Standees	8							8	High				current	Prohibiting standees would reduce the risk of falls. This could be achieved by interior design of the bus to minimise the areas suitable for standing, or with an enforcement scheme.
		Improved occupant safety on stairs (e.g. fall mitigating surface)			1					1	Medium				current	Provision of anti-slip surface to prevent falls whilst moving around the vehicle or standing.
		Eliminate Defects	4	2						4	Medium				current	Represents a maintenance scheme that is 100% successful at avoiding vehicles with any form of maintenance defects from going into service on the public road. Thus an upper ceiling for the potential benefit from improved maintenance.
Vision	Pre-Crash	Appropriate use of lights (not defects)				2				0						Driver dictates, though automated light level sensing could also be used and is available.
		Improve pedestrian and cyclist conspicuity	12			6				12	Medium				current	Improved conspicuity can be achieved through redesign of the environment, improved vision in the vehicle, or by changing the way people dress or behave.
		Improve Conspicuity	1	1						1	Medium				current	e.g. HGV conspicuity type requirements
		Fit improved mirrors (e.g. class V and VI mirrors)			2					2	Medium				current	Fitting front and nearside blind spot mirrors to vehicles that are not equipped with them due either to exemption from regulations or vehicle age.
		Improve Forward Vision	8							8	High				2020-24	Improved visibility via the windows/vehicle structure. Improved indirect vision via cameras mounted around the vehicle.
		Improve direct vision (front)	2		3	1	1			5	High				2020-24	
		Improve direct vision (side)	6		5					11	High				2020-24	
		Improve Vision to Doors	2							2	High				2020-24	
		Camera/sensor systems for detecting pedestrians and cyclists (for large vehicles)			9	1				9	Medium	3.00	4.00	2020	2020	Sensing device (camera/radar) specific for large vehicles to detect other road users in blind spots. Typically lower speed and in traffic in urban areas.

* For Buses only

Table 10: Vehicle -Crash phase – Pedestrians and cyclists, Crashworthiness & Occupant Safety Countermeasures.

There may be multiple countermeasures per case. There may be multiple injured occupants associated with each case.			Count represents one case. Sample is 169 cases with fatality and countermeasure applied for 1999-2008.		Count represents one fatal case. Sample is 48 cases of bus fatality 2009-2014.		Count represents one case. Sample is 35 cases of bus injuries (all severities) 2000-2015.			Bus fatalities count: HVCIS + police fatals files + OTS & RAIDS fatals	High = 75% + / Medium = 25-75% / Low = <25% / TRL Estimate	**Effectiveness rating from 1/lowest) to 5/highest based on stakeholder input. Figure is the average of received responses. (blanks were not requested; blanks do not mean zero effect)**		**Estimated timescale as either current or future.**		**Timescales, effectiveness indicators, and definitions provided only for bus countermeasures.**
Category	**Crash Phase**	**Countermeasure**	**HVCIS** Buses	**HVCIS** Others	**Fatal Files** Buses	**Fatal Files** Others	**OTS & RAIDS** Buses	**OTS & RAIDS** Buses (fatal)	**OTS & RAIDS** Others	**TOTAL** Total Fatals	**Effectiveness Indicator (within target population)***	**Effectiveness* (bus manufacturer; 4 responses)** Score out of 5	**Effectiveness* (bus operator; 2 responses)** Score out of 5	**Timescale*** Manufacturer responses	**Timescale*** TRL Estimate	**Definition**
Pedestrians and Cyclists	Crash	Improved pedestrian secondary safety (relative to current typical level) / pedestrian friendly front	96		13		1			109	Medium	3.00	2.50	2020-26	2020-22	Ensuring that the front of the vehicle is capable of providing a small amount (2-3 cm) of controlled crush in case of a pedestrian impact to soften blow.
		Improved front end design; prevents pedestrian underrun at front - only if not laying down			6		3			6	Medium	3.00	2.50	2020-26	2020-22	A nosecone or shaped front structure (rather than flat) to help deflect pedestrians and cyclists from being dragged down and under the bus, and instead deflects up toward the windscreen and off to the side so that they are not overrun.
		Improved side design; prevents pedestrian underrun	3		6					9	Medium				?	Pedestrians and cyclists knocked to the floor by the bus may subsequently pass under the side of the vehicle and be crushed by structure and/or wheels. This covers any device that prevents them passing under the side
Crashworthiness		Energy-absorbing Front Underrun Protection System (FUPS)	11							11	High				2020	The stiff structures of commercial vehicles like buses do not necessarily align well with the stiff structures of cars such that the crash structures of cars do not work well increasing the likelihood of stiff structures of the bus intruding into the passenger compartment. FUPS are rigid or energy absorbing structures positioned at a height to interact with car structures protecting car occupants.
		Rigid Front Underrun Protection System (FUPS)	6							6	Medium				2018	
		Fit stronger and lower side guards	5							5	Medium				current	Stronger guards at the side of bus/coaches based on truck style chassis. Aims to prevent underrun of vehicles at the sides, because existing side underrun guards are for pedestrians are not strong enough to prevent underrun of cars.
		Improve structural crashworthiness (frontal)		10	1		1	1		2	Medium				2022	Buses do not have to pass minimum standards of crashworthiness and in collisions with other heavy vehicles or fixed objects can suffer high levels of intrusion. Improved frontal crashworthiness would reduce intrusion offering benefits mainly to restrained occupants.
		Improve Side Crashworthiness		7						0						Improved side crashworthiness would reduce intrusion offering benefits mainly to restrained occupants.
		Move External Projections	1	1						1	High				2018	Re-location of external projections around the bus can help to minimise risk of injury, particularly when passing pedestrians and cyclists.
		Airbag		5						0						Improve occupant protection.
		Motorcycle Airbag or Leg Guard		2						0						Intended to be effective in crashes where cars pull out of junctions in front of motorcylists by putting airbag between head and roof rails and keeping legs in position away from impact. Available in prototype and in very limited production, will take time to embed widely
		Prevent Fire		1						0						Fire prevention in materials selection and system design.
Occupant Safety		Improved occupant secondary safety (relative to current typical level)			1		1			1	Medium				2020	General improvements to occupant safety; for example, improved crashworthiness, improved restraints etc.
		Improve Public Service Vehicle (PSV) Internal Design	15	1						15	Medium	3.00	2.50	2020	2020	Design improvements to the interior of the bus to help improve occupant safety. These might include lighting, grab handles, re-positioning of features, cushioning, anti-slip surfaces etc.
		Doors to all 'Open' Exits	8							8	High				current	Adding doors to 'open' exits will help to prevent inappropriate entry/egress of the vehicle. E.g. old routemasters
		Rear Facing Seat	2							2	Medium				current	A rear facing seat will provide restraint to an occupant when the bus is involved in a frontal collision, providing a partial substitute for a seat belt in the most severe collision type.
		Use appropriate Child Restraint		1						0						Child restraints are a proven safety feature.
		Use of available seat belt	4	31	1	2				5	High				current	A three-point belt is a proven occupant safety feature, and increasing fitment and usage will help to minimise injury risk.
		Use Lap Belt	2	1	2					4	High				current	A lap belt is a proven occupant safety feature, and increasing fitment and usage will help to minimise injury risk.
		Use of helmet		7		2				0						A proven safety feature in defined circumstances. Motorcycle helmets effective in much higher speed collisions than cycle helmets which are intended mainly to protect when head falls into collision with floor or similar low speed collisions with vehicles.
		Provide Grab Handles	5							5	Medium				current	Provision of grab handles for occupants might help them to stay standing steadily and reduce the risk of falls in a collision or during harsh braking/acceleration.

1.1 * For Buses only

Table 11: Human - Crash phase – Pedestrians and cyclists, Crashworthiness & Occupant Safety Countermeasures.

There may be multiple countermeasures per case. There may be multiple injured occupants associated with each case.			Count represents one case. Sample is 169 cases with fatality and countermeasure applied for 1999-2008.		Count represents one fatal case. Sample is 48 cases of bus fatality 2009-2014.		Count represents one case. Sample is 35 cases of bus injuries (all severities) 2000-2015.			Bus fatalities count: HVCIS + police fatals files + OTS & RAIDS fatals	High = 75% + Medium = 25-75% Low = <25% TRL Estimate	Effectiveness rating from 1/lowest) to 5/highest based on stakeholder input. Figure is the average of received responses. (blanks were not requested; blanks do not mean zero effect)		Estimated timescale as either current or future.		Timescales, effectiveness indicators, and definitions provided only for bus countermeasures.
Category	Crash Phase	Countermeasure	**HVCIS**		**Fatal Files**		**OTS & RAIDS**			**TOTAL**	Effectiveness Indicator (within target population)*	Effectiveness* (bus manufacturer; 4 responses)	Effectiveness* (bus operator; 2 responses)	Timescale*		Definition
			Buses	Others	Buses	Others	Buses	Buses (fatal)	Others	Total Fatals		Score out of 5	Score out of 5	Manufacturer responses	TRL Estimate	
Improve driver skills/behaviour	Pre-Crash	Better licensing (reduce exposure to specific high risk situations)	8	4			8		9	8	Low				current	A driver training program can cover many aspects of the driving activity, including hazard perception, rules of the road, etc. Licensing encompasses the driver training.
		Better licensing (medical/health related)	1			1				1	Medium				current	A medical review and assessment scheme can help to ensure that drivers are physically and mentally fit enough to drive.
		Public Training/Education	4	1						4	Low				current	A public training / education scheme can cover many aspects, including safety on buses, alighting and leaving buses, blindspots etc.
		Training or education to reduce other risky behaviours while driving (e.g. seat belt wearing)			1	2				1	Low				current	Training or education schemes aimed at improving driver skills or prevent risky behaviours.
		Training or education to reduce risky driving manoeuvre			1	6	4			1	Low				current	
		Training or education to reduce risky pre-driving behaviour (e.g. drink or drug use)				1				0						
		Training to improve hazard perception skill			7	16	16	3		10	Low				current	
		System design to reduce distraction from in-vehicle devices			1					1	Low				current	Systems that prevent inappropriate use of devices, or that monitor driver attentiveness.
Enforceme nt	Pre-Crash	Add speed camera at locus				1				0						

* For Buses only

Table 12: Environment – Pre-Crash phase – Signage, Road surface condition, Road layout, and Roadside Countermeasures.

There may be multiple countermeasures per case. There may be multiple injured occupants associated with each case.			Count represents one case. Sample is 169 cases with fatality and countermeasure applied for 1999-2008.		Count represents one fatal case. Sample is 48 cases of bus fatality 2009-2014.		Count represents one case. Sample is 35 cases of bus injuries (all severities) 2000-2015.			Bus fatalities count: HVCIS + police fatals files + OTS & RAIDS fatals
Category	**Crash Phase**	**Countermeasure**	**HVCIS**		**Fatal Files**		**OTS & RAIDS**			**TOTAL**
			Buses	**Others**	**Buses**	**Others**	**Buses**	**Buses (fatal)**	**Others**	**Total Fatals**
Fit/improve signage	**Pre-Crash**	Separate signal phases for cyclist's direction and oncoming right turners				2				0
		Add Road Sign					1		1	0
		Improve sign positioning (height, location)	5		1	1	1			6
		Change the layout/position of traffic light posts to make it better defined which lights are for which junction.				1				0
		Redesign signals to for clarification.				2				0
Improve road surface condition		Improve road surface friction				1				0
		Improve surface topography (pot-holes or defects)				1				0
Improved road layout/design		Add pedestrian crossing (if in urban area and appropriate)				2				0
		Relocate pedestrian crossing 20m further along to point known to be a desired line for pedestrians.				1				0
		Improve crossing facilities	31							31
		Provide cycle lane	4							4
		Provide/improve street lighting	7							7
		Repair street lighting defects in a timely manner.				2				0
		Repositioning of the Bus stop					1			0
		Prevent parking near junctions/bus lane			1		1			1
		Improve junction layout	7							7
		Improve road layout	7	1						7
		Redesign to improve junction visibility (if permanent obscurations)			1		3	1		2
		Improve sight lines (change junction design)			1					1
Vehicle has struck an object/ roadside furniture or run off the road		Add appropriate barrier			1					1
		Make hazard passively safe				1				0

* For Buses only

(page is intentionally blank, see next page for analysis of countermeasures)

5.3 Analysis of countermeasures

5.3.1 Bus countermeasures

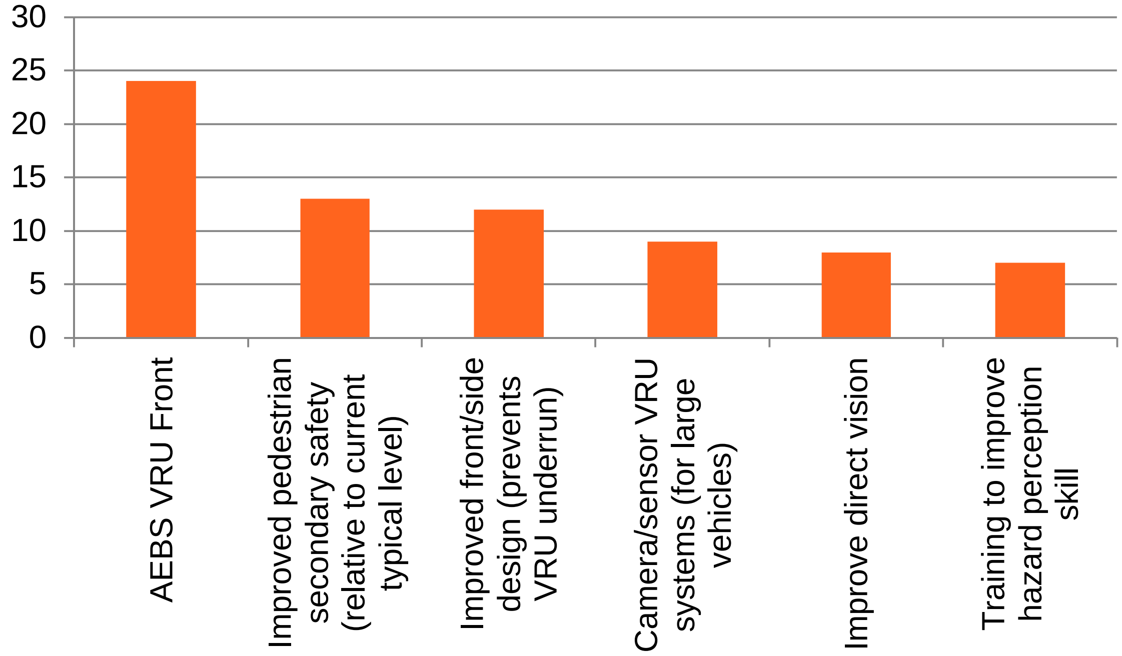
There are two primary mechanisms of injury for pedestrians in bus collisions:

- Head impacting the windscreen / A-pillar / wipers inducing severe head trauma, often followed by impact with the ground (noting that it can be difficult to differentiate between the two),
- Catastrophic crush and shear injuries when pedestrians pass under the bus.

Therefore, the associated countermeasures for buses are summarised in Figure 23, for the top six most frequent countermeasures in the police fatal files. It is very important to note that the assignment of countermeasures was an indicator of potential effect; it was not designed to represent the precise expected performance of a given system. For example, AEB systems have a range of different sensors, each with different operating parameters and effects, and then each is implemented on vehicles differently; the counts do not represent these precise systems, more a flag that an idealised AEB system had the potential to improve the outcome of the collision.

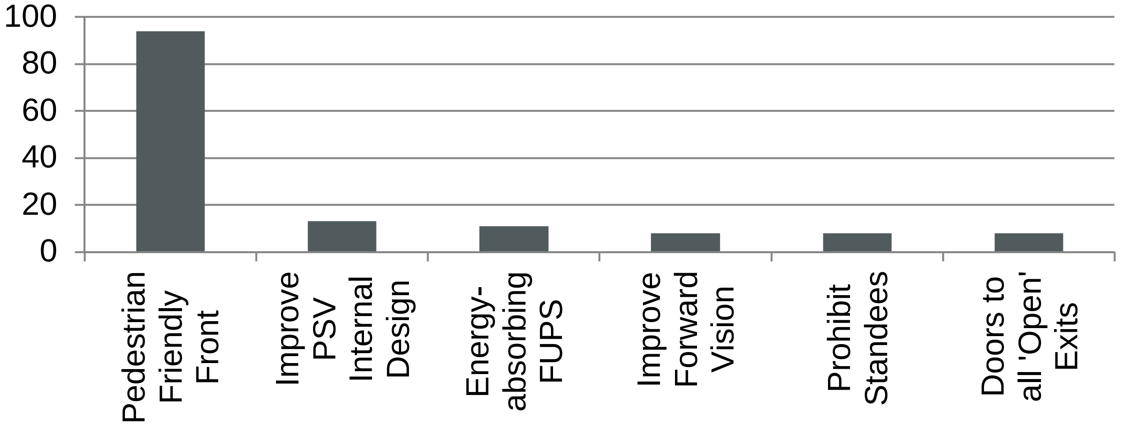
AEBS for pedestrians and cyclists at the front of buses had the highest frequency. If this is grouped with the camera/sensor systems for detecting pedestrians and cyclists and improved direct vision, which are related in terms of identification/vision of pedestrians, then this group is the largest by far. The next most frequent group is the secondary safety improvements, achieved by combining the improved pedestrian secondary safety and improved front/side design, which also accounted for a very large group of the countermeasures assigned. Overall this brings a clear message that improving the ability for the bus (driver) to identify a pedestrian hazard, and to improve the secondary safety are the two highest priorities for the Bus Safety Standard.

Figure 23: Summary of top 6 most frequently assigned bus countermeasures. Source data: police fatal files.



The HVCIS data also confirmed that protection of pedestrians and cyclists in the event of a collision would be of benefit, as shown in Figure 24 where the pedestrian friendly front structure is the most frequently assigned countermeasure. It is worth noting that AEB for pedestrians and cyclists does not appear in the HVCIS top 6; but this is primarily because it was a not a technically feasible option at the time of the data collection for HVCIS.

Figure 24: Summary of top 6 most frequently assigned bus countermeasures. Source data: HVCIS.



It is also possible to compare the most frequently occurring countermeasures in the police fatal files, HVCIS and OTS & RAIDS datasets. However, the data sets vary in their relevance to modern TfL buses operating in London and in their statistical power, so it is important to give more weight to the more relevant and robust studies. In total, from all the datasets, there were 409 countermeasures applied to bus fatality cases. However, the vast majority are from the HVCIS due to its size; 301 from HVCIS, 101 from the police fatal files and 7 from the OTS and RAIDS cases. The advantage of the HVCIS data is the volume of data available; however it is an older dataset and could only be limited to urban crashes (not London ones). Therefore the counts for the HVCIS have been scaled down to bring the totals for HVCIS and the police fatal files to an even weighting, which was by approximately two thirds. The counts for the police fatal files were not scaled because they represent London and are a more recent dataset. The OTS and RAIDS counts were scaled to 75% because that dataset, while it is current in comparison to HVCIS, represents urban collisions outside London. This weighting of data allows a more balanced comparison between the datasets in order to generate a view of the most frequently occurring countermeasures for bus fatalities.

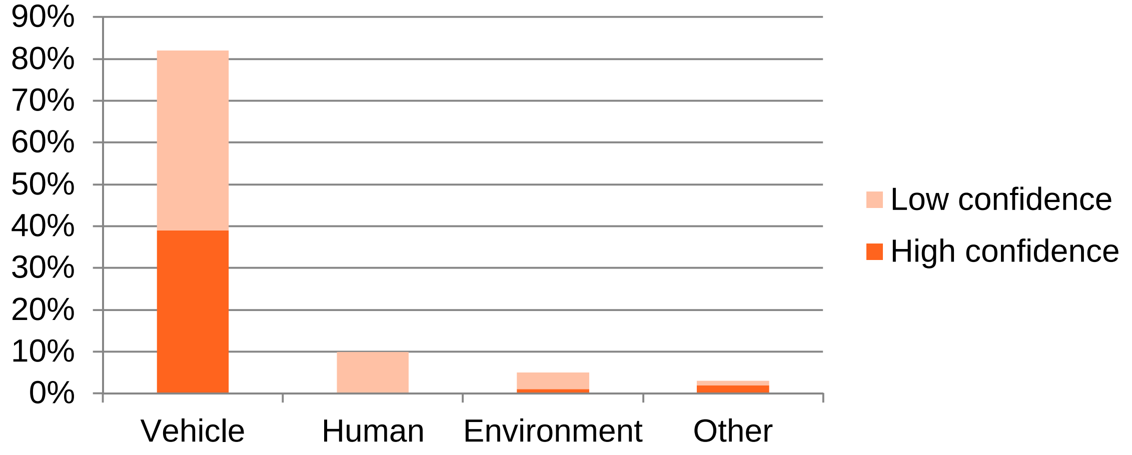
Figure 25 describes the top ten list of countermeasures after the scaling was applied. This shows that AEB for pedestrians and cyclists and Improved pedestrian secondary safety (pedestrian friendly front end) were the most frequent countermeasures that had been applied. In total, this top ten list accounts for two thirds of all the countermeasures applied.

Figure 25: Top ten bus fatality countermeasures from scaled aggregated datasets. Data source: HVCIS, police fatal files, OTS & RAIDS.

Group	Crash Phase	Category	Countermeasure	Scaled %
Vehicle	Pre-Crash	ADAS	**Advanced Emergency Braking System (AEBS) (Pedestrian/cyclist)**	12.3%
Vehicle	Pre-Crash	ADAS	**Camera/sensor systems for detecting pedestrians and cyclists (for large vehicles)**	4.3%
Vehicle	Pre-Crash	Vision	**Improve direct vision (front & side)**	6.5%
Vehicle	Pre-Crash	Vision	**Improve pedestrian conspicuity**	1.9%
Vehicle	Crash	Crashworthiness	**Energy-absorbing Front Underrun Protection System (FUPS)**	1.8%
Vehicle	Crash	Occupant Safety	**Improve Public Service Vehicle (PSV) Internal Design**	2.4%
Vehicle	Crash	Pedestrian and cyclist	**Improved pedestrian secondary safety (relative to current typical level)**	21.8%
Vehicle	Crash	Pedestrian and cyclist	**Improved front/side design (to prevent pedestrian underrun)**	6.3%
Human	Pre-Crash	Improve driver skills/behaviour	**Training to improve hazard perception skill**	4.5%
Environment	Pre-Crash	Improved road layout/design	**Improve crossing facilities**	5.0%
			Total	**66.8%**

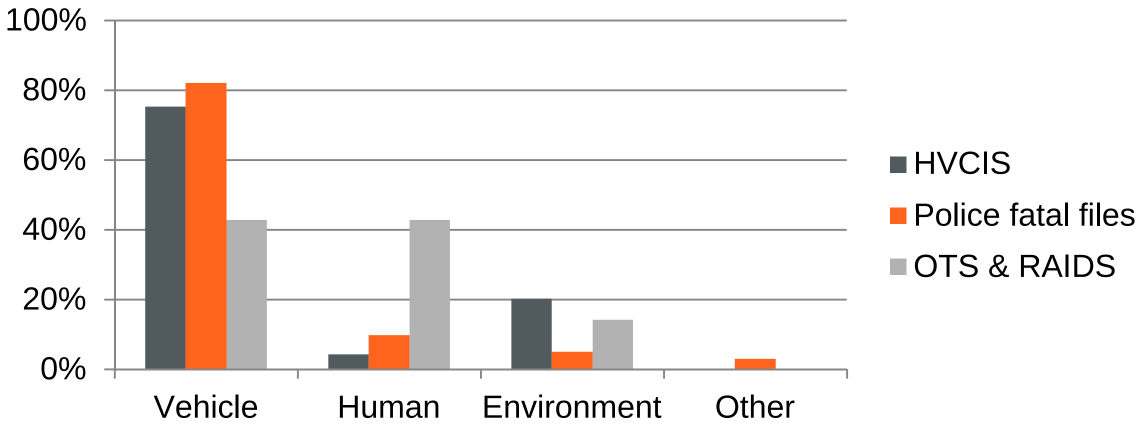
Overall, the countermeasures were also categorised as human, vehicle, environment, or other. Each countermeasure for the police fatal files was also given a confidence level (low or high) indicating how confident the investigator was of the effect of the countermeasure. For the police fatal files the countermeasures are summarised by category and confidence level in Figure 26 below.

Figure 26: Bus countermeasures by category and confidence level. Source data: police fatal files.



The bus countermeasures per category are also compared between the three datasets (HVCIS, police fatal files, and OTS & RAIDS cases) in Figure 27. This shows that there is reasonable agreement between the data sources that vehicle countermeasures are the largest group. The main difference is that there is a fairly even split between vehicle and human countermeasures in the OTS & RAIDS cases. The environment countermeasures are fairly infrequently applied in all data sources.

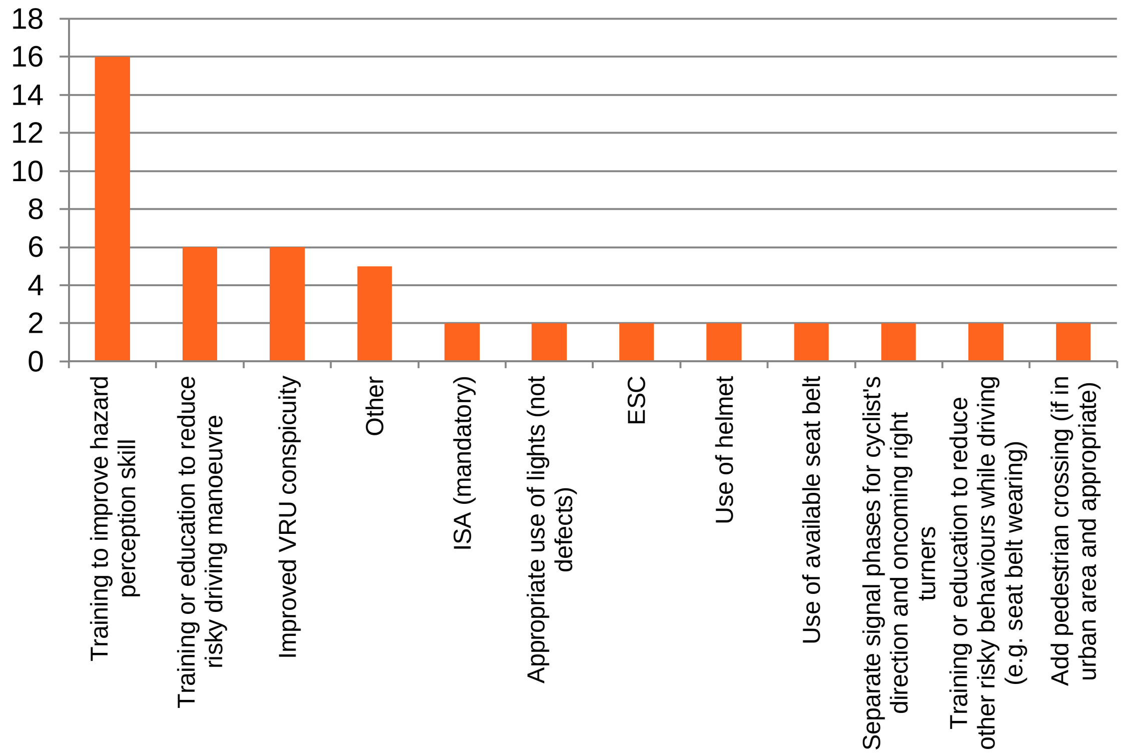
Figure 27: Bus countermeasures by category. Source data: HVCIS, police fatal files, OTS & RAIDS.



5.3.2 Other road user countermeasures

Considering the countermeasures for the other roads users as identified from the police fatal files, the analysis reveals that the most frequently applied countermeasure is training to improve hazard perception skill, as shown in Figure 28 which is using the raw unscaled counts of countermeasures. After that there is a fairly large group of countermeasures that were assigned with relatively even frequency. Training is a theme throughout the countermeasures, as is proper use of safety systems such as seat belts, helmets etc. Note that there were also many countermeasures assigned to only one case each, but these have been excluded from the figure.

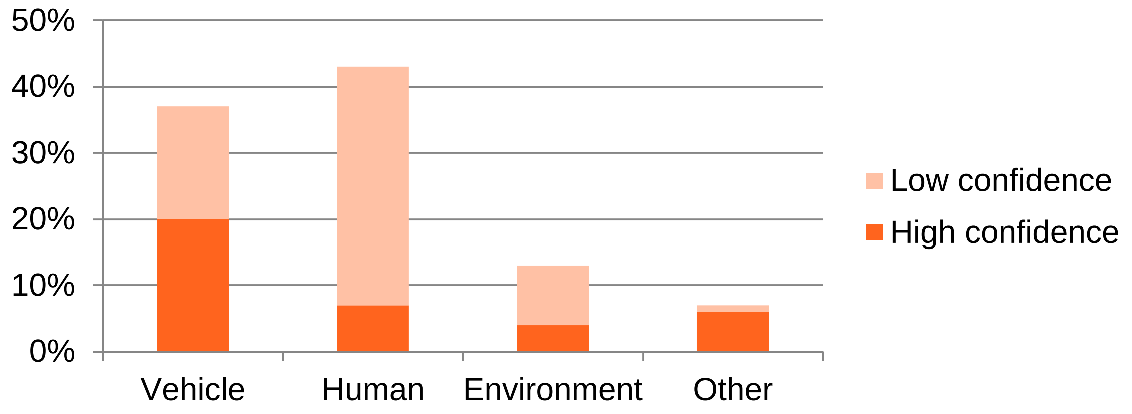
Figure 28: Summary of other road users' countermeasures.



The categories of the countermeasures (vehicle, human or environment) are summarised in Figure 29 below for the police fatal files, which also provides a summary of the level of confidence in the countermeasure's effectiveness as either high or low. The human countermeasures were the most frequent for the other road users, although mainly with low confidence. The countermeasures with the highest confidence were the vehicle related countermeasures. The 'other' countermeasures were mainly environment related and included:

- Better maintenance of existing street lights (3 defective at locus).
- Relocate pedestrian crossing 20m further along to the point where V2 & V3 crossed as this is known to be a desired line for pedestrians.
- Change the layout/position of traffic light posts to make it better defined which lights are for which junction.
- Repair street lighting defects in a timely manner.
- Although pedestrian light was red, road signed 'look right' and sign ahead stated same, its possible pedestrian thought pedestrian green light for adjacent carriageway meant safe to cross busway or saw green man on an adjacent arm.

Figure 29: Other road user countermeasures by category and confidence level. Source data: Police fatal files.



5.3.3 *Combined countermeasures*

The HVCIS dataset is different from the others in that it has an ability to identify a countermeasure that should be used in conjunction/combination with another/multiple countermeasure(s). There were 13 HVCIS cases where this ‘in conjunction with’ feature has been used for the countermeasures, and these are shown in Table 13. These are interesting because it gives some indication of how, from an engineering perspective, the countermeasures could be combined to give a better effect. For example, the intelligent speed limiter is applied in one case, but in combination with a pedestrian friendly front end for the bus; showing that a pre-crash countermeasure can be combined with a crash phase countermeasure where the pre-crash measure cannot fully avoid the collision, merely reduce the collision speed. There is one case where three countermeasures are applied in combination, which are all related to vision/lighting: improving pedestrian conspicuity, providing street lighting and improving lighting.

Table 13: HVCIS countermeasures in conjunction with other countermeasures. Source data: HVCIS.

Countermeasure	In conjunction with Countermeasure	In conjunction with Countermeasure	Buses count	Notes
Fit Electronic Brakes	Fit Anti-lock Brakes	NB, Indicates the age of the HVCIS sample	1	
Improve Driver Training	Fit Anti-lock Brakes		1	
Pedestrian Friendly Front	Fit Anti-lock Brakes		1	These two are both combining countermeasures from the pre-crash and crash phases
Pedestrian Friendly Front	Fit Intelligent Speed-limiter		3	
Improve Forward Vision	Improve Side Vision		1	
Prohibit Standees	Improve PSV Internal Design		1	
Use Lap Belt	Provide Grab Handles		1	
Improve PSV Internal Design	Provide Grab Handles		1	
Provide Street Lighting	Improve pedestrian conspicuity		1	These two are very similar
Improve pedestrian conspicuity	Provide Street Lighting	Improve Lighting	1	
Improve signage	Improve Crossing Facilities		1	

5.4 Prioritised List of Countermeasures

From the top ten countermeasures in Figure 25, it is possible to identify those that will have the greatest opportunity to affect bus collisions, i.e. those with the greatest frequency. The shortlist of the top ten was created by identifying those vehicle countermeasures with the highest combined count of fatalities from the police fatal files, HVCIS, RAIDS and OTS cases. The older and larger datasets were used in order to provide volume to the analysis, and to balance any risk posed by relying on the very small sample of the police fatal files. The effectiveness was considered as well as the frequency of the assigned countermeasures, by only including those measures that are anticipated to have medium to high effect. The top ten was then ordered by the frequency count for the police fatal files, as being the most relevant to London for the sake of the TfL BSS. This prioritised list is as follows in Table 15.

At the top of the priority list of countermeasures is AEBS for pedestrians and cyclists. This has the highest count of relevant fatalities from the police fatal files and is anticipated by the Experts Steering Group and stakeholders to have high effectiveness. However, it is important to note that for HVCIS, AEBS was not defined as a specific countermeasure, only as a generic ‘collision avoidance system’; for the purposes of this analysis, these cases have been treated as AEBS. HVCIS is likely to have proportionally lower numbers against AEBS than other more modern databases, mainly due to lack of familiarity with the system on the part of the coders at that time because AEBS was relatively new, and because AEB for pedestrians and cyclists was not technically feasible at that time.

Some stakeholders raised concerns about the consequences for unrestrained and standing bus passengers in the case that AEBS were activated and braking applied (whether that be AEBS in response to a vehicle or a pedestrian). If there are standing passengers then they would be at risk as described in the simplified scenarios in Table 14. It is also important to note that in the analysis of the 48 police fatal files for London bus collisions, in the vast majority of cases the person who was fatally injured was the only person injured in the collision. It is very important that AEBS is developed with a focus on minimising false activations.

There are different types of AEBS that deploy different levels of braking and different onset rates. It should be possible to tune the algorithms for AEBS on buses to optimise collision prevention and mitigation against the need to avoid false positives, and perhaps with earlier onset more gradual braking to help minimise the risk to standing passengers. The argument about AEBS potentially causing risk to standing passengers might also be alleviated if AEBS came as a package of measures that also aimed to make the inside of buses softer and less hostile to falling passengers (e.g. soft stanchions, grab rails etc, rubberised floor). This point is highlighted in Table 15 by arrows connecting the AEBS with the bus interior design countermeasures.

Table 14: Simplified scenarios describing risk to standing passengers in bus collisions.

	Scenario	Risk to standing passengers	Notes
1	Normal driving	Very low	In normal driving standing passengers will naturally brace themselves to the movement of the bus
2	The driver braked to try to avoid a collision (whether with a pedestrian or vehicle)	Yes	Driver is taking correct action
3	The bus suffered an impact with a vehicle	Yes	Deceleration in an impact might pose a risk to standing passengers
4	AEBS braking was activated	Yes	Whether mitigation or avoidance
5	The driver braked post-impact with a pedestrian/cyclist	Yes	A common reaction is to brake post-impact
6	The bus suffered an impact with a pedestrian/cyclist, with no post-impact braking	Very Low	Unlikely to occur often, see scenario 5. Drivers are required to stop after a collision
7	AEBS warning was falsely deployed	Very Low	Drivers will assess the situation and ignore the warning
8	AEBS braking was falsely deployed	Yes	This is the only scenario where braking would not otherwise have occurred

AEBS for pedestrians and cyclists and passive protection, or pedestrian friendly front end design, could also be complementary, although not in the same way as for passenger cars. Passive protection is only effective up to 40km/h, but car collisions happen at higher speeds e.g. up to 60km/h. AEBS can mitigate the severity of a 60km/h pedestrian crash to a 40km/h collision, but it can't completely avoid a 60km/h crash. Bus to pedestrian crashes are almost all at less than 40km/h so AEBS can potentially avoid some collisions and passive protection can also work on those same collisions; making these, theoretically, duplicates. However, AEBS works well on central impacts, but is less effective on those nearer the corners, so there might be an argument for combining AEBS with passive protection around both edges of the front of the bus. This is highlighted in Table 15 with the arrow linking the two countermeasures, which notes that the two countermeasures should be optimised to complement, and not to duplicate each other. This linking of countermeasures is building on the approach used by experts in the HVCIS, who identified countermeasures to be used in conjunction with others. The pairings are the not the same in this priority list of the Bus Safety Standard as those identified in HVCIS, but the engineering approach is the same.

As found in the collision analysis (see Appendix A.5) the pedestrians are most frequently approaching from the nearside, and there is very little time for the driver to react, however 40% of the police pedestrian fatalities had a time to collision greater than one second. In collision investigation it is typically considered that driver reaction times are in the range of 0.75 to 2 seconds and the bus will additionally take a finite amount of time to stop once the driver has applied the pedal. Thus, in principle a warning might help a driver who was distracted such that they didn't see the pedestrian move off the kerb, but who then reacted at the faster end of the spectrum expected. In other words, an AEB system that can reduce the reaction time using automation fundamentally has more potential for avoiding or mitigating the severity of pedestrian fatalities than a warning system.

In the development of AEBS for cars, the AEBS capable of responding to the rear of a car and the AEBS capable of responding to pedestrians and cyclists have been developed in close succession. In general on cars, the AEBS for pedestrians and cyclists can also respond to vehicles, and is seen as the more sophisticated system.

The top ten identified in section 5.3.1 included some measures that are not included in the prioritised list for the Bus Safety Standard. These are:

- Improve pedestrian conspicuity; out of scope of the BSS
- Training to improve hazard perception skill; shows promise although further research is needed, and is out of scope of the BSS
- Improve crossing facilities; out of scope of the BSS

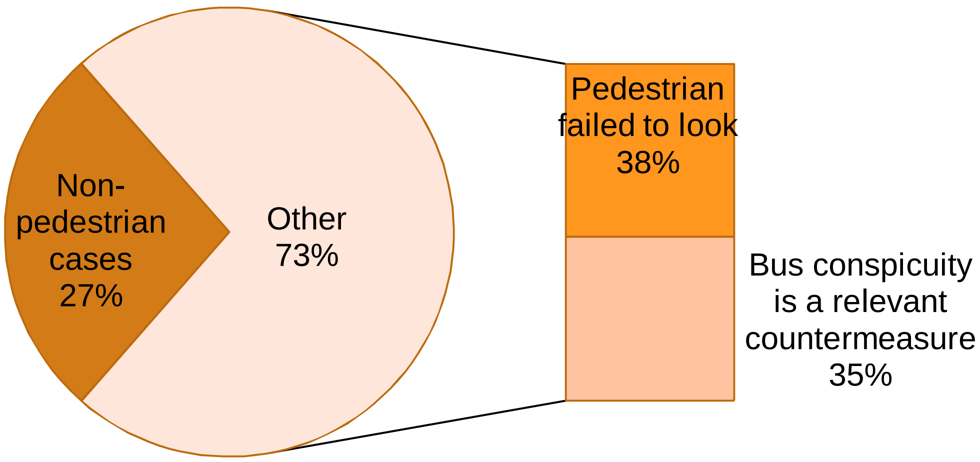
ISA is a countermeasure included in the priority list despite it not showing in the top 10 based on the bus fatalities analysis. This is because it has a high effectiveness indicator, and because it is being reviewed for implementation into the General Safety Regulation; more importantly because it might have benefits for air quality, fuel consumption and greenhouse gas emissions too. TfL is already delivering a program of research around ISA for Buses, based on commitments already in place; this research includes a TRL project to develop a specification (as yet unpublished).

The prioritised list in Table 15 includes a "Notes" column covering any regulatory aspects, additional information, and highlighting any combinations of countermeasures.

Automated Emergency Steering (AES) is a system that offers some promise for avoiding or mitigating pedestrian collisions at the front corners of the bus. Pedestrians crossing from the nearside with a small overlap are the most frequent scenario for pedestrian fatalities in bus collisions. However, this countermeasure was not coded by the investigators at the time, so it is difficult to quantify the potential benefit in the same way as others on the list. The system is very new to the car market, and we might expect implementation on buses to take at least several more years. AES is therefore perhaps a system to monitor in development for cars, and then consider for a second phase of the Bus Safety Standard.

Improved bus conspicuity might help to avoid or mitigate collisions. This countermeasure might include adding brighter or more reflective colours, adding lighting, even adding sounds etc; it could include any feature that might draw the attention of a pedestrian to the bus. An existing example would be the bus conspicuity measures on school buses in the USA. Bus conspicuity was not coded as a countermeasure by the investigators and therefore hasn't been included in the aggregated tables or priority list. However, we might assume that for any pedestrian collision, increased bus conspicuity would help, but that would be an overestimate since in 18 of 35 (about half) pedestrian deaths in the police fatal files had 'failed to look' recorded for the pedestrian. If the pedestrian does not look at all, then increased bus conspicuity cannot help. However, it still would be relevant for 17 (35%) of the police fatal files (as in Figure 30) and therefore this measure has been included on the priority list, especially because it could be implemented immediately without waiting for technological developments. Additionally, if changes are made to bus conspicuity at the front of the bus this might also affect pedestrian friendly front end design, so these two measures are also combined.

Figure 30: Estimation of relevant pool of police fatal files for bus conspicuity. Source: Police fatal files



The stiff structures of commercial vehicles like buses do not necessarily align well with the stiff structures of cars. The result in a collision is that the crash structures of cars do not work well, and there is increased likelihood for the stiff structures of the bus to intrude into the passenger compartment. Energy-absorbing Front Underrun Protection System (FUPS) are energy absorbing structures positioned at a height to interact with car structures protecting car occupants (they may also be in a rigid form). Energy-absorbing FUPS is included in the priority list on the basis of the number of times it was identified as a countermeasure in HVCIS, although it does not appear as a countermeasure in the police fatal files. This is perhaps due to the small sample size of the police fatal files and might be down to chance. However it might be that underrun is not such a problem on London's roads, or that the modern London buses often have a low floor that aligns with vehicle structures. Therefore this countermeasure was moved to the lowest position in the list, tenth; and further research on this topic is recommended before implementation into the BSS.

Table 15: Prioritised List of Countermeasures for Bus Safety Standard.

Countermeasure	Target Population	Effectiveness	Available	Notes
Advanced Emergency Braking System (AEBS) for pedestrians and cyclists	24 (police fatal files)	High (3.25 from operators, 4 from manufacturers)	2018	Buses designed for standing passengers are currently exempt from regulation.
Bus conspicuity	17 (estimate; police fatal files)		Current	Not coded by investigators, but estimated based on collision data.
Pedestrian Friendly Front End	93 (HVCIS) 13 (police fatal files)	High (3 from operators, 2.5 from manufacturers)	2020/22	Should be optimised to complement, not duplicate. AEBS for pedestrians and cyclists will help for pedestrian collisions in the middle of the bus front; so pedestrian friendly front should focus on the corners of the bus for softness and deflection out of path
Improved front/side design (to prevent pedestrian underrun)	3 (HVCIS) 12 (police fatal files)	Medium (2.5 from operators, 3 from manufacturers)	2020-22	
Camera/sensor systems for detecting pedestrians and cyclists	9 (police fatal files)	Medium (3 from operators, 4 from manufacturers)	2020	AEB technologies for the same areas might be more effective, but were not directly assessed by the coders. Further technical sophistication may be needed so implementation would be later. Under review for EC regulatory requirement for all M3 vehicles to have camera and detection: 01/09/2020 new approved types, 01/09/2022 for new vehicles
Improve Direct Vision (front and side)	8 (police fatal files)	High	2020-24	Under review for EC regulatory requirement for all M3 vehicles to have improved direct vision: 01/09/2028 for new approved types; No new vehicles date foreseen due to impact on overall truck cab designs
Advanced Emergency Braking System (AEBS) to other vehicle rear	1 (police fatal files)	High (3.25 from operators, 4 from manufacturers)	2018	Buses designed for standing passengers are currently exempt from regulation.
Bus interior design	15 (HVCIS) 1 (police fatal files)	Medium (3 from operators, 2.5 from manufacturers)	2020	Should be packaged to complement AEBS to mitigate any adverse effect of false positives; prevention of frequent minor injuries is an operator priority. Likely to be particularly important for reducing slight injuries. Top priority because two thirds of casualties occur without a collision.
Intelligent Speed Adaptation (ISA)	6 (HVCIS) 1 (police fatal files)	High	2018	Under review for EC regulatory requirement for all M3 vehicles: 01/09/2020 new approved types, 01/09/2022 for new vehicles
Energy-absorbing Front Underrun Protection System (FUPS)	11 (HVCIS)	High	2020	

5.5 Summary of analysis of countermeasures

From discussions at the Experts' Steering Group the countermeasures considered to be most suited to the collision types identified in the police fatal files are:

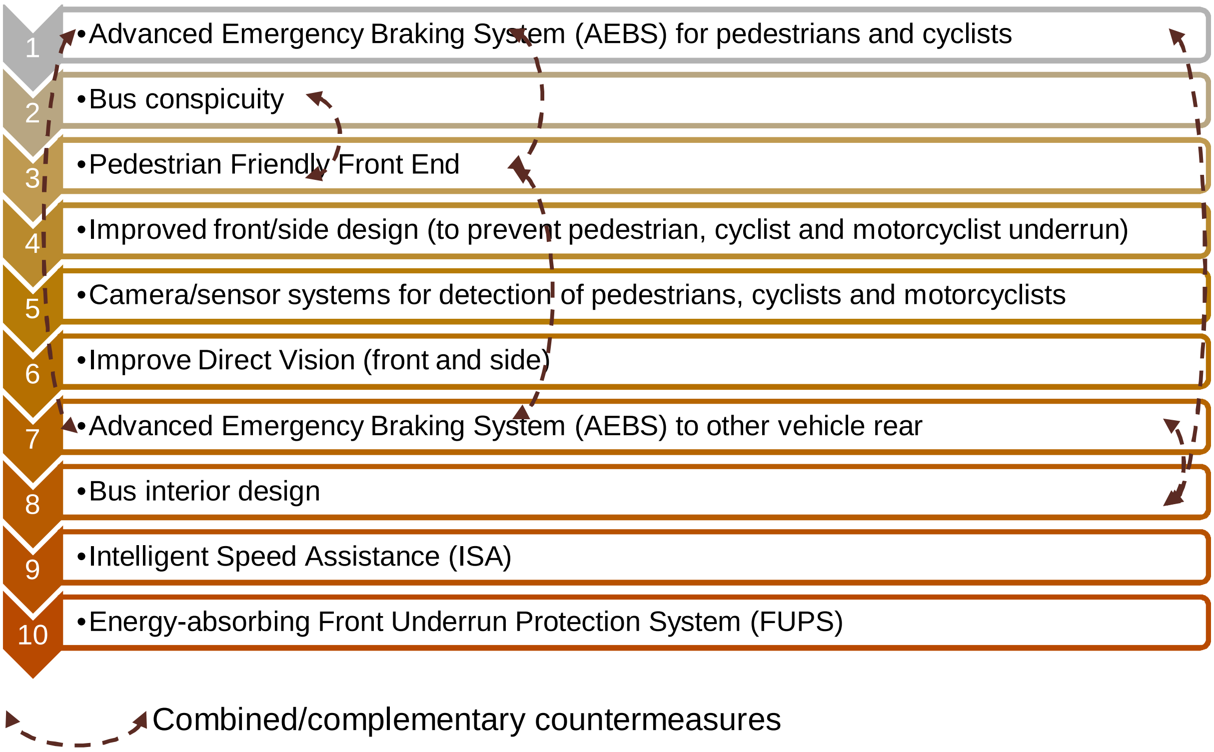
- AEB for pedestrians and cyclists (for frontal impact scenarios)
- Improved bus occupant safety
- Improved frontal structures

Stakeholder input via a questionnaire and a workshop has provided some useful insight into the enablers and barriers to implementation for many of the countermeasures. For example, there was strong concern about AEBS applying braking to avoid a pedestrian, but causing injury or even fatality to possibly multiple standing occupants on board the bus. Although in most collisions the bus will be braking anyway, whether driver braking prior to or affect impact or deceleration during the impact, so the risk to bus occupants is unavoidable; perhaps the biggest risk of additional casualties would be from false activations of AEBS.

A key finding from the human factors and behaviour change workshop was that hazard perception training shows some promise, but that the drivers and unions need to be involved and supportive of any behaviour change program. The Advanced Driving Instruction program should also consider human factors in order to best support bus drivers. Further research is needed into the field of hazard perception training.

The countermeasures identified in the police fatal files, HVCIS and OTS & RAIDS cases were compiled into aggregated countermeasures tables, following the Haddon matrix approach. This gave an indication of the total number of cases that might be affected by a given countermeasure. A scaling was applied to the counts for each dataset in order to make them more comparable, and then a top ten countermeasures list was generated by selecting the highest frequency measures and those with medium/high effectiveness. This top ten, along with some expert input from the Steering Group, was used to generate a prioritised list of countermeasures for the Bus Safety Standard based on the frequency of the police fatal files from London (the most relevant dataset for TfL). The highest priority measure is AEBS for pedestrians and cyclists, since the highest frequency of fatalities is pedestrians The priority list includes some notes of where countermeasure should be developed together, in order to harmonise performance for the greatest casualty saving effect. For example AEBS should be developed in conjunction with improved internal bus design, in order to protect the occupants on board should a braking event occur; and alongside pedestrian friendly front end design in the event that a collision is unavoidable due to a very short reaction time.

The priority list represents the top ten recommendations of bus coumtermeasures for the BSS, including those measures that are combined or inter-related, and is summarised below:


1
•Advanced Emergency Braking System (AEBS) for pedestrians and cyclists
2
•Bus conspicuity
3
•Pedestrian Friendly Front End
4
•Improved front/side design (to prevent pedestrian, cyclist and motorcyclist underrun)
5
•Camera/sensor systems for detection of pedestrians, cyclists and motorcyclists
6
•Improve Direct Vision (front and side)
7
•Advanced Emergency Braking System (AEBS) to other vehicle rear
8
•Bus interior design
9
•Intelligent Speed Assistance (ISA)
10
•Energy-absorbing Front Underrun Protection System (FUPS)
Combined/complementary countermeasures

6 Conclusions

6.1 Bus Collision Types

The analysis of bus collisions has examined a variety of data sources, including Stats19, 48 police fatal files, HVCIS, and case summaries from OTS and RAIDS. This has contributed to a detailed picture of bus collisions happening in London, and analysis summarising the findings has been generated:

1) In a European context, bus collisions have reduced by almost 50% in the period 2005 to 2014.
2) Comparing fatalities per billion vehicle kilometres travelled, the group comprising cars, taxis and vans have one-fifth of the risk compared to buses; however exposure and usage differences are likely to be important factors in this difference.
3) GB statistics show that casualties from bus collisions are reducing; fatality reduction on London's buses is only fractionally less than nationally. When only London is considered, the reduction in casualties from collisions involving buses is much less (13%) than for the national equivalent (38%).
4) In bus collisions, occupants of the bus are the most frequently injured casualties.
5) According to Stats 19 over two-thirds of the injuries on buses occur without a collision. IRIS data from TfL indicates that 76% of injuries are onboard injuries.
6) Pedestrians are the most frequent bus fatalities accounting for around two thirds of the fatalities in London.
7) Pedestrians are most often killed by buses when crossing the road, and most often in collisions with the front of the bus crossing from the nearside. The time to collision is often very low (less than a second), but in about 40% of the police fatal files the pedestrian became visible more than 1 second before impact; potentially within scope of AEB.
8) Car occupants are also most often killed in impacts at the front of the bus; belt usage by the car occupant is an important factor for these crashes.
9) Human and environmental factors were the most frequent causation factors.
10) In over half the police fatal files assessed, the bus driver was not assigned a precipitating factor because the pedestrian entered the carriageway without due care. However in other cases the drivers failed to avoid a pedestrian/object/vehicle or failed to stop.
11) Loss of control of the vehicle was the biggest precipitating factor for the car occupant fatalities in the police fatal files.

6.2 Bus Collision Countermeasures

There are a variety of countermeasures designed to help avoid or to mitigate the severity of injury in bus collisions and these can be active in any of the crash phases;

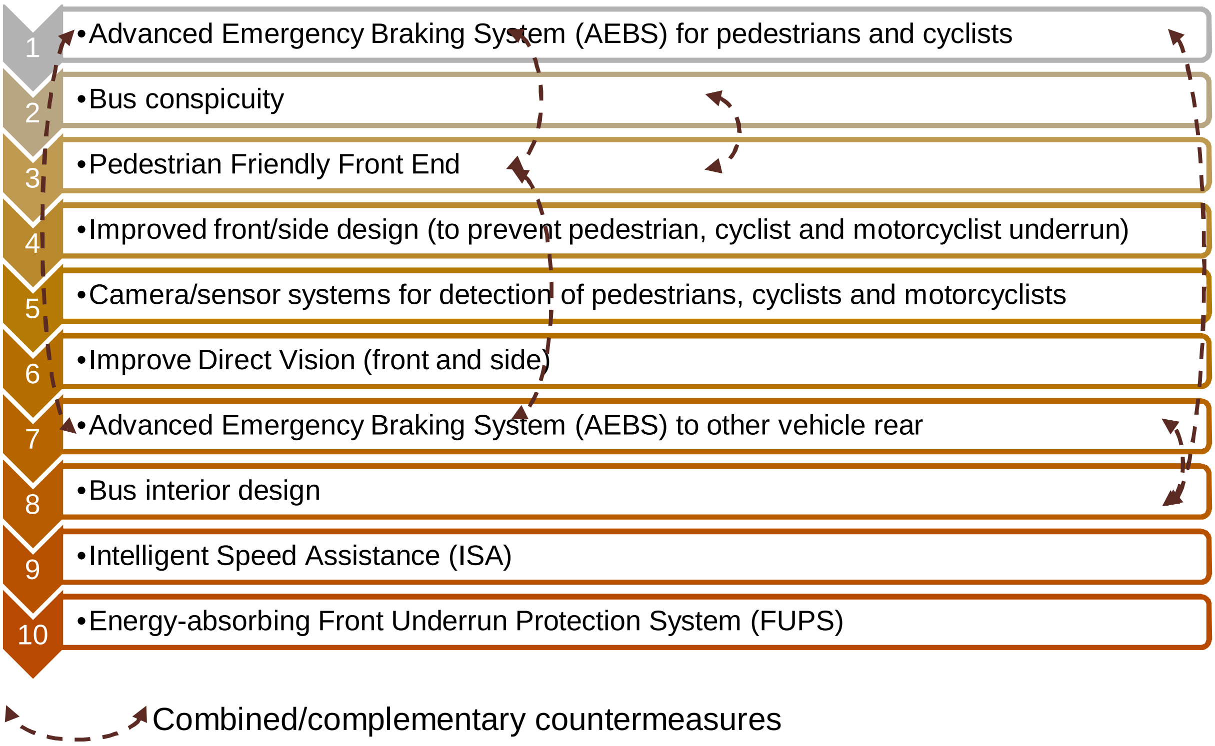
most are active in the pre-crash and crash phases. As an example, the most frequent countermeasure was Advanced Emergency Braking Systems (AEBS) that is capable of responding to pedestrians and cyclists; which is related to the majority of fatalities from bus collisions being pedestrians.

In reality there was a very long list of countermeasures that were applied to the cases in the datasets examined, and multiple countermeasures can be applied to each case. The effectiveness of the countermeasures varies depending on the specific situation and characteristics of the collision location. Combinations of countermeasures applied together may prove more effective than isolated countermeasures.

Stakeholder input via a questionnaire and a workshop has provided some useful insight into the enablers and barriers to implementation for many of the countermeasures. For example, there is strong concern about AEBS applying braking to avoid a pedestrian, but causing injury or even fatality to possibly multiple standing occupants on board the bus. Although in most collision scenarios the bus driver will brake the bus sharply at some stage, so the risk to bus occupants is unavoidable; perhaps the biggest risk of additional casualties would be from false activations of AEBS.

The countermeasures identified in the police fatal files, HVCIS and OTS & RAIDS cases were compiled into aggregated countermeasures tables, following the Haddon matrix approach. This gave an indication of the total number of cases that might be affected by a given countermeasure. A scaling was applied to the counts for each dataset in order to make them more comparable, and then a top ten countermeasures list was generated including only those measures that were medium or high effectiveness. This top ten, along with some expert input from the Steering Group, was used to generate a prioritised list of countermeasures for the Bus Safety Standard. The ordering was based on the frequency in the police fatal files, which is the most relevant dataset for TfL because it was London buses only. The highest priority measure is AEBS capable of responding to pedestrians and cyclists, mainly because pedestrians represent the majority of bus fatalities. The priority list includes some notes of where countermeasure should be developed together, in order to harmonise performance for the greatest casualty saving effect. For example, AEBS should be developed in conjunction with improved internal bus design, in order to protect the occupants on board should a braking event occur. Also, AEBS should be developed in combination with pedestrian friendly front end design, perhaps with a particular focus on the front corners of the bus, to protect those pedestrians in cases where the reaction time is so short that the collision is unavoidable. The AEBS should be implemented on buses carefully in order to minimise the risk of false activations, because these false activations might incur additional risk to any standing passengers. Manufacturers and operators should also develop suitable repair and calibration processes so that costs are minimised in the event that damage should occur to the sensors.

The priority list represents the top ten bus coumtermeasures recommended for the BSS, and is summarised below. These were prioritised on the basis of numbers of fatalities (combined from a range of sources), system effectiveness and system applicability, with the final list ordered by the frequency count for the police fatal files becasue this was judged most relevant for the BSS. The arrows on the priority list below indicate complementary/combined countermeasures that address the same collisions, or in the case of bus interior design and AEB, those that might be considered as part of the risk migation strategy for standing passengers. Additionally, if changes are made to bus conspicuity at the front of the bus this might also affect pedestrian friendly front end design, so these two measures are also combined.



6.3 Limitations

The datasets available for this study were heavily focussed on fatalities, and thus the analysis of collision distributions and relevant countermeasures is unlikely to represent an effect for slight or serious countermeasures as well it does for fatalities. The HVCIS dataset is relatively old, and may not be representative of the types of collisions and their associated countermeasures that are occurring with today's bus fleet in London. However, if data from the London bus operating companies could be accessed, then further analysis of this, potentially more relevant dataset, could be completed, and used to complement and extend the work already completed in this project. Data is gathered from London Bus operating companies using an in-house data logging system, IRIS, which every London bus operating company has access to. 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 evaluation. Data from this source, perhaps supplemented with additional detail from the operators, could be provided to TRL. This could cover all incidents which resulted in an injury, and for other event types deemed by London Buses to be serious or had the high potential to be serious, but did not result in an injury. Analysis of this data would also help to quantify any under-reporting in Stats19 (which is police reported injury collisions). This level of detailed operational data was not available to TRL for analysis within the timeframe for this report; however a further project could be used to add this analysis.

The effectiveness of the countermeasures is very difficult to assess due to a lack of exposure of some countermeasures that simply haven't been available for long enough to build up enough exposure to make an assessment; or there is a lack of evidence that relates specifically to buses. The analysis made in this report has indicated the confidence level for the countermeasure as high or low. Furthermore, the aggregated countermeasures tables have provided effectiveness estimates based on the expert opinion combined with estimates provided by stakeholders (where available). Further effectiveness studies and testing programmes to assess the countermeasures will be required to make a more detailed statistical analysis of effect, and if combined with a long term programme of data analysis, then a more accurate effectiveness for the countermeasures could be evaluated.

In the analysis for this study, countermeasures were assigned based on their applicability to certain collision types and circumstances. The implementation of any countermeasure should be monitored with respect to its actual effectiveness in service and to mitigate against the effects of any unintended consequences.

The implementation of the BSS and any countermeasures would require a full cost benefit analysis, and that is not included in this report. This research sets out the possible maximum target population of fatalities in order to create a prioritised list. The next step would be a consideration of the manufacturing and operational costs of implementation of these countermeasures. The societal benefits of the casualty savings could also be quantified in such a cost benefit analysis, including the savings in emergency services costs, insurance and damage costs, lost productivity, human costs, and congestion/emissions costs.

7 Acknowledgements

TRL would like to thank the positive and proactive cooperation from the Metropolitan police, especially Detective Inspector Dave Hindmarsh for access to the fatal files.

The project has been reviewed according to the TRL Technical Review procedure Mike McCarthy acting as Technical Reviewer has provided valuable comments and input on earlier drafts.

TRL would also like to acknowledge the input from Iain Knight of Apollo Vehicle Safety who has contributed to expertise and experience in the field, as well as providing overview of the stakeholder input and some comments on the report.

8 References

Air Accidents Investigation Branch (1989). *Boeing 767-400, G-OBME* (4/1990). Air Accidents Investigation Branch, (AAIB).

Albertsson P and Falkmer T (2005). Is there a pattern in European bus and coach incidents? A literature analysis with special focus on injury causation and injury mechanisms. *Accident Analysis and Prevention, 37*(2), 225-233.

Alexander-Dennis (2012). *Enviro 300 Low Floor City Bus Specifcation*. Alexander Dennis.

Almuina A (1989). *Pedestrian Accidents and Left-Turning Traffic and Signalised Intersections*. University of Toronto, Canada.

Björnstig U, Bylund P, Albertsson P, Falkmer T and Björnstig J (2005). Injury Events Among Bus And Coach Occupants: Non-Crash Injuries As Important As Crash Injuries. *IATSS Research , 29*(1), 79–87.

Blower D, Green P and Matteson A (2008). *Bus Operator Tyes and Driver Factors in Fatal Bus Crashes: Results from the Buses Involved in Fatal Accidents Survey*. University of Michigan Transportation Research Institute, Michigan.

Brenac T and Clabaux N (2005). The indirect involvement of buses in traffic accident processes. *Safety Science, 43*(10), 835-843.

BridgeClear, *Bridgeclear Integrated System for Buses.*, viewed 2016, <http://www.bridgeclear.com/prod2.html>.

Burka A, Qin A, Lee D and Taylor C (2014). *Pedestrian Collision Warning for SEPTA Buses*. University of Pennsylvania.

Canadian Council of Motor Transport Administration (2013). *Countermeasures to Improve Pedestrian Safety in Canada.* (ISBN 978-0-9878957-4-5). Canadian Council of Motor Transport Administration.

Chimba D, Sando T and Kwigizile V (2010). Effect of bus size and operation to crash occurrences. *Accident Analysis and Prevention, 42*, 2063-2067.

Crick JL and McKenna FP 1991. Hazard perception: can it be trained?. In Grayson GB (Eds), *Behavioural Research in Road Safety II*. Transport and Road Research Laboratory.

Deakin T 2016, *ADL's next generation developments unveiled.*, viewed 21 November 2016, <http://www.route-one.net/articles/Technology/ADL_s_next_generation_developments_unveiled>.

Delaware Valley Regional Planning Commission (2009). *Bicycle-Bus Conflict Area Study*. Delaware Valley Regional Planning Commission, Delaware.

Delmonte E, Manning J, Helman S, Basacik D, Scooons J, Chappell J, Stannard J, Jones M and Knight I (2013). *Construction logistics and cyclist safety: technical report* (PPR639). Transport Research Laboratory, TRL: Crowthorne.

Department for Transport (2006-2015). *Transport Statistics Great Britain*. Departmnet for Transport: London.

Department for Transport (2009-2014). *Stats 19*. Department for Transport, Data.gov.uk: London.

Department for Trasnport (2006-2015). *Stats 19*. Department for Transport: London.

DfT (2010). *Longer Semi-trailer Feasibility Study and Impact Assessment: Final Summary Report*. Department for Transport.

DfT (2015). *Facts on Motorcyclist Casualties*. Department for Transport.

DfT (2016). *Reported road casualties in Great Britain: main results 2015*. Department for Transport.

Ealing Council (2016). *Cycling in Ealing 2015/2016*.

ERSO (2016). *Traffic Safety Basic Facts 2016: Heavy Goods Vehicles and Buses*. European Road Safety Observatory.

ERTICO, *About eCall.*, viewed 26 Feb 2017, <http://iheero.eu/about-ecall/>.

EU (1996). *Council Directive 96/5 3/EC of 25 July 1996 laying down for certain road vehicles circulating within the Community the maximum uthorized dimensions in national and international traffic and the maximum authorized weights in international traffic*. Official Journal of the European Communities.

EU (2013). *Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) N* (347). European Union, Brussels.

EU (2015). *Regulation (EU) 2015/758 of the European Parliament and of the Council of 29 April 2015 concerning type-approval requirements for the deployment of the eCall in-vehicle system based on the 112 service and amending Directive 2007/46/EC* (758). European Union, Brussels.

Feist F, Gugler J, Giorda A, Avalle M and Puppini R (2008). Improvements to the protection of vulnerableroad users: Retrofittable, energy-absorbing front end for heavy goods vehicles. *International Journal of Crashworthiness, 13*(6), 1754-2111. doi:10.1080/13588260802412943.

Feist F and Gugler J (2009). *Guidelines for Integrated Design and Evaluation of Advanced Vulnerable Road User Protection Systems.* APROSYS deliverable D.2.1.7..

Feng S, Li Z, Ci Y and Zhang G (2016). Risk factors affecting fatal bus accident severity: Their impact on different types of bus drivers. *Accident Analysis and Prevention, 86*, 29-39.

Flodström K and Strömberg E (2011). *Vulnerable Road User Detection System For City Buses*. Luleå University of Technology. Scania CV AB.

Grayson GB and Sexton B (2002). *The development of hazard perception testing* (TRL 558). Tranport Research Laboratory, (TRL): Crowthorne.

Grayson GB and Helman S (2011). *Work related road safety: a systematic review of the literature on effectiveness of interventions* (11.3). Institute of Occupational Safety and Health, IOSH.

Greenshields S, Ball T and Barlow T (2016). *Intelligent Speed Assistance on London Buses: A trial on two London bus routes*. TRL.

Health & Safety Executive (2014). *Driving at work: managing work-related road safety*. Health & Safety Executive, HSE.

Helman S, Grayson G and Parkes AM (2010). *How can we produce safer new drivers? A review of the effects of experience, training, and limiting exposure on the collision risk of new drivers* (INS005). Transport Research Laboratory, TRL: Crowthorne.

Helman S, Grayson G and Parkes AM (2010). *How can we produce safer new driversA review of the effects of experience, training, and limiting exposure on the collision risk of new drivers* (INS005). Transport Research Laboratory, TRL: Crowthorne.

Helman S, Christie N, Ward H, Grayson G, Delmonte E and Hutchins R (2014). *Strategic review of the management of occupational road risk* (PPR6699). Transport Research Laboratory, TRL: Crowthorne.

Horswill MS and McKenna FP 2004. Drivers' hazard perception ability: situation awareness on the road. In Banbury S and Tremblay S (Eds), *A Cognitive Approach to Situation Awareness: Theory and Application*. Ashgate Publishing, Aldershot.

Hull MA and Christie RJ (1993). *The hazard perception test: the Geelong trial and future developments* (VicRoads Report GR 93–113).

Ker K, Roberts I, Collier T, Beyer F, Bunn F and Frost C (2003). Post-licence driver education for the prevention of road traffic crashes. *Cochrane Database of Systematic Reviews, Issue 3*(Article no: CD003734). doi:10.1002/14651858.CD003734.

Kirk A, Grant R and Bird R (2003). *Passenger casualties in non-collision incidents on buses and coaches in Great Britain*. Loughborough University.

Knowles J, Smith L, Cuerden R and Delemonte E (2012). *Analysis of Police Collision Files for Pedestrian Facilities in London, 2006 - 2010.* (PPR620). Transport Research Laboratory (TRL): Crowthorne.

Leverette A (2013). *TriMet Case Settles*. Fat Pencil Studio.

Lutin J (2016). *The Implications of Automated Vehicles for the Public Transit Industry: Presentation to I-95 Corridor*. NJ TRANSIT.

Mayor of London & Transport for London. *Cycle safety action plan: Working together towards roads free from death and serious injury*. Transport for London: London.

McKenna FP and Crick JL 1993. A cognitive-psychological approach to driver training: the use of video technology in developing the hazard perception skills of novice drivers. In Grayson GB (Eds), *Behavioural Research in Road Safety III*. Transport and Road Research Laboratory, Crowthorne.

McKenna FP and Horswill MS (1999). Hazard perception and its relevance for driver licensing. *IATSS Research, 23*, 36-41.

Mercedes-Benz 2016, *Intelligent Drive.*, viewed 21 November 2016, <https://www.mercedes-benz.com/en/mercedes-benz/innovation/with-intelligent-drive-more-comfort-in-road-traffic/>.

Nambisan S, Pulugurtha S, Vasudevan V, Dangeti M and Virupaksha V (2010). Effectiveness of Automatic Pedestrian Detection Device and Smart Lighting for Pedestrian Safety. *Journal of the Transportation Researc*.

Nissan 2016, *Future Technology: Autonomous Emergency Steering System.*, viewed 21 November 2016, <http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/autonomous_emergency_steering_system.html>.

Oregon Transportation Research and Education Consortium (2013). *Route Segment Level Analysis of Bus Safety Incidents*. Oregon Transportation Research and Education Consortium.

Palacio A, Tamburro G, O'Neill D and Simms C (2008). Non-collision injuries in urban buses—Strategies for prevention. *Accident Analysis and Prevention*. doi:10.1016/j.aap.2008.08.016.

Park S and Trieu V (2014). Transit Bus and Pedestrian Safety Analysis in the Context of Operator Improvements and Traffic Volume Assessment. *Open Journal of Civil Engineering, 4*, 147-158.

Perk V, Staes L, Begley J and Yegidis R (2015). *Transit Bus Safety in the US - An Analysis Using the National Transit Database*.

Prato C and Kaplan S (2012). Bus accident severity and passenger injury: evidence from Denmark. *European Transport Research Review, 6*(1), 17-30.

Quimby AR, Maycock G, Carter LD, Dixon R and Wall JG (1986). *Perceptual abilities of accident involved drivers* (TRRL Report RR27). Transport and Road Research Laboratory, TRRL: Crowthorne.

Reason J (1990). The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 327*(1241), 475–484. doi:10.1098/rstb.1990.0090.

Robinson T, Watterson B, Dodd M, Minton R and Gard R (2009). *The heavy vehicle crash injury study - phase II report*. Transport Research Laboratory.

Robinson T and Chislett W (2010). *Commercial vehicle safety priorities - ranking of future priorities in the UK: Based on detailed analysis of data from 2006-2008*. Transport Research Laboratory.

SafetyShieldSystems (2017). *European Trial Report*. Available from: http://safetyshieldsystems.com/european-road-safety-trial-of-cycle-safety-shield-shows-impressive-improvement/.

Scoons J and Posner R (2016). *Young Drivers/Riders in Fatal Collisions in London*. TRL.

Sexton B (Development of hazard perception testing). 2000. *Proceedings of the DETR Novice Drivers Conference, Bristol.*, <http://www.dft.gov.uk>.

Slobodova O (2016). *White Paper on Cycle Safety Shield Trials*. Safety Shield Systems.

Smith L, Knowles J and Cuerden R (2013). *Analysis of police collision files for motorcyclist fatalities in London 2006-09* (PPR621). TRL: Crowthorne.

Summerskill S, Marshall R, Paterson A and Reed S (2015). *Understanding direct and indirect driver vision from Heavy Goods Vehicles Final Report*. University of Loughborough.

Talbot R, Reed S, Barnes J, Thomas P and Christie N (2014). *Pedal cyclist fatalities in London: analysis of police collision files (2007-2011).* University College London and Loughborough University on behalf of Transport for London.

TfL (2014). *Pedestrian Safety Action Plan: Working together, towards roads free from death and serious injury.* Transport for London, London.

TfL (2015). *2015 GLA collision data extract - casualty*. Available at: https://tfl.gov.uk/corporate/publications-and-reports/road-safety.

TfL (2016a). *Bus Safety Data.*, viewed 2016 Available from: https://tfl.gov.uk/corporate/publications-and-reports/bus-safety-data.

TfL (2016b). *Bus/coach casualty trend: 2006-2015.*, viewed 2016 Available from: http://content.tfl.gov.uk/long-term-bus-casualty-trends-paper.pdf.

TfL 2016c, *New Routemaster.*, viewed 2016, <https://tfl.gov.uk/modes/buses/new-routemaster#on-this-page-2>.

Tindall D, York I and Greenshields S (2015). *Detection of vulnerable road users near buses*. TRL.

Transport for London (2017). *Bus Safety Data release for 2016* (release date 12 Feb 2017, version 2.0). Transport for London, TfL: London.

TUG (2004). *ECBOS – Enhanced Coach and Bus Occupant Safety Final Publishable Report*.

Tyrrell RA, Patton CW and Brooks JO (2004). Educational interventions successfully reduce pedestrians' overestimates of their own night time visibility. *Human Factors, 46*, 170-182.

Vernick JS, Li G, Ogaitis S, MacKenzie EJ, Baker SP and Gielen AC (1999). Effects of high school driver education on motor vehicle crashes, violations and licensure. *American Journal of Preventative Medicine, 16*(1), 40-46.

Viola R, Roe M and Shin H (2010). *The New York City Pedestrian Safety Study and Action Plan*. New York City Department of Transportation.

Wahlberg A (2002). Characteristics of low speed accidents with buses in public transport. *Accident Analysis and Prevention, 34*(5), 637-647.

Wahlberg A (2004). The stability of driver acceleration behaviour, and a replication of its relation to bus accidents. *Accident Analysis and Prevention, 34*(5), 637-647.

Washington State Transit Insurance Pool (2015). *Executive Committee Agenda - July 30, 2015*. Washington State Transit Insurance Pool.

Welfers T, Ginsberg S, Funcke M, Hamacher M, Matheis R and Wohlecker R (2011). *Design of a Tractor for Optimised Safety and Fuel Consumption.* Aachen: Forschungsgesellschaft Kraftfahrwesen mbH (FKA). .

Wells P, Tong S, Sexton B, Grayson G and Jones E (2008). *Cohort II: a study of learner and new drivers. Volume I: main report* (Road Safety Research Report No 81). Department for Transport, DfT: London.

Woolsgrove C (2014). *ECF report on HGV cabs direct vision and amendments to Directive 96/53*. European Cyclists' Federation .

Yang D (2007). Trends in Transit Bus Accidents and Promising Collision Countermeasures. *Journal of Public Transportation, 10*(3), 119-136.

Zeta Automotive 2017, *Zeta Automotive.*, viewed 13 April 2017, <http://www.zetaautomotive.com/econospeed/>.

(page is intentionally blank, see next page for Appendices)

Appendix A Collision Analysis

This appendix provides greater detail on the collision analysis for buses, and on injuries occurring without a collision.

A.1 Bus Collision Frequency

It is also possible to look at the improvements in bus safety between 2006 and 2015. Over this period, road safety overall has been a success story. The bars in Figure 31 are negative, which indicates a reduction in casualties for the period. The dark blue bar on the left shows a 28% reduction in all casualties in GB (from collisions involving all types of vehicles). The mid blue bar next to it shows that nationally, buses have contributed more than average with a 38% reduction; i.e. a better casualty reduction than other forms of transport. However, the light blue bar suggests that when only London is considered, the reduction in casualties from collisions involving buses is much less (13%) than for the national equivalent (38%).

Overall the actions taken nationally have been more effective for fatalities than for less serious crashes. This is shown by comparing the right and left sets of bars in Figure 31, where the left (blue) set represent all casualties, and the right (orange) set represent fatalities; the reductions for fatalities (the bars on the right) are much greater. When all road fatalities in GB are considered, there has been a 45% reduction. Nationally, collisions involving buses have contributed to that reduction in line with other vehicle types. Fatality reduction on London’s buses is only fractionally less than the national figure.

If we consider the severity of casualties and their reductions, this reveals an explanation for the smaller reduction in casualties for London overall, as shown in Figure 32. The fatality reductions are relatively similar for GB compared to London. For serious injuries there is a much greater reduction in London (56%) than for GB (38%), which is very positive progress. However, for slight injuries the reduction in London is very small (6%) in comparison to GB levels (28%).

Figure 31: Casualty reduction in percentage between 2006 and 2015: All casualties and fatalities. Source data: Stats19 (2006-2015) & transport statistics (2006-2015)

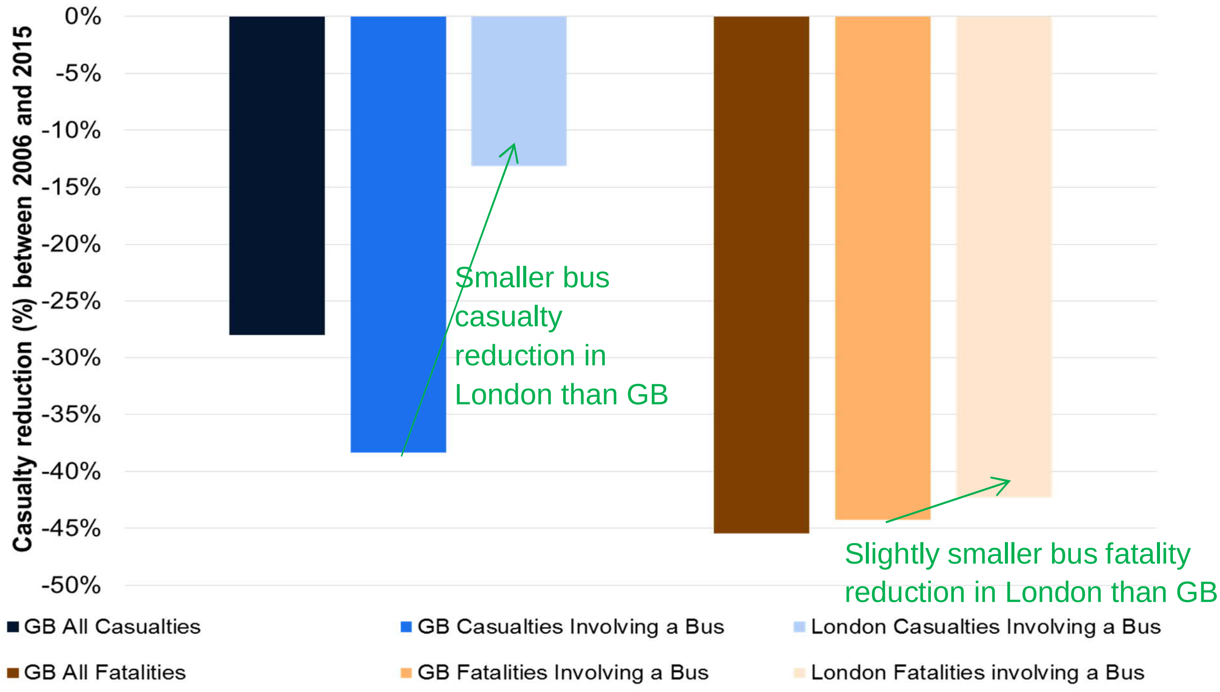


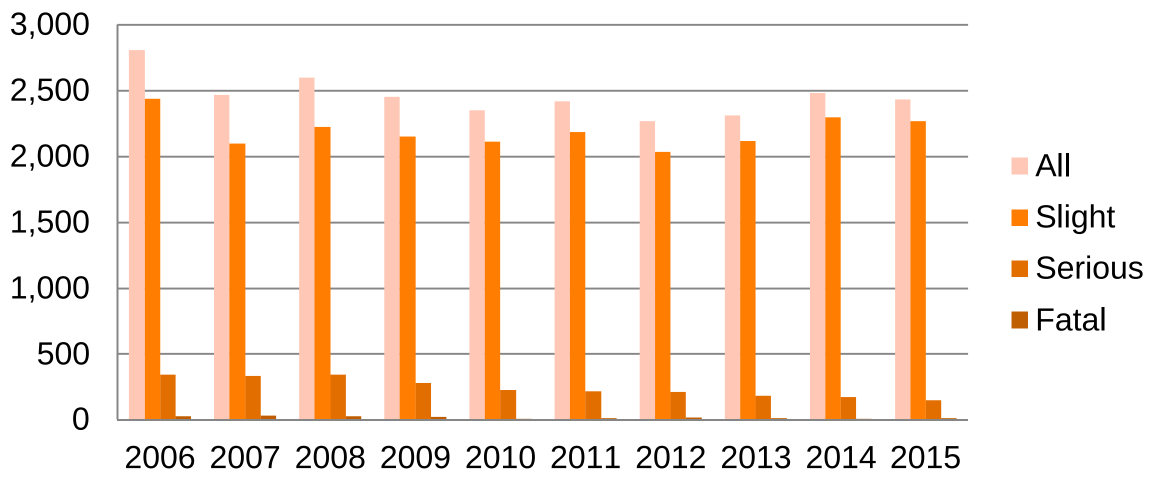
Figure 32: Casualty reduction in percentage between 2006 and 2015: Fatal, serious and slight injuries. Source data: Stats19 (2006-2015) & transport statistics (2006-2015)

A.2 Bus Casualty Types

Another factor of the analysis is to examine who is at risk of injury. TfL published a paper on bus/coach casualty trends in London between 2006 and 2015 based on Stats19 data. In London, between the years 2006 and 2015, it was recorded that 24,606 casualties resulted from a collision that involved a bus or a coach: 188 (0.8%) were fatally injured and 2,474 (10.1%) were seriously injured (TfL, 2016b). This is also illustrated in Figure 33.

It is important to note that within Stats19, buses and coaches are aggregated into one category which means there is no differentiation between TfL buses and other buses or coaches. Furthermore, this data only included casualties resulting from collisions that involved a bus or coach and so does not include casualties from non-collision incidents such as falls or slips and trips.

Figure 33: Casualties in a collision where a bus or coach was involved (by severity) in London between 2006 and 2015. Source data: (TfL, 2016b)



When considering all GB casualties in the Stats19 data from collisions involving buses/coaches, bus occupants dominate, as shown in Figure 34, with 61% of the casualties. The next largest casualty groups are car occupants (17%) and pedestrians (15%). The distribution of casualties in London is similar to that for GB, as shown in Figure 35 except that pedestrians and cyclists account for slightly larger proportions of the total and passenger car occupants a slightly lower proportion of the total.

Intuitively, it would be expected that the large number of bus casualties observed would be because buses carry large numbers of passengers that may all be at risk of injury in one collision. Stats 19 data for the years 2006-15 shows that the maximum number of bus occupants injured in any one collision was 91; although this may have involved more than one bus, it illustrates the potential. However, on average, the number of bus occupants injured per collision involving a bus was 1.43 (noting that this would be skewed upward by the maximum number of 91 bus occupants injured in one collision). The average of 1.43 casualties relates to the number of bus occupant casualties per accident involving a bus where at least one bus occupant was injured; i.e. it doesn't include in the average accidents where a bus was involved and injured a pedestrian without injuring any bus occupants. If you include those accidents the number is less than 1. This compares to an average of 1.33 casualties of any class injured per accident of any type. So bus collisions do involve a higher number of bus occupant casualties per accident, but the difference is nowhere near as large as might be expected given the different occupancy levels of buses and other vehicle types. Many bus collisions must occur either where the occupancy is low and/or where a large proportion of the occupants remain uninjured.

Figure 34: GB casualties by type in collisions involving buses/coaches. Source data: Stats19

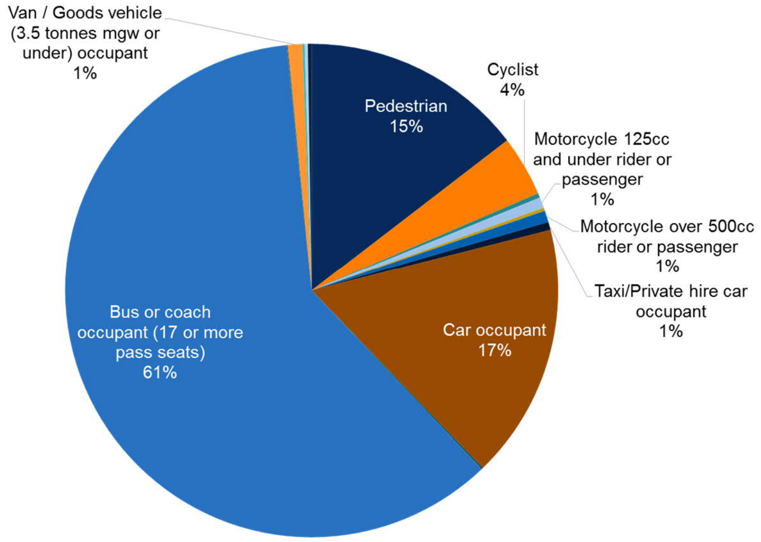
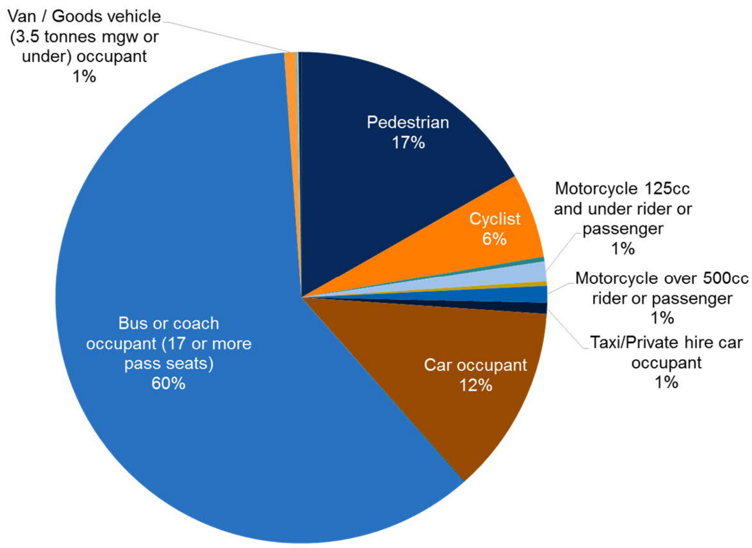


Figure 35: London casualties by type in collisions involving buses/coaches. Source data: Stats19



Stats19 data reveals in Figure 36 that in GB, pedestrians are the largest group of fatalities with 45%. The next largest groups are car occupants at 26% and bus/coach occupants at just 12%. This trend is further reinforced when considering fatalities in London (Figure 37), where pedestrian fatalities account for 64% of all the fatalities compared to 45% for GB. Similarly, car occupants and bus/coach passengers are the next largest groups of fatalities in London with bus/coach passengers accounting for just 8%.

Figure 36: GB fatalities by type in collisions involving buses/coaches. Source data: Stats19

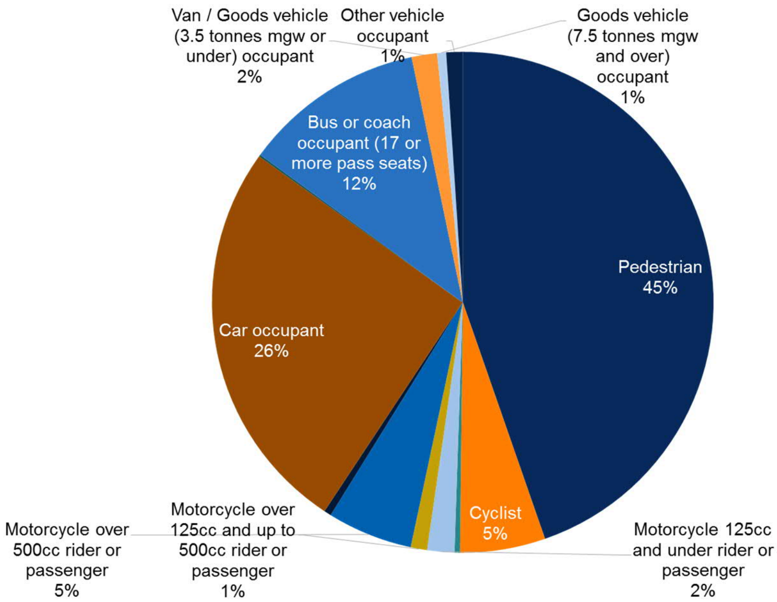
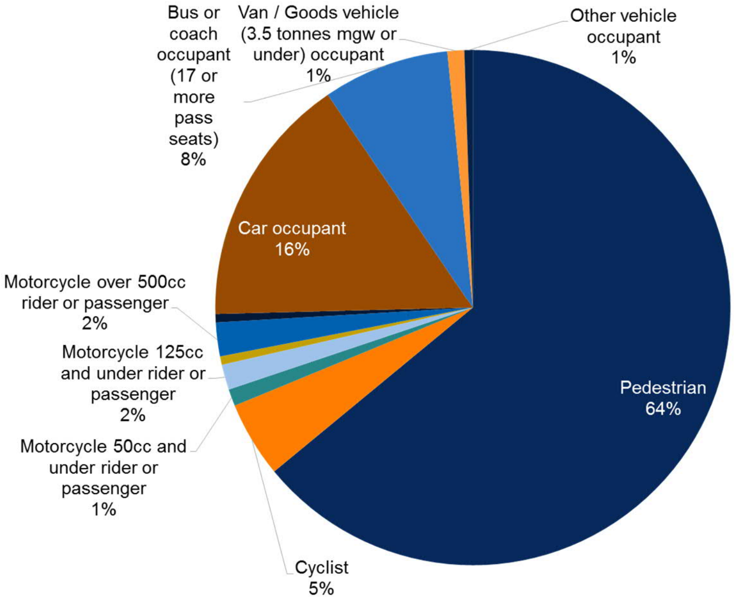
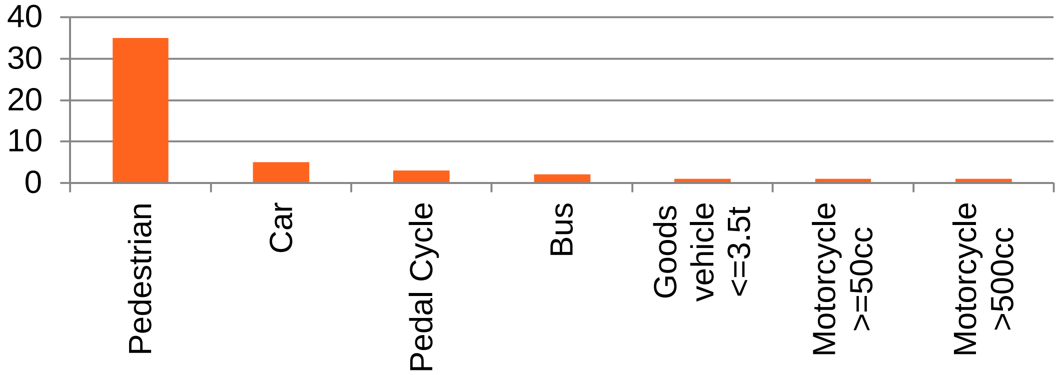


Figure 37: London fatalities by type in collisions involving buses/coaches. Source data: Stats19



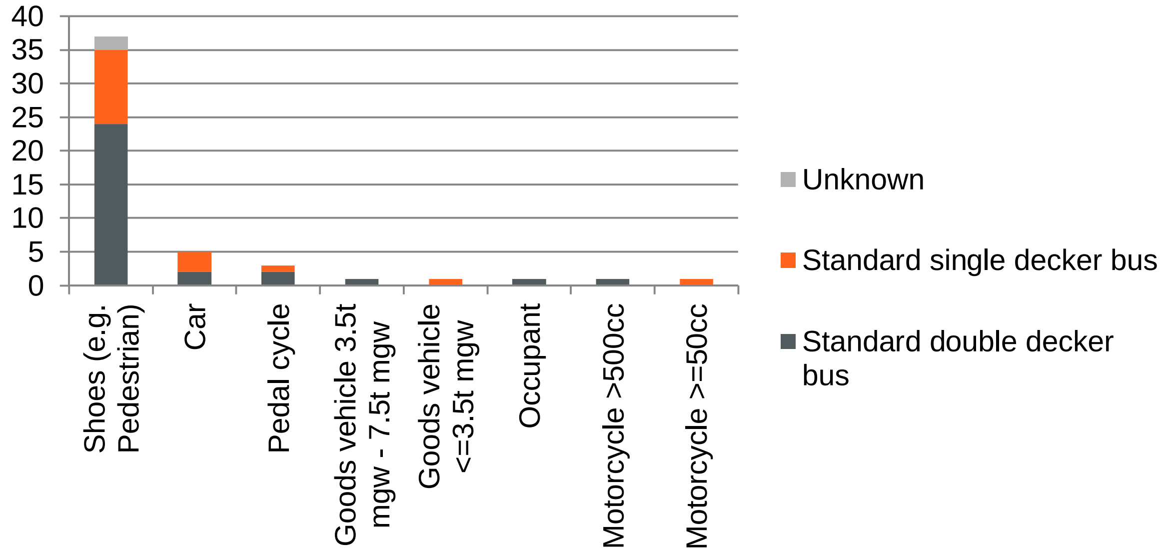
The distribution of the fatalities in the 48 Police fatal files also reiterates this finding; Figure 38 shows that the pedestrians accounted for the largest proportion of fatalities. From the 48 fatalities in the police files there were 7 other slight injuries. These occurred in 4 collisions, so, for example, one fatality was associated with 3 other slight injuries. In the vast majority of cases, the person who was fatally injured was the only person injured in the crash.

Figure 38: Fatalities from bus collisions. Source data: 48 Police fatal files



The most frequent collision partner for buses was pedestrians with 37 of 48 fatalities (77%) in the police fatal files as shown in Figure 39. For 24 of these collisions the bus was a standard double decker bus, 11 were with a single decker, and for two of the cases the bus type was unknown. The next most common collision partner was cars (5) and pedal cycles (3).

Figure 39: Distribution of collision partners by bus type. Source data: 48 Police fatal files



The slightly older HVCIS dataset also confirms that pedestrians are the largest group of road user fatalities in bus collisions, as shown in Figure 40. This distribution considers all fatalities involved in the bus collisions (i.e. not just the number of cases).

Figure 40: Distribution of fatalities in bus collisions. Source data: HVCIS

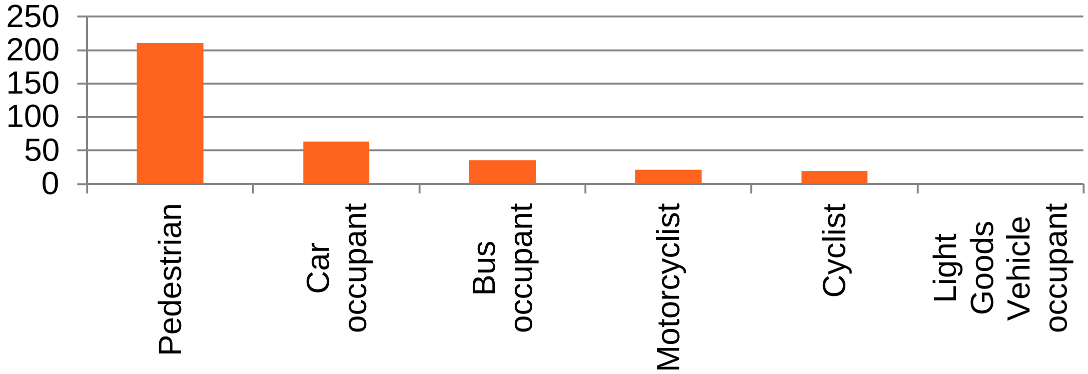
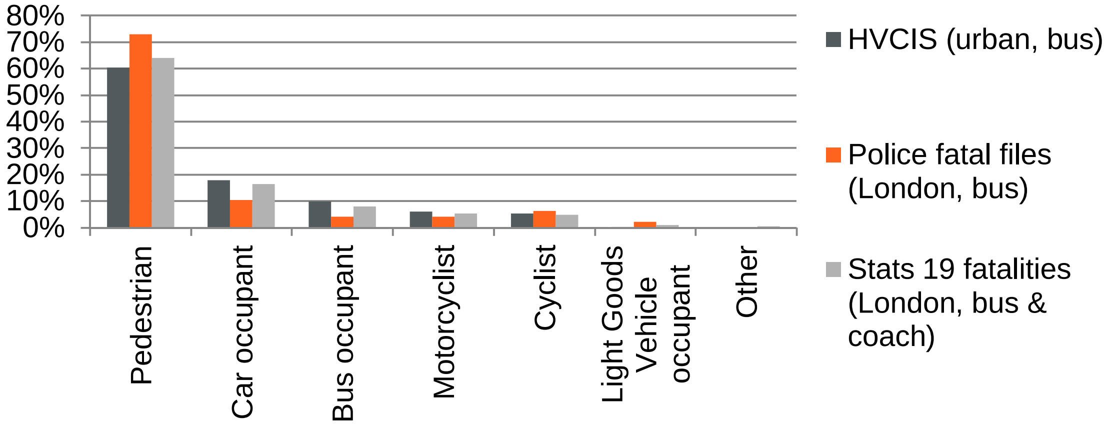


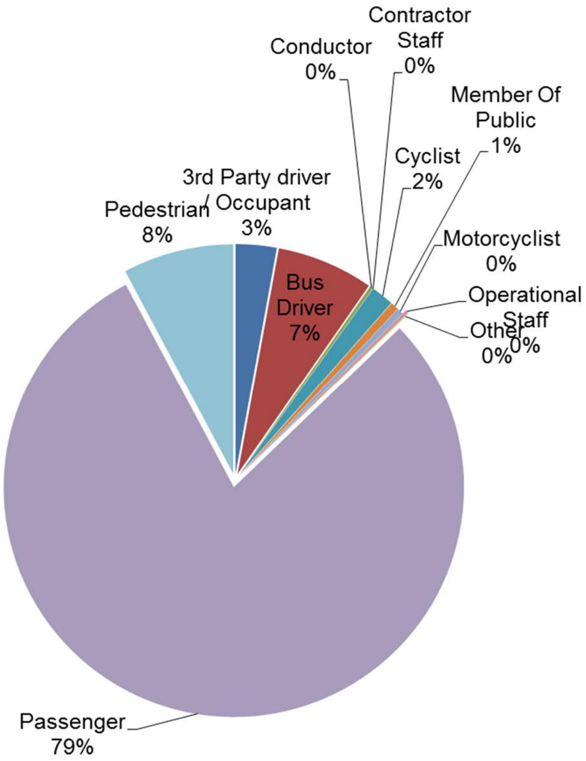
Figure 41 provides a summary of the findings for different casualty types, comparing the HVCIS, Police fatal files, and Stats19 London bus fatalities data. There is fairly good agreement between the different sources of data, despite their different sources and the differences in the samples. The pedestrian fatalities are a slightly greater proportion for the police fatal files (buses only) in comparison with the HVCIS & Stats19 fatalities that include coaches too; this is consistent with buses being more likely to be in pedestrian collisions than coaches and London having slightly more of a problem with pedestrians than other urban areas across the country. However, these differences are relatively small such that what works well in London might have a good chance of working well across the country. The pedestrians are the most frequent fatality type, with car occupants and bus occupants being of much lower frequency; casualties of other types are even lower still.

Figure 41: Summary of fatality types for bus collisions. Source data: HVCIS, Police fatal files, Stats19.



The IRIS data, which is not limited to fatalities like the police fatal files and HVCIS, reveals a slightly different picture. In the IRIS data the vast majority, 79%, of casualties are bus passengers; as shown in Figure 42. This is due to the vast majority of injuries occurring on the buses without a collision, which is described in greater detail in the following section A.4. Pedestrians make up the next largest group of injuries, which is in agreement with the findings in the other datasets.

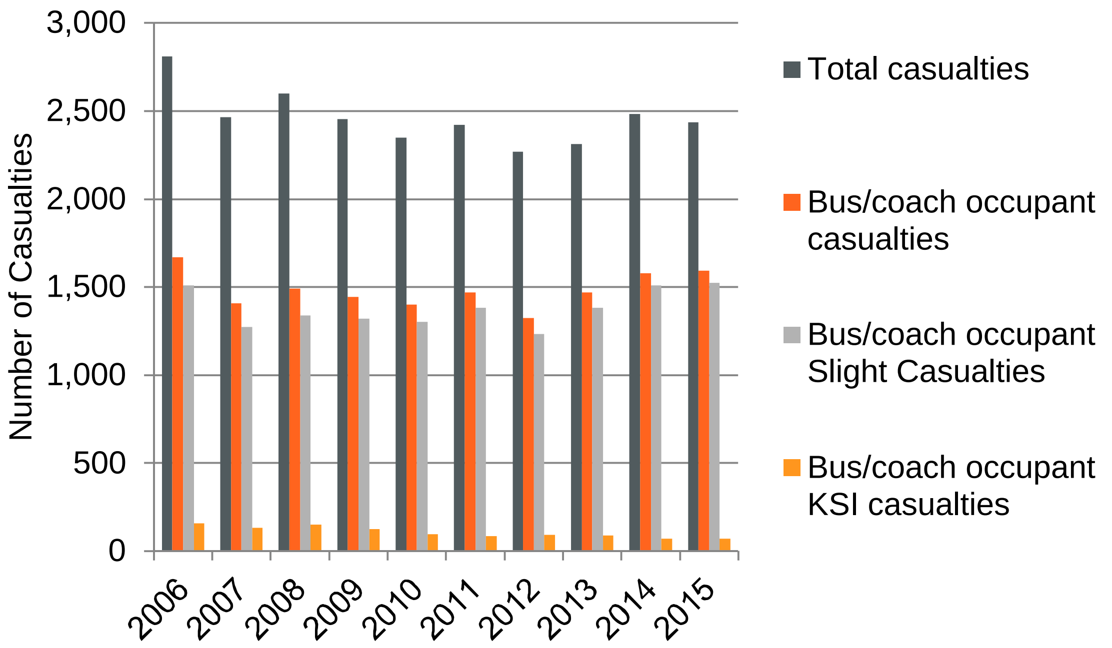
Figure 42: Injuries by victim category. Source: IRIS



A.2.1 Bus Occupant Casualties

Bus/coach occupant casualties accounted for on average 60% of all bus/coach casualties over the 10 year period (Figure 43), according to data from TfL. Considering bus/coach occupant casualties, the majority of injuries sustained were slight, with 7.3% recorded as KSI on average over the 10 years (TfL, 2016b).

Figure 43: Casualties in a collision in London where a bus or coach was involved. Source data: (TfL, 2016b)



The following data was extracted from Bus Safety tables published by TfL and in this case bus occupants include the bus driver, passengers and any other staff on board such as conductors (TfL, 2016a). In the 21 month period between October 2014 and June 2016 there were 8,704 bus occupant casualties accounting for 87% of total casualties associated with TfL buses. Bus passengers in particular, accounted for 80% of casualties with the driver and staff making up to remaining 7%. Between January 2014 and June 2016 there were only 2 reported bus occupant fatalities in London and they were both passengers who had a slip, trip or fall. On average 75.3% of occupants sustained injuries that could be treated on-scene; the remaining 24.7% were taken to hospital for treatment. Bus drivers were most likely to sustain injuries that resulted in a trip to hospital when involved in a collision incident, whereas bus passengers were most likely to sustain injuries that required hospital attention after a slip trip or fall. Mechanisms in which bus passengers sustained injuries requiring hospital attention included boarding and alighting incidents, falls down stairs, trips, slips and falls, wheelchair/buggy incidents and collisions.

It has been shown that bus occupants involved in non-collision incidents in the UK are more likely to sustain KSI injuries (63.4%) than in incidents involving a collision (Kirk *et al.*, 2003). Elderly female occupants were found to most frequently sustain injuries and had an increased risk of a serious injury.

A study of injuries sustained by bus and coach occupants in Sweden also found that injuries from non-collision incidents (54.2%) were more frequent than injuries from collision incidents (45.8%) (Björnstig *et al.*, 2005). Occupants involved in collisions with other vehicles most often sustained neck injuries (73%), occupants involved in single vehicle collisions sustained predominantly head (30%) and upper extremity injuries (27%). The majority of non-collision injuries were sustained when the occupant was alighting a stationary bus/coach and this often resulted in injuries to the lower extremities. Harsh braking was the main cause of injury to occupants when the bus/coach was in motion and this resulted in a combination of head and upper and lower extremity injuries.

Analysis of bus collision data from Denmark's national collision database between 2002 and 2011 showed that the occurrence of injury to bus passengers was positively correlated to the involvement of heavy vehicles, crossing junctions with yellow or red light, high speed limits and slippery road surfaces. In comparison with collisions with cars, the probability of more severe injuries in bus collisions are greater for accidents involving vans and heavy vehicles, with increased risk of injury of 7.3–23.4% for slight injuries, 11.7–43.2% for severe injuries, and 14.2–55.7% for fatal injuries (Prato and Kaplan, 2012).

A.2.2 Pedestrians, Cyclists and Motorcyclist Casualties

Various data and literature has highlighted the large proportion of bus collisions which involve pedestrians, cyclists and motorcyclists; also known as Vulnerable Road Users (VRUs). In accordance with statistics recorded by TfL, it is apparent that these collisions are relatively likely to result in a fatal outcome (TfL, 2016a). Statistics reveal that in London between January 2014 and June 2016, there were 33 fatalities recorded involving buses; 21 pedestrians, four motorcyclists and one cyclist, representing 85% (TfL, 2016a). Another previous TfL study revealed that between 2006 and 2015, pedestrians, cyclists and motorcyclists accounted for 25.4% of all casualties and 47.6% of all KSI casualties on average over the ten year period for bus collisions. Fatalities were not reported separately from KSI casualties. Pedestrians were the most frequent casualty (66.1%), followed by pedal cyclists (22%) and then motorcyclists (11.9%) (TfL, 2016b). When focusing on pedestrian safety in London, it has been found that pedestrians are at a higher risk of injury in a collision during darkness than during the day. It was also highlighted that pedestrians who are intoxicated are at a higher risk of being involved in a collision with a bus (TfL, 2014). In a recent study of pedestrian fatalities in London, it was found that there were a significantly higher number of pedestrian fatalities between the hours of 6pm and 6am on Saturdays and Sundays, than compared to daylight hours. It was thought that increased social activity and consumption of alcohol during these hours was a likely contributory factor (Knowles *et al.*, 2012).

The number of collisions with pedestrians was greater at bus stop segments (a 75 foot radius buffer around each stop in the bus route system) than other parts of the route and approximately half of cyclist collisions occurred at bus stop segments. Bus stops cause line of sight obstruction and can also result in the crossing of paths of cyclists and buses as cyclists overtake the stationary bus on the offside[8] (Oregon Transportation Research and Education Consortium, 2013).

Increasing bicycle use and bus usage are both desirable policy goals from a sustainability perspective for any city (Delaware Valley Regional Planning

[8] **Offside** = right/driver/road- side in the UK

Commission, 2009). On city streets, however, these two modes of transport are in several ways natural opponents: while occupying opposite ends of the size and weight spectrum, they often operate in the same place (Delaware Valley Regional Planning Commission, 2009). Park and Trieu (2014) highlighted the causes of collision when the bus was travelling forwards; shows that 'Bicycle Related' was attributed to 15% of these collisions. The study also noted that rather than the bicycles and buses making contact with each other, the presence of a bus travelling within close proximity of the bicycle caused the cyclist to collide with an object or fall from their bicycle. It was recommended that buses and bicycles should avoid travelling side-by-side, but rather one in front of the other down narrow streets or where no bicycle lane is present. It is worth noting that in this type of collision with the bike in close proximity to the bus, but no actual collision, that case might not be recorded as a bus collision in Stats19; perhaps as a single cyclist collision instead.

In the United States, between 1999 and 2005, more than 40% of fatal transit bus crashes involved a collision with a pedestrian (Blower *et al.*, 2008). Perk *et al.* (2015) studied transit bus safety in the United States. The study used a sample of National Transit Database (NTD) safety data augmented with interviews from seventeen participating transit agencies. It was found that 10% of the sample incidents involved the bus colliding with a pedestrian or cyclist. Approximately 28% of these occurred while the transit vehicle was making a turn. Between the years 2008 to 2012, there were 64 bus collisions which were recorded in the NTD. Of these 64 fatal collisions, 12.5% involved a cyclist, 15.6% involved a pedestrian using a crossing and 15.6% involved a pedestrian not using a crossing. Perk *et al.* (2015) also noted that there are several incidents where a cyclist or a pedestrian collided with the bus whilst it was stopped. In some of these cases the Pedestrians, cyclists and motorcyclists were determined to be intoxicated.

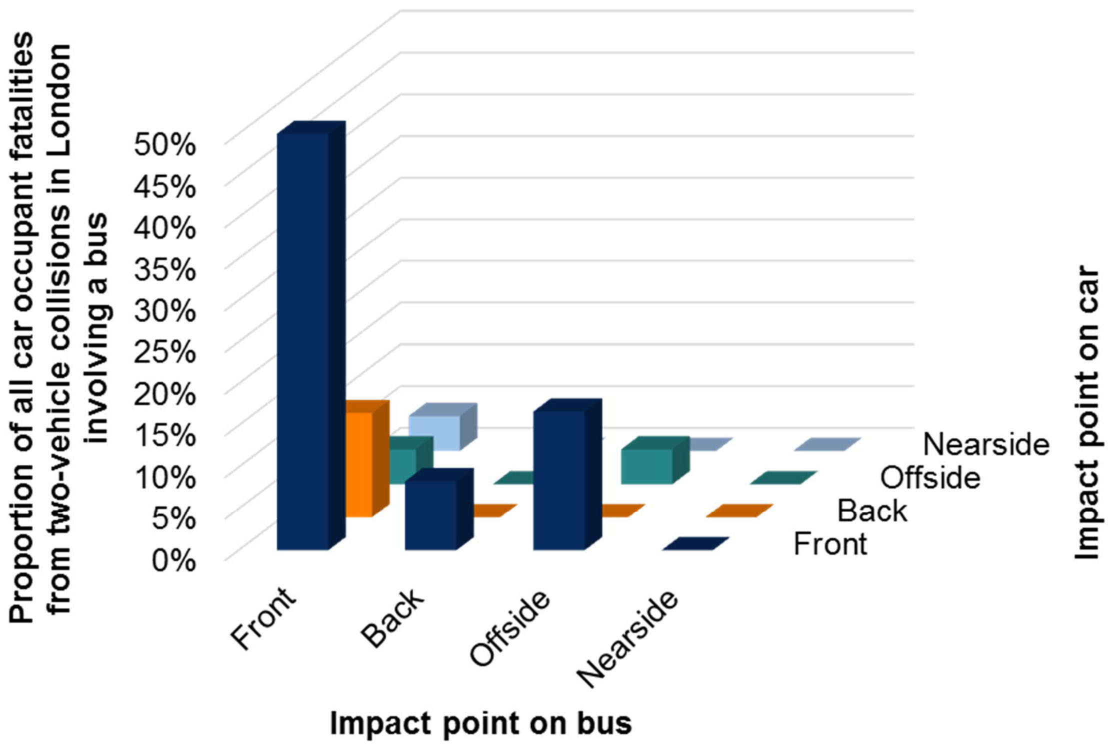
A.2.3 Car Occupant Casualties

The term 'Other Vehicle Occupants' refers to occupants of other vehicles using the road. This can include car, taxi, van or goods vehicle occupants (but not pedestrians or cyclists). As previously noted, a review of literature and data revealed that apart from pedestrians, the most frequent collision type was a bus to vehicle collision, and that car occupants were the most frequently injured occupant type. Although this may be the most frequent type, it does not necessarily mean that it is likely to result in a serious or fatal injury.

It was noted that in London, between 2006 and 2015, 2662 KSI casualties were recorded as a result of a collision involving a bus or coach (TfL, 2016a). Of these, 10.5% were classified as 'Other Road User' occupants (car, taxi, goods vehicle and other vehicle occupants). Car occupants who sustained a KSI injury were the most common 'Other Road User' (85.7% of the total 'Other Road Users'). This was subsequently followed by goods vehicle occupants (6.07%), other vehicle occupants (5%) and taxi occupants (3.21%) (TfL, 2016a).

Using Stats19 it is also possible to examine in more detail the collisions between buses and cars. describes collisions between a bus and car, noting that collisions with three or more vehicles are very complex and difficult to analyse using Stats19 so have been excluded from this analysis. Fatalities are shown in Figure 44 and these principally occur in head on, car front to bus offside[9], and bus front to car rear configurations. When all severities are considered, as shown in Figure 45, bus front to car rear is the dominant type followed by bus offside to car nearside; which perhaps indicates a lane changing type of crash. This might lead to a possible conclusion that Front Underrun Protection (FUP) might be a suitable countermeasure for bus fatalities. However, later in Appendix A.5.2 the data reveals that there is little evidence for this, due to these collisions involving low overlap, high intrusion, or the car occupants not wearing seat belts.

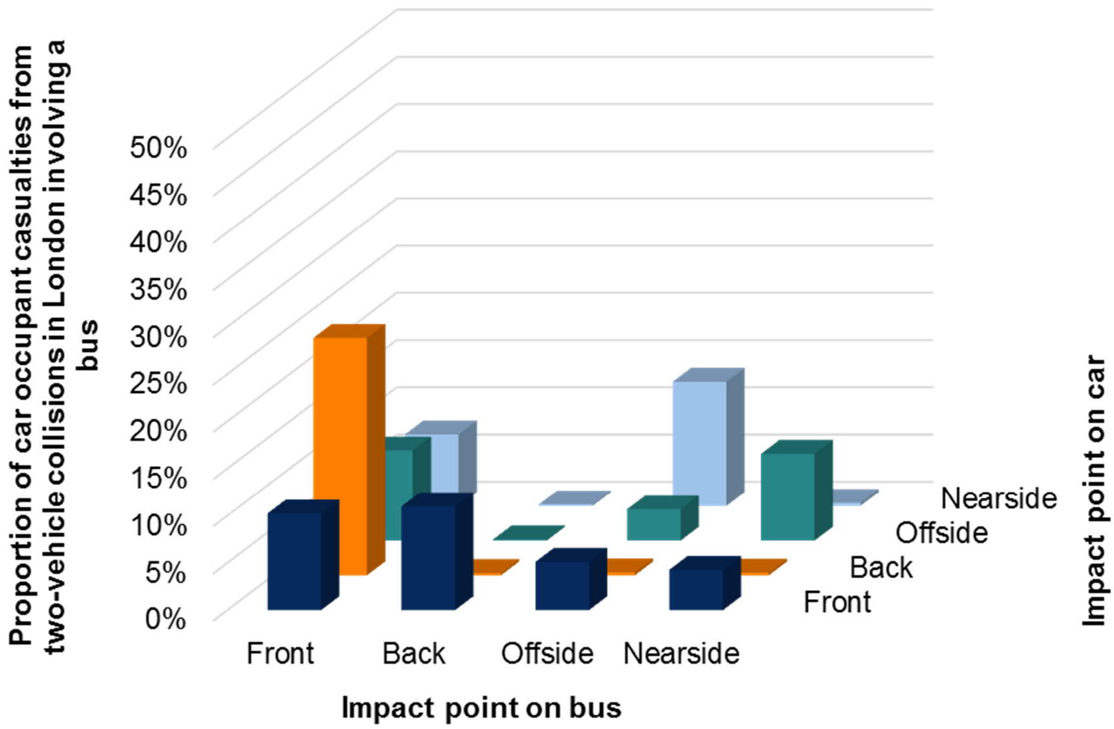
Figure 44: All car occupant <u>fatalities</u> from bus & car collisions by impact point. Source data: Stats19



[9] **Nearside** = left/passenger/kerb- side in the UK

Offside = right/driver/road- side in the UK

Figure 45: All car occupant casualties from bus and car collisions by impact point. Source data: Stats19



A.3 Bus Collision Types

A previous TRL study of pedestrian fatalities in London between 2006 and 2010 reported on 198 pedestrian fatalities, and 33 of these were involving a bus or coach. All these collisions, except one on a 40mph road, were on 30mph road and approximately two thirds of collisions occurred at junctions. All but one of the collisions occurred in fine weather and the day of the week seemed to have little effect on the occurrence of collisions. The bus or coach driver's line of sight was found to have been affected in just over a third (13 out of 33, 39%) of the collisions. This was most commonly due to vision being blocked by another vehicle (6 out of 33, 18%) or a blind spot of the vehicle being driven at the time (4 out of 33, 12%). This was most commonly due to vision being blocked by another vehicle or a blind spot of the vehicle being driven at the time. Table 16 below presents the collision types recorded between pedestrians and buses/coaches. The main collision type involved the bus/coach travelling ahead and a pedestrian crossing the road. Almost half of collisions occurred when the pedestrian was crossing from the left side as the bus was traveling forward (Knowles *et al.*, 2012).

Table 16: Bus/coach versus pedestrian collision types (Knowles *et al.*, 2012)

	Conflict	In carriageway: At pedestrian crossing	Within 50m of pedestrian crossing	Crossing elsewhere	On central island	On footway	Other/unknown	Total
N1	Bus/coach going ahead, pedestrian crossing left side	6	4	5	0	0	1	16
N2	Bus/coach going ahead, pedestrian crossing right side	2	2	1	0	0	0	5
N3	Bus/coach left turn, pedestrian crossing left side	0	1	3	0	0	1	5
P3	Walking on footpath	0	0	0	0	3	0	3
N4	Bus/coach right turn, pedestrian crossing right side	0	0	0	1	0	0	1
N6	Bus/coach right turn, pedestrian crossing left side	1	0	0	0	0	0	1
P2	Walking facing traffic	0	0	1	0	0	0	1
Q8	Miscellaneous other	0	0	0	0	0	1	1
Total		**9**	**7**	**10**	**1**	**3**	**3**	**33**

Some studies in the published literature can also provide some background context to the type of bus collisions that occur. For example, a study conducted by Albertsson and Falkmer (2005), noted that the majority of bus and coach incidents in eight European countries took place on urban roads with a speed limit of 50km/h (~30mph). The finding is highly applicable to this study since bus routes in London are generally limited to 30mph.

Other studies found that rear end and side swipe collisions were the most recurrent bus-to-vehicle collisions (Yang, 2007) (Chimba *et al.*, 2010) (Wahlberg, 2002). Rear end collisions are known to be associated with with increased 'stop-and-go' conditions, at bus stops for example. Wahlberg's (2004) findings on the characteristics of bus collisions in the Swedish town of Uppsala support this, as it was found that 26.4% of the reviewed collisions occurred at bus stops. A study into collisions on the TriMet's bus system in the United States showed that approximately 65% of collision incidents and 80% of non-collision incidents occurred at the bus stop segments of the bus route (Oregon Transportation Research and Education Consortium, 2013). The proportion of collisions occurring at a bus stop will presumably be highly dependent on the average density of bus stops on the route and without this information it is difficult to consider whether the proportion of collisions at them is high. However in the papers cited, the authors have found that a high number of collisions occur at bus stops.

Chimba *et al.* (2010) noted that side swipe collisions could be caused by erratic lane changing behaviours and merging into mainline traffic. This type of collision may also occur at bus stops or bus lay-bys. Wahlberg (2002) believed that these types of collisions are attributed to lack of space for buses. It is important to note that non-collision bus incidents also occur. Brenac and Clabaux (2005) studied the direct and indirect involvement of buses in traffic collisions in France. The study found that 11% of the recorded bus collisions were non-collision events that relate mainly to a passenger injuring themselves during boarding/alighting or moving about the bus.

Feng *et al.* (2016) stated that turning left or right in a bus is more dangerous than travelling along a straight road. This may be due to visual blind spots and the loss of perception of the surrounding situation. These visibility issues can contribute to bus to Vulnerable Road User (VRU) collisions. Yang (2007) analysed bus collision data from the US National Transit Database. It was found that the majority of bus collisions occurred at junctions and divided highways. The authors commented that the majority of buses operate in urban areas which contain mostly these types of roadway types.

A previous UK based study conducted by Robinson and Chislett (2010) reviewed Stats19 data concerning Large Passenger Vehicles (LPVs) for the years 2003 to 2005. It was noted that 63% of pedestrians in collisions with LPVs had a first point of impact of the front of the LPV. The most frequent manoeuvre for the LPV was classified as ‘Going ahead other’: this accounted for 70% of the KSI pedestrians. A further study conducted by Robinson *et al.* (2009) looked at the injuries sustained in heavy vehicle collisions. It was noted that 33% of pedestrians in collisions with buses were considered not to be paying attention and 18% of pedestrians were under the influence of alcohol. The median impact speed for collisions between pedestrians and the front of LPVs was approximately 19mph (30km/h). Furthermore, it was noted that the most frequent cause of death was head injuries.

Park and Trieu’s (2014) study highlights the vast amount of collisions that occur when the bus is travelling forwards (Table 17). Note that the vehicles studied travelled on the right hand side of the road and were left-hand drive. These collisions were mostly the result of ‘Jaywalking and Pedestrian/Operator Inattention’, followed by ‘Other’ and ‘Bicycle Related’. The locations of these collisions were approximately evenly split between junctions/bus stops and mid-block. The majority of these collisions were on the front-right side of the bus. A lower number of impacts were recorded on the left side and Park and Trieu attribute this to the fact that the driver is situated on the left side which may increase their awareness in that general direction. Data in Appendix A.5 indicates the reverse for the UK, due to driving on the other side of the road. Implementation of electronic sensors, additional mirror and bus operator educational programs were suggested to minimise these collisions.

Table 17: Cause of collisions for buses travelling forwards and making left turns. Source: (Park and Trieu, 2014)

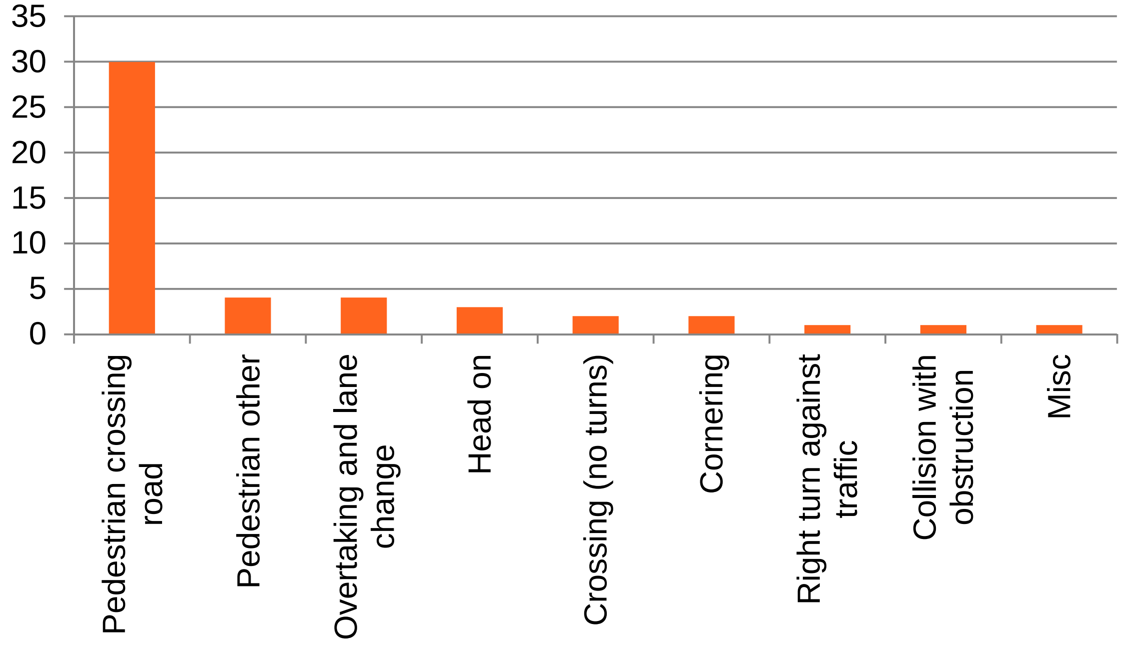
Cause of collision for a bus	Travelling forward		Turning left	
	Number	%	Number	%
Jaywalking and Pedestrian/Operator Inattention	60	49%	40	75%
Other	19	16%	0	0%
Bicycle Related	18	15%	0	0%
Pedestrian or Bus Too Close to Curb	8	7%	0	0%
Pedestrian Clumsiness	6	5%	0	0%
Unknown	5	4%	1	2%
Pedestrian Under Influence	3	2%	0	0%
Bus Operator’s Blind Spot	3	2%	12	23%
Total	**122**	**100%**	**53**	**100%**

Furthermore, a study conducted by Almuina (1989) highlighted that, compared to other manoeuvres at junctions, left turn manoeuvres are associated with a particularly high proportion of collisions with pedestrians. Note that the vehicles studied travelled on the right hand side of the road and were left-hand drive. To minimise these types of collisions Almuina recommends the installation of protected left-turn signal phasing as well as installing devices to remind and assist bus drivers to check their blind spots.

In a study carried out on public transit buses in the city of Philadelphia, 209 pedestrian related collisions were analysed. The highest proportion of collisions occurred whilst the bus was travelling forwards (58%), followed by when the bus was making a left hand turn (25%), then when the bus was stationary (10%), when it made a right turn (3%), and when it was braking (2%) (Park and Trieu, 2014).

The literature provides useful information about bus collisions; however examination of the specific bus collisions in London is of the most relevance for this research. As established previously, pedestrians are the most frequently injured, so it is not surprising that pedestrian collisions are most common type of crash in the police fatal files. The most frequent fatal collision type was hitting pedestrians crossing the road (63%), as shown in Figure 46; adding other types of pedestrian impacts brings that up to 71%. The other collisions types were far less frequent and were fairly evenly distributed.

Figure 46: Fatal collision type distribution. Source data: 48 Police fatal files



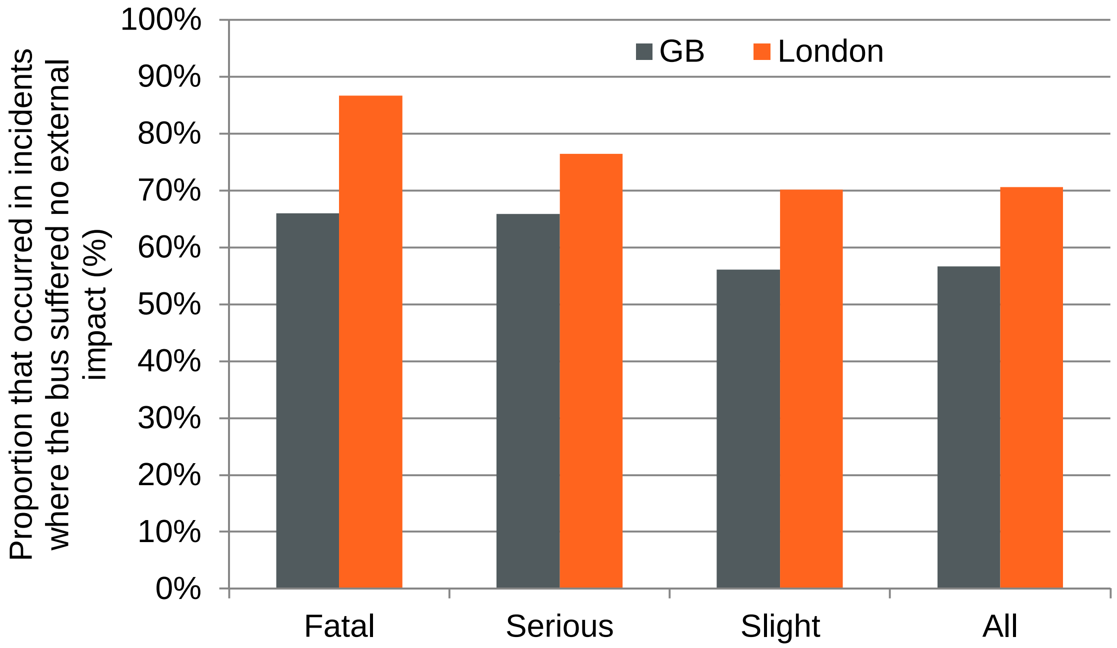
Yang (2007) also noted that the number of collisions between 13:00hrs and 19:00hrs were approximately double those than in the morning period: this correlated with the core hours of bus operation being predominantly in the afternoon/evening. As with the study by Knowles *et al.* (2012), the majority (over 75%) of collisions occurred during clear weather. Yang (2007) proposed that the effect of bad weather such as fog, rain, and snow had minimal impact on the likelihood of a collision; however, this could also be due to the fact that there were larger periods of clear weather rather than bad weather and so the numbers of collisions in clear weather conditions would naturally be higher. The effect of poor lighting conditions was also found to have minimal impact on the likelihood of a collision occurring as over 90% of bus collisions occurred in well-lit conditions. Day of the week has also been shown to be associated with collision severity; results showed that driving during the week has a decreased probability of serious collisions occurring when compared to the weekend (Feng *et al.*, 2016).

A.4 Injury Without a Collision

Injuries can occur without a bus actually being involved in a collision. TfL has published Bus Safety tables containing information reported to TfL by bus companies of incidents involving TfL buses that resulted in injury or fatality. In London between January 2014 and June 2016, there were 33 fatalities recorded involving buses; 31 of which were due to a collision incident and the remaining two were due to a slip trip or fall (TfL, 2016a).

According to the Stats19 data, the majority of bus occupant injuries occur without an impact to the external parts of the bus; injury without a collision. Figure 47 compares the proportion of injuries without a collision for GB against the proportions for London, and the trend is clearly higher for London than for GB. Given that Stats19 combines buses and coaches, this difference is perhaps due to the influence of coaches being more frequently used outside of London for longer distance journeys. It may well also be influenced by different bus occupancy rates. The proportion of fatal and serious injuries is both more frequent than slight injuries too.

Figure 47: Proportions of injuries that occurred in incidents without a collision; GB vs London. Source: Stats19



This finding in the Stats19 data that a high proportion of injuries occur without a collision is echoed in the IRIS data. 76% of injuries occur onboard the bus, and 20% occur in collision, as shown in Figure 48. The small remainder are a mix of safety critical failures and assaults. The IRIS dataset also provides an overview of the severity of the injuries according to how the injuries were treated, as shown in Figure 49. This indicates that the vast majority of injuries were not severe enough to warrant hospitalisation, and were treated on scene; this is aligned to the data showing that the vast majority of injuries occur without a collision.

Figure 48: Injuries by event type. Source: IRIS

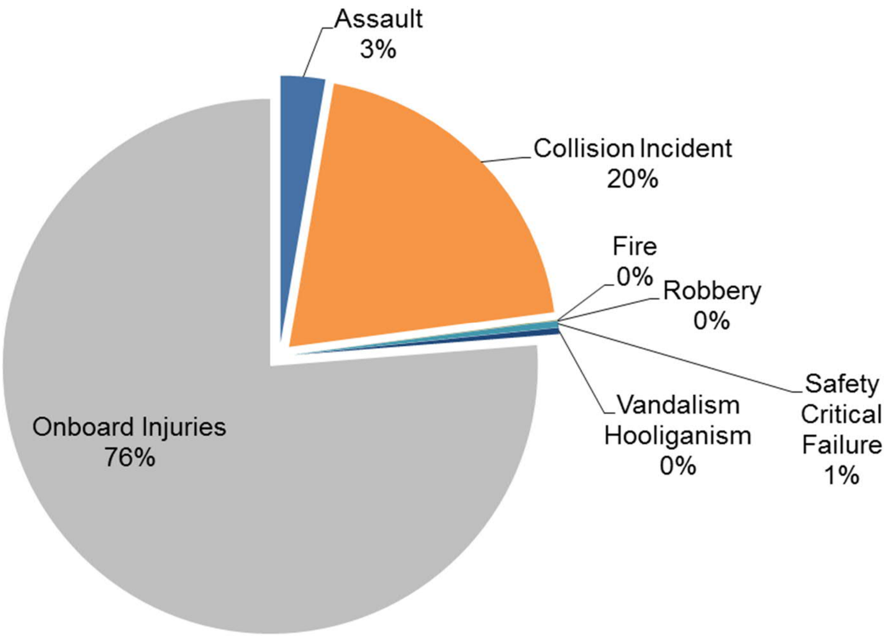
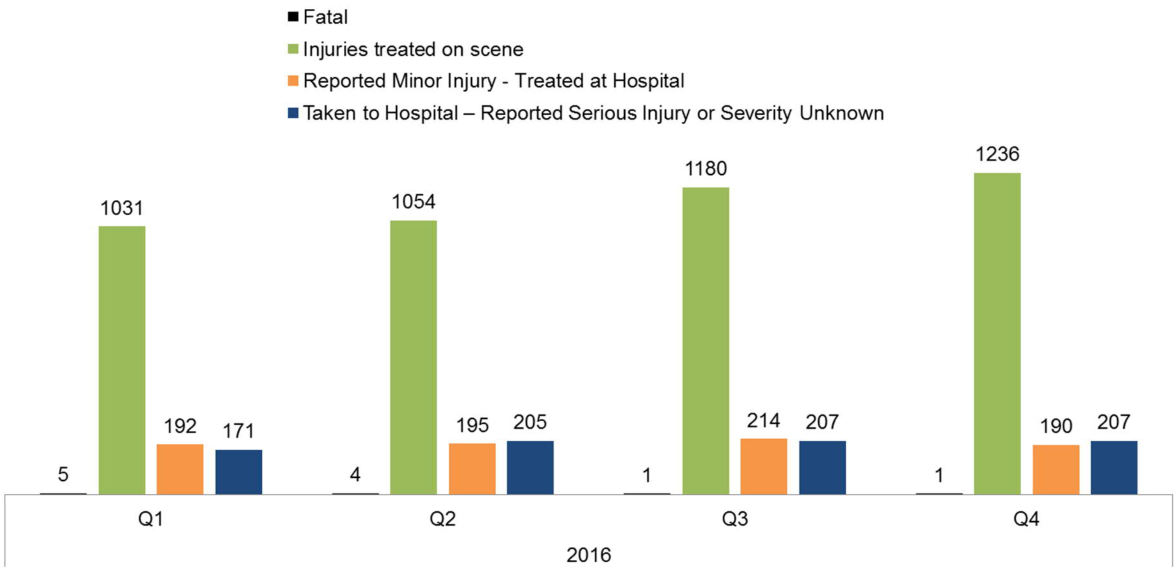
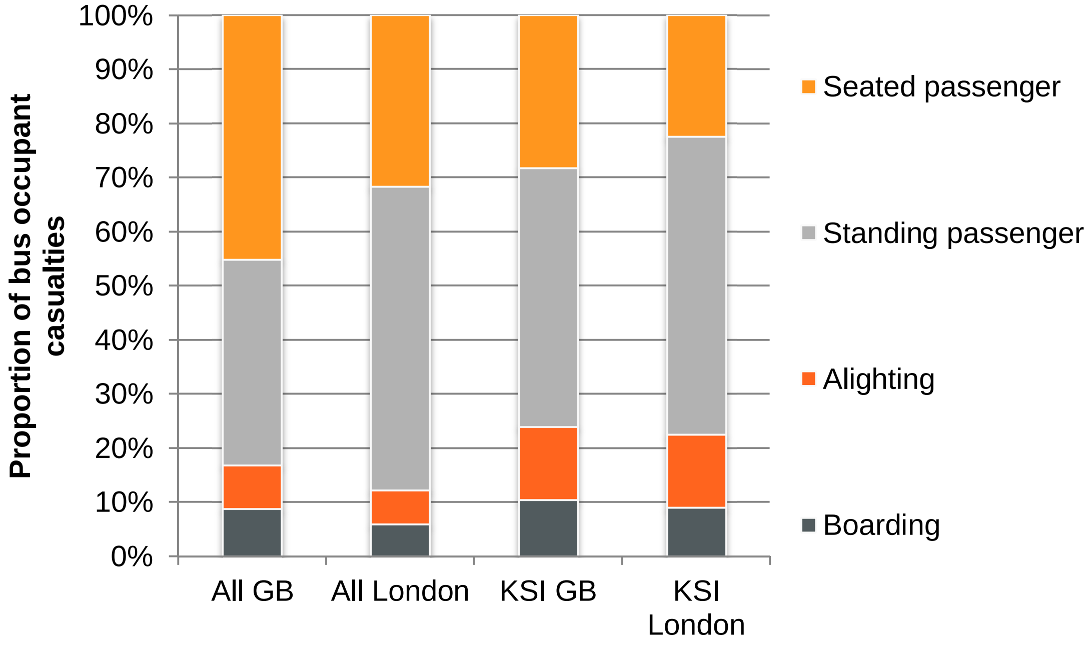


Figure 49: Injury severity over time; by treatment type. Source: IRIS



The activities of the passengers that were injured without external impact were also analysed as shown in Figure 50. Most injuries occurred whilst passengers were standing, followed by seated. A minority of injuries occurred whilst passengers were alighting or boarding. Comparison between GB and London in the Stats19 data reveals that injuries whilst sitting are more frequent for GB than for London, which is perhaps due to exposure factors, for example passengers might stand more often in London.

Figure 50: Activity of passengers at time of injury. Source: Stats19



An alternative means of analysis is to examine what the bus was doing at the time of an injury, as shown in Figure 52. For example accelerating and 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 then when cornering; 6% of injuries for standing passengers were when the bus was stationary. The standing passengers are important because they account for the biggest portion of injuries, so more data on these types of injuries would be very useful; for example on board video data, telematics, or claims data could help to understand the injury mechanisms and therefore help to design the most cost-effective countermeasures.

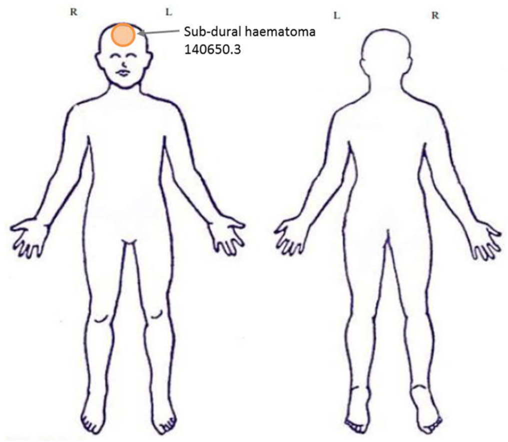
Injuries to passengers that are boarding and alighting buses are dominated by situations where the bus is stationary, but perhaps not to the extent expected. 35% of KSIs while boarding involve a moving vehicle; which suggests that either people are boarding when the bus is pulling away, or that the bus 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, 20% 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.

Two case examples are provided in Figure 51 that describes fatalities occurring on buses without an associated collision.

Figure 51: Case examples of fatalities on buses without collisions

CASE EXAMPLE 1

A 71-year-old male was stood at the top of the stairs waiting. The bus accelerated normally from stationary at a bus stop. The man fell down the stairs and suffered a subdural haematoma (AIS 3) resulting in fatal myocardial infarction at the hospital.



CASE EXAMPLE 2

A 70-year-old male was sat on the rear bench seat. The bus emergency braked to avoid a minor collision. The man slid to the floor. He suffered three injuries, two to his right arm and one to his pelvis; the result was a fatal pulmonary embolism. Two other passengers also sustained minor injuries.

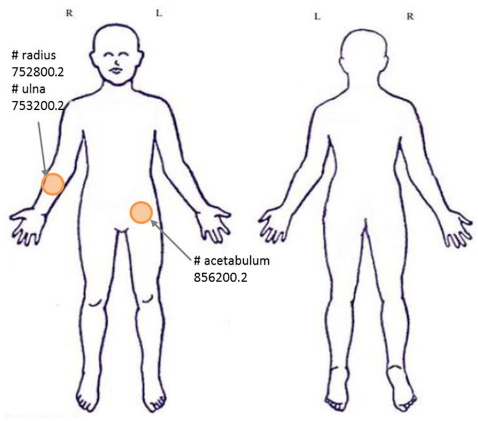
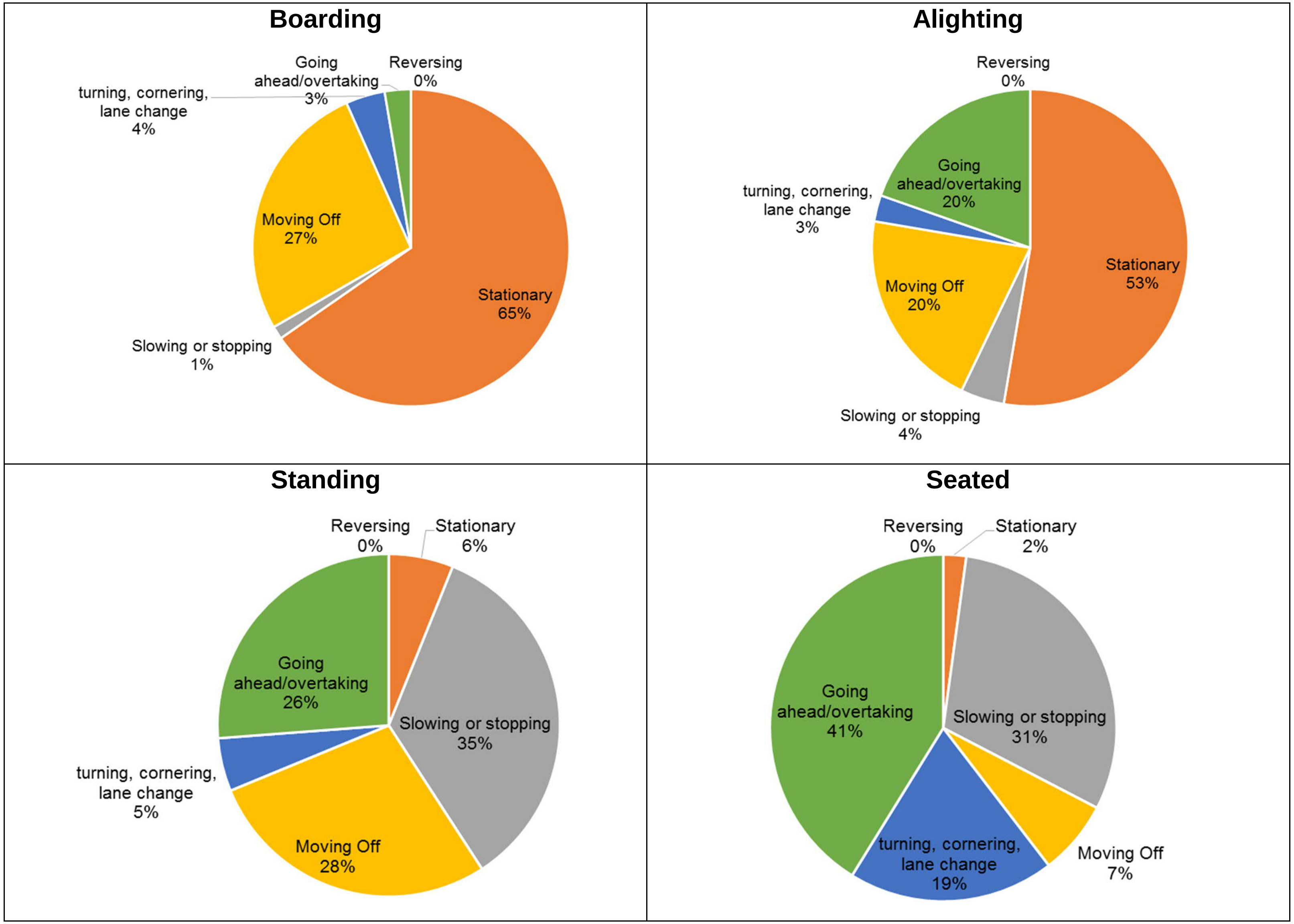


Figure 52: Activities of buses at the time of injury; by passenger activity. Source: Stats19.

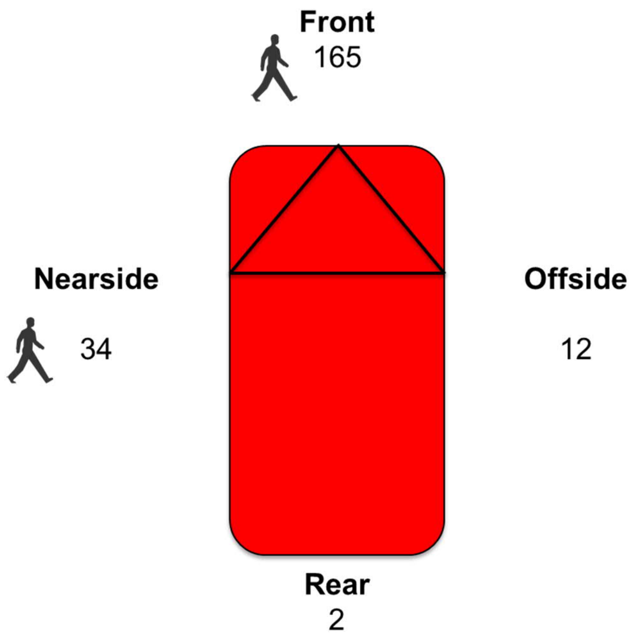


A.5 Collision Distribution around the Vehicle and Collision Features

A.5.1 Pedestrian, cyclist and motorcyclist fatalities

Given that these road users account for such a large proportion of the fatalities, it is important to examine these collisions in greater detail. In the HVCIS data shown in Figure 53, the vast majority 77% of pedestrians were injured by the front of the bus. Nearside is then the most frequent at 16%, offside at 6% and the remaining 1% injured at the rear.

Figure 53: Collisions involving pedestrian fatalities: distribution around the bus. Source data: HVCIS.



In the Police fatal files, these collisions are similarly dominated by frontal collisions (26 out of 27 cases), as shown in Figure 54. Around 70% of the collisions involved double decker buses, which is approximately proportionate to the fleet in London. The summary of the collision distributions around the bus is given in Figure 55, which compares the police fatal files and HVCIS data. The two datasets are in agreement that the front of the bus is the most frequent area of impact with a pedestrian. It is probably a feature of the small dataset for the fatal files that it shows as 100% for pedestrians; we might expect that with a larger sample size, the distribution would be similar to the HVCIS data.

Figure 54: Collisions involving pedestrian/cyclist fatalities: distribution around the bus. Source data: Police fatal files.

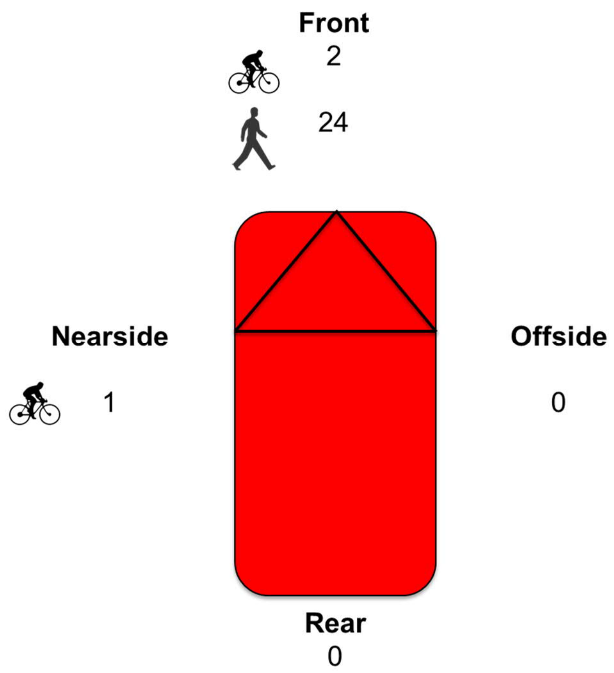
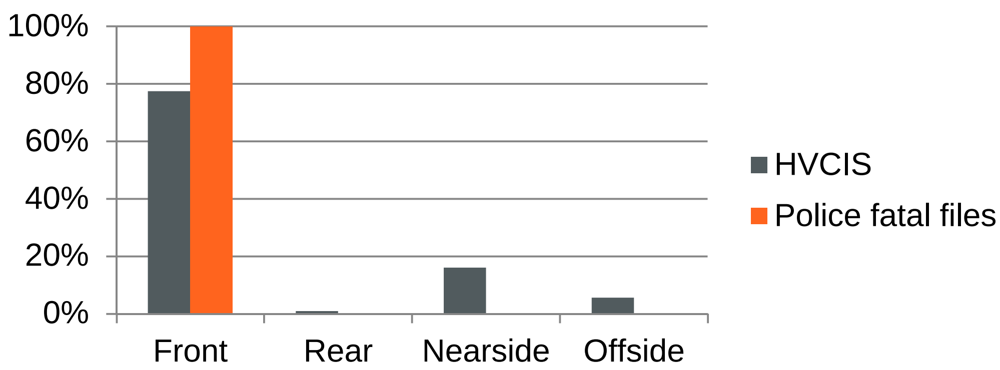
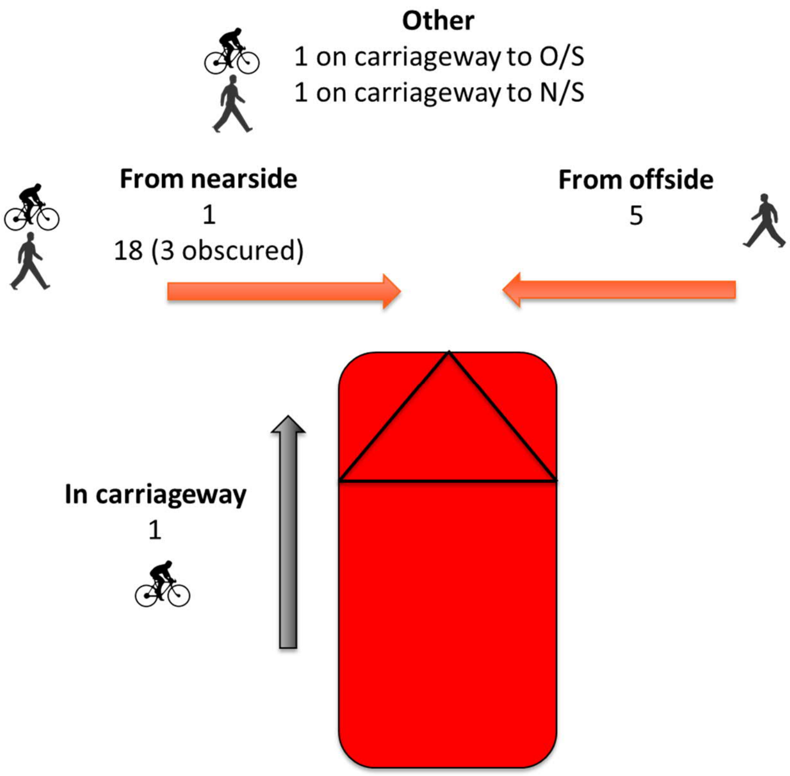


Figure 55: Summary of collisions involving pedestrian fatalities: distribution around the bus. Source data: HVCIS and Police fatal files.



By going into further detail about the movements of the pedestrians and cyclists, it is possible to learn more about the circumstances of the collisions. This is feasible from the police fatal files where the investigators were able to review cases and compile additional data. For example, Figure 56 describes the motion paths in more detail. Most pedestrians were crossing from the nearside, with a minority from the right or ahead. One cyclist was to the left side of the bus.

Figure 56: Movements of the pedestrians and cyclists in relation to the buses. Source data: police fatal files.



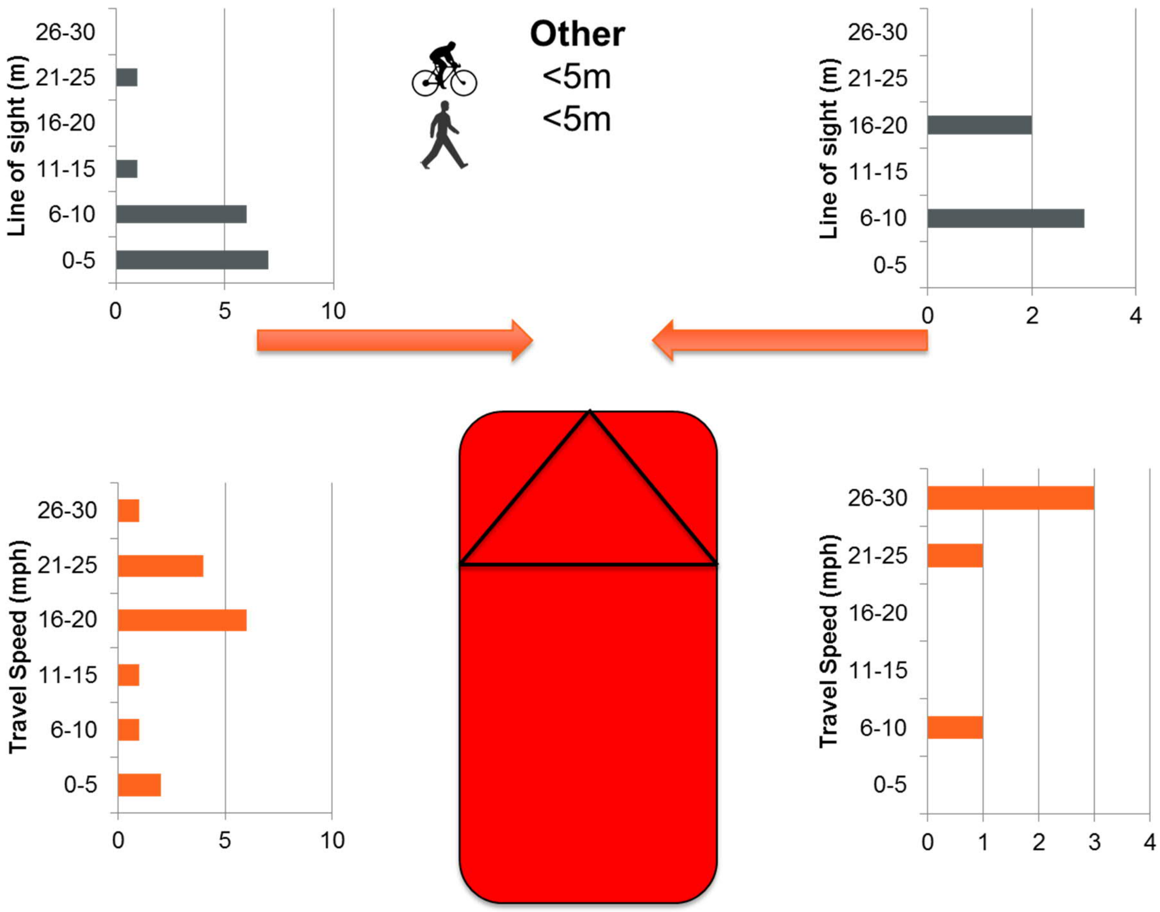
The depth of the data available by reconstruction of the fatal files allows another layer of detail to be considered, and this is important for defining the potential effect of countermeasures. The reconstruction work allows consideration of the following factors:

- Line of sight
- Travel speed of the bus
- Pedestrian point of contact
- Pedestrian Time To Collision (TTC)

Line of sight was defined as the distance at which it would first have been possible for the driver to identify the pedestrian as an imminent threat. For example, how far was the bus from the point of impact at the first moment a pedestrian emerging from behind a parked car would become visible? Where a pedestrian is not obscured from view but is simply walking along the pavement before suddenly changing direction and crossing the road they would be visible for a long distance before the collision, but it would only really be possible for the driver to identify them as a threat at the moment they clearly commenced crossing the road. The line of sight distance would, therefore, refer to the moment they commenced crossing. Figure 57 summarises the line of sight findings for the police fatal files where a pedestrian was crossing, alongside the bus travel speeds too. There were 3 cases where the point of perception is unknown and the travel/impact speed is unknown.

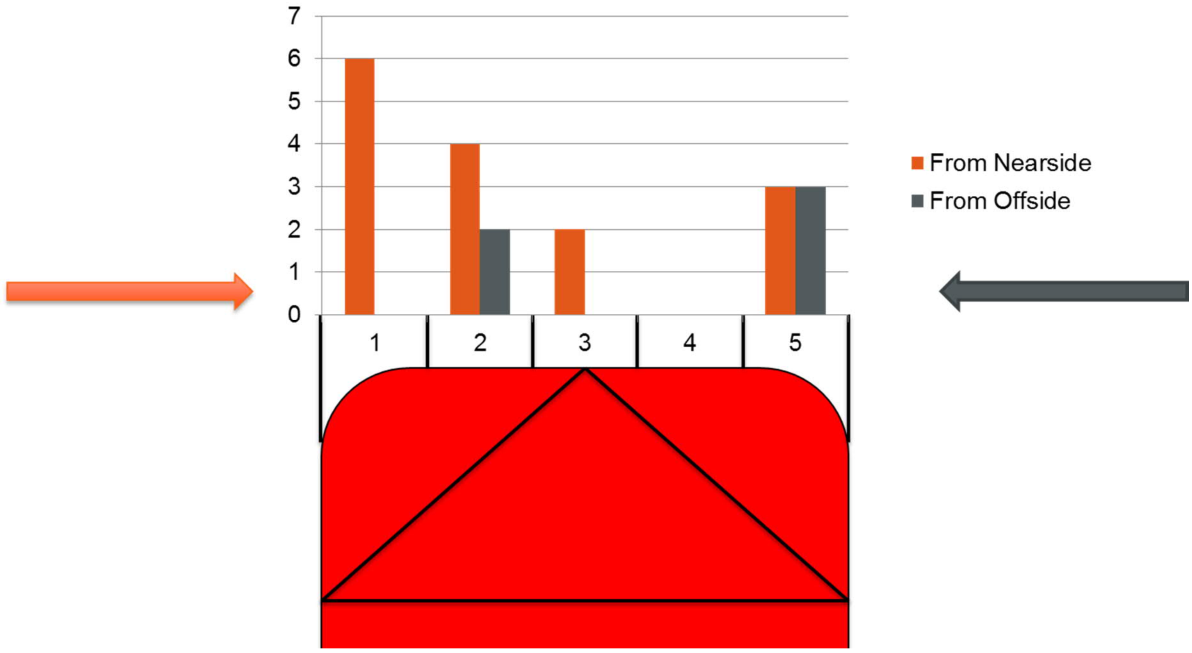
The reconstructions of the police fatal files indicate that for the pedestrians and cyclists crossing from the nearside the line of sight was small; 13 of 15 cases had line of sight <10m, and 7 of those were <5m. For the collisions where the pedestrians approach from the offside the bus is typically at higher speed. Assuming bi-directional traffic and identical pedestrian speeds, the reaction time available from the point when the pedestrian leaves the kerb is much greater for the offside. So, with greater driver reaction time available, why is it not being used? One potential explanation is that on average, pedestrians coming from the offside were moving faster than those from the nearside, eroding or reversing the reaction time advantage; this is examined in a subsequent section. The 'other' cases refer to a pedestrian and a cyclist cases where the line of sight was less than 5m; these people were in/on the road, but not from the near/offside.

Figure 57: Line of sight and bus travel speed. Source data: Police fatal files.



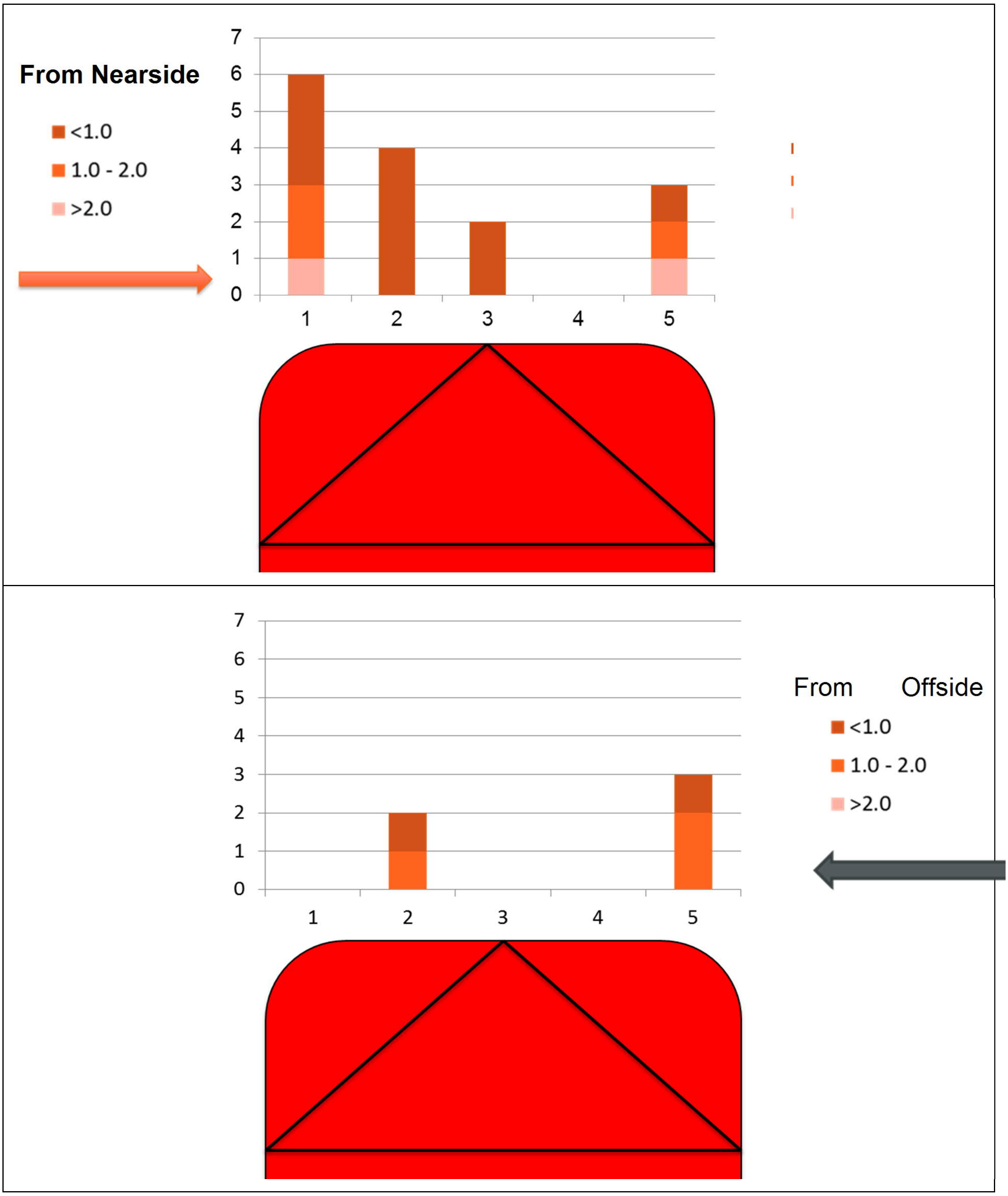
Using the police fatal files the point of contact of the pedestrian on the front of the bus was also identified, and coded as within one of five zones as shown in Figure 58. Unsurprisingly, the majority of the pedestrians crossing from the nearside made contact with the bus closest to the nearside in zone 1; and the majority of pedestrians crossing from the offside made contact closest to the offside in zone 5. It is interesting to note that in 3 of the cases the pedestrian crossing from the nearside did make it all the way across to zone 5 before contact was made.

Figure 58: Pedestrian point of contact across front of bus. Source data: Police fatal files.



The time to collision was also calculated by the reconstruction experts for the police fatal files and is show in Figure 59. The majority of cases had <1.0 second, whether crossing from the nearside or offside, indicating that very little reaction time was available to the driver/vehicle or pedestrian. Given the additional distance the pedestrians covered from the kerb to the point of impact when approaching from the offside, the fact the available reaction time remains similar shows that pedestrians in collisions from this side were typically moving faster than those coming from the nearside.

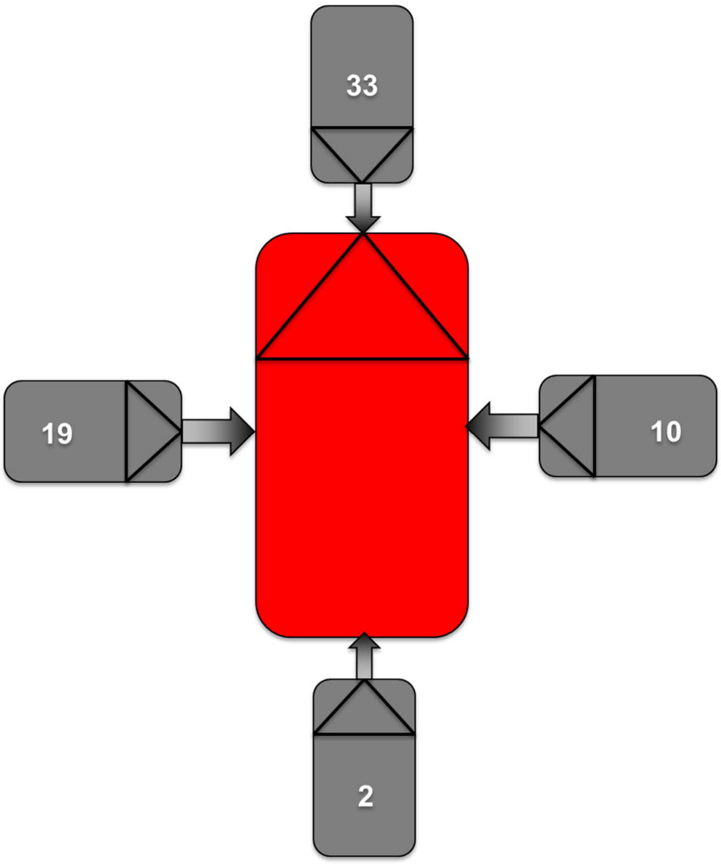
Figure 59: Pedestrian time to collision from the nearside (upper) and offside (lower). Source data: Police fatal files.



A.5.2 Car Occupant Fatalities

In the HVCIS data there were 64 car occupants injured where the impact point on the bus is known, as shown in Figure 60. The majority 52% were impacting with the front of the bus. The nearside was the next most frequent impact point at approximately 30%, offside was 15% and the remaining 3% were at the rear. Note that for this dataset it is not possible to distinguish in any greater granularity (such as rear nearside) where the impact location was, whereas the police fatal files were examined to gather that greater level of information.

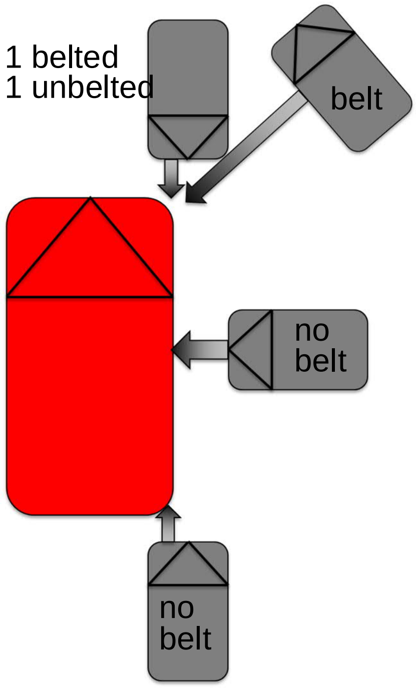
Figure 60: Collisions involving car occupants: distribution around the bus. Source data: HVCIS.



In the police fatal files there were five fatal collisions involving car occupants. One of these car collisions included three slight injuries on the bus. All the fatalities were drivers; no passengers were present. Overall, bus crashworthiness and collision compatibility was not deemed a factor in any of these five car occupant fatalities. The main factors were reckless driving / excessive speed, lack of seat belt use by the car driver (three of the five fatalities were for car drivers not wearing their seat belts), and collision configuration (e.g. small overlap).

Three of five of the buses were single decker buses. The impact distribution around the buses is described in Figure 61, with the majority being at the front of the bus.

Figure 61: Impact distribution for bus collisions involving car occupant fatalities. Source data: Police fatal files.



Three of the car driver fatalities lost control of their vehicle; two of them were not wearing their seat belts and were travelling with excessive speed. In another case the loss of control occurred after an impact with a pedestrian island. In this case, vehicle deformation was very significant and the seat belt was not worn. However, the cause of death was attributed to a head strike with planks of wood inside the car.

For the remaining two cases that did not involve loss of control, one involved an unbelted car driver suffering a diabetic episode resulting in multiple impacts with other road users and roadside furniture, culminating in a severe rear-end offside collision with a stationary bus. The last was an alcohol related collision, where the car drifted on to the wrong carriageway and collided head-on with the bus.

Appendix B Stakeholder Questionnaire

B.1 Introduction

Transport for London (TfL) are in the process of developing a new Bus Safety Standard with the aim of reducing the frequency and/or mitigating the consequences of collisions involving buses. TRL has been commissioned as part of the first phase of the development of this standard, to undertake a detailed analysis of collisions involving buses in order to better understand the circumstances. Based both on the findings and a study of best practice on London's buses, international best practice and possible technology transfer from other vehicle types, the research aims to identify the most effective vehicle technologies and design features in terms of casualty reduction.

At this stage, preliminary analysis of research literature, data from the GB national collision database (stats 19) and data from a sample of police fatal collision reports have been analysed. The aim of this questionnaire is to help the project team fill the remaining gaps in the knowledge with particular reference to:

- The detailed circumstances of groups of collision types where the available data is limited
- The cost of collisions and incident claims to bus operators (e.g. self-insured payouts, reinsurance premiums, driver absence, vehicle downtime etc.)
- Identifying countermeasures which we have missed

Giving views on:

- The effectiveness of the countermeasures identified
- Their technical feasibility
- Any barriers to implementation or constraints that would be imposed on operation
- When it would be possible to implement them
- How much they would cost

The project team will be grateful for your expert opinion in these matters. However, if you had data, for example from insurance claims data or from telematics systems that you would be prepared to anonymously share for TRL to analyse this would be enormously beneficial to the research. If you are willing to discuss the provision of hard data, please contact Kerri Cheek (kerricheek@tfl.gov.uk) or Jane Lupson (JaneLupson@tfl.gov.uk).

B.2 Frequently asked questions

Who is conducting the research? This research is being carried out by TRL (the Transport Research Laboratory) on behalf of Transport for London (TFL).

How long will the survey be open for? The survey will be open for responses until 5 pm GMT on 20th December 2016 .

Will my answers be confidential? You will be asked to provide your name and your organisation name. This information will only be shared within the TRL team and Transport for London. You will not be identified in any published materials unless you provide permission. Neither will you be contacted by anyone who does not work at TRL or TfL, and you will only be contacted if you provide permission.

How long will it take? It is anticipated that you would be able to reply with your expert opinion in 60 minutes or less. However, if you were able to share objective data with us we would be very grateful but this would be expected to take longer to define exactly what is available, what it means and what constraints and agreements are necessary to protect the privacy and commercial interests of those involved.

Who can I contact if I have any questions? If you require any further information please contact TRL on ageorge@trl.co.uk

B.3 Consent

1. Please state whether you agree with the following statements:

- I have read and understood all of the information above (if you have any questions, please email survey@trl.co.uk)
- I feel sufficiently informed as to the survey's purpose
- I am aware that I am free to withdraw from the survey at any time

Yes, I agree with these statements

No, I do not agree with these statements

2. Please provide your name, organisation and email address:

Name:

Organisation

Email address:

If you are willing to, please also provide your phone number:

3. Please indicate whether you provide permission for your responses to be published:

☐ Yes

☐ No

B.4 Collision data

TRLs analyses of on-road injury collision data and police fatal collision files suggest the following groups of road users are most commonly injured in collisions involving buses. Which of these has the most impact on your operation, balancing consideration of disruption, costs, and any corporate and social responsibility objectives you may have as a company? Please give a rank order (1 is highest impact, 3 is lowest)

Road user injured	Rank order of impact on business objectives
Car occupants	
Pedestrians	
Bus Occupants	

Please explain your reasoning for the selection above.

Do injuries to any other road user groups have a significant impact on your business objectives? If so, which and in what way?

How do you think the safety of buses compares with that of other road vehicles (better, worse, similar)? Why do you think this?

How do you think the safety performance of bus operations in London compares to GB as a whole?

Analyses of on-road injury collision data suggests overall reductions in the number of casualties from collisions involving buses and coaches (can't be separated in national data) during the period 2006-15. It suggests that proportionally there have been greater reductions in the number of people killed than in the number of all those injured, whatever the severity. Can you think of any reasons why this might be?

The data suggest that in London, the fatality reduction is broadly comparable to GB but that the reduction in injuries of lesser severity is considerably less than for GB as a whole. Can you think of any reason why this might be?

The collision data identifies that for a substantial proportion of those classified as bus or coach occupants, their injuries were sustained in an incident that did not involve the bus colliding with another vehicle or object. Relatively few of this group were killed. Please can you list the types of incident that might occur to cause the injuries within this group and provide a rank order to indicate which you think are the most common causes (use additional sheet if required)?

Collision type/circumstances/causes	Rank order indicating which are most common

Are you able to supply data that would allow us to examine the circumstances and causes of collisions involving buses in more detail? If so, please elaborate.

B.5 Countermeasures

The number of casualties arising from collisions involving buses has reduced over the period 2006-15. What safety changes do you think will have influenced this change and why. Please separate by the categories of safety intervention indicated below.

Bus design and performance

Bus operation (e.g. scheduling, routing, matching vehicle choice to route, maintenance etc)

Bus driver behaviour (training, speeding, distraction, fatigue etc)

Improvements to infrastructure (road layout, markings, signage, bus stop design etc)

Design and performance of other vehicles (cars, trucks, motorcycles etc)

Behaviour of other road users (pedestrians, other drivers etc)

In terms of the design of buses, TRL has identified the following potential countermeasures based on literature describing existing best practice and technology transfer from other vehicle types. Their function is described below. Please could you add any additional measures which you consider might be beneficial.

Blind spot warnings: Systems that use sensors such as ultrasound, radar, or camera to identify pedestrians or cyclists in blind spots around the vehicle, particularly the front nearside corner in the event of a left turn

AEB: Automated Emergency Braking system. This uses advanced sensors such as radar, camera or lidar to scan areas around the vehicle and detect situations where there is a risk of collision. Where urgent action is necessary but the driver has not responded, the vehicle will apply braking automatically in order to avoid a collision or to at least reduce the collision speed. Different forms of AEB exist and will be effective in different collision scenarios as identified below;

AEB (BVR): Bus front to Vehicle Rear – works where the bus is about to collide with the rear of a vehicle ahead travelling in the same direction and the same lane.

AEB (pedestrian and cyclist): Effective where the front of the bus collides with a pedestrian or cyclist crossing the road approximately at right angles to the direction of bus travel.

AEB (Left turn): Effective where the bus turns left across the path of a pedestrian or cyclist positioned to the nearside of the vehicle.

AES: Automated emergency steering, where sensor systems detect that swerving around a hazard will provide a better avoidance strategy than braking. Initially considered only in relation to avoiding frontal collisions with pedestrians crossing the road where the impact point is near the edge of the vehicle.

Pedestrian friendly front structure: The shape of the vehicle can be changed (curved) to reduce the severity with which pedestrians are pushed to the ground, and deflect them out of the path of the vehicle to lessen the chance of running over. The materials used can be changed to ensure they allow 2-3 cms of controlled deflection to reduce the risk of serious injury in the primary impact.

Runover prevention structures: addition of structure intended to prevent pedestrians being run over by wheels

Improvements to direct vision: Eliminate blind spots at source.

Improved interior design: Measures to reduce the chance of falls, to minimise the distance an occupant could fall or slide before impacting an interior structure and/or ‘softening’ of interior structures to present less injury risk in the event of a collision, these could include gating the stairs while in motion, large radius, soft material or frangible grab rails, higher seat backs etc.

Additional Measures

Please could you give your view as to how effective each countermeasure considered might be for bus operations in London. Please rate each measure on a scale of 1 (not effective at all) to 5 (highly effective) and provide any comments or explanations associated with your rating.

Measure	Effectiveness rating (1-5)	Comment/explanation
Blind spot warning		
AEB BVR		
AEB pedestrians and cyclists		
AEB Left turn		
AES		
Pedestrian friendly front		
Runover prevention structure		
Direct vision		
Interior design		

How technically feasible do you think each solution might be if it were assumed that it was fitted to new buses in 2018, 2023, or 2028. Rate on a scale of 1 (not technically feasible) to 5 (already in production). So a measure already in production in 2016 would score 5 in all boxes. A complex measure not yet in prototype form but where problems are solvable might start at 1 in 2018 and progress to 5 by 2026.

Measure	Feasibility in year (score 1-5)					Comment/explanation
	2018	2020	2022	2024	2026	
Blind spot warning						
AEB BVR						
AEB pedestrians and cyclists						
AEB Left turn						
AES						
Pedestrian friendly front						
Runover prevention structure						
Direct vision						
Interior design						

What barriers to implementation could you foresee and what constraints would it cause in terms of vehicle operation?

Measure	Barriers and constraints
Blind spot warning	
AEB BVR	
AEB pedestrians and cyclists	
AEB Left turn	
AES	
Pedestrian friendly front	
Runover prevention structure	
Direct vision	
Interior design	

What do you think each countermeasure might cost focussing mainly on the purchase cost per vehicle? If there are additional on-going costs please identify these and any rationale or explanation in the comments section.

Measure	Cost (£)	Comment/explanation
Blind spot warning		
AEB BVR		
AEB pedestrians and cyclists		
AEB Left turn		
AES		
Pedestrian friendly front		
Runover prevention structure		
Direct vision		
Interior design		

Appendix C Bus Countermeasures Master List

Vehicle and Equipment	
Pre-crash	**Vehicle condition**
101	Better maintenance of vehicle consumables/features (brakes, tyres, lights etc.)
102	Appropriate use of lights (not defects)
103	Ensure proper adjustment of mirrors
104	Fit mirrors that are currently legislated (only apply if mirrors fitted do not meet legislation)
	Vehicle features
110	ESC
111	Lane departure warning
112	Lane keep assist
113	AEBS (city - low speed shunts ONLY)
114	AEBS
115	AEBS (Pedestrian/cyclist)
116	ISA (voluntary)
117	ISA (mandatory)
118	Blind spot warning (motorway lane changes)
119	Overtake assist
120	Fatigue monitoring
121	Alco-lock
122	Driver alert for approaching permanent hazard (sharp bend, steep decline)
123	Driver alert for approaching temporary hazard (road works, broken down vehicle, queuing traffic)
124	Intersection assistance
125	do not use code
126	Improved mirror visibility
127	Camera/sensor systems for detecting pedestrians and cyclists (for large vehicles)
128	Improved sideguards
129	Improved rear underrun guards

130	Post impact braking system
131	Intersection AEBS (prevents vehicle from setting off into oncoming vehicle from stationary)
132	Traffic sign recognition (warning only)
133	Cross traffic AEBS
134	ABS (motorcycles only)
135	Forward collision warning (motorcycles only)
136	Distraction monitoring
137	Buses only - Fit improved mirrors (e.g. class V and VI mirrors)
138	Buses only - Improve direct vision (front)
139	Buses only - Improve direct vision (side)
140	Buses only - System preventing harsh acceleration
141	Buses only - System preventing harsh deceleration
142	Buses only - Prevent ejection NFS
143	Buses only - Improve structural crashworthiness (frontal)
144	Buses only - Improve structural crashworthiness (rollover)
145	Buses only - Improve structural crashworthiness (rear)
146	Buses only - Bridge impact prevention system
147	Buses only - improved front end design (prevents pedestrian underrun at front - only if not laying down)
	Pedestrian, Cyclist, Motorcyclist accidents
190	Improved pedestrian and cyclist conspicuity
Crash	
201	Improved pedestrian secondary safety (relative to current typical level)
202	Improved occupant secondary safety (relative to current typical level)
203	Better helmet
204	Use of helmet
205	Use of available seat belt
206	Pedestrian friendly mirrors (impacts with large vehicles)
207	Fit and use lap belt

208	Fit and use 3 point belt
209	Buses only - improved occupant friendly structures (e.g. deformable handrails)
210	Buses only - improved occupant safety on stairs (e.g. fall mitigating surface)
211	Buses only - Use front facing seating
212	Buses only - Use rear facing seating
213	Buses only - Eliminate steps and other trip hazards
214	Buses only - Prevent door entanglement
215	Buses only - Prevent boarding/alighting while in motion
216	Buses only - Reduce swept path during turn (e.g. eliminate nose/tail swing)
220	Proper use of helmet
221	Use of appropriate secondary safety clothing (eg. motorcycle leathers)
Post-crash	
301	eCall
302	Improve emergency exits

Human Factors	
401	do not use code
402	do not use code
403	do not use code
	Improve driver skills/behaviour
420	Better licensing (reduce exposure to specific high risk situations)
421	Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)
422	Better licensing (medical/health related)
423	Training to improve hazard perception skill
424	Training or education to reduce risky driving manoeuvre
425	Training or education to reduce risky pre-driving behaviour (e.g. drink or drug use)
426	Training or education to reduce other risky behaviours while driving (e.g. seat belt wearing)
427	System design to reduce distraction from in-vehicle devices
428	System design to reduce distraction from out-of-vehicle sources
	Enforcement
410	add speed camera at locus
411	Improved road traffic police profile/checks
412	Add red light camera
413	Add red light camera that detects cyclists
414	Prevent parking within 50m of a junction

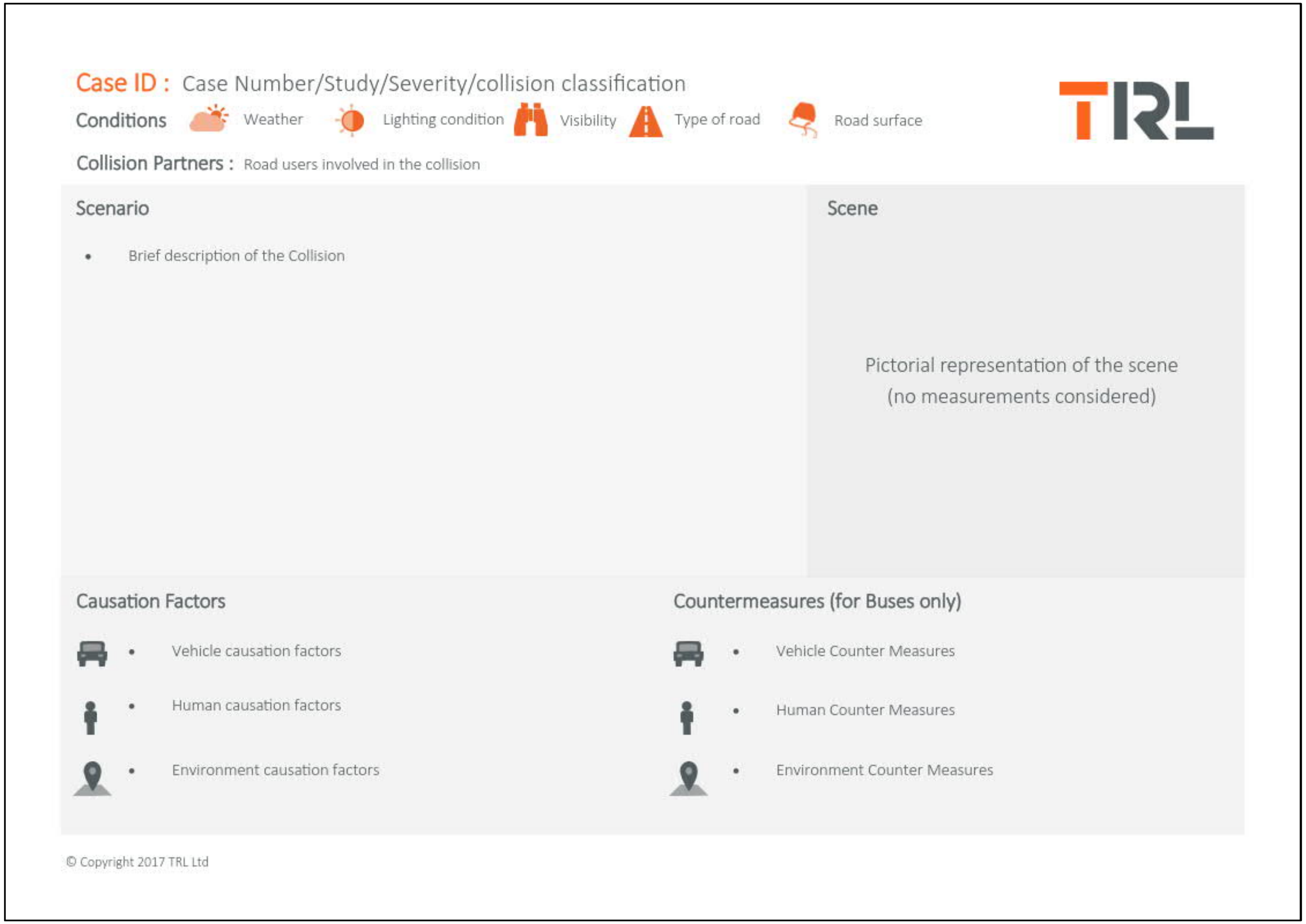
Environmental factors	
Pre-crash	**Improve road surface condition:**
701	Improve road surface friction
702	More effective drainage
703	Improve surface topography (pot-holes or defects)
704	More effective surface treatment (e.g. gritting)
	Fit/improve signage:
710	Add signs
711	Better sign visibility in visual scene
712	Improved sign positioning (height, location)
713	More effective sign type/design - Intelligent signage
714	Separate signal phases for cyclist's direction and oncoming right turners
	Improved road layout/design:
720	stagger junction (break sightlines)
721	add traffic light control to junction (reduce conflicts)
722	add roundabout (reduce conflicts - maintain flow)
723	sign alternative route (avoid road feature - narrow bridge etc)
724	add pedestrian crossing (if in urban area and appropriate)
725	Redesign to improve junction visibility (if permanent obscurations)
726	Add street lighting
727	Reduce speed limit
728	Add or widen pedestrian pathway
729	Improve sightlines (change junction design)
730	Prevent parking near junctions/bus lane
732	add pedestrian crossing (overpass or underpass when 724 is not appropriate e.g. on fast roads)
733	Physical segregation of cycle lane (e.g. kerb separated cycle lane)
734	Move stop line further away from crossing to allow large vehicles to see pedestrians and cyclists

	When the vehicle has struck an object/roadside furntiture or run off the road:
740	1) Remove hazard
741	2) Relocate hazard beyond clear zone
742	3) Make the hazard passively safe
743	4) Shield hazard with Vehicle Restraint System (VRS) /Improve type of VRS – not further specified
744	Add appropriate barrier
745	More effective barrier type
746	Higher containment level barrier (Mitigates crossover)
747	Better barrier position (Hits object behind)
748	Motorcycle protection system (Mitigates motorcycle impacts)
749	Presence of a safety barrier (May be correct barrier but has failed due to age/poor maintenance)
750	Better maintained barrier
752	5) Delineate the hazard
Post-crash	**Emergency access**
901	Better access for emergency vehicles (road layout)
902	Better access for emergency vehicles (through congestion)

Other	
888	Other (add comments)
999	Unknown (if you can’t think of any, or none in the list are appropriate)

Appendix D OTS & RAIDS Case Summaries

Legend:



Case ID : Case1/OTS/Fatal/Pedestrian

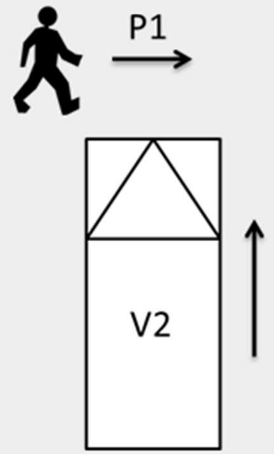
Conditions Fine Daylight Good Single Carriageway Wet/damp

Collision Partners : 1- Pedestrian 2-Local Bus

Scenario

- A pedestrian (P1) was crossing a street from the nearside in a built-up urban area.
- A local bus (V2) was approaching the bus stop.
- V2 driver claims not to have noticed P1 until the last instant and could not avoid him.
- P1 was knocked to the ground and suffered head injuries.
- Whilst recovering from his injuries, P1 suffered fatal complications within 30 days of the collision.
- P1 was not visible to the V2 driver due to obscuration by bushes around the bend leading up to the collision scene.

Scene



Causation Factors

- Bus Driver: Failed to look properly .
- Pedestrian: Careless, reckless or in a hurry

- Obscuration due to vegetation.

Counter Measures

- Pedestrian AEB.
- Improved pedestrian secondary safety

- Training to improve hazard perception skill.

- Redesign to improve junction visibility (if permanent obscuration).

Case ID : Case2/OTS/Fatal/Pedestrian

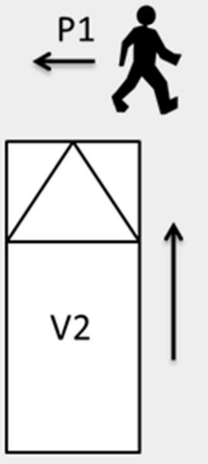
Conditions Fine | Daylight | Good | Single Carriageway | Unknown

Collision Partners : 1-Pedestrian 2-Local Bus

Scenario

- A pedestrian (P1) (believed to be intoxicated) got out of a taxi and placed his hands on the boot to steady himself.
- As the taxi pulled away, P1 appears to have lost balance and then staggered, backwards, into the path of the oncoming bus (V2).
- P1 had crossed into the path of V2 from the driver's offside.
- P1 struck the front offside of V2, which dragged him underneath the bus and fatally injured him.

Scene



Causation Factors

- Pedestrian: Careless, reckless or in a hurry

Counter Measures

- Pedestrian AEB.
- Improved pedestrian secondary safety
- Training to improve hazard perception skill.

Case ID : Case3/OTS/Fatal/Head-on

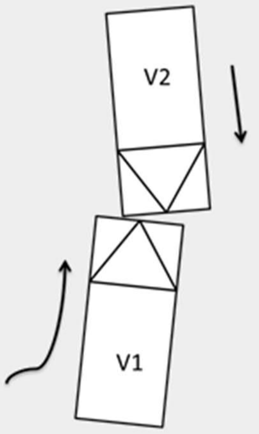
Conditions Unknown Daylight Good Single Carriageway Snow

Collision Partners : 1-Car 2-Local Bus

Scenario

- The driver of a car (V1) was driving the vehicle along the single carriageway road around the right hand bend.
- At the locus, the bend was moderate and there was a slight downhill gradient.
- The driver of V1 was possibly inexperienced at driving in adverse road conditions and lost control of the vehicle as it began sliding on the icy road surface.
- The driver of a local bus (V2) was driving along his regular route in the opposite direction to V1, steered to the nearside and braked in an attempt to avoid the collision.
- V1 slid across the carriageway to the offside and directly into the path of the V2. V1 then collided head on with the V2.
- The impact caused the driver of V1 to suffer fatal injuries and the driver of V2 suffered from what was believed to be a heart attack at the scene and was hospitalised.

Scene



Causation Factors

- Car-Loss of control
- Car Driver- Learner or inexperienced driver/rider
- Car-Travelling too fast for conditions
- Slippery road (due to weather)

Counter Measures

- Improve structural crashworthiness (frontal)
- Training to improve hazard perception skill.
- Reduce speed limit

Case ID : Case4/OTS/Serious/Pedestrian

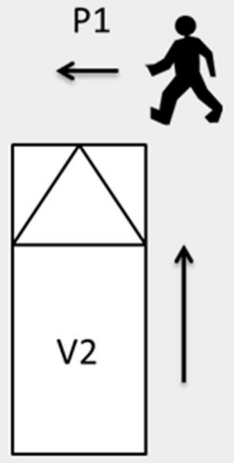
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Pedestrian 2-Local Bus

Scenario

- A local bus (V2) was travelling along an A-road approaching some traffic lights on a pelican crossing.
- V2 driver saw flashing amber, but nobody was crossing, so he proceeded across the traffic lights.
- A child pedestrian (P1) stepped out right in front of V2 as it passed over the pelican crossing.
- V2 driver had no time to react and P1 hit the bumper and then the windscreen.
- P1 was thrown and dragged 17m as V2 braked to a halt.
- Hospital notes record that P1 was crossing the road behind another pedestrian.

Scene



Causation Factors

- Pedestrian- Careless, reckless or in a hurry

Counter Measures

- AEBS (Pedestrian/cyclist)
- Improved pedestrian secondary safety
- Training to improve hazard perception skill.

Case ID : Case5/OTS/Serious/Pedestrian

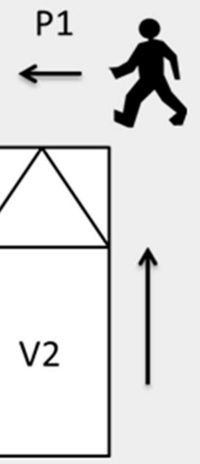
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Pedestrian 2-Local Bus

Scenario

- Driver of a foreign HGV (now classed as a pedestrian) (P1) stopped and alighted from the vehicle intending to ask directions.
- P1 stepped out into the carriageway (passing behind the parked HGV) and looked in the wrong direction (forgetting, momentarily, that traffic in the U.K. drives on the left) and stepped out.
- P1 stepped straight into the path of an oncoming bus (V2).
- The front offside wheel of V2 has driven over the left foot of P1.

Scene



Causation Factors

- Pedestrian-Failed to judge vehicle's path or speed

Counter Measures

- AEBS (Pedestrian/cyclist)
- Training to improve hazard perception skill.

Case ID : Case6/OTS/Serious/Sideswipe & Head-on

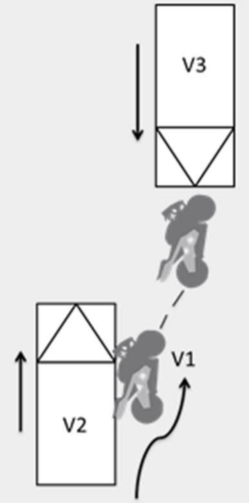
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Motorcycle 2-Car 3-Local Bus

Scenario

- A car (V2) was passing an unknown stationary bus at a bus stop.
- Rider of a motorcycle (V1) tries to overtake V2 from the right side and panics.
- V1 swipes the offside of V2 and gets deflected.
- V1 is then sent across to the offside of the road and collides head-on with a bus (V3) travelling in the opposite direction.

Scene



Causation Factors

- Rider- Poor turn or manoeuvre
- Rider- Careless, reckless or in a hurry

Counter Measures

- AEBS
- Training to improve hazard perception skill.

Case ID : Case7/OTS/Serious/Rear-end

Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Motorcycle 2-Local Bus

Scenario

- A motorcycle (V1) lost control when the rider panicked and braked hard on the front wheel only after seeing a local bus (V2) stationary in the lane ahead but indicating to pull out of the lane.
- Due to the wheel lock, V1 skidded before falling and collided with the rear V2.
- Both V1 and the V1 rider came to rest underneath V2.

Scene

Causation Factors

- Rider-Nervous, uncertain or panic
- Rider-Travelling too fast for conditions

Counter Measures

Case ID : Case8/OTS/Serious/Pedestrian

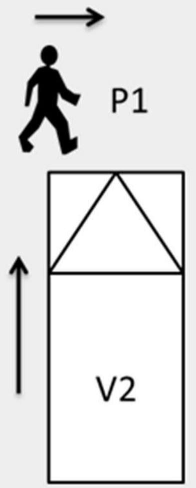
Conditions Unknown Daylight Good Single Carriageway Dry

Collision Partners : 1-Pedestrian 2-Local Bus

Scenario

- On a dry day during the morning rush hour, a pedestrian (P1) began to run across a road near a train station.
- P1 was crossing from the nearside of an oncoming local bus (V2) and failed to use the pedestrian crossing metres away.
- P1 was struck by V2 and their head hit the lower part of the front screen on the nearside.
- V2 stopped and P1 was thrown to the ground.

Scene



Causation Factors

- Pedestrian-Failed to judge vehicle's path or speed

Counter Measures

- AEBS (Pedestrian/cyclist)
- Improved pedestrian Secondary safety
- Training to improve hazard perception skill

Case ID : Case9/OTS/Serious/Front-side

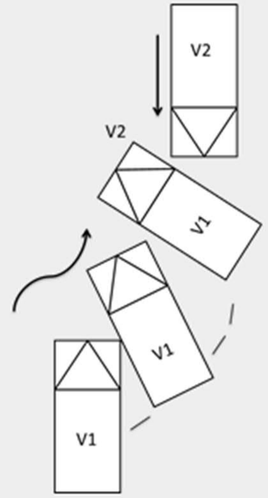
Conditions Fine Darkness Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- During late evening at a busy junction in town centre, a car (V1) carrying 4 occupants swung wide around left hand bend down hill to be confronted by a local bus (V2) in the opposing lane.
- V1 driver reacted by braking hard while V2 began to spin anti-clockwise.
- As V2 became nearly stationary the driver of V1 swerved to the left leaving the offside of V1 exposed to the front of V2.
- The offside door of V1 struck the front offside corner of V2 and V1 rolled over onto it's nearside.
- All 4 occupants were trapped in V1 and were cut out by Fire and Rescue Services.
- The driver of V1 was sober though the other 3 passengers were heavily intoxicated by alcohol.

Scene



Causation Factors

- Car- Swerved
- Car driver- Careless, reckless or in a hurry
- Road layout

Counter Measures

- Training to improve hazard perception skill

Case ID : Case10/OTS/Slight/Other

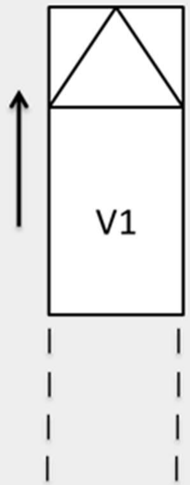
Conditions Fine Daylight Good Dual Carriageway Dry

Collision Partners : 1-Local Bus

Scenario

- A Local bus (V1), braked heavily due to an unknown vehicle cutting in front of it.
- No other vehicles contacted and the offending vehicle was never traced.
- One passenger on-board was thrown forward and injured in the incident.

Scene



Causation Factors

- Bus driver- Failed to judge other person's path or speed
- Bus driver– Sudden Braking

Counter Measures

- Improved occupant friendly structures
- Training to improve hazard perception skill

Case ID : Case11/OTS/Slight/Junction

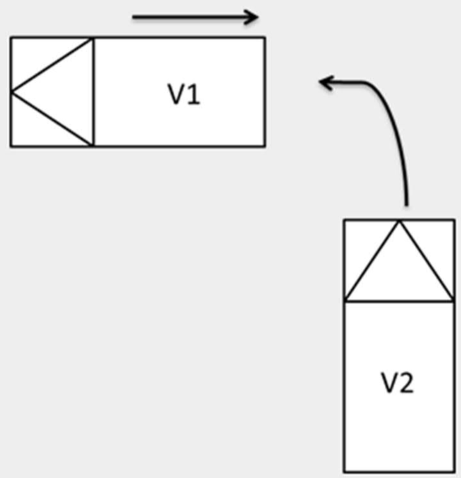
Conditions Fine Darkness Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) started to reverse as it had missed a turning to the left.
- A single decker bus (V2) pulled out from a side road turning left to follow V1.
- It was too late by the time V2 driver found V1 reversing back along the carriageway.
- V1 reversed into the V2 and both the vehicles came to rest in the centre of the junction.

Scene



Causation Factors

- Car- Careless, reckless or in a hurry
- Bus- Failed to judge other person's path or speed

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill

Case ID : Case12/OTS/Slight/Rear-end

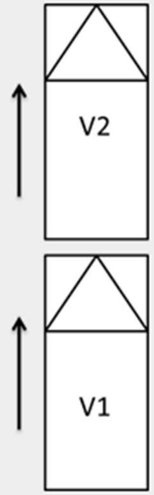
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Van 2-Local Bus

Scenario

- A single decker bus (V2), slowed down suddenly while approaching a traffic signal.
- A van (V1) was following V2 closely.
- V1 failed to stop behind and stuck the rear of V2.

Scene



Causation Factors

- Van – Following too close
- Van-Failed to look properly
- Inadequate or masked signs or road markings

Counter Measures

- Training or education to reduce risky driving manoeuvre
- Add signs

Case ID : Case13/OTS/Slight/Junction

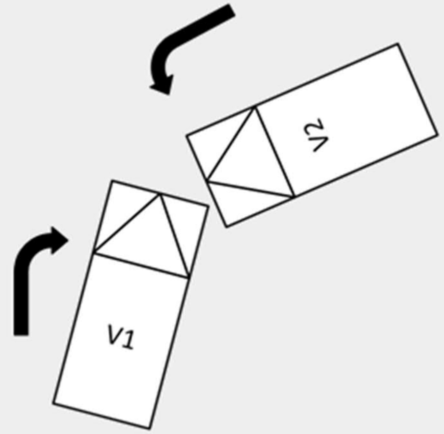
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) failed to give way to traffic on the main road and was turning right out of a car park.
- A single decker bus (V2) approaching from the right of V1 on the main carriageway was turning left.
- Front of V1 collided with the front of V2 in the centre of the junction.

Scene



Causation Factors

- Car- Junction overshoot
- Car-Failed to look properly
- Car- Disobeyed Give Way or Stop sign or markings
- Bus- Failed to judge other person's path or speed

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill

Case ID : Case14/OTS/Slight/Junction

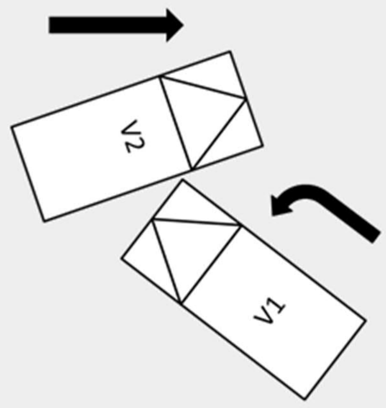
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) approached the T-junction, intending to turn left, onto the main road. V1 stopped at the give-way line and the driver looked left, and saw a local bus (V2) approaching.
- V2 driver slowed down and moved to the centre of the road, to pass the line of parked vehicles.
- V1 driver thought that V2 was slowing down to allow him to pull out and started to pull out onto the main road. The front offside of V1 scraped along the offside of the V2 as it passed.
- V1 came to rest with the front in the main road and the rear in the side road. V2 was brought to rest on the main road.
- Vehicles on the main road were legally parked , opposite the entrance to a side road.

Scene



Causation Factors

- Bus- Failed to look properly
- Car- Failed to judge other person's path or speed
- Road Layout

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill
- Prevent parking near junctions/bus lane

Case ID : Case15/OTS/Slight/Rear-end

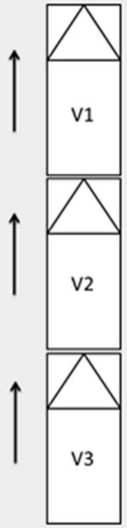
Conditions Fine Darkness Good Single Carriageway Wet/damp

Collision Partners : 1-Car 2-Car 3-Local Bus

Scenario

- A car (V1) was being followed by another car (V2), which in turn was being followed by a local bus (V3) on a single carriage way.
- All three vehicles were travelling along a main road with heavy traffic.
- Both V1 and V2 stopped in a queue of traffic approaching the traffic light controlled junction.
- V3 driver didn't notice the stopped vehicles ahead and ran into the rear of V2. Which in turn was pushed forward and stuck the rear of V1.

Scene



Causation Factors

- Bus- Failed to look properly
- Bus- Following too closely

Counter Measures

- AEBS (city - low speed shunts ONLY)
- Training to improve hazard perception skill
- Improved sign positioning (height, location)

Case ID : Case16/OTS/Slight/Junction

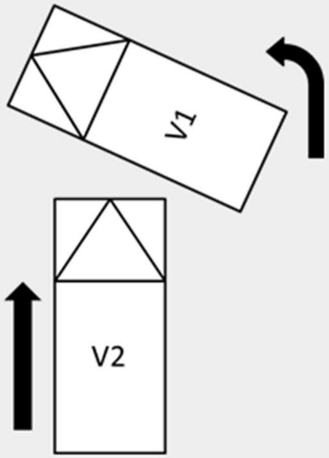
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- Driver of a car (V1) overtook a bus (V2) travelling in the bus lane.
- V1 passed the bus in lane 1,indicated and started to turn left in front of V2.
- V1 stopped across the bus lane as a pedestrian was crossing the minor road where V1 intended to travel.
- V2 was unable to stop in the available distance and collided with nearside of V1 pushing it sideways.

Scene



Causation Factors

- Car-Poor turn or manoeuvre
- Car-Careless, reckless or in a hurry

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill

Case ID : Case17/OTS/Slight/Junction

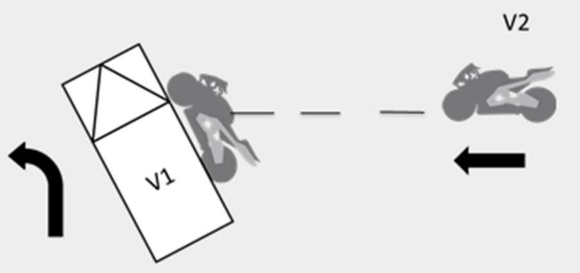
Conditions: Unknown | Daylight | Good | Single Carriageway | Dry

Collision Partners : 1-Local Bus 2-Motorcycle

Scenario

- A bus (V1) was at T-junction, waiting to turn left. Driver of V1 had a restricted view to the right obscured by a bend in the road, a fence and vegetation, and was possibly not helped by bright sunlight.
- A motorcycle (V2)(young rider) was travelling downhill along main road.
- Rider of V2 heard rattling noise at the rear wheel and looked down to see.
- V1 saw no traffic approaching, so decides to pull out of the junction (possibly watching to the right, as that side has poor visibility).
- V1 blocks the entire road as it makes the turn. V2 rider looks up to see V1 at about 50m from him blocking the road. V2 brakes and steers slightly left.
- Front of V2 collided with Offside V1 (probably <5mph). V2 slid for about 3m, under O/S V1. V2 rider slightly grazed left hip.

Scene



Causation Factors

- Motorcycle- Learner or inexperienced driver/rider

- Road layout (e.g. bend, winding road, hill crest)
- Vegetation

Counter Measures

- Improved side design (prevents VRU underrun)

- Training or education to reduce risky pre-driving behaviour

- Redesign to improve junction visibility (if permanent obscuration)

Case ID : Case18/OTS/Slight/Front-side

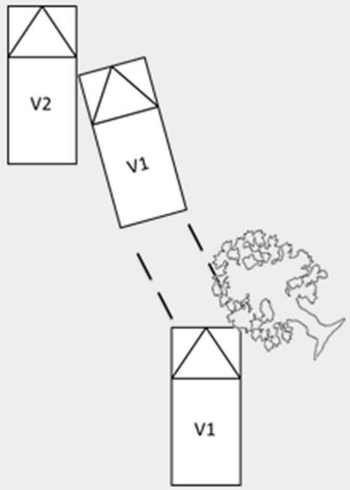
Conditions Unknown Daylight Good Single Carriageway Dry

Collision Partners : 1-Local Bus 2-Car

Scenario

- On a 30mph speed limit residential road, lined with trees and parked vehicles a single deck bus (V1) was travelling along its usual bus route.
- Suspect V1 driver fell asleep and the upper front offside corner V1 hit tree off road to offside.
- V1 driver reacted by flinging himself down over the steering wheel, and trying to apply the brakes (but missed, and hit the accelerator instead).
- V1 driver steered left. Front nearside V1 hit right offside of a car (V2), which was parked on the road, near the nearside kerb.
- V1 came to rest some distance along the road.
- V1 driver was possibly fatigued and was due to have a break a few minutes before the accident happened.

Scene



Causation Factors

- Bus Driver: Fatigue
- Bus Driver: Nervous, uncertain or panic

Counter Measures

- Fatigue monitoring
- Training or education to reduce risky pre-driving behaviour

Case ID : Case19/OTS/Slight/Sideswipe & Rear-end

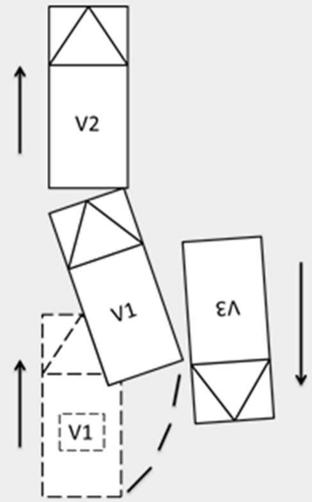
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Car 2-Car 3-Local Bus

Scenario

- A car (V1) approached from around a left hand bend at speed and saw another car (V2) stationary in lane 1 ahead, waiting for a bus (V3) to pass around a parked vehicle.
- V1's driver panicked and braked hard on seeing the obstruction ahead and started to skid.
- V1 then continued to skid colliding with the offside of V3 and the rear of V2.
- V2 was pushed forward and half onto the footpath where it came to rest.
- V1 and V3 came to rest in the centre of the carriageway.

Scene



Causation Factors

- V1 driver – Nervous uncertain or panic
- Road layout (e.g. bend, winding road, hill crest)

Counter Measures

- Training to improve hazard perception skill.
- Add signs
- Improved sign positioning

Case ID : Case20/OTS/Slight/Junction

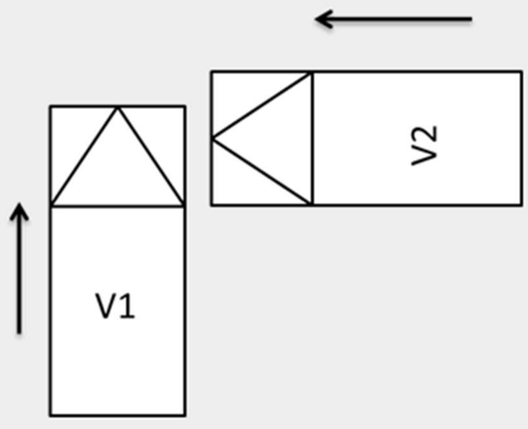
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) failed to give-way to vehicles entering from the right on a mini roundabout .
- V1 entered the roundabout without stopping intending to take the second exit.
- A single decker bus (V2) already on the roundabout from the right was unable to stop in time
- V2 collided with the offside of V1 pushing it to the nearside of the carriageway.
- The driver of V1 only had a provisional licence

Scene



Causation Factors

- Car-Learner or inexperienced driver/rider
- Car-Careless, reckless or in a hurry

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill.

Case ID : Case21/OTS/Slight/Pedestrian

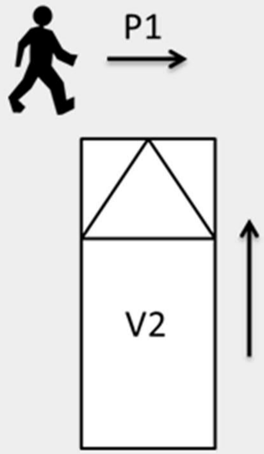
Conditions Fine Daylight Good Single Carriageway Dry

Collision Partners : 1- Pedestrian 2-Local Bus

Scenario

- A pedestrian (P1) ran out on a pedestrian crossing into the path of a double decker bus (V2) travelling from the pedestrians right.
- V2 braked heavily but still collided with P1 knocking them to the floor.
- P1 sustained minor injuries.

Scene



Causation Factors

- Pedestrian- Careless, reckless or in a hurry

Counter Measures

- AEBS (Pedestrian/cyclist)
- Training to improve hazard perception skill.

Case ID : Case22/OTS/Slight/Junction

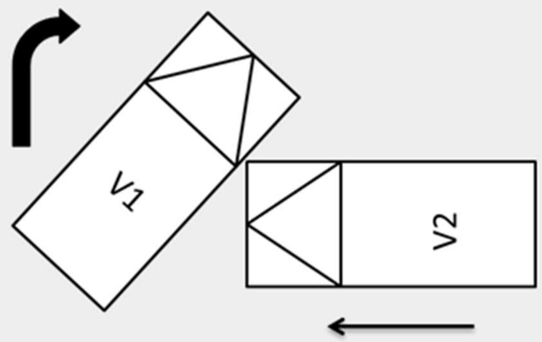
Conditions Rain Daylight Good Dual Carriageway Wet/damp

Collision Partners : 1-Car 2-Local Bus

Scenario

- On a wet day during a period of rain, a car (V1) was waiting to turn right onto a busy one way class A dual carriageway.
- V1 was required to cross a contra flow bus lane to make the turn.
- The driver looked right and saw a bus (V2), but thought there was plenty of time to make the right turn having seen a gap in traffic.
- V2 had begun moving from the bus stop. The driver pulled out and the front offside of the V1 was struck by the front of V2.
- V1 came to a halt in the road and V2 pulled over on the nearside.

Scene



Causation Factors

- Car- Careless, reckless or in a hurry
- Car-Poor turn or manoeuvre

Counter Measures

- Cross Traffic AEB
- Training to improve hazard perception skill.

Case ID : Case23/OTS/Slight/Junction

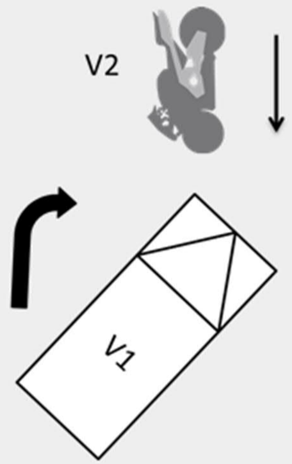
Conditions Rain Darkness Good Dual carriageway Wet/damp

Collision Partners : 1-Local Bus 2-. Motorcycle

Scenario

- A single decker bus (V1) was waiting in a right turn lane ready to turn right into the side road.
- The driver of V1 failed to notice a motorcycle (V2) travelling from the opposite side and turned across it's path.
- V2 braked hard and skidded before colliding with nearside of V1.

Scene



Causation Factors

- Bus- Careless, reckless or in a hurry
- Bus-Poor turn or manoeuvre

Counter Measures

- Buses only - Improve direct vision (Front)
- Training or education to reduce risky driving manoeuvre

Case ID : Case24/OTS/Slight/Junction

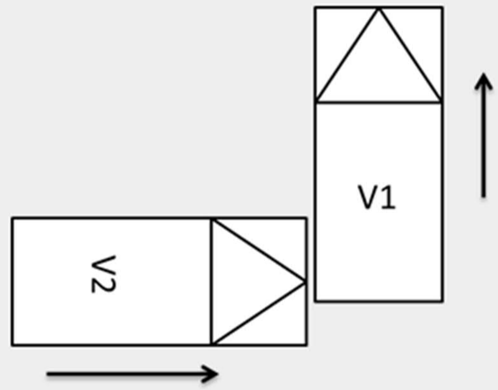
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Lorry 2-Local Bus

Scenario

- An HGV (V1) failed to stop at a give-way crossroads junction.
- V1 drove into the path of a bus (V2) travelling from the left of V1.
- V2 collided with the rear nearside of V1 forcing it to rotate and tip over onto it's offside.

Scene



Causation Factors

- Truck- Careless, reckless or in a hurry
- Truck- Failed to look properly
- Bus- Failed to judge other person's path or speed

Counter Measures

- Cross traffic AEBS
- Training to improve hazard perception skill

Case ID : Case25/OTS/Slight/Rear-end

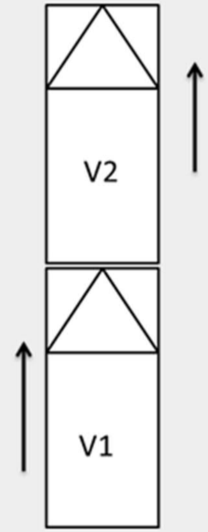
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) was travelling along an urban, residential road that was subject to a 30mph limit.
- A bus (V2) was stationary and letting off passengers at a bus stop.
- V1 failed to notice the stationary V2 and drove into the rear of V2.
- No injuries were sustained by any of the bus passengers but the occupants of V1 were injured.

Scene



Causation Factors

- Car driver-Failed to look properly

Counter Measures

- Add Signs to indicate Bus stop

Case ID : Case26/OTS/Slight/Rear-end

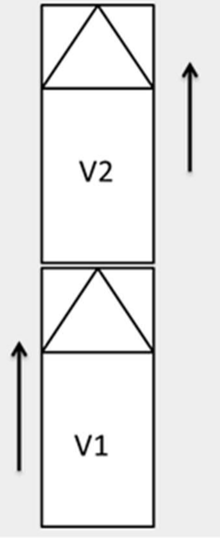
Conditions Fine Daylight Good Single carriageway Wet/damp

Collision Partners : 1-Local Bus 2-Car

Scenario

- The driver of a single deck bus (V1) failed to see that a car (V2) in front that had stopped to turn right.
- Driver of V1 was distracted in checking the bus stop for passengers.
- When driver of V1 looked up, it was too late and braked hard.
- Front of V1 collided with rear of V2.

Scene



Causation Factors

- Bus driver- Failed to look properly
- Bus driver– Distraction in vehicle

Counter Measures

- AEBS
- Training to improve hazard perception skill

Case ID : Case27/OTS/Slight/Rear-end

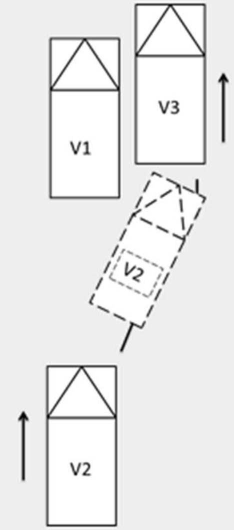
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Unknown car 2-Local Bus 3-Van

Scenario

- An unknown car (V1) stopped abruptly at shops with no indication and just prior to a junction.
- A single decker bus (V2) tried to take evasive action to avoid colliding with the rear of V1.
- V2 moved out into lane two and collided with a van (V3) which was in lane 2 in the blind spot of V2.
- V1 made off from the scene without stopping and giving details to other parties and was not traced.

Scene



Causation Factors

- Vehicle blind spot
- Bus- Failed to judge other person's path or speed
- Bus- Nervous, uncertain or panic

Counter Measures

- AEBS
- Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)

Case ID : Case28/OTS/Slight/Junction

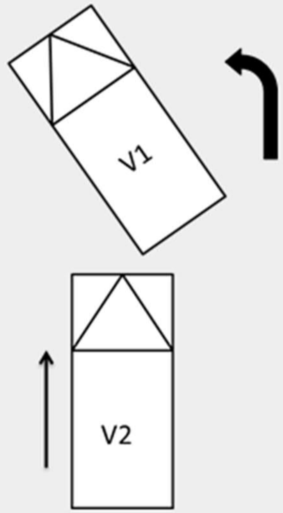
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) was travelling in lane 1 when the driver decided to turn left.
- V1 had to turn across the bus lane, into a side road.
- The driver of a single decker bus (V2) had no time to react.
- Front of V2 and collided into the rear nearside of V1.

Scene



Causation Factors

- Bus- Failed to judge other person's path or speed
- Car-Poor turn or manoeuvre

Counter Measures

- AEBS (city - low speed shunts ONLY)
- Training to improve hazard perception skill

Case ID : Case29/RAIDS/Serious/Junction

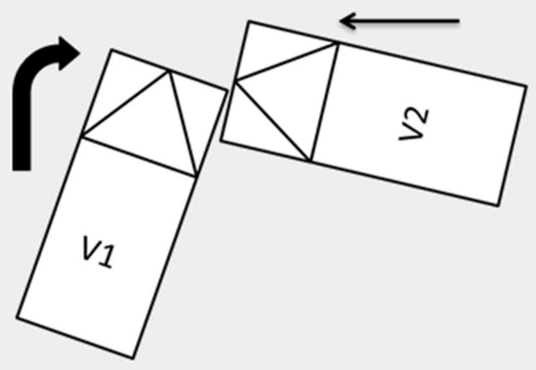
Conditions Rain Daylight Good Single carriageway Wet/damp

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1) emerged from a minor road, believed to be turning right onto main road into path of a double decker bus (V2) approaching from right.
- V2 driver unable to avoid the collision, struck offside front of V1.
- V1 projected along carriageway, coming to rest approximately 41m from point of impact.
- Driver of V1 suffered serious injury, an occupant in child seat was uninjured, unrestrained V2 driver suffered slight injury.

Scene



Causation Factors

- Car- Failed to judge other person's path or speed
- Bus- Failed to judge other person's path or speed

Counter Measures

- Cross traffic AEBS
- Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)

Case ID : Case30/RAIDS/Slight/Junction

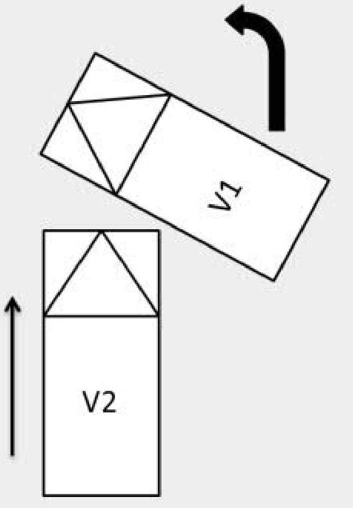
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Van 2-Local Bus

Scenario

- A van (V1) passed a stationary bus (V2) at a bus stop and continued along road for a further 150m.
- V1 indicated left, then turned intending to enter business premises, crossing the adjacent bus lane having failed to check before doing so.
- V2 moving along the bus lane was unable to stop the vehicle and collided with the nearside of V1.
- V1 came to rest across front of V2 in bus lane.
- Driver of V1 suffered pain to right leg.
- Driver & 3 passengers in the V2 suffered slight injury, no hospital attendance for any involved party.

Scene



Causation Factors

- Bus- Failed to judge other person's path or speed
- Van- Careless, reckless or in a hurry
- Van- Poor turn or manoeuvre

Counter Measures

- Cross traffic AEBS
- Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)

Case ID : Case31/RAIDS/Slight/Junction

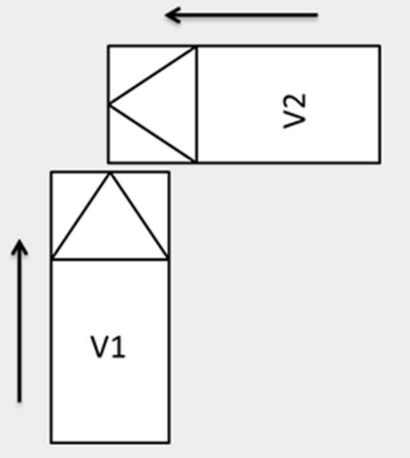
Conditions Fine Daylight Good Roundabout Dry

Collision Partners : 1-Local Bus 2-Car

Scenario

- On a clear sunny day, a single-decker bus (V1) carrying 6 passengers approached a 4-arm roundabout.
- The sun was shining in the eyes of the driver of V1 who states that the vehicles to her right allowed her to pull out onto the roundabout.
- As V1 has crept out onto the roundabout a car (V2) approached from the right (with right-of-way) intending to continue straight over.
- V1 then collided with the front nearside of V2 as it tried to continue over the roundabout.

Scene



Causation Factors

- Bus- Failed to judge other person's path or speed
- Car- Failed to look properly
- Dazzling sun

Counter Measures

- Cross traffic AEBS
- Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)

Case ID : Case32/RAIDS/Slight/Junction

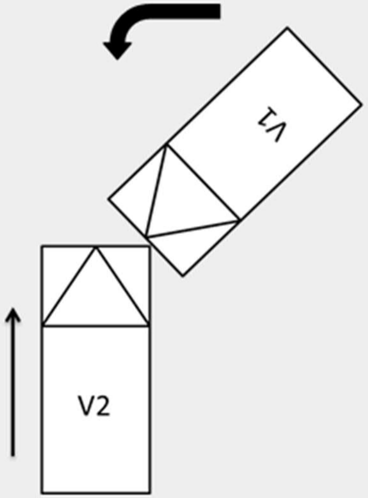
Conditions Fine | Daylight | Good | Single carriageway | Dry

Collision Partners : 1-Car 2-Local Bus

Scenario

- A car (V1), approaches T-Junction with intention of turning left.
- V1 emerges left into the path of a double-decker bus (V2), approaching from the left.
- V2 was driving along the centre of the carriageway, due to the presence of parked vehicles.
- A traffic calming feature and speed humps present along this path.
- The front offside corner of V2 impacts with the front of the V1.
- The subsequent forward motion of V2, rotates the V1 clockwise.
- The driver of the V1 sustained slight injuries.

Scene



Causation Factors

- Bus- Failed to judge other person's path or speed
- Car- Failed to look properly
- Car- Poor turn or manoeuvre
- Dazzling sun

Counter Measures

- Intersection AEB
- Training to improve hazard perception skill

Case ID : Case33/RAIDS/Serious/Head-on

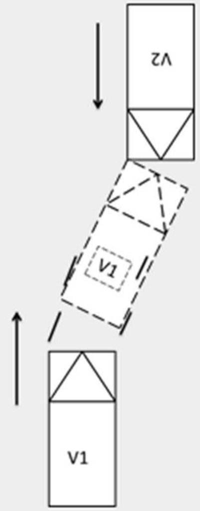
Conditions Fine Darkness Good Single carriageway Dry

Collision Partners : 1- Car 2-Local Bus

Scenario

- A car (V1) travelling along a single carriageway road drifts into the opposing carriageway
- While drifting V1 collides with the front of a double decker bus (V2).
- Driver of V1 states they fell asleep whilst attempting to overtake another vehicle. No witnesses mentioned any other vehicle.
- Driver of V1 sustained serious injuries and a number of passengers on V2 sustained slight injuries.

Scene



Causation Factors

- Bus- Failed to judge other person's path or speed
- Car– Fatigue
- Car- Poor turn or manoeuvre

Counter Measures

- Intersection AEBS
- Training to improve hazard perception skill

Case ID : Case34/RAIDS/Serious/Pedestrian

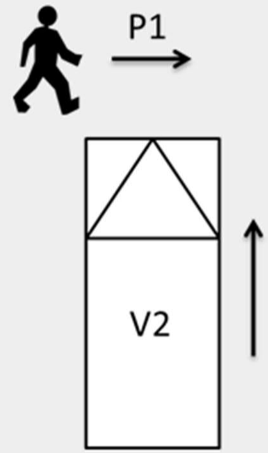
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1.-Pedestrian 2-Local Bus

Scenario

- A single decker bus (V2) was travelling away from bus stop at slow speed
- A pedestrian (P1) walked off the kerb in front of V1 colliding with the front nearside of it.
- P1 falls back and hits head on the carriageway.

Scene



Causation Factors

- Pedestrian-Failed to look properly
- Pedestrian-Careless, reckless or in a hurry

Counter Measures

- AEBS (Pedestrian/cyclist)
- Training to improve hazard perception skill

Case ID : Case35/OTS/Slight/Sideswipe

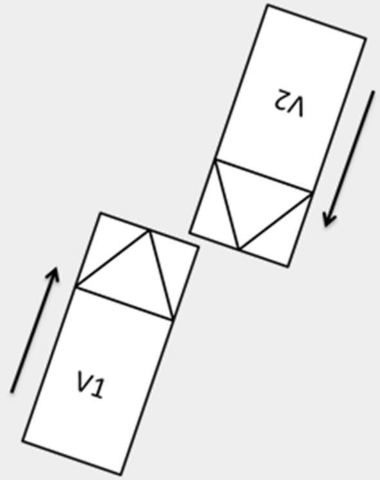
Conditions Fine Daylight Good Single carriageway Dry

Collision Partners : 1-Local Bus 2-Local Bus

Scenario

- A bus (V1) travels around a sharp and narrow left hand bend .
- While negotiating the curve V1 driver drives over the centre line into opposing lane.
- Another bus (V2) travelling in the opposite direction sideswipes with V1.

Scene



Causation Factors

- Bus1- Aggressive Driving
- Bus1- Poor turn or manoeuvre
- Bus2- Failed to judge other person's path or speed
- Road layout

Counter Measures

- Intersection AEBS
- Training to improve hazard perception skill
- Better licensing (increase on-road experience driving in specific situations e.g. weather, busy traffic)
- Redesign to improve junction visibility (if permanent obscuration)

Appendix E Human Factors & Behaviour Change Workshop Slides

This appendix contains the slides from the Human Factors Workshop held on 13/02/2017 at TfL.

Attendees included:

- Shaun Helman, TRL (presenter)
- Nora Balfe, TRL (presenter)
- Courtney Newbould, TRL
- Jane Lupson, TfL
- Kerri Cheek, TfL
- Alex Moffat, TfL
- George Marcar, TfL
- Jasmine Moss, TfL
- Lizi Mountford, TfL
- Stephan Hatcher, TfL
- James Wooller, TfL
- Joanne Page, TfL
- Peter Evans, RATP Dev
- Keiran McDonnell, Tower Transit


THE FUTURE
OF TRANSPORT
Human Factors and Behaviour Change Workshop
February 2017


Agenda
1200 - 1220: Background and introductions
1220 - 1250: Introduction to Human Factors
1250 - 1320: Introduction to Behaviour Change
1320 - 1330: Break
1330 - 1415: Group exercise 1
1415 - 1500: Group exercise 2
1500 - 1515: Break
1515 - 1530: Top three take-home messages
1530 - 1600: Report back, discussion, wrap up


Introductions
TRL
© Copyright 2017 TRL Ltd
3


TRL
Introduction to Human Factors
© Copyright 2017 TRL Ltd

What is Human Factors?

Anything that affects human performance

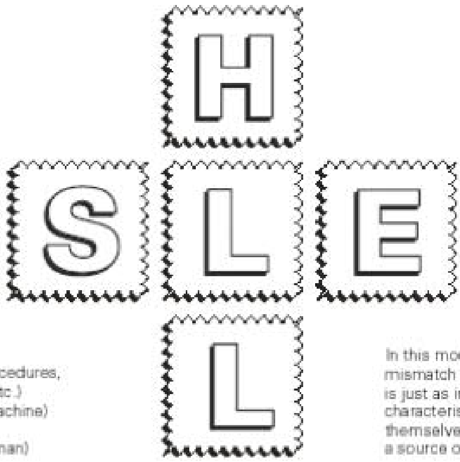
EASA

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

IEA (2002)

5

SHELL Human Factors Model



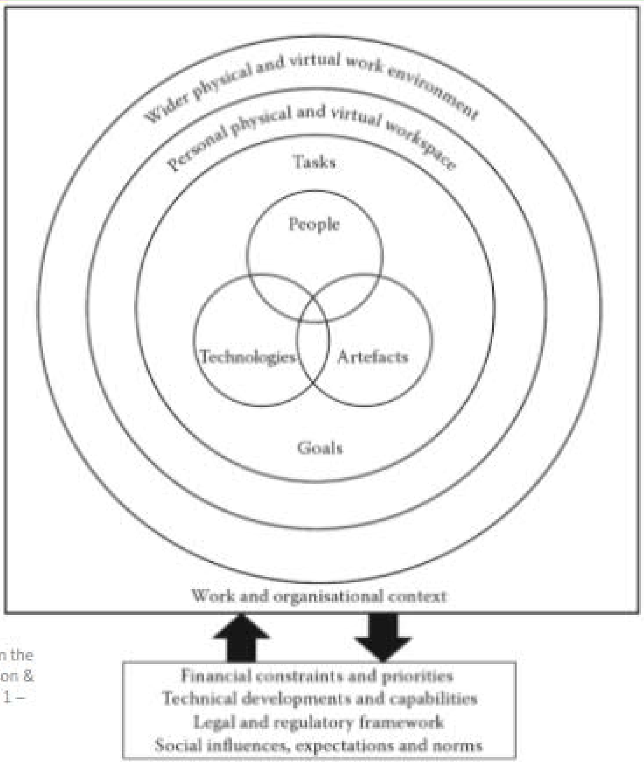
S = Software (procedures, symbology, etc.)
H = Hardware (machine)
E = Environment
L = Liveware (human)

In this model the match or mismatch of the blocks (interface) is just as important as the characteristics of the blocks themselves. A mismatch can be a source of human error.

Hawkins, F.H. (1987). Human factors in flight. Aldershot: Ashgate

6

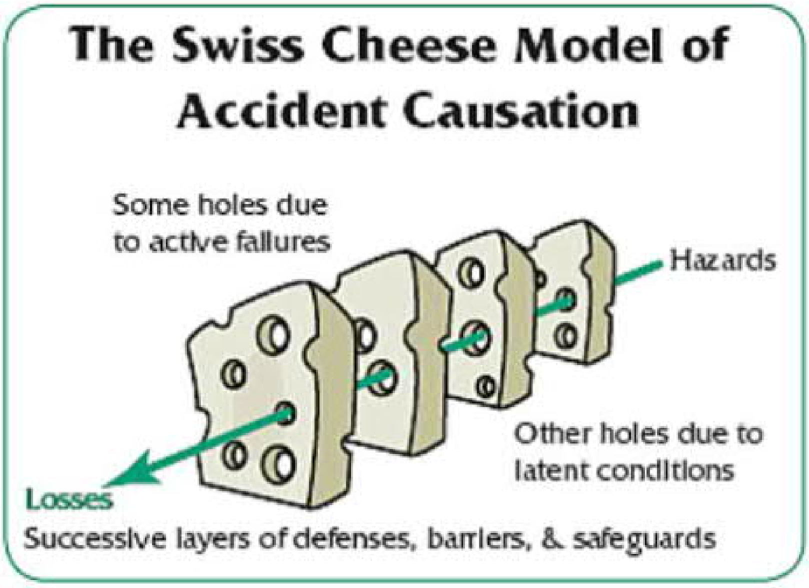
Onion Model



Wilson, J.R. & Sharples, S. (2015). Methods in the understanding of Human Factors. In J.R. Wilson & S. Sharples (Eds) Evaluation of Human Work, 1 – 36. Boca Raton: CRC Press.

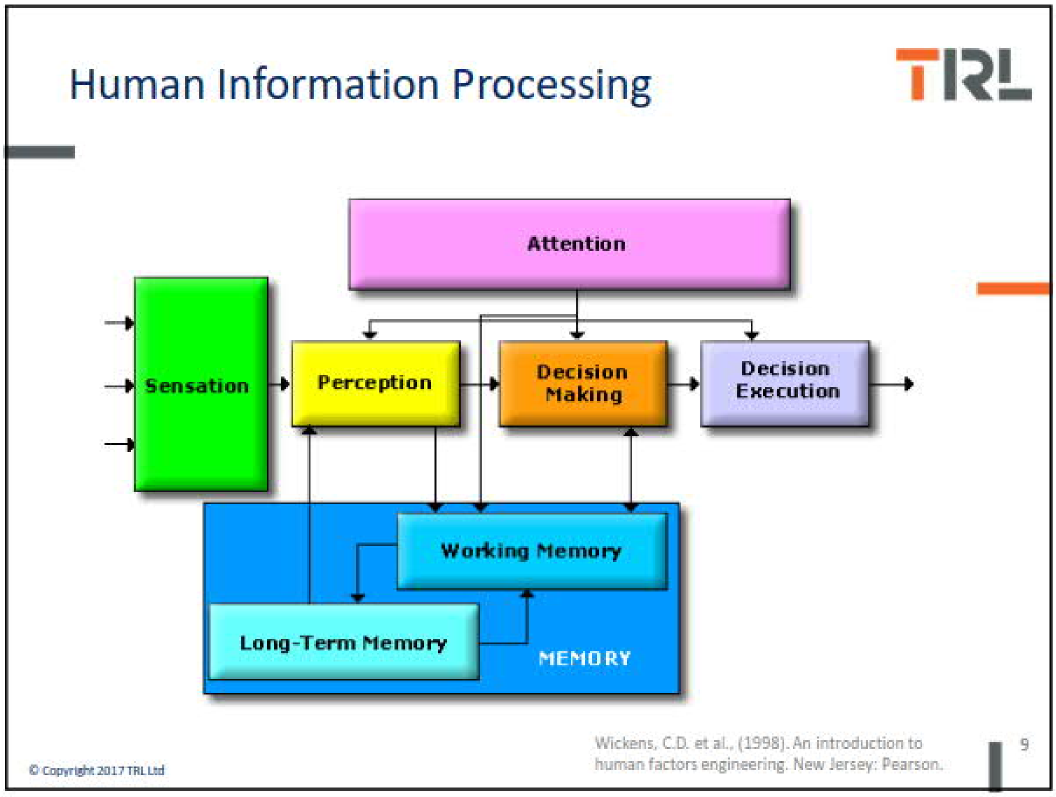
7

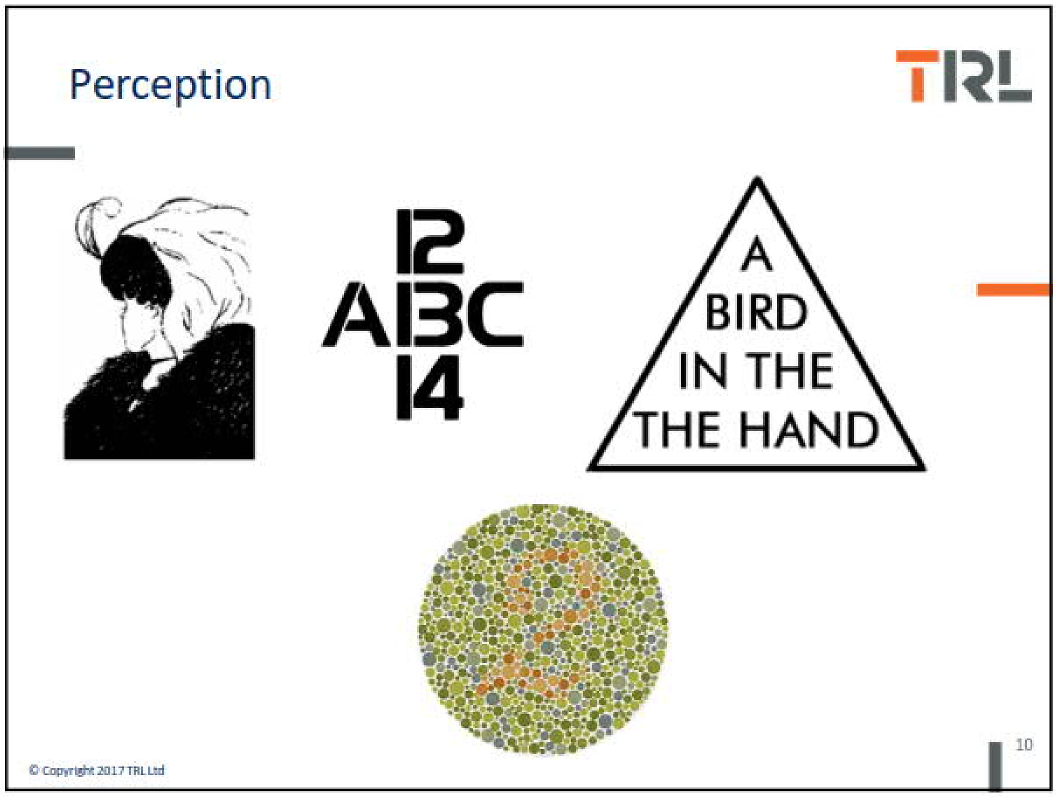
Swiss Cheese Model



Reason, J. (1997). Managing the risks of organisational accidents. Aldershot: Ashgate.

8


Human Information Processing
TRL
Attention
Sensation
Perception
Decision Making
Decision Execution
Working Memory
Long-Term Memory
MEMORY
Wickens, C.D. et al., (1998). An introduction to human factors engineering. New Jersey: Pearson.
9
© Copyright 2017 TRL Ltd


Perception
TRL
12
ABC
14
A
BIRD
IN THE
THE HAND
10
© Copyright 2017 TRL Ltd

Attention

- Attention is the behavioural and cognitive process of selectively concentrating on a discrete aspect of information while ignoring other perceivable information
- Humans have limited information processing capacity, so attention must be allocated or shared (divided attention)
  - It is easier to share attention over tasks that do not use the same type of resources
  - Task performance is reduced when attention is divided
- Attention span is also limited – estimates vary depending on the definition of attention but it is usually around 40 minutes
- Sustained attention over time is also called Vigilance

11

Memory

- Short-term (or working) memory:
  - Holds information for about 30 seconds
  - Has limited capacity (7±2 'chunks' of information)
  - Rehearsing allows information to be retained for longer
- Long term memory:
  - Long term memory encodes information for later retrieval
  - Sleep helps encode information and store it in LTM

12

Human Error

- Human errors are a result of inappropriate or undesirable actions that fail to achieve an intended outcome
- The variation in human performance that results in errors is normal and impossible to completely eradicate
- The design of the socio-technical system can make errors more likely

13

Human Error Classification

- Slip
  - Perceptual slip – error in perceiving information
  - Action slip – right idea, wrong action
- Lapse – forgetting an action
- Mistake – missing some information or knowledge to come to the right decision

Think of an example of an error you made recently – was it a slip, lapse or mistake?

14

Violations

- Differ from errors as they are intentional actions
- Types of violation
  - Routine – Not following the rule or procedure has become normal practice for everyone
  - Situational – Outcomes cannot be met, or easily met, if the rule is followed
  - Optimising – There is a personal benefit to not following the rule
  - Exceptional – Extreme circumstances

15

Some Factors Influencing Human Error

Individual	Team	Environment	Equipment	Task	Organisation
Physical Limitations	Communi-cations	Lighting	Complexity	Workload	Culture
Psychological Limitations	Coordination	Temperature	Reliability	Time pressure	Resources
Fatigue	Leadership	Noise	Usability	Complexity	Training provision
Skill/Ability	Supervision	Vibration	State	Information	Regulations
Experience/ Knowledge		Accessibility	Appropriate	Repetitiveness	Rostering

Adapted from Human Error Classification tools: HFACS, ADREP, HEIDI and MEDA

16

Individual Factors – Situation Awareness

- "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995)
- A person's real time mental model of the world around them
    - Perceiving what's going on around you
    - Understanding what that means
    - Predicting what's going to happen next

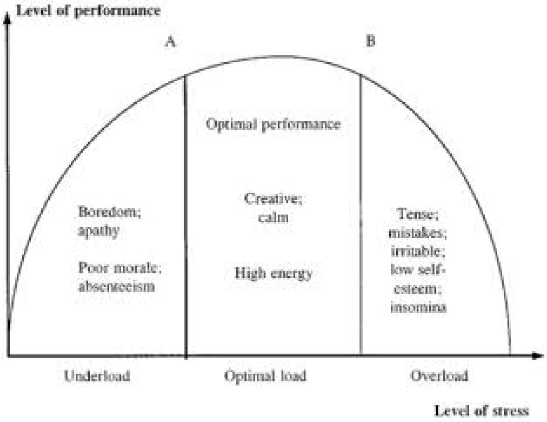
17

Equipment Factors - Automation

- Benefits
    - More efficient
    - More reliable
    - Faster
    - More precise
    - Reduced workload
    - Smaller workforce
- Human Factors Issues
    - Reliability and trust
    - Increased mental workload
    - Poor feedback
    - Vigilance difficulties
    - Lack of flexibility
    - Manual skill degradation
    - Latent errors

18

Task Factors - Workload



- Workload refers to the load or demand placed on the human, and their individual ability to cope with that load or demand

Sutherland, V.J. and Cooper, C.L. (1993). Identifying distress among general practitioners: Predictors of psychological ill-health and job dissatisfaction. Social science and medicine, 37(5), 575-581.

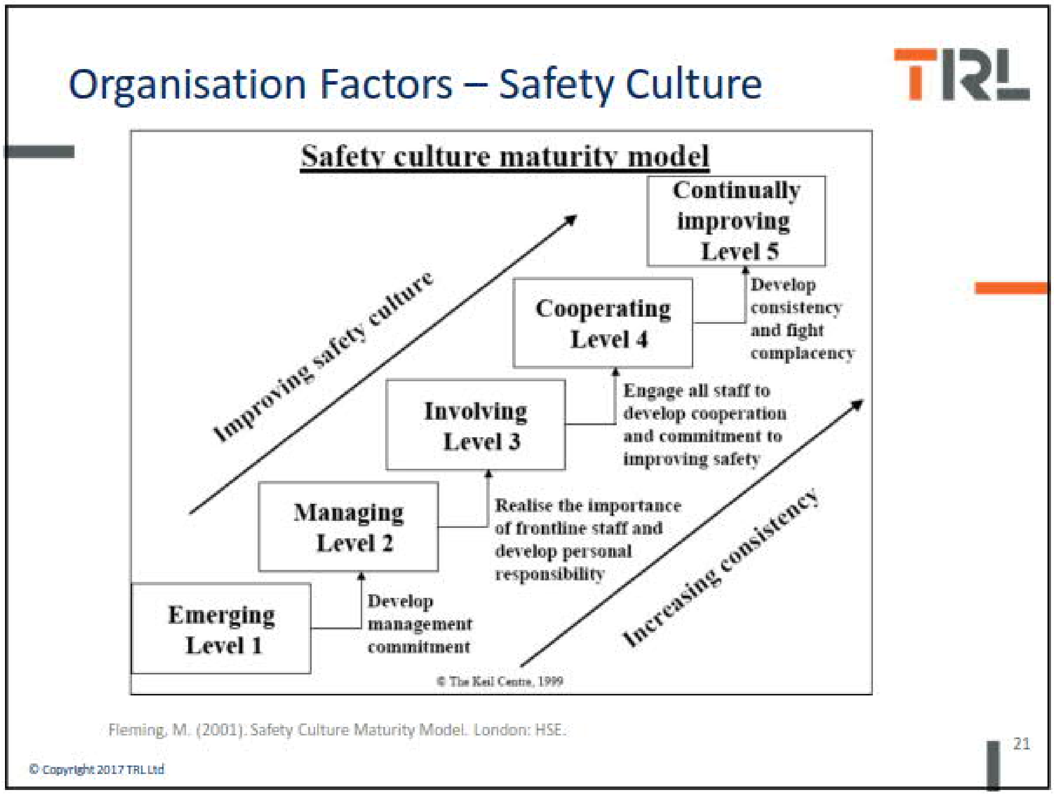
19

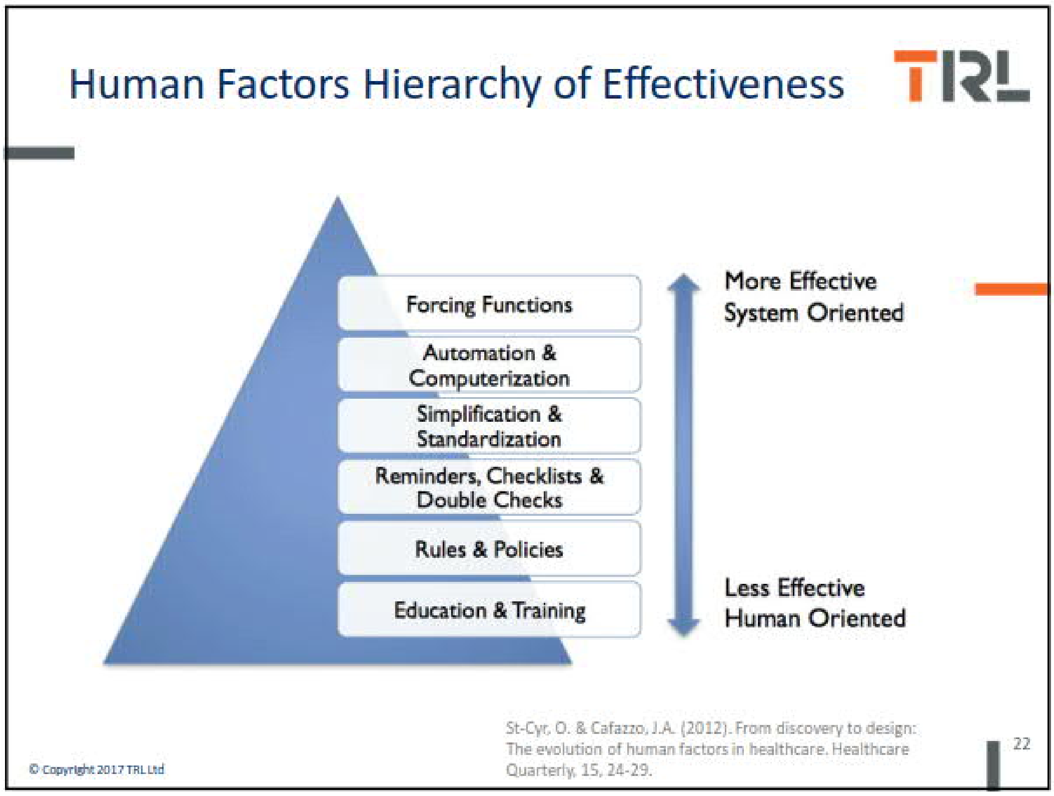
Organisation Factors – Safety Culture

- “Safety culture reflects **the attitudes, beliefs, perceptions, and values** that employees share in relation to safety *(Cox & Cox, 1991)*
- “The way we do things around here”
- Investigation of major accidents has revealed that they are not caused by simple, individual errors, but rather by malpractices that corrupted large parts of the organisation/system

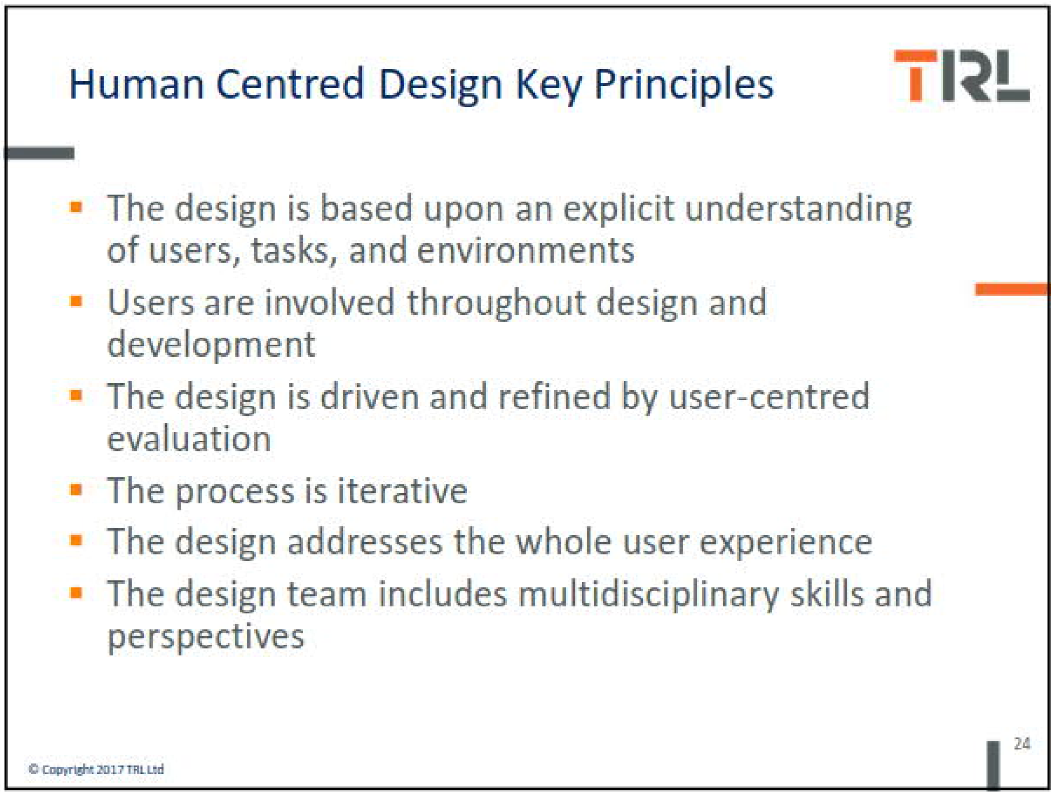
Cox, S and Cox, T. (1991)., The structure of employee attitudes to safety: A European example. Work and stress, 5(2), 93-106.

20


Organisation Factors – Safety Culture
Safety culture maturity model
Continually improving Level 5
Develop consistency and fight complacency
Cooperating Level 4
Engage all staff to develop cooperation and commitment to improving safety
Involving Level 3
Realise the importance of frontline staff and develop personal responsibility
Managing Level 2
Develop management commitment
Emerging Level 1
Improving safety culture
Increasing consistency
© The Keil Centre, 1999
Fleming, M. (2001). Safety Culture Maturity Model. London: HSE.
© Copyright 2017 TRL Ltd
21


Human Factors Hierarchy of Effectiveness
Forcing Functions
Automation & Computerization
Simplification & Standardization
Reminders, Checklists & Double Checks
Rules & Policies
Education & Training
More Effective System Oriented
Less Effective Human Oriented
St-Cyr, O. & Cafazzo, J.A. (2012). From discovery to design: The evolution of human factors in healthcare. Healthcare Quarterly, 15, 24-29.
© Copyright 2017 TRL Ltd
22


Human Centred Design
TRL
An approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics and usability knowledge and techniques.
Enhances effectiveness and efficiency
ISO 9241-210: 2010. Ergonomics of human-system interaction – Part 210: Human centred design for interactive systems.
23
© Copyright 2017 TRL Ltd

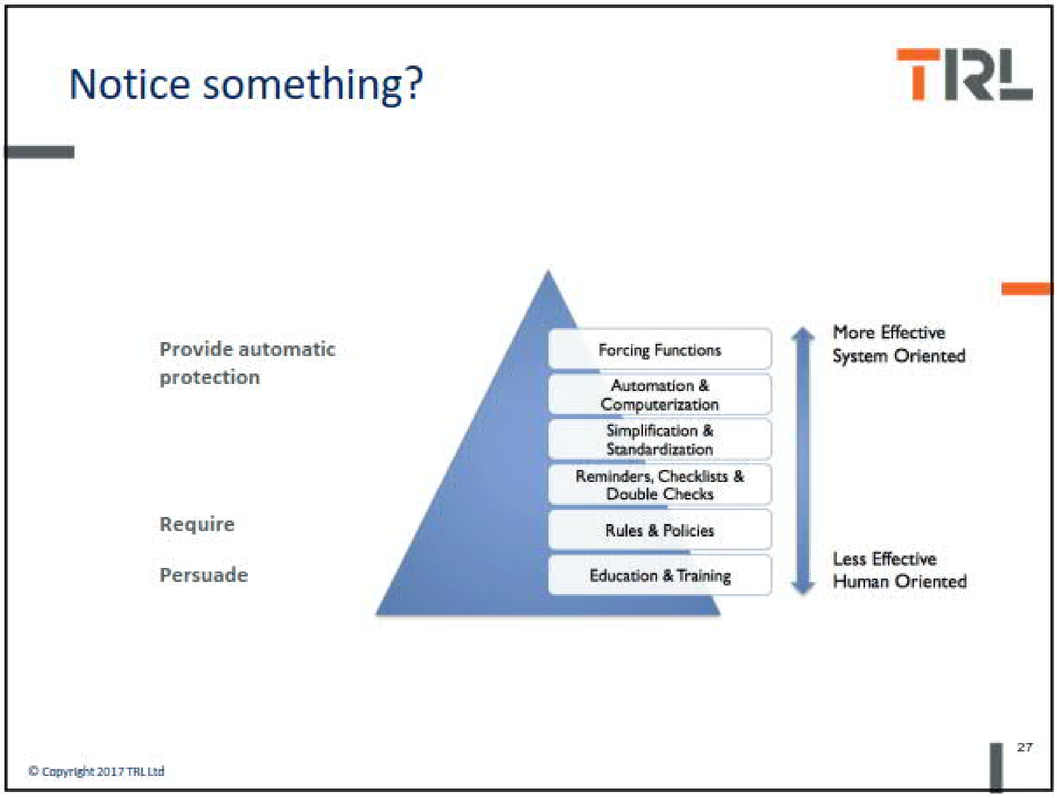

Human Centred Design Key Principles
TRL
The design is based upon an explicit understanding of users, tasks, and environments
Users are involved throughout design and development
The design is driven and refined by user-centred evaluation
The process is iterative
The design addresses the whole user experience
The design team includes multidisciplinary skills and perspectives
24
© Copyright 2017 TRL Ltd

Injury reduction

- In a comprehensive and influential report 'Injury in America' (National Research Council, Committee on Trauma Research, Committee on Trauma Research & Institute of Medicine, 1985) it is suggested that there are three general strategies available to prevent injury (reproduced below from Page 7 of that report):
  - **Provide automatic protection** by product and environmental design—for example, by the installation of seatbelts that automatically encompass occupants of motor vehicles or built-in sprinkler systems that automatically extinguish fires.
  - **Require** individual behavior change by law or administrative rule—for example, by laws requiring seatbelt use or requiring the installation of smoke detectors in all new buildings.
  - **Persuade** persons at risk of injury to alter their behavior for increased self-protection—for example, to use seatbelts or install smoke detectors.

National Research Council (US). Committee on Trauma Research, Committee on Trauma Research (US), & Institute of Medicine (US). (1985). Injury in America: a continuing public health problem. Natl Academy Press.

26


Notice something?
Provide automatic protection
Require
Persuade
Forcing Functions
Automation & Computerization
Simplification & Standardization
Reminders, Checklists & Double Checks
Rules & Policies
Education & Training
More Effective
System Oriented
Less Effective
Human Oriented
© Copyright 2017 TRL Ltd
27


Can't we just train people to behave differently?
© Copyright 2017 TRL Ltd
28

Behaviour versus performance

- Evans (1991; 2004)
  - Driver performance (what the driver CAN do)
  - Driver behaviour (what the driver DOES do)
- In 'normal driving' driver behaviour seems to be more important than driver performance in determining risk

Evans, L. (1991). *Traffic Safety and the Driver*. New York: Van Nostrand Reinhold.
Evans, L. (2008). *Traffic Safety*. Michigan: Science Serving Society.

29

Training for behaviour

- "The only direct benefits imparted by broad driver education and training would appear to be the basic vehicle control skills and knowledge of road rules necessary for entering the driving population. According to the evidence it has no measurable direct effect on collision risk, and its continued use should therefore be set against much lower expectations in terms of what it can contribute directly to the safety of new drivers."

Helman, Grayson and Parkes (2010, p8)

Helman, S., Grayson, G. B., & Parkes, A. M. (2010). How can we produce safer new drivers. *TRL Report*. INS05: Crowthorne: Transport Research Laboratory.

30

Training for behaviour

- Similar inconsistent or null-findings in post-test education and training (Ker et al., 2003).
- Also defensive driving (Lund & Williams, 1985).

Ker, K., Roberts, I., Collier, T., Beyer, F., Bunn, F. & Frost, C. (2003). Post-licence driver education for the prevention of road traffic crashes. Cochrane Database of Systematic Reviews 2003, Issue 3. Art. No.: CD003734. DOI: 10.1002/14651858.CD003734.

Lund, A. K & Williams, A. F. (1985.) A review of the literature evaluating the Defensive Driving Course. *Accident Analysis & Prevention*, 17, 449–460.

31

Training for performance

- Häkkinen(1979) showed that bus driver crash rate was associated with a series of performance tests…
  - …so maybe the regulated nature of professional driving does provide some performance-based opportunities
- Hazard perception training may also be relevant (but not known in non-novice-driver populations)
- The behaviour/performance distinction remains, however – BEHAVIOUR IS CRITICAL

Häkkinen, S. (1979). Traffic accidents and professional driver characteristics: A follow-up study. *Accident Analysis & Prevention*, *11*(1), 7-18.

32

Some notes on campaigns

33

Campaigns

http://think.direct.gov.uk/drink-driving.html

34

Campaigns

http://think.direct.gov.uk/mobile-phones.html

35

Campaigns

http://think.direct.gov.uk/speed.html

36

Campaigns

http://think.direct.gov.uk/drug-driving.html

37

Campaigns

http://www.advertolog.com/office-of-road-safety/print-outdoor/drink-drive-and-score-a-date-with-a-blonde-10176703/

38

Campaigns

https://www.youtube.com/watch?v=h-8PBx7isoM

(Nearly 20m views…)

39

Summary

- Road users **behave** in ways that (occasionally) lead to injury and death
- Part of our 'armoury' in trying to minimise this is persuasion/encouragement, to try and change this **behaviour**
- Example – fear based campaigns

40

Fear-based campaigns

- Basic reasoning:
  - Fear is bad
  - If we make people fearful of crashing they are less likely to do it

41

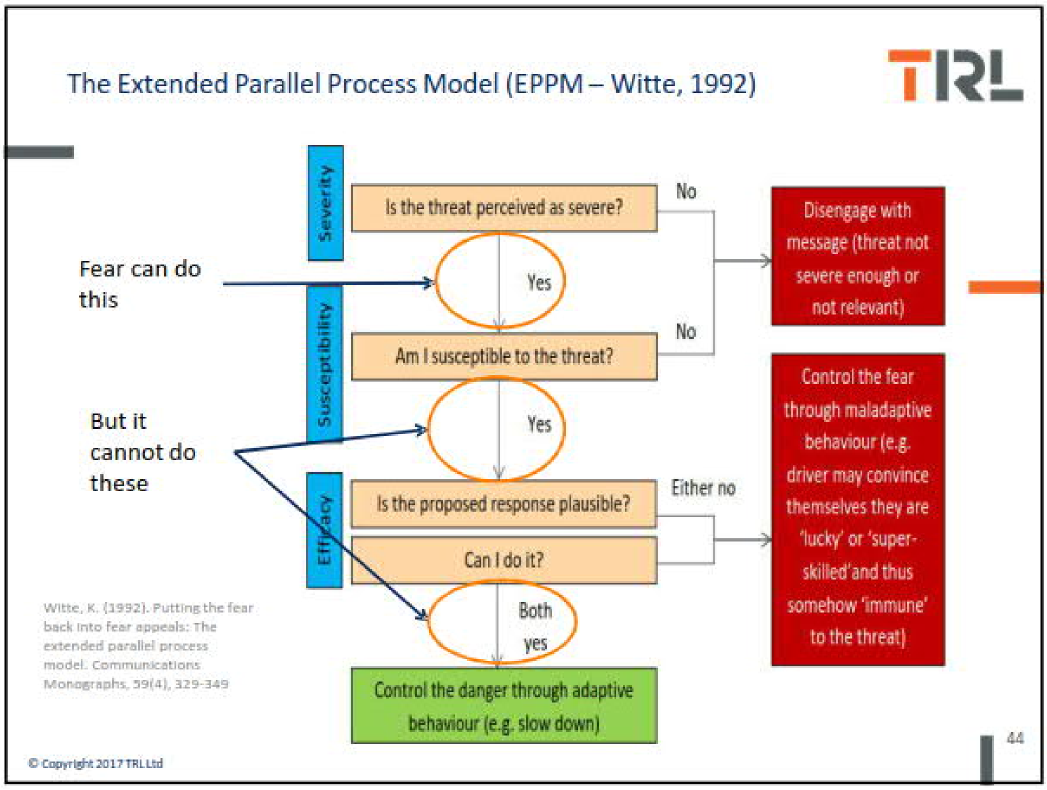
Carey, McDermott and Sarma (2013)

- Meta-analysis of fear-based campaigns – conclusions:
  - They increase fear
  - They **do not** change behaviour

Carey, R. N., McDermott, D. T., & Sarma, K. M. (2013). The impact of threat appeals on fear arousal and driver behavior: A meta-analysis of experimental research 1990–2011. PloS one, 8(5), e62821.

42


Carey et al. (2013) – recommendations
Check which emotions are actually being caused (fear, disgust, guilt, anger etc.)
Focus on susceptibility, response-efficacy and self-efficacy, in addition to causing fear (if you want to do more than simply cause fear)
Carey, R. N., McDermott, D. T., & Sarma, K. M. (2013). The impact of threat appeals on fear arousal and driver behavior: A meta-analysis of experimental research 1990–2011. PloS one, 8(5), e62821.
43
© Copyright 2017 TRL Ltd


The Extended Parallel Process Model (EPPM – Witte, 1992)
Severity
Susceptibility
Efficacy
Is the threat perceived as severe?
No
Yes
Am I susceptible to the threat?
No
Yes
Is the proposed response plausible?
Can I do it?
Either no
Both yes
Control the danger through adaptive behaviour (e.g. slow down)
Disengage with message (threat not severe enough or not relevant)
Control the fear through maladaptive behaviour (e.g. driver may convince themselves they are 'lucky' or 'super-skilled' and thus somehow 'immune' to the threat)
Fear can do this
But it cannot do these
Witte, K. (1992). Putting the fear back into fear appeals: The extended parallel process model. Communications Monographs, 59(4), 329-349
44
© Copyright 2017 TRL Ltd

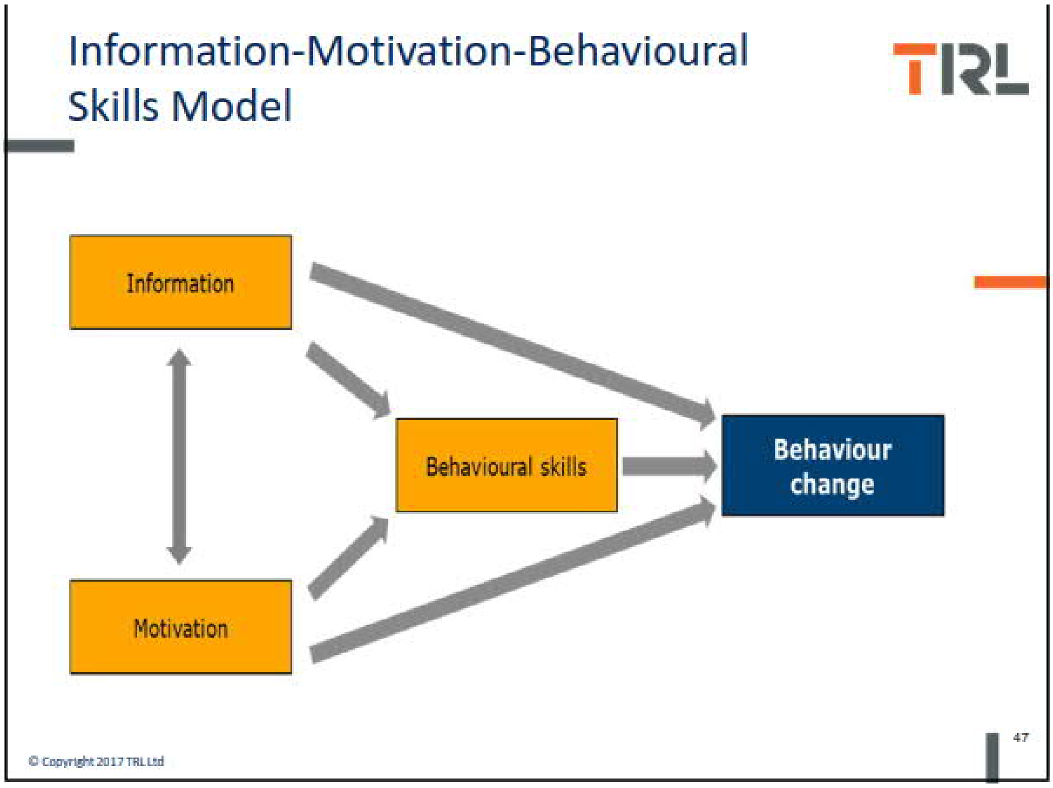
Behaviour change models and research examples

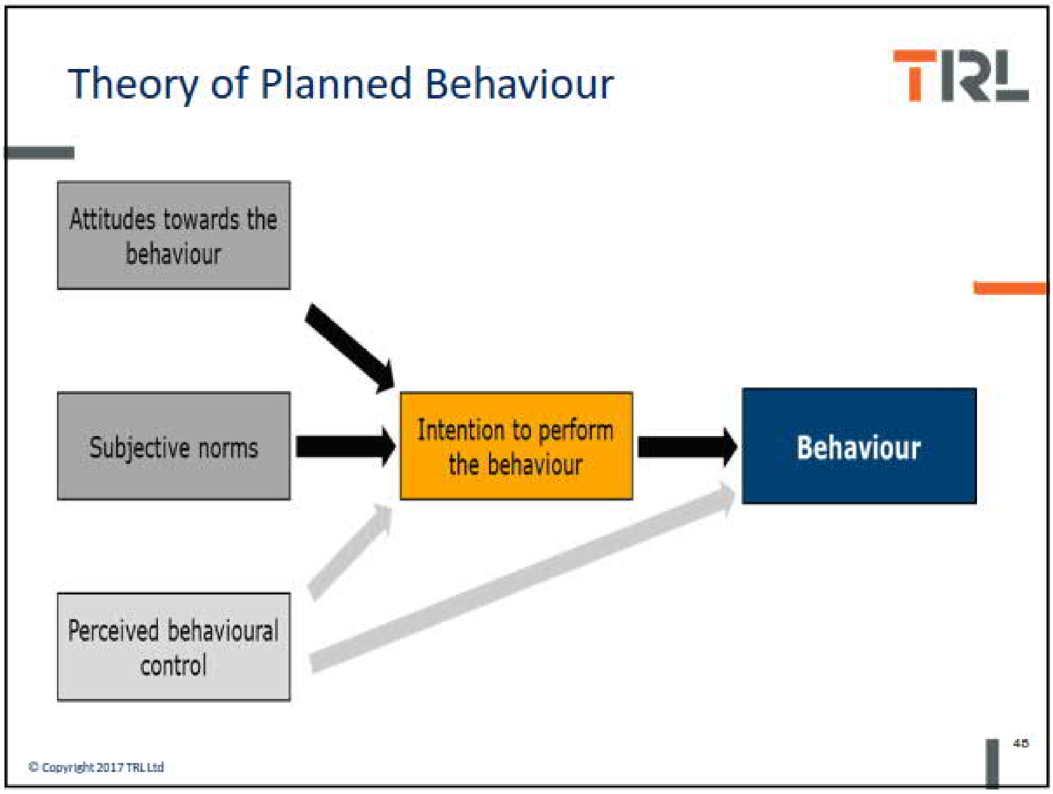
45

Behaviour change

- Any modification in behaviour
- Can refer to the outcome (what we wish to achieve)
- Often used to refer to the process undertaken to achieve that outcome
- Can be prompted by some intervention

46


Information-Motivation-Behavioural Skills Model
Information
Behavioural skills
Behaviour change
Motivation
© Copyright 2017 TRL Ltd
47


Theory of Planned Behaviour
Attitudes towards the behaviour
Subjective norms
Intention to perform the behaviour
Behaviour
Perceived behavioural control
© Copyright 2017 TRL Ltd
48

Behaviour Change Techniques

- 40 specific behaviour change techniques have been identified in the literature
- Originally developed (from the models we just discussed) to assist people with health behaviours such as changing their physical activity and diet
- Modified for road safety behaviours

49

Behaviour Change Techniques

- Provide information on:
  - Behaviour-health link
  - Consequences
  - Others' approval
- Set graded tasks
- Model or demonstrate behaviour
- Teach or use prompts as cues
- Agree on behavioural contract
- Provide:
  - Contingent rewards
  - Social comparison
  - General encouragement
  - Instruction
  - Feedback
- Use follow-up prompts
- Plan social support or social change
- Relapse prevention
- Management of:
  - Time
  - Stress
- Prompt
  - Identification as a role model
  - Self-talk
  - Intention formation
  - Barrier ID
  - Specific goal setting
  - Review of behavioural goals
  - Self-monitoring
  - Practice
- Motivational interviewing

50

Goal setting and behavioural feedback to increase safe driving

- Hickman and Geller (2005) investigated a self-monitoring intervention for short-haul truck drivers, to reduce speeding and harsh braking
- Drivers assigned to two groups
  - 'Pre-behaviour' group asked to record intentions to speed and brake harshly before the start of each shift
  - 'Post-behaviour' group was asked to record their actual speeding and harsh braking behaviour at the end of each shift

51

Goal setting and behavioural feedback to increase safe driving

- Participants attended a training session which included:
  - Identification of precursors and consequences associated with risky and safe driving
  - Goal setting
  - How to administer self-reward after meeting goals
  - Instructions on the incentive component

52

Goal setting and behavioural feedback to increase safe driving – findings

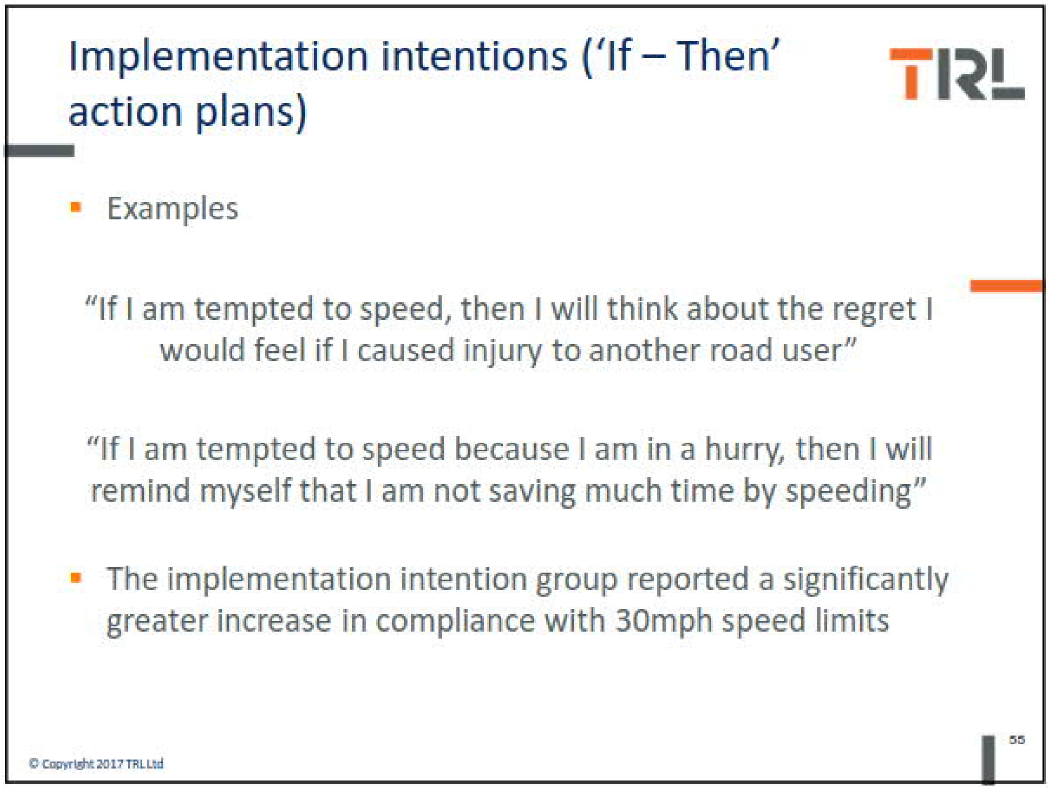
- End of each week, drivers received a feedback report displaying their objective behaviour (from telematics), alongside their intended performance (pre-behaviour group) or estimated performance (post-behaviour group)
- Results showed that during the four-week intervention, both groups significantly reduced their mean percentage of over-speeding and their mean frequency of harsh braking incidents

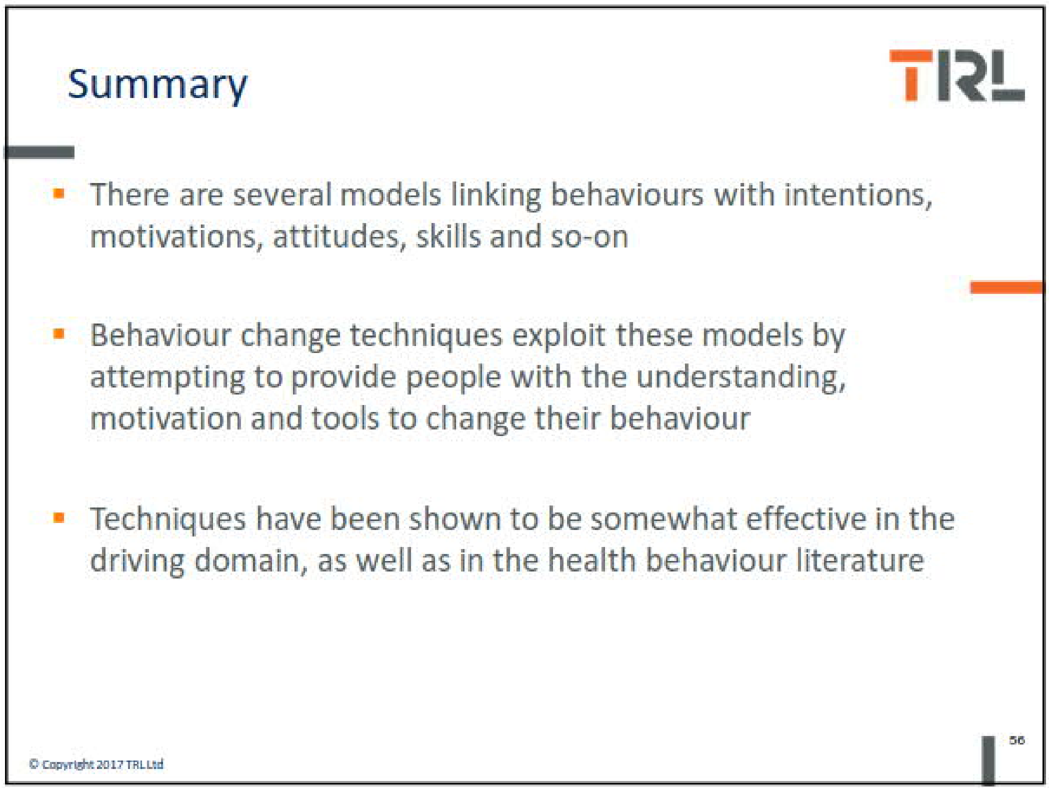
53

Implementation intentions ('If – Then' action plans)

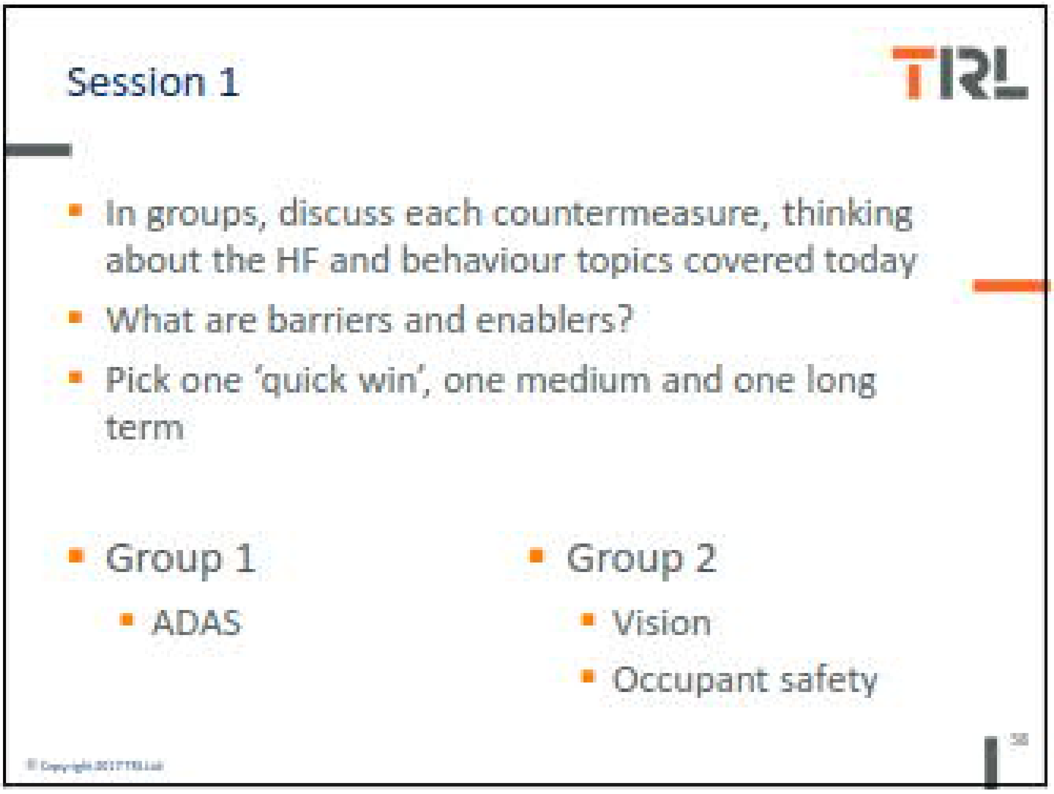
- Elliott and Armitage (2006) – overcoming habit in speeders – using 'implementation intentions'
  - Two groups of drivers asked to specify their goal intention (keep to 30mph limits) including how much they wanted to achieve this – one group just given information and one group asked to form implementation intentions
  - These are are 'If...Then...' statements that can cue intentions
  - 'Implementation intentions' group asked to write these plans to help them remember their intended behaviour (complying with 30mph limits)

54

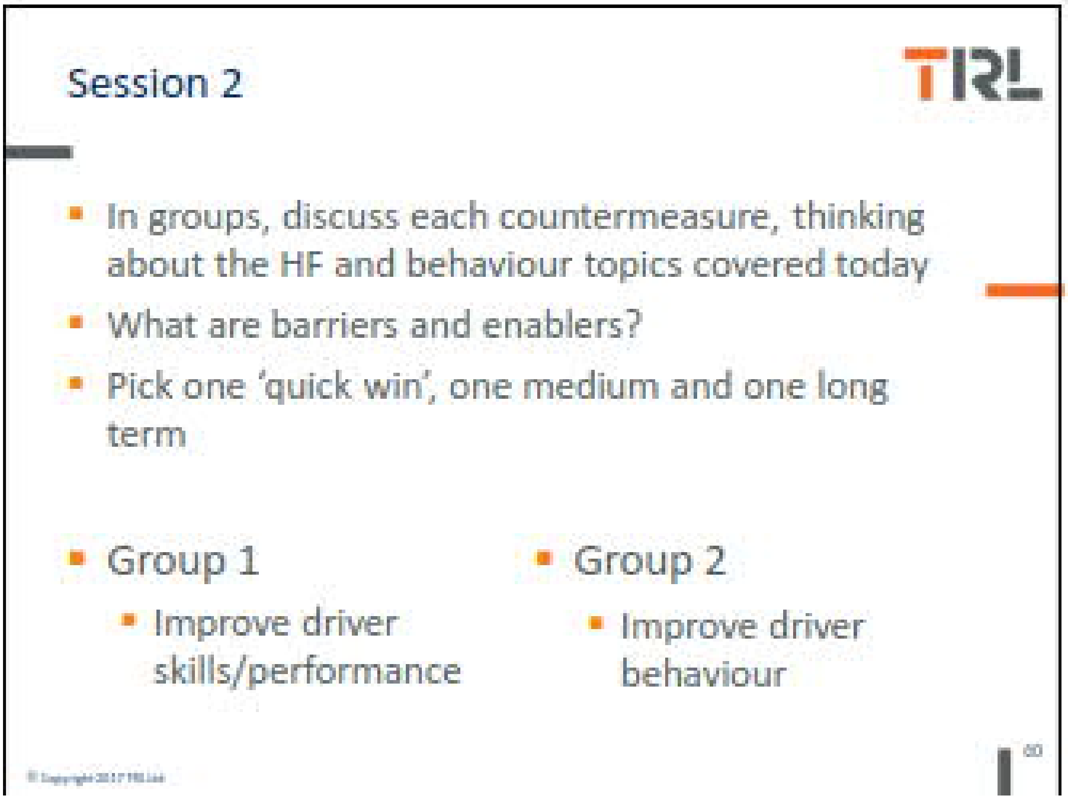

Implementation intentions ('If – Then' action plans)
TRL
Examples
"If I am tempted to speed, then I will think about the regret I would feel if I caused injury to another road user"
"If I am tempted to speed because I am in a hurry, then I will remind myself that I am not saving much time by speeding"
The implementation intention group reported a significantly greater increase in compliance with 30mph speed limits
© Copyright 2017 TRL Ltd
55


Summary
TRL
There are several models linking behaviours with intentions, motivations, attitudes, skills and so-on
Behaviour change techniques exploit these models by attempting to provide people with the understanding, motivation and tools to change their behaviour
Techniques have been shown to be somewhat effective in the driving domain, as well as in the health behaviour literature
© Copyright 2017 TRL Ltd
56


Session 1


Session 1
In groups, discuss each countermeasure, thinking about the HF and behaviour topics covered today
What are barriers and enablers?
Pick one 'quick win', one medium and one long term
Group 1
ADAS
Group 2
Vision
Occupant safety


TRL
Session 2


Session 2
TRL
In groups, discuss each countermeasure, thinking about the HF and behaviour topics covered today
What are barriers and enablers?
Pick one 'quick win', one medium and one long term
Group 1
Improve driver skills/performance
Group 2
Improve driver behaviour


Group Discussion and Wrap Up
Report back to the group on:
The barriers and enablers for one of the countermeasures you discussed
Your top three take home messages
81

Appendix F Presentation of Findings

This appendix contains the slides from the presentation of the findings of this report on 27th and 30th March at TfL. Attendees included:

From TRL:

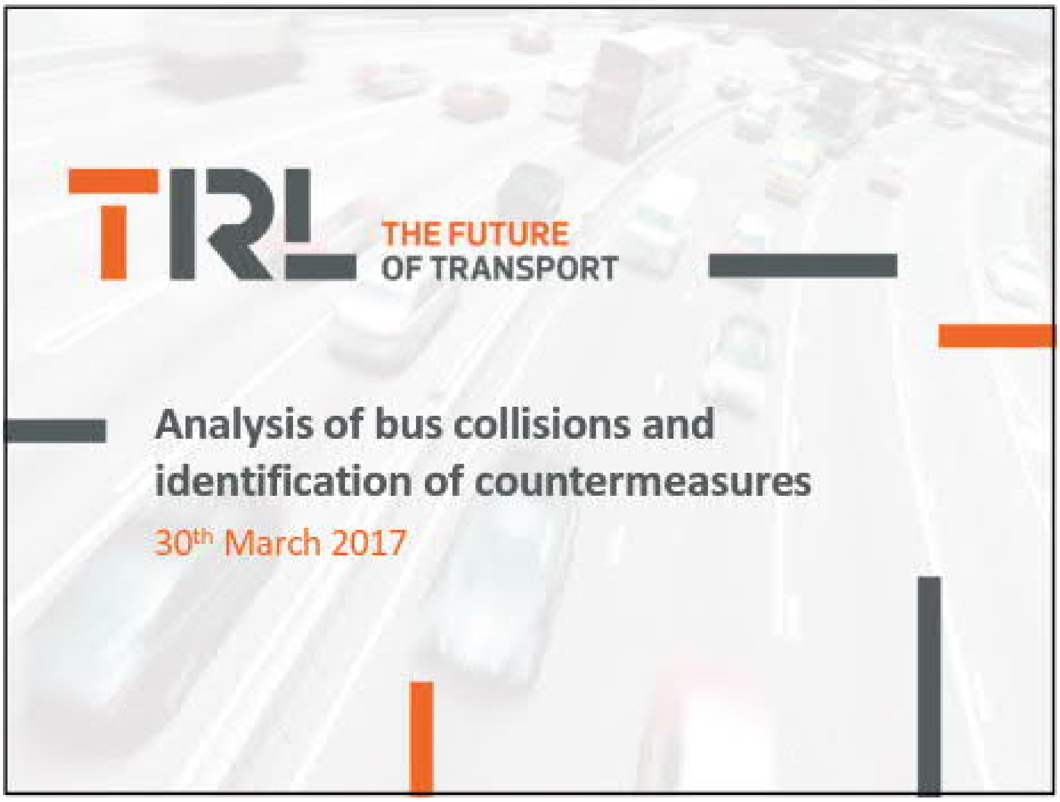
- Alix Edwards, TRL (presenter)
- Shaun Helman, TRL (presenter)
- Iain Knight, Apollo Vehicle Safety (subcontractor and presenter)

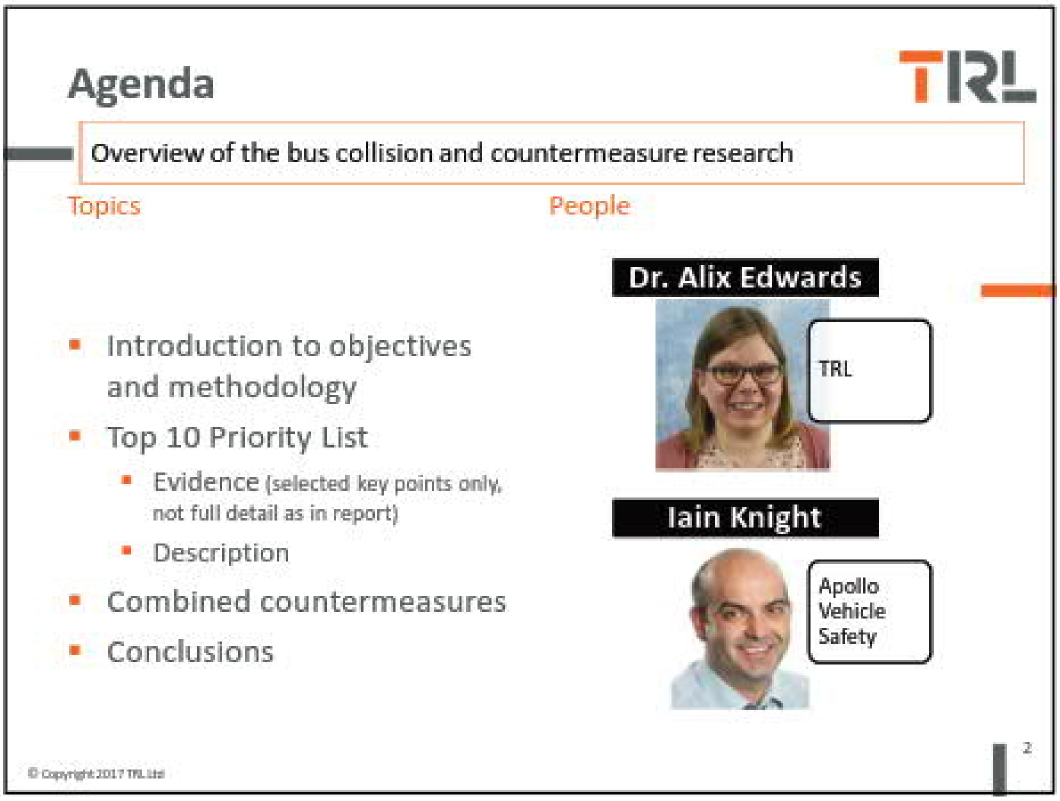
From TfL:

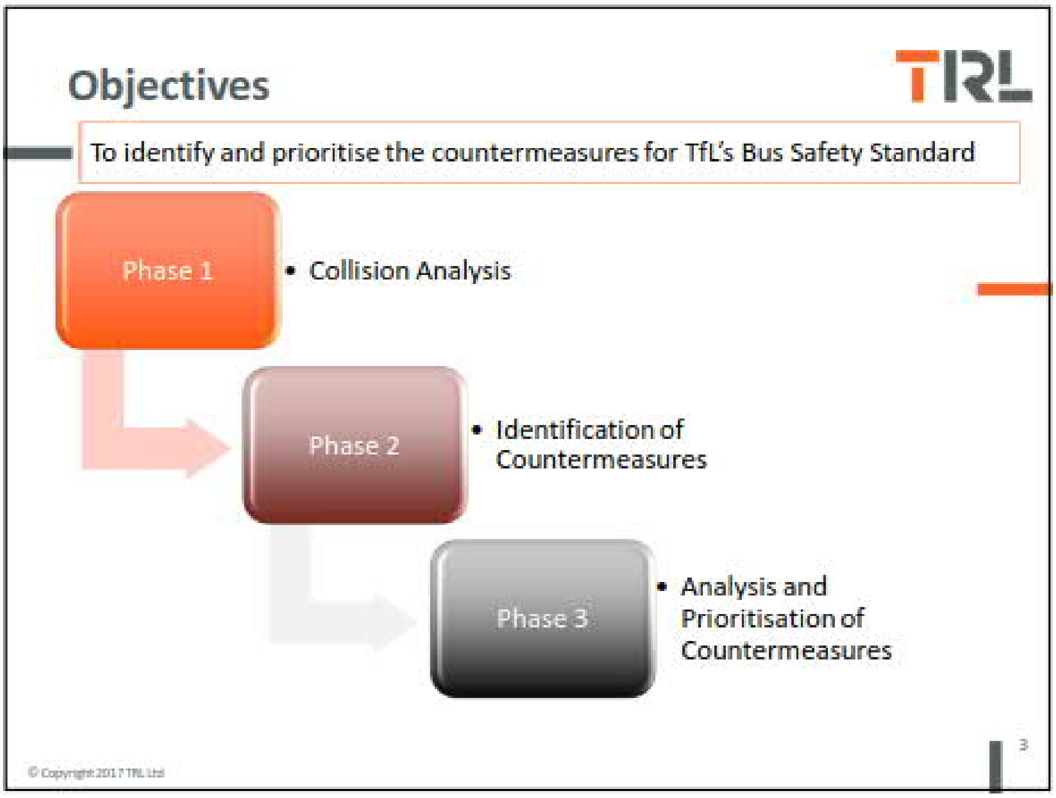
- Jane Lupson
- Valentina Trozzi
- James Wooller
- Cathy Behan
- Tony Daly
- Richard Rampton
- Tony Akers
- Peter Sadler
- Claire Mann
- Andrew Cruickshank

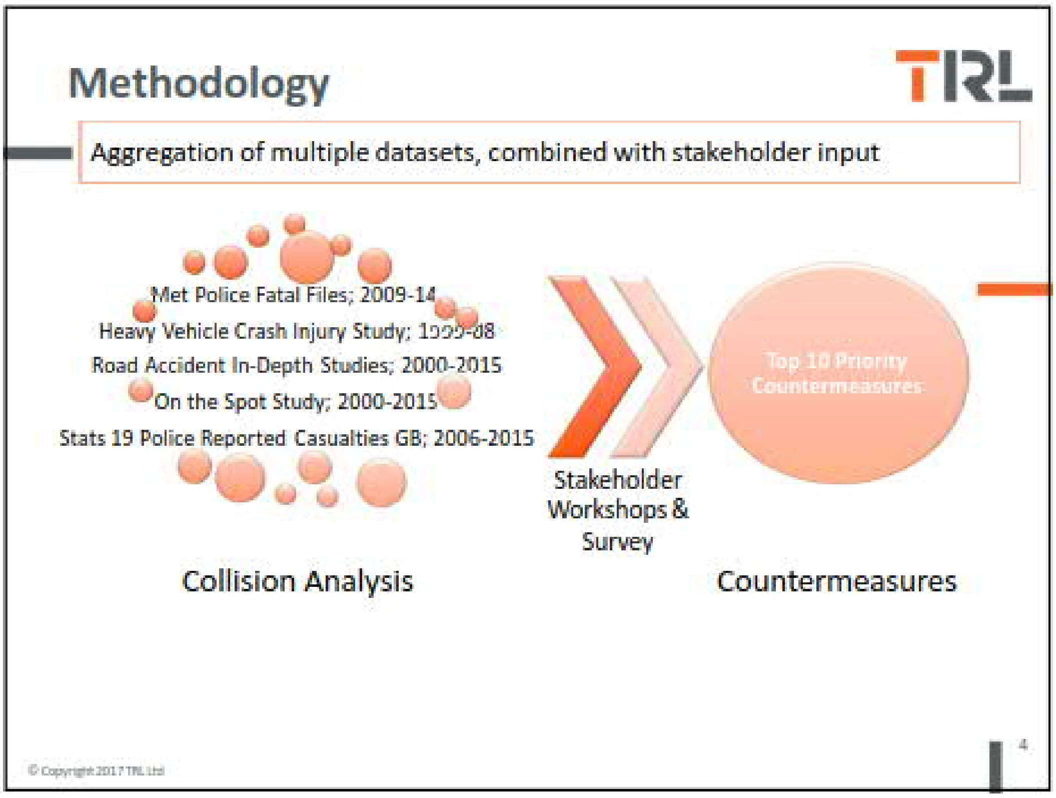
From Bus Operators:

- Tony Wilson – Abellio
- Paula Tansley – Arriva
- Jane Desmond – CT Plus
- Andrew Smith – Go Ahead
- John Trayner – Go Ahead
- Sinead Maguire – HCT Group
- Jon Pike – RATP Dev
- Dareen Roe – Stagecoach
- Charlie Beaumont – Tower Transit


THE FUTURE
OF TRANSPORT
Analysis of bus collisions and
identification of countermeasures
30th March 2017


Agenda
Overview of the bus collision and countermeasure research
Topics
People
Introduction to objectives and methodology
Top 10 Priority List
Evidence (selected key points only, not full detail as in report)
Description
Combined countermeasures
Conclusions
Dr. Alix Edwards
TRL
Iain Knight
Apollo Vehicle Safety
© Copyright 2017 TRL Ltd
2


Objectives
To identify and prioritise the countermeasures for TfL's Bus Safety Standard
Phase 1
Collision Analysis
Phase 2
Identification of Countermeasures
Phase 3
Analysis and Prioritisation of Countermeasures
© Copyright 2017 TRL Ltd
3


Methodology
Aggregation of multiple datasets, combined with stakeholder input
Met Police Fatal Files; 2009-14
Heavy Vehicle Crash Injury Study; 1999-08
Road Accident In-Depth Studies; 2000-2015
On the Spot Study; 2000-2015
Stats 19 Police Reported Casualties GB; 2006-2015
Stakeholder Workshops & Survey
Top 10 Priority Countermeasures
Collision Analysis
Countermeasures
© Copyright 2017 TRL Ltd
4

Bus Countermeasure Priority List

Top Ten

1. Advanced Emergency Braking System (AEBS) for Vulnerable Road Users (VRU)
2. Bus conspicuity
3. Pedestrian Friendly Front End
4. Improved front/side design (to prevent VRU underrun)
5. Camera/sensor Vulnerable Road User (VRU) systems
6. Improve Direct Vision (front and side)
7. Advanced Emergency Braking System (AEBS) to other vehicle rear
8. Bus interior design
9. Intelligent Speed Adaptation (ISA)
10. Energy-absorbing Front Underrun Protection System (FUPS)

Increasing fatality frequency

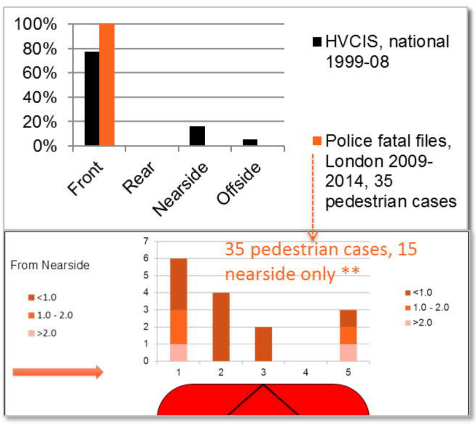
Criteria: Highest scores when summing police fatal files + HVCIS + OTS & RAIDS case counts; then ordered by police fatal files frequency as most relevant to London

5

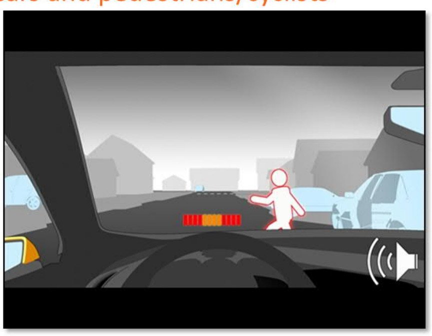
1) Advanced Emergency Braking System (AEBS) for Vulnerable Road Users (VRU)*

Human driver reaction time c0.75 to 2 seconds; AEB reaction time c0.3 seconds

Evidence: Majority of pedestrian fatalities are frontal with short reaction time

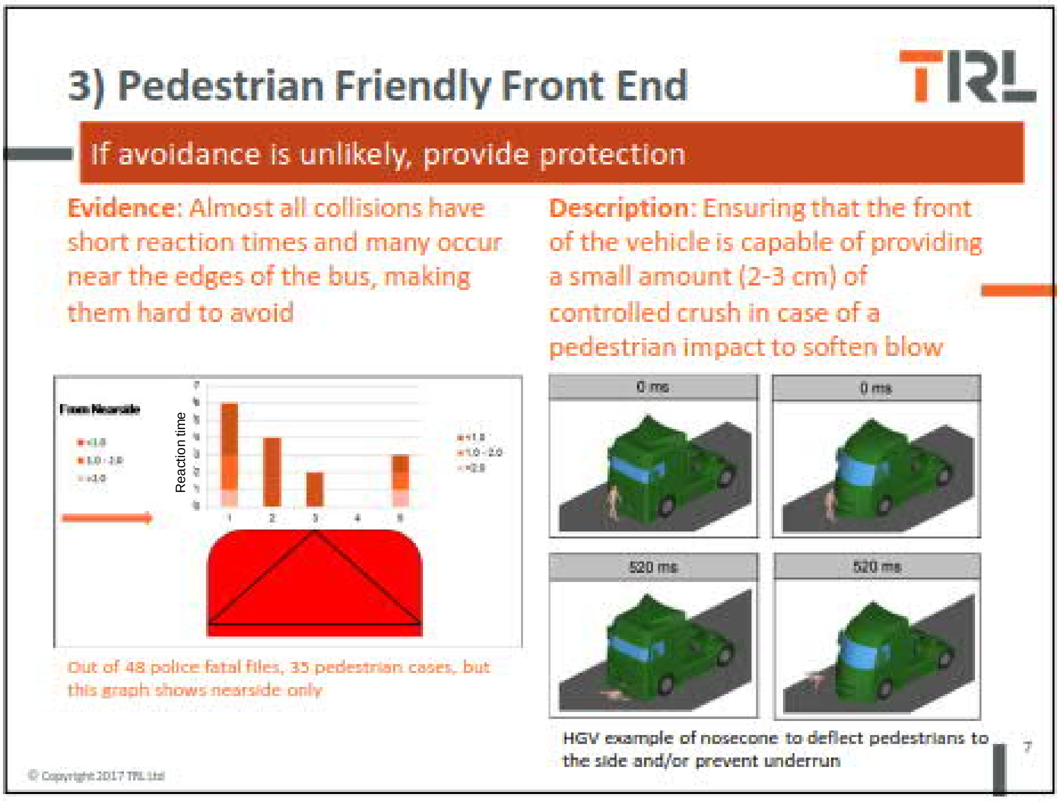


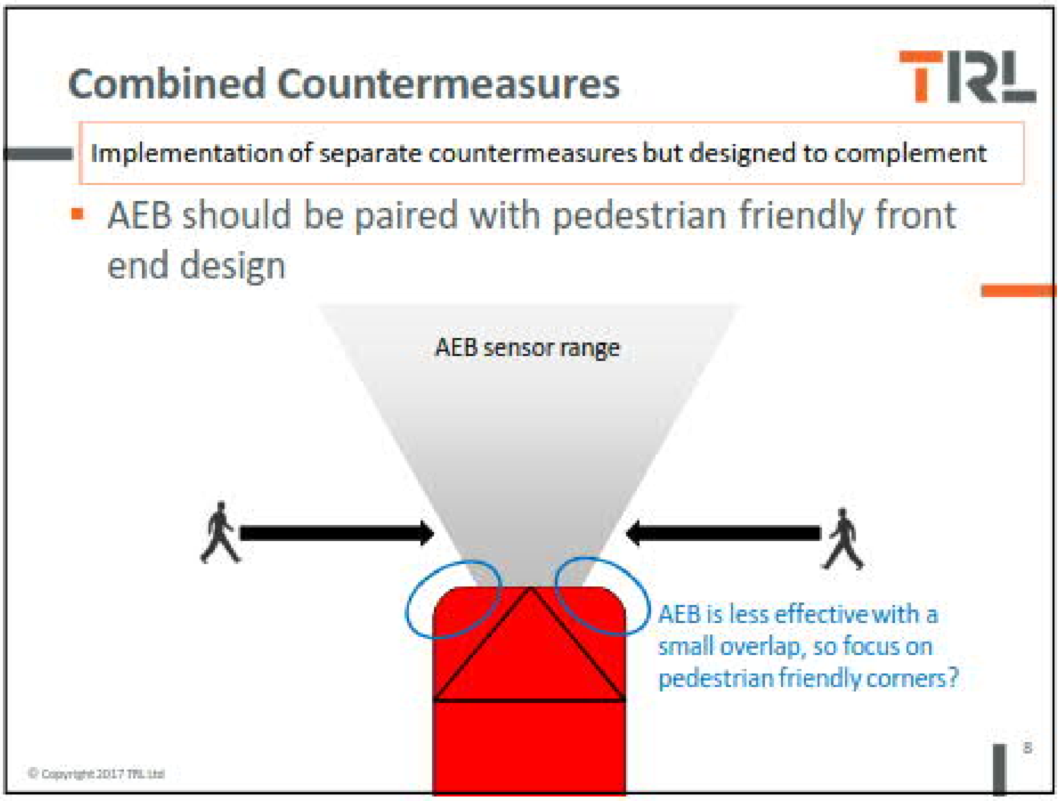
Description: AEBS combines sensing of the environment ahead of the vehicle with the automatic activation of braking (without driver input) to mitigate or avoid an accident with cars and pedestrians/cyclists



* Tuned to minimise false activations
** Where sufficient detail available for accident reconstruction calculations

6


3) Pedestrian Friendly Front End
If avoidance is unlikely, provide protection
Evidence: Almost all collisions have short reaction times and many occur near the edges of the bus, making them hard to avoid
Description: Ensuring that the front of the vehicle is capable of providing a small amount (2-3 cm) of controlled crush in case of a pedestrian impact to soften blow
From Nearside
Reaction time
1
2
3
4
5
Out of 48 police fatal files, 35 pedestrian cases, but this graph shows nearside only
0 ms
0 ms
520 ms
520 ms
HGV example of nosecone to deflect pedestrians to the side and/or prevent underrun
7
© Copyright 2017 TRL Ltd


Combined Countermeasures
Implementation of separate countermeasures but designed to complement
▪ AEB should be paired with pedestrian friendly front end design
AEB sensor range
AEB is less effective with a small overlap, so focus on pedestrian friendly corners?
8
© Copyright 2017 TRL Ltd

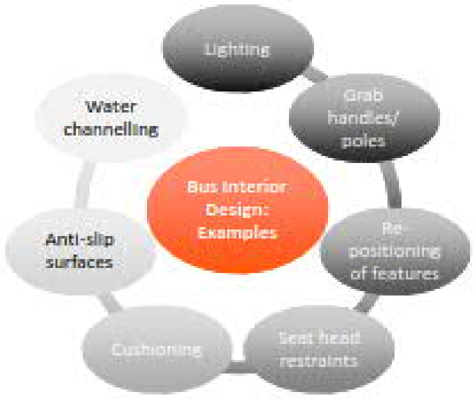
8) Bus Interior Design

Non-impact injuries are most frequent; improve interior protection

Evidence: Over two thirds of casualties occur where buses were not in a collision

National Stats 19 data, 2006-2015, includes both bus and coach

Description: Design improvements to the interior of the bus to help improve occupant safety



9

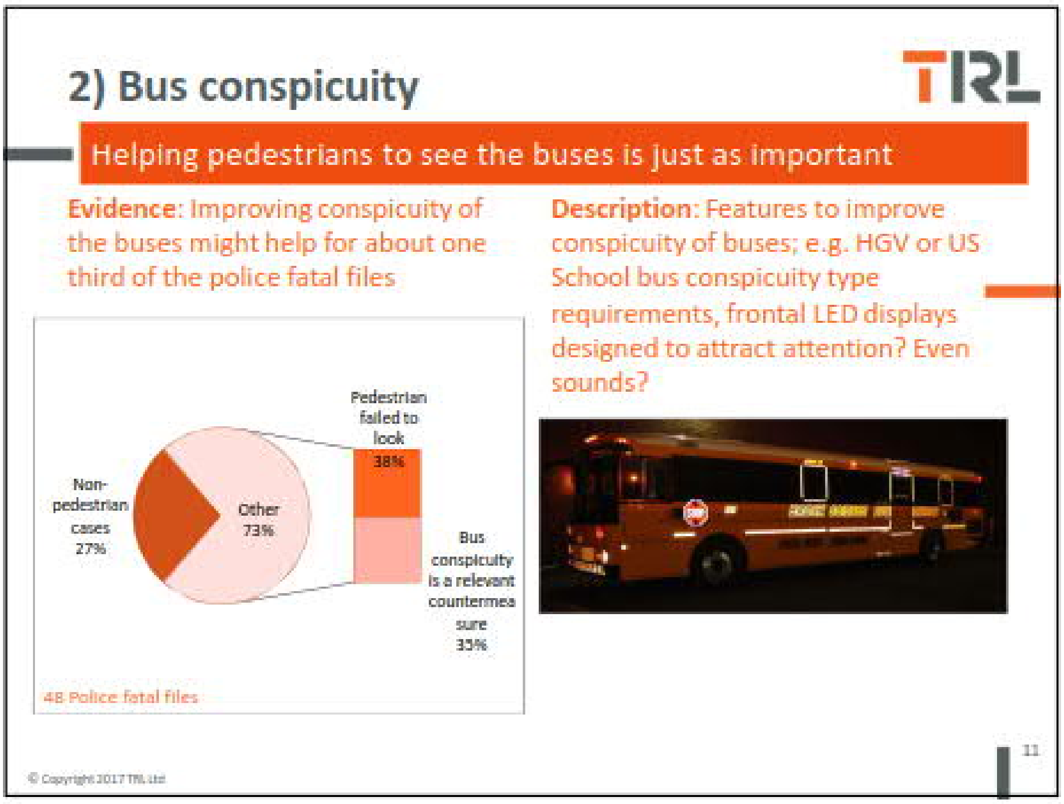
Combined Countermeasures

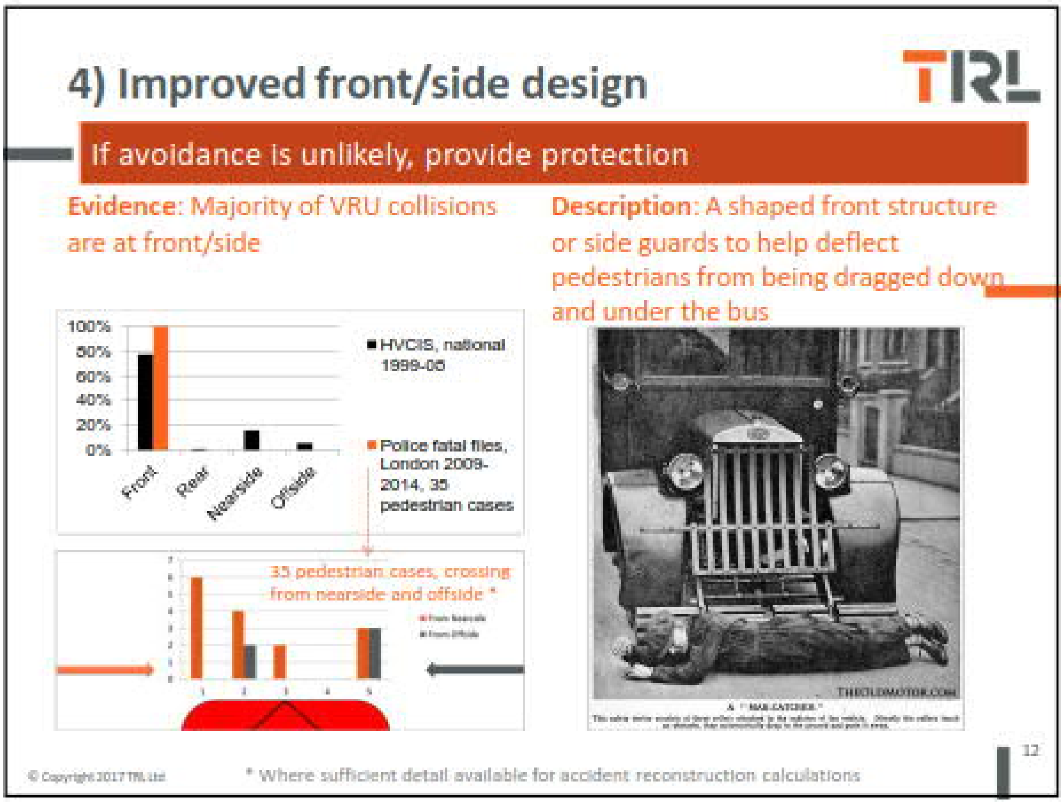
Implementation of separate countermeasures but designed to complement

- AEB and bus interior design should be combined
  - Stakeholder concerns:
  - AEB braking might injury bus occupants

	Scenario	Risk to standing passengers	Notes
1	Normal driving	Very low	In normal driving standing passengers will naturally brace themselves to the movement of the bus
2	The driver braked to try to avoid a collision (whether with a VRU or vehicle)	Yes	Driver is taking correct action
3	The bus suffered an impact with a vehicle	Yes	Deceleration in an impact might pose a risk to standing passengers
4	AEBS braking was activated	Yes	Whether mitigation or avoidance
5	The driver braked post-impact with a VRU	Yes	A common reaction is to brake post-impact
6	The bus suffered an impact with a VRU, with no post-impact braking	Very Low	Unlikely to occur often, see scenario 5. Drivers are required to stop after a collision
7	AEBS was falsely deployed	Yes	This is the only scenario where braking would not otherwise have occurred

10


2) Bus conspicuity
Helping pedestrians to see the buses is just as important
Evidence: Improving conspicuity of the buses might help for about one third of the police fatal files
Description: Features to improve conspicuity of buses; e.g. HGV or US School bus conspicuity type requirements, frontal LED displays designed to attract attention? Even sounds?
Pedestrian failed to look 38%
Non-pedestrian cases 27%
Other 73%
Bus conspicuity is a relevant countermeasure 35%
48 Police fatal files
© Copyright 2017 TRL Ltd
11

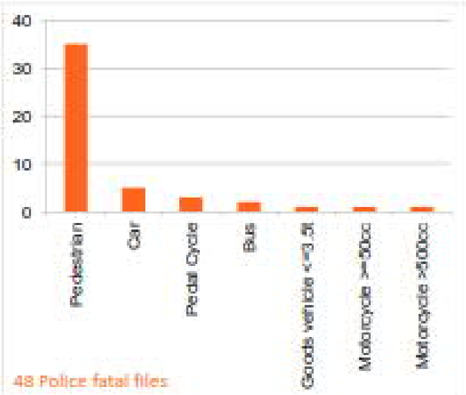

4) Improved front/side design
If avoidance is unlikely, provide protection
Evidence: Majority of VRU collisions are at front/side
Description: A shaped front structure or side guards to help deflect pedestrians from being dragged down and under the bus
100%
80%
60%
40%
20%
0%
Front
Rear
Nearside
Offside
HVCIS, national 1999-06
Police fatal files, London 2009-2014, 35 pedestrian cases
35 pedestrian cases, crossing from nearside and offside *
THEOLDMOTOR.COM
A "MAN-CATCHER."
© Copyright 2017 TRL Ltd
* Where sufficient detail available for accident reconstruction calculations
12

5) Camera/sensor Vulnerable Road User (VRU) systems

Cameras can help, but consider driver workload

Evidence: Pedestrians account for the majority of fatalities

Description: 360 degree 'birds eye' view in single screen and/or collision warnings



To turn off above a certain speed, and to turn on by default in reverse gear

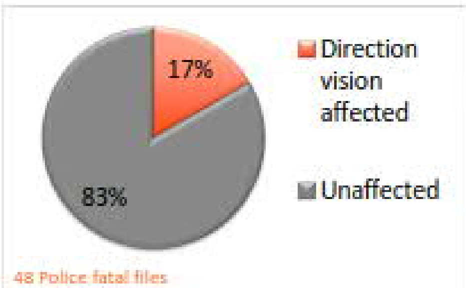
13

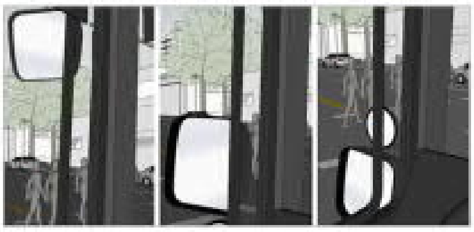
6) Improve Direct Vision (front and side)

Support drivers in collision prevention by improving vision

Evidence: Direct vision improvements identified in 17% of police fatal files

Description: Improved visibility via the windows/vehicle structure





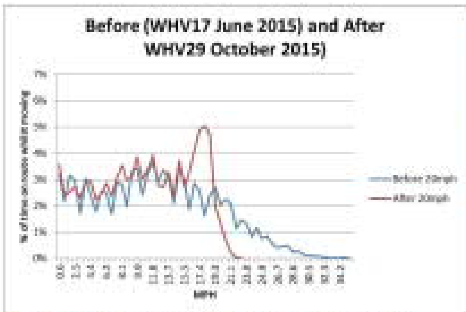
14

9) Intelligent Speed Adaptation (ISA)

Speed limit compliance improvements

Evidence: speed limit compliance improved, marginal increase in journey time, models showed a £0.5M to £0.6M reduction in costs related to injuries

Description: A range of technologies to aid drivers in observing the appropriate speed for the road environment; either voluntary or mandatory



Example graph from: Greenshields et al. (2016) Intelligent Speed Assistance on London Buses: A trial on two London bus routes, TRL for TfL

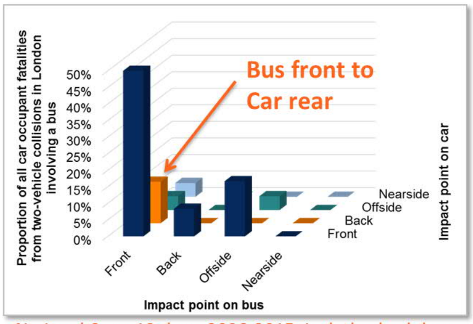
15

7) Advanced Emergency Braking System (AEBS) to other vehicle rear*

AEB can avoid crashes with other vehicles

Evidence: Car occupant fatalities most often occur in collisions at the front of the bus

Description: AEBS combines sensing ahead of the vehicle with the automatic activation of braking (without driver input) to mitigate or avoid an accident with other vehicles



National Stats 19 data, 2006-2015, includes both bus and coach

* Tuned to minimise false activations

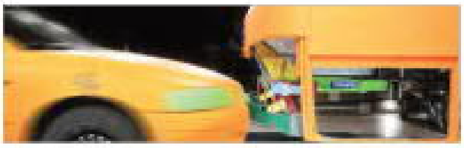
16

10) Energy-absorbing Front Underrun Protection System (FUPS)

Protection against underrun

Evidence: 11 cases in HVCIS identified FUPS, 0 in London data*

Description: Energy absorbing structures positioned at a height to interact with car structures protecting car occupants



* difference could be a result of unique London characteristics or small sample size

17

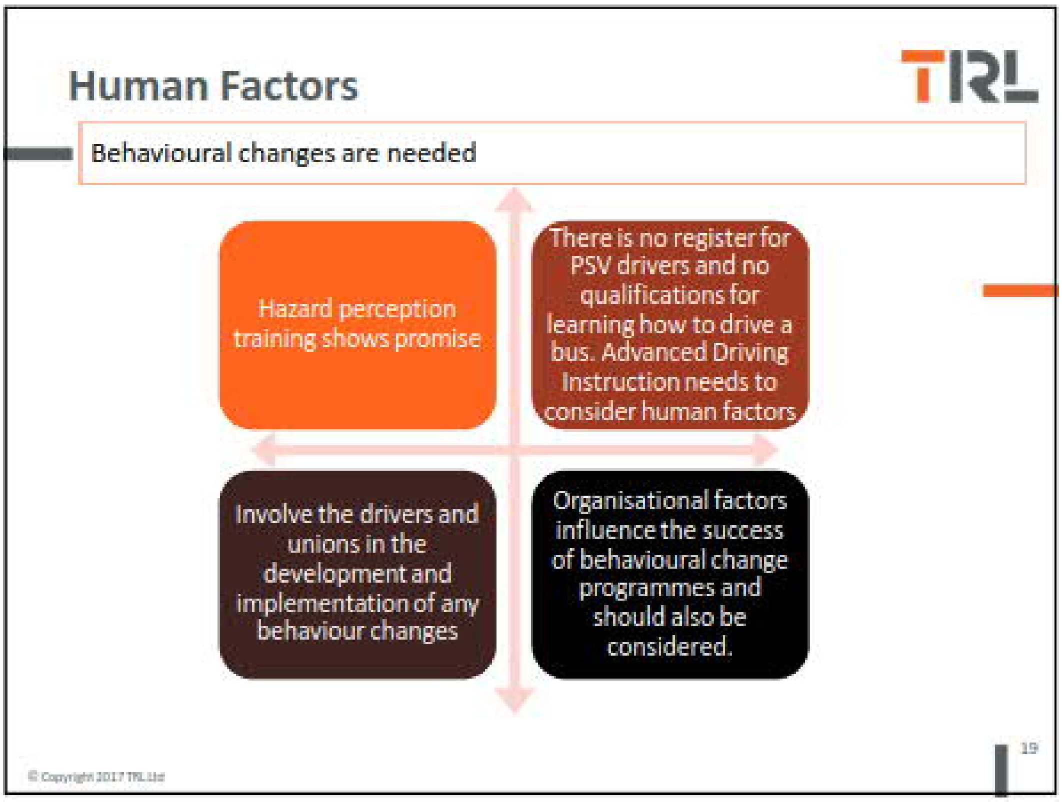
Bus Countermeasure Priority List

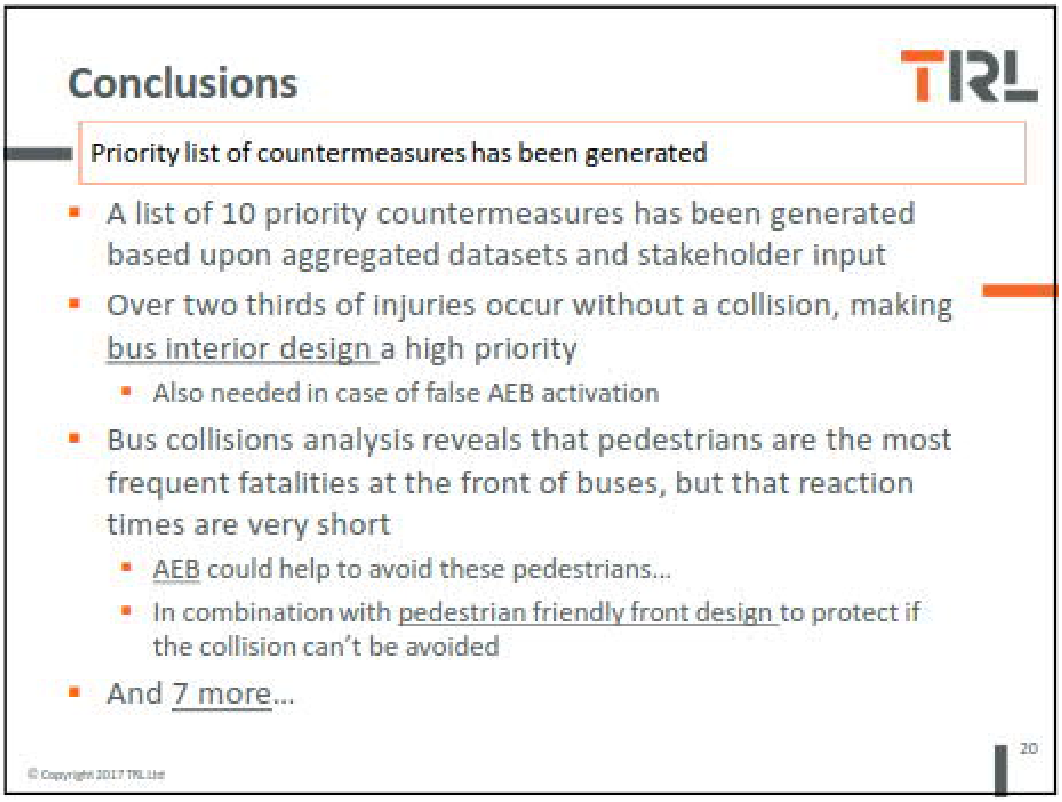
Top Ten, including combinations

1. Advanced Emergency Braking System (AEBS) for Vulnerable Road Users (VRU)
2. Bus conspicuity
3. Pedestrian Friendly Front End
4. Improved front/side design (to prevent VRU underrun)
5. Camera/sensor Vulnerable Road User (VRU) systems
6. Improve Direct Vision (front and side)
7. Advanced Emergency Braking System (AEBS) to other vehicle rear
8. Bus interior design
9. Intelligent Speed Adaptation (ISA)
10. Energy-absorbing Front Underrun Protection System (FUPS)

Increasing fatality frequency

18


Human Factors
Behavioural changes are needed
Hazard perception training shows promise
There is no register for PSV drivers and no qualifications for learning how to drive a bus. Advanced Driving Instruction needs to consider human factors
Involve the drivers and unions in the development and implementation of any behaviour changes
Organisational factors influence the success of behavioural change programmes and should also be considered.
© Copyright 2017 TRL Ltd
19


Conclusions
Priority list of countermeasures has been generated
A list of 10 priority countermeasures has been generated based upon aggregated datasets and stakeholder input
Over two thirds of injuries occur without a collision, making bus interior design a high priority
Also needed in case of false AEB activation
Bus collisions analysis reveals that pedestrians are the most frequent fatalities at the front of buses, but that reaction times are very short
AEB could help to avoid these pedestrians…
In combination with pedestrian friendly front design to protect if the collision can't be avoided
And 7 more…
© Copyright 2017 TRL Ltd
20

Analysis of bus collisions and identification of countermeasures

Transport for London (TfL) is working through a programme of research designed to develop a Bus Safety Standard (BSS) with the objective of reducing the frequency of collisions involving buses in London and the associated bus casualties. This report is the first phase of that research and is focussed on examining casualties involving buses and their potential countermeasures in detail.

Data from Stats19, the Police Fatal Archive (police fatal files) the Road Accident In Depth Studies (RAIDS), and the Heavy Vehicle Crash Injury Study (HVCIS), plus research and evidence from literature, stakeholders, and experts in the field, have all been combined to examine bus collisions. The first step was to analyse the distributions of bus collisions, their configurations, circumstances, and the associated casualties. The second step was to then use the in-depth collision details to assign, using engineering judgement, countermeasures that might help to avoid or mitigate the severity of each collision. The approach was based on the Haddon matrix and assigned countermeasures in the pre-crash and crash phases. Causation factors and Countermeasures were classified as related either to the vehicle, human or environment. Finally, the countermeasures that had been assigned were then analysed to quantify the number of fatalities that they might prevent and to develop a prioritised list of countermeasures to be considered as part of the Bus Safety Standard.

The priority list represents the top ten bus coumtermeasures recommended for the BSS. These were prioritised on the basis of: numbers of fatalities (combined from a range of sources), system effectiveness and system applicability, with the final list ordered by the frequency count for the police fatal files becasue this was judged most relevant for the BSS. In terms of reducing fatalities in London the prioritised list indicates that AEBS, improved bus conspicuity, and improved pedestrian friendly front end design are the top three measures.

Other titles from this subject area

PPR753 Vehicle Safety Design Features and Future Safety Benefits in London. Wallbank C, Lloyd L, Scoons J, Muirhead M, McCarthy M, Carroll J and McRae-McKee K. 2015

PPR621 Analysis of Police collision files for motorcyclist fatalities in London, 2006-09. Smith L, Knowles J, Cuerden R. 2013

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN 2514-9652

ISBN 978-1-912433-02-5

PPR819