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The Transport for London Bus Safety Standard: Pedal Application Error Prevention & Recovery

Evaluation of Safety Measure

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1.1	30/07/2022	Corrections to Table 1 Added reference to TfL for latest specification in the executive summary and recommendations	AE	PSM & DH

Executive Summary

Bus Safety Standard (BSS)

The Mayor of London's Transport Strategy sets out a commitment to vision zero: no deaths or serious injuries from any collisions on the roads of the capital by 2041, and no fatalities involving a London bus by 2030. The BSS is focussed on the contribution that vehicle safety features can make towards these challenging targets.

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

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

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

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

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

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

Pedal Application Error

Pedal Application Error refers to situations where the driver presses the accelerator when they think they are pressing the brake pedal, which leads to an unintended acceleration. It happens extremely rarely but carries a risk of very severe outcomes. It is very difficult to understand exactly what happens in these events, and drivers are unaware of their mistake. TfL is now requiring CCTV cameras to be fitted in the footwell to provide evidence in case of future incidents. In the meantime, there are a variety of measures to help a driver place their foot correctly or recover from an unintended acceleration incident.

Foot Placement

One solution that might help driver's to correctly place their foot on the brakes is brake 'toggling'. This refers to an additional press of the brake pedal at a bus stop or bus stand (not in flowing traffic) to update the driver's recent memory of the brake pedal position. The idea is that if the driver's brain has more frequent memory updates of where the brake pedal is, then they are less likely to place their foot incorrectly.

Another theory about pedal application error is that the driver's feet might become misaligned from the pedals if the driver must move to see into a blind spot. The Bus Vision Standard is intended to reduce the blind spots, and as a consequence might also help to reduce the risk of pedal foot placement error.

The design of bus pedals is controlled by regulation, and many manufacturers build following ISO standards. However, there is still some variation between models, and if a driver drives different buses, they may become confused by different pedal layout or feel. In an ideal world, all the bus pedal configurations would be identical.

Recovery

It may be possible to help the driver recover from an error if a pedal application error incident does occur. CCTV evidence shows that a small proportion of incidents last for a surprisingly long time, with some even approaching a minute in duration. The driver is so convinced that they have their foot on the brake, they just keep pressing it. In these cases, a driver feedback system may help the driver to realise their mistake. Feedback could include visual indication or the addition of engine noise simulation in quiet (electric/hybrid) vehicles.

Intervention

Future Advanced Emergency Braking (AEB) systems might be able to intervene in the case of pedal application error. AEB is intended to help the driver when they are distracted or cannot react fast enough, so an AEB is generally overridden if there is a strong input (braking or acceleration or steering) from the driver. However, it would be feasible to adapt the logic and allow advanced emergency braking if the accelerator pedal was depressed fully, and the AEB system detected an imminent collision, particularly if the system could distinguish between normal throttle activation and one where the driver really meant to hit the brake.

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1 Introduction to the Bus Safety Standard (BSS)

1.1 The BSS

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

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

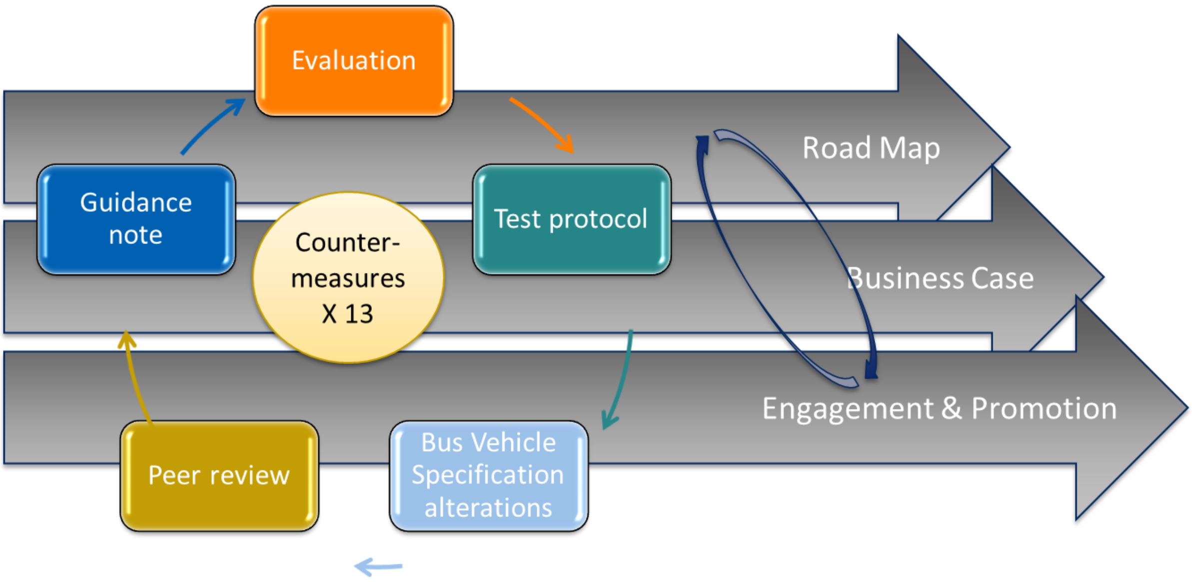

Figure 1: Summary of the BSS research programme

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

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

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

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

1.2 Bus Safety Measures

The measures selected for consideration in the BSS were wide ranging, as shown in Figure 2. Some will address the most frequent fatalities, which are the group of pedestrians and cyclists killed by buses, mostly whilst crossing the road in front of the bus. There are several measures that could address this problem, for example, Advanced Emergency Braking (AEB, which will apply the vehicle's brakes automatically if the driver is unresponsive to a collision threat with a pedestrian) or improved direct and indirection vision for the driver. These are both driver assis safety measures, which are designed to help the driver avoid or mitigate the severity of incidents. Intelligent Speed Assistance (ISA) is another example of driver assist, and TfL has already started rolling this out on their fleet. The last two driver assist measures are pedal application error (where the driver mistakenly presses the accelerator instead of the brake) and runaway bus prevention; both of which are very rare but carry a high risk of severe outcomes.

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

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

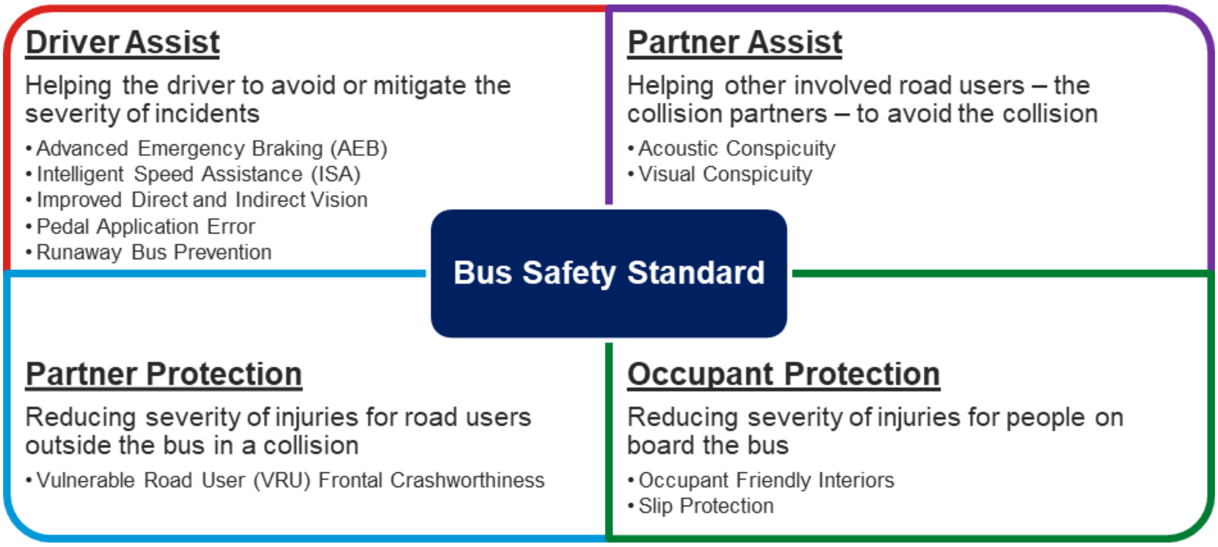

Figure 2: Bus Safety Measures

1.3 Pedal Application Error

Unintended acceleration (UA), also called pedal error or pedal application error, is a rare occurrence but has potentially severe consequences, with an analysis of IRIS data (TfL, 2017) revealing that two pedestrians were killed in incidents in London, one person in 2002 and another person in 2010. Pedal error is not solely associated with bus drivers. It is also known to be correlated with age in the wider driving population; increasing age is associated with increased risk of UA, leading some researchers to suggest that dysfunction in cognitive executive processes may be an important contributor to pedal error events (Freund et al., 2008). TRL understands that previous research for TfL by Human Engineering Ltd. (Bright, 2011) suggested a number of possible countermeasures to help avoid pedal application error errors and help drivers recognise and recover from an error should it occur. These countermeasures include changing the size and feel of the pedals, haptic or auditory feedback, standardising the pedal design and position across the fleet, and a technological solution. This evaluation will aim to establish which of these countermeasures may be most effective as a way of mitigating pedal errors.

2 Defining the problem

2.1 Casualty priorities for TfL

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

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

2.2 Casualty problem due to pedal application errors

The Stats 19 data from the Department for Transport UK does not specifically identify pedal application errors. It would likely be coded as CF410 loss of control or 607 unfamiliar with vehicle, however other error would be mixed in.

Therefore the bus operator incident data reported to TfL is the only way to identify the pedal application frequencies. This reveals that there were 43 incidents from 2002 to 2018.

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

Casualty Type	Collision type	Fatal	Serious	Slight	KSI	Total
Bus Passenger	Injured in non-collision incidents - standing passenger	4.2%	17.1%	23.3%	11.9%	15.2%
	Injured in non-collision incidents - seated passenger	0.5%	6.4%	13.0%	4.0%	6.6%
	Injured in non-collision incidents - boarding/alighting/other	1.6%	7.6%	5.3%	5.2%	5.2%
	Injured in collision with a car	0.5%	4.6%	10.1%	2.9%	5.0%
	Injured in collision with another vehicle	0.0%	3.1%	5.0%	1.8%	2.8%
	Total	6.9%	38.7%	56.7%	25.9%	34.8%
Pedestrian	Injured in a collision while crossing the road with a bus travelling straight ahead	30.7%	20.0%	7.0%	24.3%	19.3%
	Injured in a collision, not while crossing the road, with a bus travelling straight ahead	10.6%	7.9%	4.6%	9.0%	7.7%
	Injured in a collision with a bus turning left or right	12.2%	3.1%	1.2%	6.8%	5.2%
	Injured in other collision with a bus	2.1%	1.4%	0.7%	1.7%	1.4%
	Total	55.6%	32.5%	13.6%	41.8%	33.6%
Car Occupant	Injured when front of bus hits front of car	6.3%	1.9%	0.9%	3.7%	2.9%
	Injured when front of bus hits rear of car	1.6%	0.8%	2.8%	1.1%	1.6%
	Injured when front of bus hits side of car	1.1%	1.1%	1.8%	1.1%	1.3%
	Injured in side impact collision with a bus	2.6%	1.9%	3.9%	2.2%	2.7%
	Injured in other collision with a bus	2.1%	1.0%	1.4%	1.5%	1.4%
	Total	13.8%	6.6%	10.8%	9.5%	9.9%
Cyclist	Injured in a collision with the front of a bus travelling straight ahead	2.1%	1.2%	0.9%	1.5%	1.4%
	Injured in a collision with another part of a bus travelling straight ahead	0.0%	2.6%	1.5%	1.6%	1.6%
	Injured in a collision with the nearside of a bus which is turning	1.6%	0.8%	0.4%	1.1%	0.9%
	Injured in other collision with a bus	0.5%	3.1%	2.1%	2.1%	2.1%
	Total	4.2%	7.8%	5.0%	6.4%	6.0%

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

3 Summary from literature

3.1 Pedal error causes

Extensive research in unintended acceleration has been conducted in the automotive sector. The National Highway Traffic Safety Administration (NHTSA) (Lococo, Staplin, Martell & Sifrit, 2012) conducted research on the relationships between foot placement errors and unintended acceleration from a human factors perspective. The first part of their report focuses on the understanding of:

- The source of foot placement errors
- The late detection of pedal error by drivers
- The persistence of the pressing of the wrong pedal sometimes applied for as much as 12 seconds before a crash.

3.1.1 Source of foot placement errors

Lococo et al. (2012) emphasize in their literature review that pedals are “invisible” controls as they are hidden underneath a vehicle dashboard and operated by users without looking at them. People have to rely almost entirely on their proprioception[1] senses or knowledge of a body part location in space including foot direction, position, movement, amplitude, speed and effort. Furthermore these incidents are not restricted to novice drivers but also occur in experienced drivers. Lococo’s findings included:

- Foot movements are not exactly reproducible, and because of the variability of foot movement and the relative sizes of the foot and brake pedal, a deviation to the right could result in an unintended application of the accelerator pedal (Schmidt, 1989). Force, timing, and time pressure are also influencing factors of this variability
- The initial position of the right foot and travel required to reach the brake pedal is also an influencing factor of movement variability. The more space from the intended pedal when initiating a movement toward it, the larger the variability/inaccuracy will be
- Head and body position can influence drivers’ foot proprioception: “Movements in head position activate proprioceptive receptors in the neck which may in turn, alter the perceived spatial position of the brake pedal with respect to the body, influencing limb placement” (Lococo et al., 2012, p.18)
- A change in seating position can also alter drivers’ orientation creating a bias and offset of the memorised pedal position leading to an erroneous accelerator application
- Experience with driving other vehicles can contribute to a reduction in accuracy of pedal movements and create bias in foot placement.

[1] “the neurological ability of the body to sense movement and position” https://www.collinsdictionary.com/dictionary/english/proprioception accessed on the 17/01/2018

3.1.2 Late detection of pedal error

It has been observed both in cars and buses that pedal error incidents could last more than ten seconds without being noticed by the driver making the error. This failure of detection has been explained by Lococo et al. (2012) as follows:

- Schmidt (1989) mentions “efference copy” theory; when the central nervous system sends a motor signal to apply the brakes, a copy of this command (efference copy) is saved in another part of the brain in parallel in order to be reused as a “correctness” measure against future movement signals. The theory suggests that the efference copy may substitute the feedback from the leg/foot movement and perception, meaning that an incorrect movement cannot be detected by the driver (e.g. the driver believes his or her foot is on the brake, whereas the accelerator is being pressed).
- Selective attention is another factor highlighted; little attention might be paid to a foot movement which is performed in an almost automatic nature (lack of focused attention being a hallmark of ‘skill-based’ actions – see Rasmussen, 1986). Once the foot movement is performed, other more salient stimuli such as traffic may hold a driver’s attention, thus decreasing the probability of detecting a pedal error.

3.1.3 Persistence in pedal error

Some pedal error incidents have been reported to last more than a few seconds. Persistence of the pressing of the wrong pedal has been studied by the NHTSA and extracted from a study released by Schmidt (1989), in which it has been explained as a consequence of several factors:

- Panic reaction; a driver reacting to visual stimuli representing a direct danger will tend to rely on protective and automatic reactions (reflex). Multiple cognitive cues are happening at the same time, impeding the driver’s ability to react in a normal way (perceive stimuli, process stimuli, interpret stimuli, start action, action, perceive an action feedback), and leading to the bypassing of information processing to move straight to a reaction. In the context of a pedal application error incident, the panic reaction is created with the sudden acceleration while the driver intends to brake, and believing his or her foot is already being placed on the brake pedal (leading the driver to press even more the brake pedal, as expected in the context of a brake pedal failure)
- ‘Tunnelling’ or narrowing effect (Schmidt 1989); a stressful situation can involve the shrinking of the perceptual field, as the attention is diverted to a focus point. The narrowing effect does not only apply to visual cues (e.g. peripheral events less detected) but to other perception cues such as hearing and touch. In the context of a pedal incident, the perceptual field of view may be restricted to the obstacle or danger to be avoided impeding the undertaking of effective solutions (or detection of any pedal misapplication).

3.1.4 Modern Bus Design and Pedal Application error

One factor that may contribute to pedal application error incidents in modern buses is the introduction of hybrid power unit systems. One consequence of these systems is the loss of engine noise that could otherwise be used as a cue to indicate that the accelerator pedal is being pressed rather than the brake pedal. A further consequence of hybrid systems is that they utilise energy regeneration systems, whereby the bus can use a form of engine braking to recover energy when the accelerator is not being pressed. This process slows the bus quite significantly and acts as a brake for the bus. With regards to the behaviour of drivers, this leads to extended periods of coasting where the driver is not pressing either pedal but instead has their foot covering one of the pedals. These extended periods of not pressing either pedal may result in the driver losing awareness of where their foot is in relation to the pedals, in turn leading to pedal application error.

3.2 Pedal error mitigations

3.2.1 Automobile

3.2.1.1 Systems

Up to now, pedal error remains an incident that has not been resolved; no complete technical solution has been developed in the general automotive domain although more data are available in this field than is the case with buses. However, pedal error has been reduced on automatic cars thanks to the introduction of an interlock fitted on the brake pedal (the driver has to press the brake pedal while switching gear from stationary). This technology has been shown to eliminate 60% of pedal errors when shifting from Park to Drive or Reverse (Schmidt, 1989).

Some researchers have investigated if a specific pedal layout (pedal spacing) could be related to pedal error. Trachtman, Shmidt and Young (2005) made a comparison of the different lateral and vertical spaces between the accelerator pedal, brake pedal and steering wheel axis, and cross-referenced them with a pedal error database of over 200,000 accidents. No differences in the pedal measurements of vehicles involved in accidents (when compared with their non-accident peers) were found.

Other research conducted by the NHTSA (Colins, Evans & Hughes, 2014) investigated application forces on accelerator and brake pedals and if any specific forces applied on pedals were linked with pedal error. The researchers did not find any relationships between pedal forces and pedal error.

More recently, some predictive models of pedal error have been developed by researchers but these are still under testing and not available on the market. Tran, Doshi and Trivedi (2012) developed a potential solution to modelling and predicting driver behaviour, foot gesture analysis (FGA), which has a 94% accuracy rate for predicting the action of the foot. FGA uses optical flow foot tracking and a HMM (Hidden Markov Model) to map and divide movements into seven semantic categories:

1) Neutral
2) Moving towards brake pedal
3) Moving towards acceleration pedal
4) Engaging brake pedal
5) Engaging acceleration pedal
6) Release from brake pedal
7) Release from acceleration pedal

This new technology opens new opportunities in the future to control and prevent pedal error using vehicle intervention systems, so long as false alarm rates can be brought to acceptable levels (i.e. near zero).

Detailed analysis of foot placement errors during naturalistic driving was carried out by Wu, Boyle, McGehee et al. (2017). They recorded foot placement during driving and used a random forest algorithm[2] to predict pedal application errors based on foot placement, driver characteristics (e.g. annual mileage), driver cognitive function levels and anthropometric measurements (body weight, height, foot length and foot width). The findings of the research revealed that prior foot placement (i.e. having previously placed the foot on the accelerator rather than the brake), driver seat position and the foot being in transition between the pedals during a manoeuvre were all predictors of foot placement errors during driving.

Wu, Boyle and McGehee (2018) carried out a further study in which they used functional principal components analysis[3] in order to understand the patterns of foot movements that underlie pedal application errors. Three categories of brake pedal responses were analysed in a simulator study: direct hits, corrected trajectories and pedal errors. The analysis was able to reveal common patterns of foot movement for direct hits and corrected trajectories. The analysis was also able to reveal foot movements associated with foot slips and missing the pedal, which were due to the foot being insufficiently raised towards the pedal.

Combined, these studies demonstrate the pontential for foot movement analysis to be incorporated into safety systems. For example, a system could be developed that is able to use foot movement to predict when a foot placement error is about to occur. The system could then engage AEB in order to stop an unintended acceleration from occurring.

A number of vehicle manufacturers have begun installing technology that aims to stop collisions related to pedal application error incidents. Nissan have developed a sonar technology called “Emergency Assist for Pedal Misapplication”. The system works by warning the driver with a visual alert and warning sound if it detects an obstacle in the direction of travel or if it detects a strong application of the accelerator pedal when the car is moving at low speed during parking. The system simultaneously supresses any accelerator input and if it determines that there is potential for a collision with an obstacle it will apply the brake.

Toyota has also developed a similar sonar-based technology for reducing pedal application error collisions called “Intelligent Clearance Sonar”. This technology also incorporates a system called “Drive-start Control” that prevents unintended acceleration caused by incorrect gear selection when the accelerator pedal is pressed. If abnormal gear shifting is detected then the system will display a warning and reduce engine output.

Subaru has a camera-based technology that offers a number of driver assistance systems, including "Pre-Collision Throttle Management”. This system can reduce unintended forward acceleration caused by incorrect gear selection or the accelerator pedal being pressed accidentally or depressed too much.

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[2] A type of algorithm that uses randomised decision trees in order to carry out classification tasks.

[3] A statistical method for investigating the dominant modes of variation within functional data.

3.2.1.2 Training and medical countermeasures

As described above in section 3, the cause of pedal error is likely due to a cognitive error and/or upper body movements leading to incorrect foot placement. Considering this context, different types of training and medical countermeasures have been suggested by researchers to reduce pedal error.

In the NHTSA report from Lococo et al. (2012), the authors suggest several countermeasures. The most relevant ones for the purpose of this project have been listed below:

- **Teach drivers to use the neutral gear:** as described previously, when panic situations occur the reflex of the drivers can be to resort in pumping the accelerator pedal (as they believe it is the brake). Lococo et al. state that if drivers were to change gear to neutral when the car goes out of control, pedal error could be corrected. Obviously, this countermeasure could be effective if there is sufficient time to change gear before collision.

- **Drivers/physicians awareness on peripheral neuropathy and hand controls technology:** peripheral neuropathy develops when nerves in the body's extremities are damaged (e.g. fingers, hands, feet). According to the NHS[4], the symptoms of peripheral neuropathy can include[5]:
  - "Numbness and tingling in the feet or hands"
  - "Burning, stabbing or shooting pain in affected areas"
  - "Loss of balance and co-ordination"
  - "Muscle weakness, especially in the feet"

  Lococo et al. emphasise the importance of physicians' awareness to the consequences of peripheral neuropathy on driving. By advising car drivers to fit and use hand controls on their car, several incidents (not only pedal error) could be avoided.

- **Therapists/Drivers awareness on loss of feet sensation:** testing drivers' lower extremities' sensations (to check for any loss of sensation) is another countermeasure that could reduce pedal errors.

- **Targeted drivers campaigns:** Lococo et al. suggested that the following elements should be part of a wider media and driver education campaign:
  - The importance of correct seating position, and the impacts of position on drivers feet
  - The importance of the knowledge of the driven car (including pedals)
  - The importance of adequate footwear
  - The impact of cell phones on driving performance and distraction
  - The existence of pedal error incidents and behaviours to adopt when they occur: remove feet from all pedals, and in case the car continues to accelerate, shift the car into neutral gear.

[4] Source: https://www.nhs.uk/conditions/peripheral-neuropathy/ consulted on the 10/01/2018

- **Improvements of traffic records:** Lococo et al. advise that an additional field is added to traffic collision records to describe pedal error incidents, with a clear report code for pedal application error, and additional drivers' information (e.g. distractions, medical conditions, and feet behaviour during the incident).

3.2.2 Buses (TfL re port)

Only a few reports on pedal application error in buses have been published – far fewer than the number of reports available on pedal application error in the general automotive sector.

A previous report released to TfL in 2011 by Lloyd's Register Group investigated the possible countermeasures for pedal error using focus groups and subject matter experts. The solutions suggested to pedal application error were evaluated by the subject matter experts during workshops in which the benefits, limitations and technical feasibility of the solutions were considered.

According to Lloyd's Register Group, the following solutions could be investigated further in order to reduce pedal error:

- **Standardisation of bus pedals layouts:** to ensure that all cab layouts are aligned to a mental model, a single and standardised pedal layout was proposed to reduce the occurrence of pedal error.
- **Engine cut-off when the driver's door is opened:** to ensure that the drivers are correctly seated, the bus engine could be cut-off every time the drivers leave the cab (driver's door open). This way, the driver will have to start the bus and re-position his or her foot on the brake pedal in order to switch gear from 'neutral' to 'drive'.
- **Improvement of seat adjustments controls:** as stated above a correct driving position could reduce the number of pedal errors. This countermeasure consists of improving and standardising driving seat controls in order to allow a quicker and more accurate seat adjustment, especially for small drivers.
- **Provide training on pedal error:** drivers are not necessarily aware of pedal error incidents and not necessarily taught about how to recognise and react to one. Provide training on pedal error could reduce occurrence and/or minimise consequences.

4 Task Analysis

4.1 Pedal configurations

A visit at a Bus Operator's Depot enabled the review of existing pedal configurations of two buses from different manufacturers currently operating in London. This review showed that the braking and accelerator pedals were very similar in size, shape and location from one bus model to another (see Figure 3).

Manufacturer A

Manufacturer B

Figure 3: Two pedal configurations from Manufacturer A (top) – Three pedal configurations from Manufacturer B (bottom)

Most of the pedals are treadle type pedals (in difference with most automobile pedals which are pendulum types[6]). This level of similarity (pedal size and type) between brake and accelerator pedals may reduce drivers' ability to differentiate them using haptic feedback, although the most significant cues are the pedal feel (force) and position (direction and curvature of the movement to press on a pedal) according to Lococo et al. (2012). In terms of pedal positioning there was an example with the

[6] Pendulum (or hanging) pedals are similar to accelerator pedal mechanisms fitted in cars (disconnected from the floor). Treadle pedals are the pedals in the pictures here, and are commonly fitted on buses.

accelerator pedal located a bit further back (brake and accelerator pedals not positioned on the same vertical axis).

Only one difference in pedal shape could be noted on one bus model (Manufacturer B), on which the accelerator pedal presents a heel stop (highlighted in red on Figure 2). This pedal type supposes that the driver presses the accelerator pedal with the heel positioned on the heel stop, in comparison with the treadle type on which the driver's heel is placed on the floor of the cab.

Figure 4: Accelerator pedal fitted with a heel stop

It was noted on CCTV footage for two pedal application error events that the heel stop did not seem to be correctly used by the drivers. Instead, their right heel wasn't observed to be in contact with the heel stop but with the floor.

Data on the amount of effort applied to pedals could not be gathered during site visits; however the bus cabs delivered in London by the two manufacturers are described as being compliant with the ISO cab standard 16121 Part-1 that describes the recommended/tolerable range of effort to be applied on pedals. It has to be noted that this standard is currently under review by the relevant ISO committee.

4.2 Body movements

In order to study and evaluate the potential causes of pedal application error in a bus, a review of the body movements involved by the operation of the pedals was conducted. The review was conducted on two buses designed by two different manufacturers.

4.2.1 Foot and leg movement

In regards of the lower-body movements, similar observations were gathered on both bus models. In order to operate the accelerator pedal while the right foot is being placed on the brake pedal, the driver has to move the entire leg with a rotation (a foot/ankle rotation is not sufficient to press the accelerator pedal when the foot is initially placed on the brake pedal). This means that if we consider a driver correctly seated (facing the road, seat correctly adjusted to the heel points) a large amplitude movement of the upper body will be required to move from one pedal to another (see Figure 5 and Figure 6), thus helping with the distinction of the two pedals (positioning cues introduced in section 4).

Figure 5: Bus from Manufacturer A – pedal configuration and leg movement

Figure 6: Bus from Manufacturer B – pedal configuration and leg movement

4.2.2 Upper thigh, waist and shoulders

Schmidt et al. (2010) provides interesting insight on the potential causes of pedal misapplications in the automobile sector, emphasising the importance of simple limb, upper limb and body movements as a participating factor of pedal error. The influence of upper limb or body movements (deviation from a normal straight driving position) can create erroneous lower-limb conditions which can lead to foot misplacement. Some support for this hypothesis is provided in Schmidt et al. (2010) through calculations indicating that pedal errors occur more frequently in driving situations that involve left/right turning.

In buses, it has been noted that the effect of body movements and misalignments have already been targeted by safety/training departments of some operators' bus companies. In a training video released by Arriva NW and Wales – Road Safety (2018) for example, the impacts of upper-body movements on drivers' legs are highlighted when the drivers check their blind spots. On Arriva's video, one driver is being filmed while checking his right hand side blind spot area:

- The first time (see Figure 7), the driver is seen leaning and twisting the upper body part while lifting his left thigh to facilitate the blind spot check, leading to an entire rotation of the right leg on to the accelerator pedal (the misalignment of the body required for the blind spot check involves an unintended rotation of the left thigh which generates an "automatic" rotation of the right leg)

Figure 7: Arriva training video on pedal application error – impact of upper body movements on lower body parts when checking the blind spots

- The second time (see Figure 8), the driver is seen leaning and twisting the upper body part without lifting his left thigh, keeping his foot on the brake

Figure 8: Arriva training video on pedal application error – impact of upper body movements on lower body parts when checking the blind spots

This video aims to make drivers aware about pedal errors in general, and pedal errors resulting of a body misalignment due to blind spot checks. It also reinforces driver training on correct driving position.

In order to check the frequency and level of body movements required for the blind spot checks, a site visit was conducted in a Bus Depot. Three bus models from three different manufacturers were reviewed with a driver, demonstrating the driving positions to check the right hand side blind spot (see Figure 9).

Figure 9: Review of upper/lower body movements while checking the right blind spot area - from left to right Manufacturer A, B (C not shown)

Our observations on drivers movements required to check blind spots are quite clear:

- The upper-body movements involve both leaning forward and twisting from the seat backrest on all bus models
- The angles observed between the seat backrest and the driver's back are quite significant, making it obvious that the driver cannot check blind spots without performing such movements of considerable amplitude (blind spot checks cannot be performed by rotating the head and shoulders only)
- These movements generate a lot of body displacements in the lower body parts, thus potentially causing body misalignment and pedal error

TfL data analysis on pedal error locations/bus manoeuvres also reinforces this hypothesis. Among the 43 pedal application error incidents that occurred between 2002 and 2017:

- 9% occurred while turning left
- 7% occurred while turning right
- 3% occurred while approaching bus stand
- 7% occurred while approaching bus stop
- 5% occurred while leaving bus stand
- 9% occurred while leaving bus stop

The above locations represent a total of 40% of pedal error incidents on which body misalignments could have been involved due to the blind spot checks and body movements required to perform such driving manoeuvres.

4.3 Review of start-up/bus stop procedures

According to the TfL analysis on the locations of the unintended acceleration incidents, it appeared that some of the incidents happened while starting the bus or while departing from a bus stop (5% while leaving a bus stand, 9% while leaving a bus stop). A detailed task analysis was performed with Manufacturer B to review the bus starting procedures as well as the bus stop procedures.

4.3.1 Task Analysis: bus start-up procedures

The start-up procedures of different bus models are reported below in Table 2.

Table 2: Task analysis of bus start-up driving procedures

Step	Bus variant 1	Bus variant 2	Bus variant 3	Bus variant 4
Start engine				
1	Turning on battery master (power)	Turning on battery master (power)	Turning on battery master (power)	Turning on battery master (power)
2	Switch on ignition	Switch on ignition	Switch on ignition	Switch on ignition
3	Press start switch	Driver login (using key fob)	Press start switch + start lock switch	Driver login (using key fob)
4	-	Press start switch	-	Press start switch
Engine started – air pressure build up 3-5min wait – Start Driving				
5	Close doors (press button)	Close doors (press button)	Close doors (press button)	Close doors (press button)
6[7]	Select gear (D,N,R[8] – by default N) – while pressing the foot brake pedal	Select gear (D,N,R – by default N) – while pressing the foot brake pedal	Select gear (D,N,R – by default N) – while pressing the foot brake pedal	Select gear[9] (D,N,R – by default N) – while pressing the foot brake pedal
7	Release handbrake – **the bus cannot roll (interlock)**	Release handbrake **– the bus cannot roll (interlock)**	Release handbrake **– the bus cannot roll (interlock)**	Release handbrake **– the bus can roll**
8	Press the accelerator pedal to move the bus. **The bus will start only if the doors are closed**	Press the accelerator pedal to move the bus. **The bus will start only if the doors are closed**	Press the accelerator pedal to move the bus. **The bus will start only if the doors are closed**	Press the accelerator pedal to move the bus

[7] Steps 6 and step 7 can be performed in any order

[8] The 3 bus gears are D = drive N = neutral R = reverse

[9] The bus engine cannot be started if the bus is not in “N” gear

4.3.2 Task Analysis: bus stop procedures

The driving procedures at a bus stop are reported below in Table 3, this time analysing different driving styles (theory/real driving tasks) as well as different bus models.

Table 3: Task analysis of bus stop driving procedures

Step	Standard bus operation with doors interlock[10]	Real driving (what drivers usually do) operation with doors interlock	Standard bus operation with rear doors interlock only	Standard bus operation with rear doors interlock only (front doors need to remain open while running slowly for visibility reasons)
Approaching bus stop				
1	Brake until bus stops	Brake until bus stops	Brake until bus stops	Brake until bus stops
2	Apply the hand brake	Hand brake not applied	Hand brake applied	Hand brake not applied
3	Select N gear	Gear still in D	Gear still in D	Gear still in D (or gear in N)
4	Open doors **– interlock activated**	Open doors **– interlock activated**	**No interlock activation** (note: the rear door won't open if the parking brake is not applied)	**No interlock activation** – the door has sometimes to remain open – foot remains on the brake pedal
Departing from bus stop				
5	Close doors (press button)	Close doors (press button)	Close rear doors	Front doors remain open to check visibility
6	Select gear (D,N,R – by default N)	Gear still in D	Gear still in D	Gear still in D (or gear in N)
7	Release handbrake **- the bus cannot roll (interlock)**	(No handbrake release) **- the bus cannot roll (interlock)**	Handbrake release **– the bus can roll**	(No handbrake release) **– the bus can roll**
8	Press the accelerator pedal. **The bus will start (interlock off) only if the doors are closed**	Press the accelerator pedal. **The bus will start (interlock off) only if the doors are closed**	Press the accelerator pedal	Press the accelerator pedal

[10] The interlock is a safety system that engages the halt brake when the bus doors are opened.

4.3.3 Observations

It can be noted from the task analysis completed above that:

- Foot proprioception (sense of the relative position, strength and forces of the different body parts) during start up procedures is reinforced as a gear switch from “neutral” to “drive” requires the driver to press both the brake pedal and the gear switch at the same time (but see below).
- Some interlocks[11] (e.g. automatic brake bus options when parking brake is released) reduce the likelihood of bus runaway while departing from a bus stand or a bus stop once the parking brake has been released. When fitted on a bus, such technology can prevent the bus rolling when the driver starts the bus without keeping the right foot on the brake pedal.
- The driver has to press the accelerator pedal first in order to move the bus from a stand state (see steps 8 of Table 2 and Table 3).
- Some drivers tend to leave the bus in “drive” gear before starting the bus or pulling out from a bus stop: this could result in a decrease in foot proprioception (reference position of the brake pedal thus becomes ‘lost’, or not ‘initialised’) as the switch from ‘neutral’ to ‘drive’ is being missed.

In conclusion, the task analysis suggests that drivers may not always experience foot initialisation/proprioception on to the brake position when starting the bus/pulling out from a bus stop. This could be a contributory factor for pedal error.

[11] Safety options or logics fitted on buses

5 Error analysis

5.1 Review of CCTV footage

Six different CCTV pedal incident footage clips were provided by Operator A and reviewed by two TRL researchers. The limited number of videos available may not be representative of all the pedal error incidents but in the context of the project, such analysis provides additional useful input for the understanding of this error. It was unknown whether these buses were quiet running at the time of the incident.

5.1.1 Pedal error CCTV 1

5.1.1.1 Summary of the incident

Table 4: Pedal error CCTV 1 summary

Vehicle type	Manufacturer B
Driver description	Unknown length of time holding licence. Driver was sat correctly and had both hands on the steering wheel at the time of the collision. The driver does not appear to be distracted by any external or internal interference. The driver was looking in his mirrors a lot while he was navigating the tight right hand turn. As soon as he navigated the turn, his attention was back on the road in front of him which is when the pedal application error occurred. After the crash, the driver looks into the foot well, at the same time the CCTV shows that the accelerator pedal is released and the brake pedal is applied. The driver was stationary reading a newspaper for some time before beginning his journey. The bus appears to not be in service at the time of the collision. There is only 1 minute and 2 seconds between starting the journey and the beginning of the pedal application error.
Environment description	The street is very narrow and the bus has difficulty in entering the street due to the swing needed on the bus. To get into the street, the rear wheels of the bus mounted the offside kerb. The street is single lane with stationary traffic. There is a 10m wide footpath to the offside with some shops on the far side of the pavement.
Contributory factors	Narrow street, coasting with no pedals Driver panic
Injuries	There are no passengers on the bus during the time of the collision. Very lucky to avoid pedestrians with both the bus and the falling debris. The driver looks shaken but appears to be uninjured.

5.1.1.2 Detailed description of pedal application

Table 5: Pedal error CCTV 1 detailed description

Time	Acceleration (g)	Accelerator pedal activation Y/N	Brake pedal Y/N	Environment description	Comments
15:15:01.49	0.02	N	N	Very narrow road, Traffic ahead	Driver rounds tight corner. Rear wheels mount kerb in attempt to get around. No acceleration at this stage.
15:53:02.09	0.08	Y	N		Accelerates to wait behind the line of traffic in front.
	Pedal application error starting (estimation)				
15:53:02.99[12]	0.14	Y	N		Driver accelerates hard at the point where it would be expected for the bus to wait behind the Vehicle 2 in front.
15:53:04.09	0.19	Y	N	Kerb and pavement on offside	Driver swerves onto pavement in attempt to avoid Vehicle 2. Speed is 3mph.
	Collision with the rear of a cab				
15:53:04.49	-0.36	Y	N		Front nearside of bus collides with rear offside of Vehicle 2
15:53:05.19	0.15	Y	N		Accelerates on to pavement.
	Collision with a ticket machine				
15:53:05.59	-0.23	Y	N		Collides with and drives through a ticket machine. Now almost fully on the pavement
15:53:06.29	0.36	Y	N		Accelerates across pavement and peaks at a speed of 5 mph. Fortunate to avoid pedestrians.
	Collision with a shop front				

[12] This time is the estimated time of the pedal confusion start

Time	Acceleration (g)	Accelerator pedal activation Y/N	Brake pedal Y/N	Environment description	Comments
15:53:08.09	-0.82	Y	N		Bus becomes wedged under an overhanging building with the front offside colliding with a shop front.
15:53:13.70	0.00	N	Y		Bus is fully stopped for 4.6 seconds, looks into the foot area and applies brakes.
	Bus final stop				

5.1.1.3 Observations

- The driver was not applying any pedals while negotiating the right turn, thus did not have any “default” foot proprioception
- The driver has then pressed the wrong pedal while the turn finished
- The driver appeared to believe that the pedal being pressed was the brake pedal
- The bus operated at low speed (less than 5mph) and did not provide any feedback (haptic, sounds, light etc.) to the driver that the accelerator pedal was being pressed
- Once stopped the driver looks at his right foot and corrects the foot misplacement

5.1.2 Pedal error CCTV 2

5.1.2.1 Summary of the incident

Table 6: Pedal error CCTV 2 summary

Vehicle type	Manufacturer B
Driver description	Driver has 15 years of PCV licence experience. At the time of the collision, the driver is not sat normally in his seat. He is slouching to the right hand side, with his right arm on the window sill and his right hand supporting his head. From the camera angle, it is not possible to ascertain whether or not the driver is awake. There are no passengers on the bus to interact with, and there appear to be no other distractions. It is not possible to know when the previous stop was, however due to the lack of passengers on the bus, it is likely that bus is not in service.
Environment description	The driver appears to stamp, multiple times, on the pedals. Does not attempt to press any buttons during the pedal application error and collision.
Contributory factors	Bus is in heavy traffic. The bus moves no more than 100m in the 5 minutes preceding the event. There are 2 lanes of traffic on each carriageway with a pavement in the middle separating the two. The bus is in lane 2 of 2 waiting to cross the opposite carriageway. Vehicle 2 is in front for the duration of the CCTV footage. The driver looks very relaxed with his arms resting on the sills. He doesn't look to be giving the vehicle his full attention. Slow moving, bumper to bumper traffic.
Injuries	Not recorded

5.1.2.2 Detailed description of pedal application

Table 7: Pedal error CCTV 2 detailed description

Time	Acceleration (g)	Accelerator pedal activation Y/N	Brake pedal Y/N	Environment description	Comments
13:35:02	0	N	N	Heavy Traffic	Driver 'slouching' while waiting for traffic to move
13:35:05.11	0.05	Y	N	Heavy Traffic	Vehicle 2 moves forward, Bus 1 begins to follow
	Pedal application error starting (estimation)				
13:35:06.85	0.17	Y	N	Heavy Traffic	Driver accelerates hard at the point where he usually stops behind Vehicle 2 (based on previous footage).
	Collision with Bus 2				
13:35:08.09	-0.65	Y	N	Heavy Traffic	Bus 1 collides with Vehicle 2, pushing Vehicle 2 forwards slightly.
13:35:08.59	0.24	Y	N	Heavy Traffic	Bus 1 accelerates again, up to 2 mph.
13:35:09.09	-0.96	Y	N	Heavy Traffic	Bus 1 has second, more forceful collision with Vehicle 2.
13:35:09.84	0.07	N	Y	Heavy Traffic	Driver applies brakes; bus is already nearly stationary.
	Bus final stop				

5.1.2.3 Observations

- The driver seems to be distracted from his main driving task (observed fatigue)
- The driver did not seem to be correctly seated – he was 'slouching' to his right hand side
- The driver appeared to believe that the pedal being pressed was the brake pedal
- The bus operated at low speed (less than 5mph) and did not provide any feedback (haptic, sounds, light etc.) to the driver that the accelerator pedal was being pressed
- The driver finally rectifies his foot position

5.1.3 Pedal error CCTV 3

5.1.3.1 Summary of the incident

Table 8: Pedal error CCTV 3 summary

Vehicle type	Manufacturer B
Driver description	Driver has 36 years of PCV experience. Driver had started shift three minutes prior to collision. This is known due to the CCTV showing him getting into the cab and driving from depot. The accident occurred on the first public road that the driver drove on. Driver was sat normally in his seat. There were no passengers on the bus at this stage and no obvious distractions. The driver was concentrating on the road ahead, ensuring he didn't pull out on anyone. He seemed to have full attention on the road.
Environment description	Unable to see pedal actions due to camera angle. No obvious stamping. Doesn't look to press any buttons prior or during the collision.
Contributory factors	T junction. Driver waiting to merge into traffic to the right. Queue of traffic at traffic lights opposite the T junction. 2 lanes at the T junction, with the majority of vehicles in lane 1, including Vehicle 2 and Vehicle 3.
Injuries	None apparent

5.1.3.2 Detailed description of pedal application

Table 9: Pedal error CCTV 3 detailed description

Time	Acceleration (g)	Accelerator pedal activation Y/N	Brake pedal Y/N	Environment description	Comments
08:14:50.06	0.0	N/A[13]	N/A	T junction. Turning right to join traffic at traffic lights.	Driver waiting at T junction to turn right. The traffic the bus is trying to turn into is waiting at some traffic lights. Vehicle 2 and Vehicle 3 are directly opposite the bus.
08:14:51.56	0.11	N/A	N/A		Driver pulls out of junction to force his way into traffic. At this point the other Vehicles haven't moved.
	Pedal application error starting (estimation)				
18:14:53:36	0.34	N/A	N/A		As driver approaches the traffic lane, he accelerates sharply as he realises he is going to crash. Speed is 5mph.
	Collision with SUV and hatchback				
08:14:54:25	-0.72	N/A	N/A		Driver crashes into the front of Vehicle 3 and the rear of Vehicle 2 simultaneously. Causing Vehicle 2 to rotate clockwise.
18:14:55.05	-0.43	N/A	N/A		Bus then continues forwards, crashes into metal railings and comes to a stop.
	Bus final stop				

[13] It has not been possible to analyse foot and pedal activity due to camera orientation.

5.1.3.3 Observations

- It has not been possible to analyse foot and pedal activity due to the camera orientation
- The pedal error occurred in a right turn, suggesting that an body misalignment could be a contributory factor to the pedal error incident
- The driver appeared to believe that the pedal being pressed was the brake pedal
- The bus operated at low speed (less than 5mph) and did not provide any feedback (haptic, sounds, light etc.) to the driver that the accelerator pedal was being pressed

5.1.4 Pedal error CCTV 4

5.1.4.1 Summary of the incident

Table 10: Pedal error CCTV 4 summary

Vehicle type	Manufacturer A
Driver description	Driver with 15 years of experience approached a car park following a bus travelling at about 14-15mph. The speed of the bus gradually reduces to about 8-10mph. The driver turns through a 90° right hand turn, and then through another 90° right hand turn. At this point the bus in front is a considerable distance away. The driver takes a wide line through the turn with the intention of pulling up behind a row of stationary buses. The bus is travelling at about 3-4mph at this point. The bus then continues travelling forward into the rear of Vehicle 2, forcing Vehicle 2 forward. There is no obvious increase in speed before the impact. The driver panics and responds by applying the handbrake immediately following the collision and comes to rest very quickly. The impact smashes the windscreen of the bus. There is no acceleration data or accelerator pedal information available, therefore it is not possible to determine at what point the accelerator pedal was pressed. The brake light indicator appears on screen 7.3 seconds after the bus comes to a stop.
Environment description	The road is a wide one way street and the bus takes a wide line in order to pull up behind Vehicle 2. The bus had not stopped at a bus stop in the previous two minutes.
Contributory factors	Driver appears to be concentrating, checking mirrors and making the 90° turns. No obvious distraction, not talking to passengers. Very quick reaction of the driver, he appears to press the pedal (presumably the accelerator) heavily and also to apply handbrake.
Injuries	Approximately eight passengers on board. Pedestrian in wheelchair, within the designated wheelchair area, is facing sideway in the bus. As a result of the impact, the pedestrian is thrown forwards and collides with the vertical grab rail. Standing passenger next to the wheelchair is thrown forward into the partition at the bottom of the stairs. Passenger sat on upper deck behind stairs is thrown forward into the partition above the stairs.

5.1.4.2 Detailed description of pedal application

Table 11: pedal error CCTV 4 detailed description

Time	Acceleration (g)	Accelerator pedal Y/N	Brake pedal Y/N	Environment description	Comments
09:40:12.213	N/A	N/A	No	Negotiating right bend.	Large amount of steering wheel input.
	Pedal application error starting estimation				
09:40:17.813	N/A	N/A	No	Start of pedal application error.	Approaching rear of stationary Vehicle 2.
	Impact with stationary vehicle (collision with stationary bus)				
09:40:19.613	N/A	N/A	No	Impact with stationary Vehicle 2.	Smashed front windscreen.
	Bus comes to a stop				
09:40:21.413	N/A	N/A	No	Bus comes to a stop.	
09:40:28.713	N/A	N/A	Yes	Brake light indicator appears on screen.	

5.1.5 Pedal error CCTV 5

5.1.5.1 Summary of the incident

Table 12: pedal error CCTV 5 summary

Vehicle type	**Manufacturer B**
Driver description	Driver (with 14 years of experience) is in lane one of the carriageway and has been in slow moving traffic for several minutes. The bus is following Vehicle 2. The bus has been stationary for 2 minutes and 10 seconds. Vehicle 2 in front begins to move forward. The driver releases the handbrake and slowly moves forward. As Vehicle 2 in front slows to a stop the bus suddenly accelerates and collides with the rear of Vehicle 2. The data indicates that the bus reaches a speed of 2mph prior to the impact. The bus comes to a stop very quickly after impact. The pedal information is not available, therefore it is not possible to determine at what point the driver presses the brake pedal. Peak acceleration before impact = 0.14g Peak deceleration on impact = -0.4g
Environment description	The road is a two lane one way street and the bus is travelling in lane one following Vehicle 2. The bus had been in stationary/slow moving traffic for several minutes prior to the collision.
Contributory factors	Driver does not appear to be concentrating fully; he is slouched in his seat and looking out of the window. His legs are bouncing up and down. As driver pulls away, no hands are on steering wheel and he is leaning towards the window. He does not appear to be concentrating fully. As the pedal application error occurs, the driver leans forward and puts his left hand on the steering wheel and his right hand on the handbrake, before the collision the driver will grab the steering wheel with both hands. Not talking to passengers.
Injuries	Approximately seven passengers on board, all on upper deck. No significant passenger movement, no injuries.

5.1.5.2 Detailed description of pedal application

Table 13: pedal error CCTV 5 detailed description

Time	Acceleration (g)	Accelerator pedal Y/N	Brake pedal Y/N	Environment description	Comments
11:50:48.82	0	No	N/A	Driver puts the handbrake on and releases footbrake.	Stationary in traffic.
11:52:41.82	0	Yes	N/A	Driver releases handbrake and starts to move forward.	
	Pedal application error starting (estimation)				
11:52:46.04	0.09g	Yes	N/A	Start of pedal application error.	Bus speed 2mph.
11:52:47.32	0.14g	Yes	N/A	Peak acceleration prior to impact.	Driver has reacted by grabbing steering wheel with two hands before the collision.
	Collision with stationary van				
11:52:48.26	-0.40g	Yes	N/A	Impact with stationary Vehicle 2.	Light contact with bumper.
	Bus comes to a stop				

5.1.5.3 Observations

- It has not been possible to analyse the foot and pedal activity on the brake pedal due to the camera orientation
- The pedal error occurred in a straight line with heavy traffic, the driving position has reported to be incorrect (leg movements)
- The driver has then pressed the wrong pedal when moving forward
- The driver appears to believe that the pedal being pressed was the brake pedal
- The bus operated at low speed (less than 5mph) and did not provide any feedback (haptic, sounds, light etc.) to the driver that the accelerator pedal was being pressed

5.1.6 Pedal error CCTV 6

5.1.6.1 Summary of the incident

Table 14: Pedal error CCTV 6 summary

Vehicle type	Manufacturer B
Driver description	Driver has 13 years of PCV experience. Driver had started shift three minutes prior to collision. This is known due to the CCTV showing him getting into the cab and driving from depot. The accident occurred on the first public road that the driver drove on. Driver was sat normally in his seat. There were no passengers on the bus at this stage and no obvious distractions. The driver was concentrating on the road ahead, ensuring he didn't pull out on anyone. He seemed to have full attention on the road. While waiting to turn, the driver is seen to be adjusting the offside mirror.
Environment description	During the collision, it can be seen that the driver presses the accelerator very hard, thinking it was the brake. (Hard enough that the driver is standing up to press the pedal as hard as possible.) No buttons are pressed during the collision.
Contributory factors	T junction. Driver waiting to merge into traffic to the right. Queue of traffic at traffic lights opposite the T junction. 2 lanes at the T junction, with the majority of vehicles in lane 1. Vehicle 2 is in lane 1 and Vehicle 3 is slightly ahead of Vehicle 2 in lane 2.
Injuries	None apparent

Note that it is unknown whether this was the same junction as pedal error 3.

5.1.6.2 Detailed description of pedal application

Table 15: Pedal error CCTV 6 detailed description

Time	Acceleration (g)	Accelerator pedal Y/N	Brake pedal Y/N	Environment description	Comments
12:56:25.40	0.0	N/A	N/A	T junction. Turning right to join traffic at traffic lights.	Driver waiting at T junction to turn right. The traffic the bus is trying to turn into is waiting at some traffic lights. There is Vehicle 2 and Vehicle 3 directly opposite the bus.
12:56:37.50	0.14	N/A	N/A		Driver pulls out of junction to force his way into traffic. At this point the other vehicles haven't moved.
	Pedal application error starting (estimation)				
12:56:38.90	-0.35	N/A	N/A		As driver approaches the traffic lane, he accelerates sharply as he realises he is going to crash. Speed is 5mph.
	Collision with stationary Nissan				
12:56:39.29	0.80	N/A	N/A		Bus crashes into the side of Vehicle 3 at a peak speed of 5 mph.
12:56:40:79	0.46	N/A	N/A		Bus pushes Vehicle 3 into Vehicle 2 (still accelerating) and Vehicle 2 mounts the kerbs sideways.
12:56:41.49	0.0	N/A	N/A		Bus comes to a stop against the other Vehicles.
	Bus comes to a stop				

5.1.6.3 Observations

- It has not been possible to analyse the foot and pedal activity on the brake pedal due to the camera orientation
- Driver distraction has been reported before the pedal error occurred (mirror adjustment before the turn). The adjustment of the right hand mirror potentially had an impact on driver's position as this adjustment requires both leaning forward and twisting (consequences on lower-body movements and foot proprioception)
- The pedal error occurred after a right turn joining heavy traffic
- The driver appeared to believe that the pedal being pressed was the brake pedal
- The bus operated at low speed (less than 5mph) and did not provide any feedback (haptic, sounds, light etc.) to the driver that the accelerator pedal was being pressed
- Once stopped the driver looks at his right foot and corrects the foot misplacement

5.2 Summary of observations

The analysis of CCTV footage aimed to highlight different types of factors that could lead to a pedal error. It has been observed that most of the incidents happened in a left/right turn at low speed (less than 5mph).

Independently of the accident locations, it appeared among the videos analysed that the most frequent factors of pedal error incidents were linked with:

- Body misalignments and/or incorrect driving position
- Lack of foot proprioception
- Driver distraction
- Lack of feedback (vehicle intervention, vehicle visual/audible/haptic indicator)

6 Countermeasures

6.1 Introduction of the countermeasures

The literature review, the driving task and error analysis enabled the identification of potential ways to mitigate the appearance of pedal application error incidents. Three categories of countermeasures were identified:

1) **Prevention:** prevention countermeasures aim to prevent and reduce any foot misplacement error
2) **Recovery:** recovery countermeasures aim to provide a direct feedback about foot misplacement to help the driver to recover from pedal errors
3) **Intervention:** intervention countermeasure includes automated technology capable of detecting unintended acceleration errors and intervene (e.g. automatic emergency braking interpreting the acceleration signal as a brake signal when a pedal error is detected)

Sections 6.2, 6.3 and 6.4 describe these in more detail.

6.2 Prevent foot misplacement

By preventing foot misplacement, unintended acceleration incidents will be less likely to happen. Foot misplacement could be avoided using the following mitigations:

1) **Brake toggling**
2) **Standard pedal layouts**
3) **Improved direct/indirect vision**

These mitigations are described in the following subsections.

6.2.1 Brake toggling

6.2.1.1 Description

The solution principle suggested here consists of slightly changing the driving tasks to increase foot proprioception, in order to make sure the right foot is reinitialised onto the brake pedal before leaving the bus stop/bus stand. As explained in previous sections, proprioception seems to be challenged when the driver is not correctly seated (see Lloyds Register’s 2011 report) and/or when checking blind spots and these are conditions which are likely to occur at bus stands/stops. This solution would enable the driver to re-initialise his or her right foot/driving position and update recent memories of the brake position. This solution would also avoid errors linked with a misuse of the system (especially when the driver is not following expected protocol and does not switch gear back to neutral when stopped at a bus stop/stand).

The suggestion of this solution is based on a similar principle and system that has already been implemented (interlocks are fitted on the brake pedals of most buses fitted with automatic gears). When starting a bus, the bus is by default in ‘neutral’ gear and in order to switch to a ‘drive’ gear, the brake has to be pressed at the same time that a gear is selected (thus avoiding pedal misapplication in a parked state). This technology, according to the available evidence, has reduced pedal errors by 60% in the automobile sector (Schmidt, 1989). If a pedal misapplication is made at the start of a driving cycle (i.e., pressing the accelerator rather than the brake that was intended), the vehicle will not move, as it is safely locked in park.

This solution could be useful in the bus context, as the task analysis performed on bus stop driving procedures highlighted that a bus driver could start pulling out from a bus station/stand without putting the right foot on the brake pedal.

6.2.1.2 Benefits and limitations

The solution described above has benefits and limitations, which are listed in Table 16 below.

Table 16: Brake toggling benefits and limitations

Benefits	Limitations
• Improves right foot proprioception • Reduces foot misplacements • Quick retrofit on buses • This solution could be tested this year as a proof of concept • Short driver training time	• Retrofit limitations depending on bus models • Limited effectiveness (effectiveness expected at bus stop, bus stand only)

6.2.2 Standard pedal layout

6.2.2.1 Description

The different site visits led to the conclusion that several brake and accelerator pedal configurations (in terms of size, measurements) exist and that despite the application of the international ISO standard 16121 part 1, a wide variety of layouts could be designed to be compliant with this.

Bus operating companies stated that approximately 80% of their drivers only drive one type of bus, with the remaining drivers potentially driving more than one type of bus on a regular basis. We have discussed above the challenges linked with a bad proprioception which could be reinforced in the context of operating different buses with different pedal layouts. One of the solutions could be to have one standard pedal layout based on existing bus model layouts. This standard pedal layout would include consistency in pedal types, pedal dimensions, pedal angles, and position relative to the driver's seat.

Based on an advanced analysis of the different pedal layouts, up to four reference pedal configurations could be analysed in detail and prototyped in order to be tested by a panel of drivers. The different pedal configurations would be evaluated for their ability to differentiate the brake and the accelerator pedal in the cab while simulating various driving tasks, to evaluate pedal differentiation. The reference pedal configuration that has obtained the maximum differentiation score would be the one advised as a standard for the London bus specification.

Two limiting factors could reduce the effectiveness of such mitigation:

- It has been noted from the CCTV analysis that a movement of high amplitude is already required in order to move the right foot from the brake pedal to the accelerator pedal (entire rotation of the leg); this means that a high level of differentiation already exists to distinguish the two pedals and that a differentiation error is likely to happen in a context of a body misalignment (i.e. if the driver is not correctly seated and the first pedal accessed without a leg rotation is the accelerator pedal), which could also happen with any optimised pedal configuration
- The CCTV analysis also showed that in some of the cases, the driver is observed to move successfully the right foot from the brake to the accelerator pedal in a straight road for several consecutive times until the pedal error happens (i.e. after several brake/accelerator pedals transitions, the driver remains on the accelerator pedal and does not move the leg as previously done before, and believes the brake is being pressed). These specific incidents have not been quantified as a limited amount of CCTV analysis could be performed on the project; however, its analysis reveals that even the best optimised pedal configuration will not address this pedal error scenario which seems to be the result of a cognitive error (e.g. conviction that the leg has moved on to the brake pedal coupled with the conviction that the foot is being placed on the brake pedal)

It is also important to emphasise that the ISO 16121-Part 1 standard that describes the various cab elements and pedal layouts is currently under review. If a standard pedal layout is selected by the drivers and updated in the London bus specification, it is possible that this pedal layout would not comply with the updated version of the ISO standard. However it might be possible to feed the results of this research into the ISO committee for their consideration, although the timescales are not well aligned in this respect.

6.2.2.2 Benefits and limitations

The solution described above has benefits and limitation, which are listed in Table 17 below.

Table 17: Pedal standardisation benefits and limitations

Benefits	Limitations
• Improves bus standardisation • Reduces foot misplacements and adaptation time to a new bus model • No driver training time • Could be fitted on new buses	• Heavy retrofit for existing buses that could include driver's seat retrofit • Limited effectiveness (e.g. does not address cognitive errors) • International standard currently under review (updated version expected in 2018) • Requires advanced mock-ups

6.2.3 Improved direct/indirect vision

6.2.3.1 Description

The CCTV analysis and the training videos provided by Arriva showed that body misalignment could be a contributory factor to pedal error caused by direct/indirect (blind spots) checks. This has been found especially relevant when emphasising that of the 43 pedal error incidents that happened over the last 10 years, 40% may be related to vision issues.

Direct and indirect vision mitigations are already included under a separate countermeasure called “direct/indirect vision” as part of the Bus Safety Standard project. The mitigations suggested in this countermeasure will contribute to the reduction of pedal error especially if the blind spots areas can directly be monitored by bus drivers without requiring any leaning/twisting movements (e.g. additional monitors, mirrors).

6.2.3.2 Benefits and limitations

The solution described above has benefits and limitations, which are listed in Table 18.

Table 18: Improved direct/indirect vision benefits and limitations

Benefits	Limitations
• Improves drivers visibility and driving comfort • Reduces foot and body misplacements • Reduces pedal error in left-right turn locations (e.g. includes bus stop)	• Additional equipment to be fitted to a bus (additional cost) • Less applicable in a “straight road” pedal error scenario

6.3 Help the driver recover

By helping the driver recover from a pedal error, the consequences of pedal error incidents could be reduced, possibly quickly enough to prevent adverse outcomes. Pedal error recovery could be achieved using the following mitigations:

1) **Accelerator noise conspicuity**
2) **Brake/Accelerator lights**

These mitigations are described in following subsections.

6.3.1 Accelerator noise conspicuity

6.3.1.1 Description

It has been observed in many CCTV videos that most of the drivers could not even detect the occurrence of a pedal error incident and that most of the collisions occurred at low speed (around or below 5 mph). A study by Volvo (2016) compared internal bus noise levels between a bus in diesel mode and a bus in electric mode:

- A difference of 13dB[14] has been observed at 0 km/h, meaning that a bus in electric mode is almost 2.5 times quieter when set in electric mode than in diesel mode
- A difference of 9 dB has been observed at 50km/h, meaning that a bus in electric mode is almost 2 times quieter when set in electric mode than in diesel mode even at 50km/h

Given these figures, it is possible that bus speed (acceleration audible feedback) may not be correctly perceived by the drivers, especially at low speed when the bus is in electric mode.

Additional research in accelerator noise conspicuity could be coupled with the noise conspicuity countermeasure already addressed in a different work package of the Bus Safety Standard project. Additional testing in this countermeasure could include drivers' evaluation of the bus acceleration noise and its conspicuity. A laboratory study evaluating the detection time of drivers to detect application on the accelerator pedal (as opposed to a brake pedal) could be undertaken.

This new piece of research could be separated in three parts:

- A first part evaluating the bus noise conspicuity mitigations included in the noise conspicuity countermeasure, this time focusing on drivers' perceptions. For example:
  - Conspicuous noise 'annoyance'
  - Speed noise level (e.g. are additional loudspeakers needed in the cab)
  - Speed differentiation (i.e. would a sound varying with speed be sufficient to indicate that the accelerator throttle is being pressed? Would a sound varying with bus speed AND when the accelerator being pressed (sound intensity, tone) be more effective (and easier to detect)?
- A second part evaluating drivers and their time to detect an accelerator pedal application by listening to recorded low speed profiles of different buses fitted/not fitted with the new bus accelerating sound
- A third part evaluating drivers operating a real service with this new sound fitted in an operated bus, in order to get feedback on drivers satisfaction and perception

6.3.1.2 Benefits and limitations

The solution described above has benefits and limitations, which are listed in Table 19 below.

[14] Decibels, abbreviated dB

Table 19: Accelerator noise conspicuity benefits and limitations

Benefits	Limitations
• Helps the driver recover from a pedal error at any location/time • Reduces pedal error consequences and occurrence • No additional driver training • Easy to implement in a bus (loudspeakers)	• Additional time to design the solution on a bus (depends on manufacturers' possibility to prototype) • Additional/specific testing required

6.3.2 *Accelerator/Brake lights*

6.3.2.1 Description

Similarly to the accelerator noise conspicuity countermeasure, it has been observed in many CCTV videos that most of the drivers could not even detect the occurrence of a pedal error and that no specific indicator currently exists on a bus dashboard to indicate that the brake/accelerator pedal is being pressed.

One of the mitigations could consist of fitting additional lights to a bus dashboard to indicate the status of the applied pedal. Driver satisfaction and effectiveness could then be evaluated.

It has to be noted that this mitigation could possibly achieve greater performance when coupled with the accelerator noise conspicuity mitigation previously described in part 6.3.1.

6.3.2.2 Benefits and limitations

The solution described above has benefits and limitations, which are listed in Table 20.

Table 20: Accelerator/brake lights benefits and limitations

Benefits	Limitations
• Helps the driver recover from a pedal error at any location/time • Reduces pedal error consequences and occurrence • Short additional driver training • Easy to implement in a bus (LEDs)	• Effectiveness when used alone (expected to be more effective when coupled with accelerator noise conspicuity) • Additional equipment to be fitted in a bus (could not necessarily be fitted in the main field of view on current buses)

6.4 Vehicle intervention

Pedal error could be avoided by using an alternative decision-making technology that would either:

- Cancel the acceleration of the bus
- Apply the brakes instead of an acceleration

Similar technology to Automated Emergency Braking could be used, in order to allow a vehicle intervention in the context of a pedal error incident.

6.4.1 Automated Emergency Braking – Unintended acceleration

6.4.1.1 Description

Automated Emergency Braking (AEB) is part of another work package/countermeasure of the Bus Safety Standard project. It currently consists of applying the brakes when an obstacle is being detected in the front of a bus or when the driver applies the brake but not sufficiently to avoid/reduce collision with the obstacle detected.

Currently no specific technologies exist to predict and/or prevent the occurrence of unintended acceleration. However, it has been observed that several technologies currently under development are targeting the prediction of such pedal errors (Tran et al., 2011). Indeed, based on sensor data (distance with front vehicle, obstacle), driver's pedal application (brake/accelerator activation) and, driver's expected foot location on the brake pedal (i.e. expected patterns between accelerator/brake pedals) it is possible that an unintended acceleration event could be detected by such systems in the future.

In order to accommodate such a solution, fitting AEB on London buses could be one of the first steps in the reduction of pedal error incidents. Fitting all London bus models with a pedal footage camera could be useful for future algorithms developed for the prediction of pedal error.

In the development of AEB on cars, the typical implementation deactivates AEB if a strong acceleration, braking, or steering input is received, which is based on the logic that the driver always knows best. If such a logic were implemented on buses, then a strong acceleration input such as an that occurring during unintended acceleration would deactivate the AEB, which is the exact opposite of what is needed. A different logic would need to be developed to either limit further acceleration, or to allow full AEB activation. This type of logic is now seen on a few car models from Asia, and the Safety Support Car program in Japan actually has a test to help encourage uptake of this modified logic of AEB[15]. So it would be possible to implement similar logic on buses fitted with AEB, but this is dependent on the development of AEB first.

It has to be noted that among the mitigations suggested, this system is estimated to be likely to be the most effective, as it builds safety into the system (rather than relying on driver intervention).

[15] https://www.safety-support-car.go.jp/technology/

6.4.1.2 Benefits and limitations

The solution described above has benefits and limitation, which are listed in Table 21 below.

Table 21: Automated Emergency Braking benefits and limitations

Benefits	Limitations
• Potential to mitigate most pedal error events depending on the level of performance of the algorithm developed • Corrects driver's cognitive errors by applying the brakes instead of the accelerator throttle	• Additional equipment to be fitted to a bus (additional cost) • Specific algorithm will need to be developed in a safe way to impede unexpected emergency braking

7 Estimated effectiveness of countermeasures

TfL undertook a study on driving manoeuvres performed during pedal application error collisions (see Figure 10). It has to be noted that even though the results collected by TfL are only based on a sample of 43 incidents (and are therefore not suitable for formal statistical analysis) these data have been used here to support a Delphi panel approach for the evaluation of pedal error countermeasures.

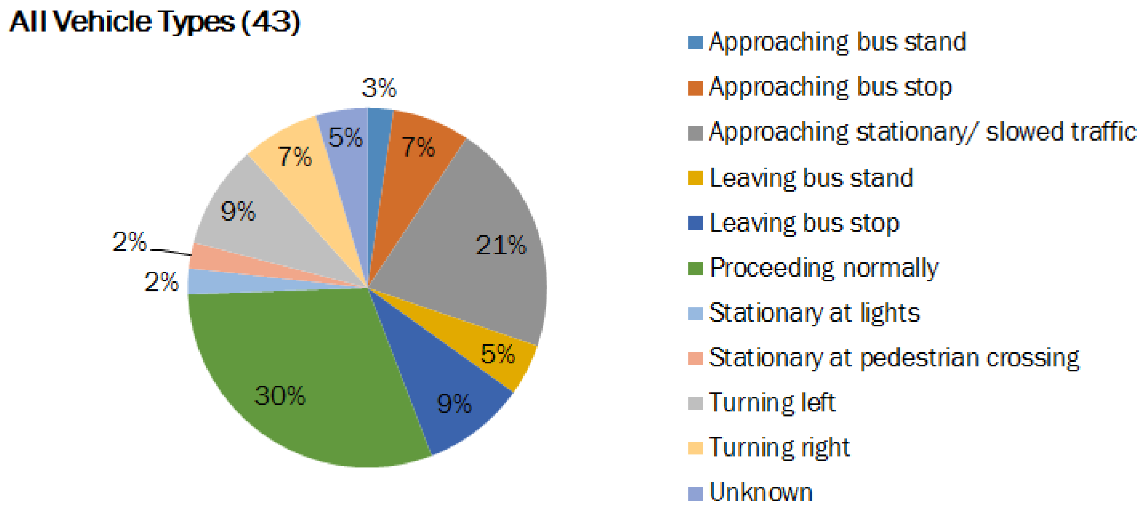

Figure 10: Bus driving manoeuvres performed in pedal application error incidents (Source: TfL)

Based on these percentages, the countermeasures were rated according to their estimated level of effectiveness by Human Factors experts in TRL using a Delphi method (a structured communication method that relies on a panel of experts – see Dalkey & Helmer, 1963).

Each unintended acceleration countermeasure was rated with various estimated effectiveness coefficient:

- **0** meaning that the estimated effectiveness of the countermeasure cannot be evaluated
- **0.5** meaning that the estimated effectiveness of the countermeasure is considered to be effective as a long-lasting effect to reduce pedal error
- **1** meaning that the estimated effectiveness of the countermeasure is considered to be effective to reduce pedal error
- **2** meaning that the estimated effectiveness of the countermeasure is considered to be very effective to reduce and prevent pedal error
- **3** meaning that the estimated effectiveness of the countermeasure is considered to be totally effective to reduce and prevent pedal error

7.1 Prevent foot misplacement countermeasures

The following mitigations to prevent foot misplacement were evaluated as in below.

The estimated relevant target population of the countermeasures was calculated as follow:

- First, Human Factors experts evaluated the effectiveness of each countermeasure by associating an effectiveness coefficient (described above), for every bus manoeuvres type
- Second, the total estimated effectiveness score of each countermeasure was obtained by multiplying the effectiveness coefficient with the percentage of pedal error events at each location

Table 22: Prevention mitigations estimated effectiveness

Prevent Foot Misplacement	%	Countermeasures		
		Brake Toggling	Pedals Layout Standardisation	Improved Direct/Indirect Vision
Unknown	5	0	0	0
Stationary at lights	2	0.5	1	1
Stationary at pedestrian crossing	2	0.5	1	1
Turing left	9	0.5	1	2
Turning right	7	0.5	1	2
Approaching bus stand	3	0.5	1	2
Approaching bus stop	7	0.5	1	2
Approaching stationary/slowed traffic	21	0.5	1	1
Leaving bus stand	5	2	1	2
Leaving bus stop	9	2	1	2
Proceeding normally	30	0.5	1	1
	Total	68.5	95	135

Table 22 shows the estimated effectiveness for each of the countermeasures at preventing foot misplacement errors for each type of recorded pedal application error collision.

7.2 Help the driver recover countermeasures

The following mitigations to prevent foot misplacement were evaluated as in Table 23 below, using the same method.

Table 23: Recovery mitigations estimated effectiveness

Help the driver recover	%	Countermeasures	
		Accelerator Noise Conspicuity	Accelerator/Brake Light
Unknown	5	0	0
Stationary at lights	2	2	1
Stationary at pedestrian crossing	2	2	1
Turing left	9	2	1
Turning right	7	2	1
Approaching bus stand	3	2	1
Approaching bus stop	7	2	1
Approaching stationary/slowed traffic	21	2	1
Leaving bus stand	5	2	1
Leaving bus stop	9	2	1
Proceeding normally	30	2	1
	Total	**190**	**95**

Table 23 shows the estimated effectiveness for each of the countermeasures at aiding recovery from foot misplacement errors for each type of recorded pedal application error collision.

7.3 Vehicle intervention countermeasures

The following mitigation enabling vehicle intervention in the context of a pedal error was evaluated as in Table 24 below.

Table 24: Vehicle intervention mitigation estimated effectiveness

Help the driver recover	%	Countermeasures
		AEB-UA Detection
Unknown	5	0
Stationary at lights	2	2
Stationary at pedestrian crossing	2	3
Turing left	9	2
Turning right	7	2
Approaching bus stand	3	2
Approaching bus stop	7	2
Approaching stationary/slowed traffic	21	3
Leaving bus stand	5	2
Leaving bus stop	9	2
Proceeding normally	30	3
	Total	**243**

Table 24 shows the estimated effectiveness of the countermeasure at intervening after foot misplacement errors for each type of recorded pedal application error collision.

7.4 Summary of countermeasures effectiveness

The overall scores of estimated effectiveness (and potential number of incidents that might be avoided) of the suggested mitigations are summarised in Table 25 below.

Table 25: Pedal error mitigations – summary of estimated effectiveness

Countermeasures	Totals	Estimated Performance Level	Number of incidents avoided
Brake Toggling	68.5	23%	10
Accelerator/Brake Light	95	32%	14
Pedals Layout Standardisation	95	32%	14
Improved Direct/Indirect Vision	135	45%	19
Accelerator Noise Conspicuity	190	63%	27
AEB-UA Detection	243	81%	35
Target Population (43 cases)	**300**	**100%**	**43**

Considering just the evaluation of the estimated effectiveness of the mitigations, the three most promising mitigations are:

- Automatic Emergency Braking for unintended acceleration
- Accelerator noise conspicuity
- Improved direct/indirect vision

8 Roadmap

The mitigations discussed previously have various likely deployment dates depending on the technology adopted.

Table 26: Pedal error mitigations – Roadmap

Countermeasures	Prototype delivery	In service on bus type & model	In service on all bus types & models
Brake toggling	Mid-2018	2019	2021 (depends of the bus technology)
Accelerator/Brake Light indicators	Mid-2018	2019	2019 (light retrofit)
Pedal layout standardisation	2019	2019 on buses currently fitted with the pedal layout	2021 (heavy retrofit)
Improved direct/indirect vision	Refer to the direct/indirect vision countermeasures roadmap		
Accelerator noise conspicuity	2019 (depending on the progress of the noise conspicuity countermeasure)	End 2019	2021 (light retrofit)
AEB – Unintended Acceleration	Fitting foot cameras on a bus model: 2018 Fitting sensors and gather bus data: refer to the AEB countermeasure roadmap Update AEB with pedal error algorithm: 2024	Fitting foot cameras on all bus models: 2018 Fitting sensors and gather bus data: refer to the AEB countermeasure roadmap Update AEB with pedal error algorithm: 2024	After 2024

9 Countermeasures testing procedures

This section of the report describes the detailed testing procedures associated to each countermeasure. It should be noted that these testing procedures have to be aligned in the roadmap and that the most detailed testing procedures have been provided for the countermeasures technically feasible in the timelines of the project (e.g. brake toggling and accelerator/brake light indicators) and taking into account the other countermeasures that are being investigated in the wider Bus Safety Standard Project.

9.1 Brake toggling

Solution description:

This solution would enable the driver to re-initialise his or her right foot/driving position and update recent memories of the brake position before leaving a bus stand/stop. This solution would also avoid errors linked with a misuse of the system (especially when the driver is not following expected protocol and does not switch gear back to neutral when stopped at a bus stop/stand). The addition of such a solution is not safety critical and could be fitted on an operated bus as long as (light) training is provided to the drivers.

In order to test this solution, TRL suggests that a first test should be conducted on track (off road) to review the impact of the solution on the driving tasks. The driving test will then be followed by a safety analysis conducted with a safety expert, to discuss the potential risks and benefits of adding such technology on buses.

Solution testing:

- Solution prototyped by the bus manufacturer
- Review of the solution by HF experts
- Manufacturer's update of the prototype (if any needed)
- Testing at a depot with 1-2 drivers to assess any specific training needs before putting the solution on one bus in service
- Train/provide training documentation to the drivers of this new solution
- Prepare ethics for the research to gather CCTV recordings
- Put solution on a prototype bus/on a test track for a 1 hour. Run 2 comparative driving tests between a baseline bus and a new fitted bus (minimum number of drivers operating the bus = 10). The 10 drivers will be completing different driving scenarios including stop/start and bus stop use cases.
- Feedback on effectiveness, usability, workload on questionnaire/interviews
- Report including questionnaire feedback and CCTV analysis
- One safety analysis conducted by a safety expert
- Final report

Needs:

- One bus fitted with this solution (manufacturer development time)
- One bus operated with this solution (test track/bus prototype)
- Minimum 10 drivers driving a prototype/baseline bus

9.2 Accelerator/Brake light indicators

Solution description:

Add two LEDs/lights (one light for the brake pedal activation, one light for the accelerator pedal activation) to a bus dashboard. The LEDs/lights should be dimmed between day/night conditions. The addition of such a solution is not safety critical and could be fitted on an operated bus as long as brief training is provided to the drivers.

The testing procedure is the same as the one described above, and if this concept is developed on time it could be tested in parallel with the brake toggling solution.

Solution testing:

- Same as above.

Needs:

- Same as above

9.3 Accelerator noise conspicuity

Solution description:

Add/Amplify the accelerator engine sounds when the bus is in electric mode and at low speed (below 20mph) using the noise conspicuity countermeasures of the Bus Safety Standard project (pedestrian bus sound solutions). The selected sounds to be tested will be fitted in the cab using a loudspeaker at a predetermined noise level.

Note: this is a separate test from the track test proposed for the audio conspicuity work stream; however the tests could be carried out one after the other to minimise costs.

Solution testing:

9.3.1 Part 1: first driving test and sound recordings

- Recommendation/Specification of up to 5 sounds based on noise conspicuity countermeasure – the prototype needs to have a sound varying with bus speed
- Solution prototyped by the sound system manufacturer
- Review by HF/Acoustics experts of the solution
- Update of the prototype by the manufacturer
- Up to 6 drivers will be asked to drive on a straight line and perform the following manoeuvres several times (see Table 27) in order to be able to provide pedal differentiation ratings (perception of an acceleration noise from the background noise when the accelerator is being pressed)

Table 27: Accelerator noise conspicuity – Part 1 suggested testing conditions on a test track (draft)

Speed	Manoeuvres	Evaluated parameters
0-5mph	From idle accelerate to upper speed Release accelerator Brake	Acceleration noise conspicuity (differentiation scale). Is the press on the accelerator pedal in alignment with the noise answer? (delayed noise/intensity of noise)
0-10mph	From idle accelerate to upper speed Release accelerator Brake	
0-15mph	From idle accelerate to upper speed Release accelerator Brake	
0-20mph	From idle accelerate to upper speed Release accelerator Brake	
1-5mph	Accelerate to upper speed Coast to upper speed Release accelerator Accelerate to upper speed	
5-10mph	Accelerate to upper speed Coast to upper speed Release accelerator Accelerate to upper speed	
10-15mph	Accelerate to upper speed Coast to upper speed Release accelerator Accelerate to upper speed	
10-20mph	Accelerate to upper speed Coast to upper speed Release accelerator Accelerate to upper speed	
20-25mph	Accelerate to upper speed Coast to upper speed Release accelerator Accelerate to upper speed	

- Using the results of the trial, assess any specific training needs before putting the solutions on a bus in service (test speeds up to 20 mph)
- Track speed (1 day) recordings to prepare laboratory evaluations to be tested on a panel of 30 drivers (user trials in depots) in order to check acceleration detection times. The following speed recordings will have to be performed on track for each bus type:
  - Diesel
  - Electric
  - Electric bus fitted with the most conspicuous sound
  - Electric bus fitted with the most conspicuous sound with accelerator press highlighted (difference in sound intensity each time the accelerator is being pressed)

Note: the bus will have to be fitted with an LED/CCTV system is order to be able to check in real time the accelerator pedal application and angle variation.

9.3.2 Part 2: acceleration detection time laboratory testing

- Driver laboratory testing. Up to 30 drivers will be asked to listen to the previous recordings and will be asked to press a button each time they detect a noise they associate to an acceleration/press on the accelerator.
- Results will be analysed and the sound profile that has achieved the best performance score will be fitted on a bus in service.

9.3.3 Part 3: real test on operated bus

- Bus manufacturer fits the most conspicuous sound on a real bus in service
- Training documentation is provided to the drivers of the new sounds introduced
- Prepare ethics for the research to gather CCTV/sound/bus modes recordings
- Put solution on a baseline and bus prototype for a test on roads or on a test track (minimum number of drivers operating the bus = 10)
- Feedback efficiency and usability on questionnaire/interviews
- Final report including questionnaire feedback and CCTV/sound/bus modes recordings

Needs:

- Test track – straight line and one acoustics expert to perform the measurements – one tested bus
- One bus fitted with this solution (manufacturer development)
- One bus operated with this solution
- Minimum 10 drivers operating with this system on a baseline/prototype bus
- Minimum 30 drivers tested for the accelerator sound conspicuity (laboratory testing)

9.4 Pedal position standardisation

Solution description:

Propose a standard pedal configuration (pedal location, size, angle) for all London buses.

Solution testing:

- Review of all bus pedal configurations in London (pictures, compared with fleet proportion)
- Pedal configuration classification into four pedal categories maximum (classification workshop)
- Detailed measurement of the designated four pedal categories including bus seat/cab configuration
- Perform a 2D and 3D anthropometric analysis
- Create four mock-ups to be evaluated by drivers at depots
- Prepare ethics for the research
- Feedback efficiency and usability on questionnaire/interviews
- Analysis and ratings of the four pedal configurations for the bus specification

Needs:

- Pictures of pedal configuration for each bus types (visits to depots)
- Measurement tools and 3D CAD modelling tools
- Four pedal configuration mock-ups
- Minimum 30 drivers evaluating the four pedal configurations

9.5 Improved vision

The testing procedures are described in the improved vision countermeasure.

9.6 AEB – Unintended Acceleration detection

AEB system activation for unintended acceleration scenarios is currently not available on the market but is under development. Specific testing procedures will be available when more research in this domain is released by AEB manufacturers.

The scenarios likely to be tested will involve the detection of an obstacle while pressing the accelerator pedal in following contexts:

- Stationary at lights
- Stationary at pedestrian crossings
- Turning left
- Turning right
- Approaching bus stand/stop
- Approaching stationary/slowed traffic
- Leaving bus stand
- Leaving bus stop

First steps could be made in advance in order to accommodate such technology:

- Fitting foot cameras in all London buses
- Fitting AEB/distance sensors in all London buses

10 Overview of study design and procedure

In this section we describe the design and procedure for testing the brake toggling and brake/accelerator light countermeasures as implemented on a test bus. These two countermeasures were tested as they could be completed in the project timescales and were not covered elsewhere in the wider Bus Safety Standard project.

10.1 Participants

In total, 10 drivers from London bus operating companies were recruited to take part in the trial, which took place at Millbrook Providing Ground testing centre between 30th April and 4th May 2018.

Recruitment criteria included age (mostly over 40 years old), gender (mostly male) and driving experience with the specific bus model used (at least 6 months). Participants were aged between 39 and 63 years old (mean age = 52) with the majority of them male (8/10). All participants had been working as a bus driver for more than 3 years, with six of them having driven the New Route Master bus model (NBFL) for more than 3 years and the remaining four between 1 and 3 years.

10.2 Test track

A section of the Alpine Route at the Millbrook test track was used for the trial, comprising a ‘hilly’ steep and a flat route section (see Figure 11). There were four simulated bus stops, two of which were on the steep route section and the other two were on the flat section of the route. A bus depot was simulated within the flat section of the route.

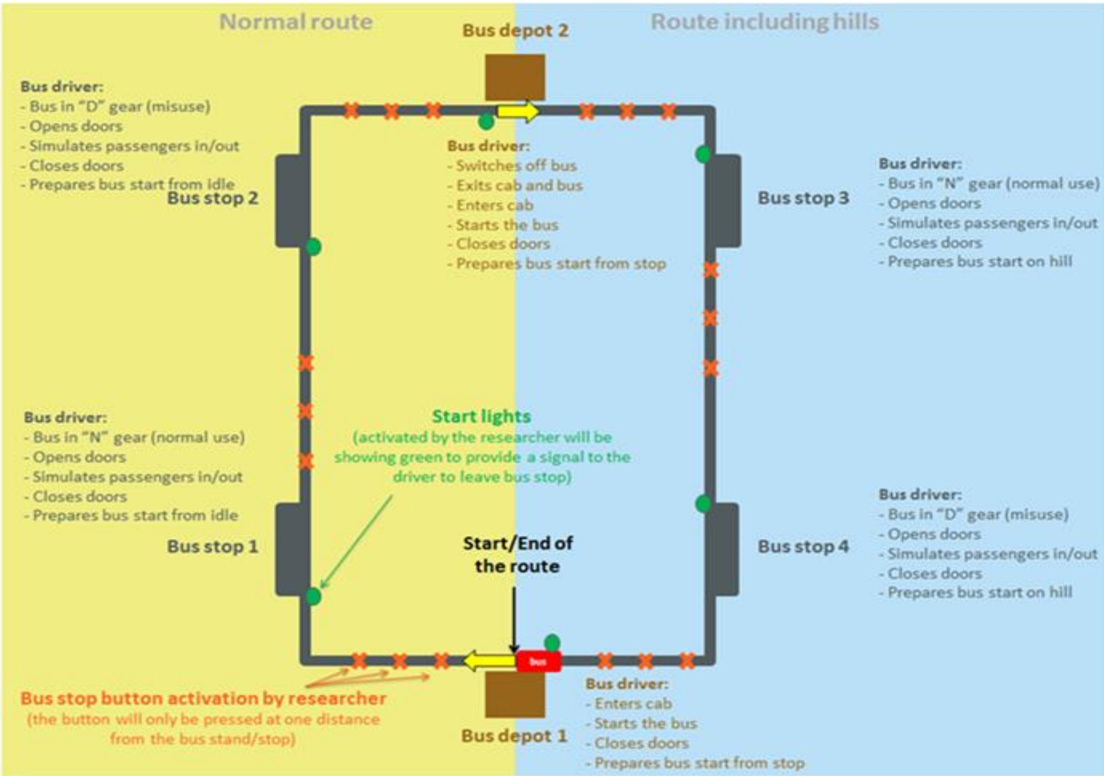

Figure 11: Driving route used during the user trial

10.3 Apparatus and procedure

The test bus was equipped with the prototype system that consisted of a brake toggling solution and a brake/accelerator light indicator solution. The brake toggling solution consisted of a change to the interlock system that required the drivers to press the brake pedal before the accelerator pedal in order to deactivate the halt brake and move the bus from being stationary. The brake/accelerator light indicator solution (see Figure 12) consisted of adding an additional set of lights to the A pillar, as well as using a strip of pixels surrounding the bus icon on the LCD dashboard screen. When the brake pedal was pressed the lights turned red and when the accelerator pedal was pressed the lights turned green. When neither of the pedals was being pressed the lights did not activate.

Figure 12: Brake/Accelerator light indicator solution

The prototype system was activated and deactivated from the driver's seat using a combination of button presses. A light was also placed in the bus cabin in such a position that the drivers had to look over their right shoulder and above to see it. The light was operated by one of the researchers on the bus, who switched it from being red to green in order to instruct the driver to leave the simulated bus stop or simulated bus depot. The purpose of this was to simulate a driver having to wait for a gap in the traffic and having to look over their shoulder to see any approaching vehicles.

Prior to the user trial, all participants undertook a familiarisation drive on the trial route, first without the prototype system activated and then with the brake toggling system and the brake/accelerator light indicators activated simultaneously. During the familiarisation drives participants were given the opportunity to practice stopping at all bus stops and at the simulated bus depot.

During the user trial each participant drove two laps of the same route with the prototype system activated and another two laps without it (i.e. standard mode). The order of standard and prototype drives was counterbalanced across participants to avoid order effects (e.g. biased performance associated with familiarity with the task or fatigue).

Within each lap, participants were given instructions by a researcher on the bus to stop at two of the simulated bus stops (i.e. one at the steep and one at the flat section of the route) and at the simulated bus depot. They were either asked to remain in gear 'D' or to switch to gear 'N' while stopped at the bus stops. While stopped at the bus stops the drivers were asked to open all of the bus doors and then close them in order to simulate passengers getting on and off the bus. The order of this task was counterbalanced across participants and alternated between the two laps of each mode (i.e. standard vs. prototype). When parked at the bus depot, participants were always instructed to switch to gear 'N' before opening the doors and turning off the engine. Within each lap, drivers were required to complete a speed decrease task at least two times. One of the researchers on the bus pressed the bus stop request button before arriving at the simulated bus stop and bus stand. It is important to note that researchers only issued a bus stop request if safe to do so, considering the presence of other road users and the current speed at which the bus was moving. Upon hearing the bell that chimes as a result of the bus stop request button being pressed, the bus driver was required to safely slow the bus down by 5mph, after which they could return to their previous speed.

After the user trial participants completed a post-trial questionnaire designed to collect feedback on both the Brake Toggling system and on the Accelerator/Brake Light indicators.

10.4 Material

10.4.1 Usability questionnaire

The post-trial questionnaire measured different aspects of the perceived usability of the system; the perceived effectiveness and efficiency of the system and participants' overall satisfaction with the system (see Figure 13).

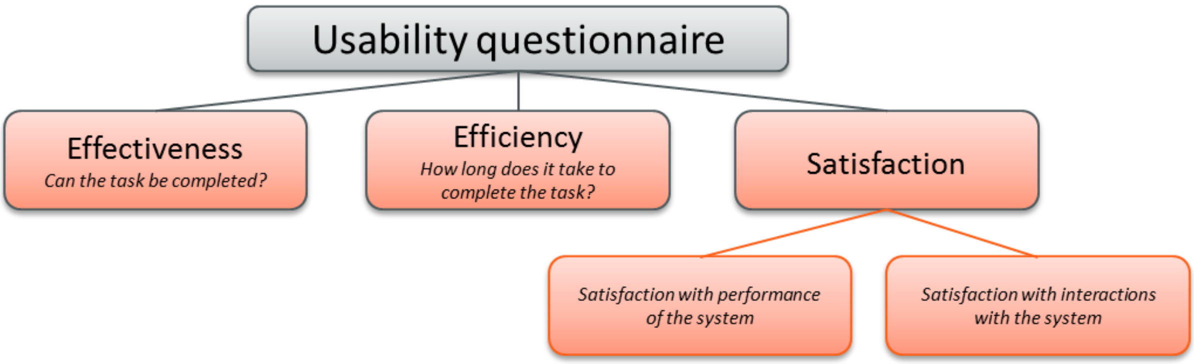

Figure 13: Structure of the items measuring usability of the system

Separate questions assessed effectiveness, efficiency and satisfaction with each system and in different experimental conditions. For example, two questions measured the effectiveness of the Brake Toggling system, respectively when the bus was parked in gear 'N' and when the bus was parked in gear 'D'. The questions measuring the three usability aspects of the Accelerator/Brake Lights indicators did not differentiate between conditions when the bus was parked in different gears. Examples of the exact wording of each question are provided below:

- **Effectiveness**
    - How effective was the Brake Toggling system at helping you distinguish between the accelerator and the brake pedal *when parked in gear 'N' and the brake pedal had to be applied twice vs. when parked in gear 'D' and the brake pedal had to be applied once*?
    - How effective were the Accelerator/Brake Light indicators at helping you distinguish between the accelerator and the brake pedal *when the bus was at a standstill or slowly moving in traffic vs. while at a bus stop or bus stand?*
- **Efficiency**
    - How easy/difficult was it for you to use the Brake Toggling system *when parked in gear 'N' and the brake pedal had to be applied twice vs. when parked in gear 'D' and the brake pedal had to be applied once?*
    - How easy/difficult was it for you to use the Accelerator/Brake Lights indicators?
- **Satisfaction**
    - How satisfied were you with *the performance vs. your interaction* with the Brake Toggling system *when parked in gear 'N' and the brake pedal had to be applied twice vs. when parked in gear 'D' and the brake pedal had to be applied once?*
    - How satisfied were you with the *performance vs. your interaction* with the Accelerator/Brake Lights indicators?

The NASA-TLX scale was used to assess different aspects of drivers' workload while using the Brake Toggling system in different experimental conditions:

- Before departing after being parked in gear 'N'
- Before departing after being parked remaining in gear 'D'

The same scale assessed different aspects of workload when using the Accelerator/Brake Lights indicators.

A number of additional multiple choice and open questions collected opinions on the perceived overall safety impact of the system (e.g. How do you feel the system affected the safety of the bus?) and on potential issues and ways of further improving the system. Participants were also asked for feedback in terms of training needs for drivers prior to the potential implementation of such measure.

10.4.2 Driver performance data related to the speed decrease task

Data from the bus telematics was extracted for each "Bell Press Event" (i.e. the event where the researcher on the bus pressed the bus stop request button), defined as the duration from the press of the bus stop request button until speed was decreased by 5mph (or as soon as the driver stopped pressing the brake pedal). A detailed description of the extracted variables is provided in Table 28. Data from two drivers were excluded from analyses[16].

Table 28: Data measures recorded from the CAN bus

	Variable	Description
1	**Time 1-Start event**	Time bus stop request button activated by researcher
2	**T1 – Speed**	Speed at T1
3	**Foot position at T1**	Foot on accelerator or brake pedal
4	**Time accelerator released**	The exact time when the accelerator was fully released (i.e. the time at which accelerator pedal position is 0%)
5	**End accelerator cover**	Time when driver's foot moved from accelerator as coded by researcher watching the video recording of each drive
6	**Foot covering brake pedal**	Time when driver's foot moved to brake pedal as coded by researcher watching the video recording of each drive
7	**Brake pedal pressed**	The exact time when the brake pedal was pressed as (i.e. the time at which the brake pedal position increased from 0%)
8	**T2 – End event**	Time when task accomplished (i.e. speed decreased by 5mph) and foot released brake pedal.
9	**T2 - Speed**	Speed at T2
10	**Road type**	Flat vs. Downhill vs. Uphill

[16] Data of participant 1 was excluded from analysis due to technical issues with cameras and data of participant 3 was excluded due to failure to understand the task (participant kept decreasing speed to 5m/h at each bus stop bell press)

11 Results

This section provides an overview of the feedback received after the testing procedure of the Brake Toggling system and the Accelerator/Brake Light indicators followed by the analysis of performance data.

Non-parametric statistical tests (Friedman Analysis of Variance – ANOVA) were used to identify any statistically significant differences in scores on usability and the NASA-TLX scale between the Brake Toggling system (D and N examples) and the Brake/Accelerator light indicators (A/B light indicators). Wilcoxon signed rank tests were used to examine the direction of any detected statistically significant effects.

Performance data was used to examine significant differences in time taken to complete the speed decrease task (i.e. slow down by 5mph) between standard and prototype mode using Paired t-tests.

Statistically significant results ($p < .05$) are reported in the sections below to indicate that the differences in the average scores are unlikely to be attributed to random chance; it should be noted however that the small sample size means that only very large changes in scores can be detected, and therefore it is possible that small (but still operationally meaningful) effects exist in some measures. The findings here should only be used as a basis for further research or operational monitoring.

11.1 Feedback from survey

11.1.1 Perceived impact of the systems

Slightly above half of participants thought that the systems increased safety and the rest were of the opinion that these new features made no difference. None of the respondents thought that the systems decreased safety (see Figure 14). It is worth noting here that even though drivers did not perceive any negative impact of the tested countermeasures on safety, their opinion cannot be considered as a valid measure of the objective performance of the countermeasures. Their feedback however is a valuable indication of drivers' potential acceptance of such newly implemented changes to the bus interface and functionality.

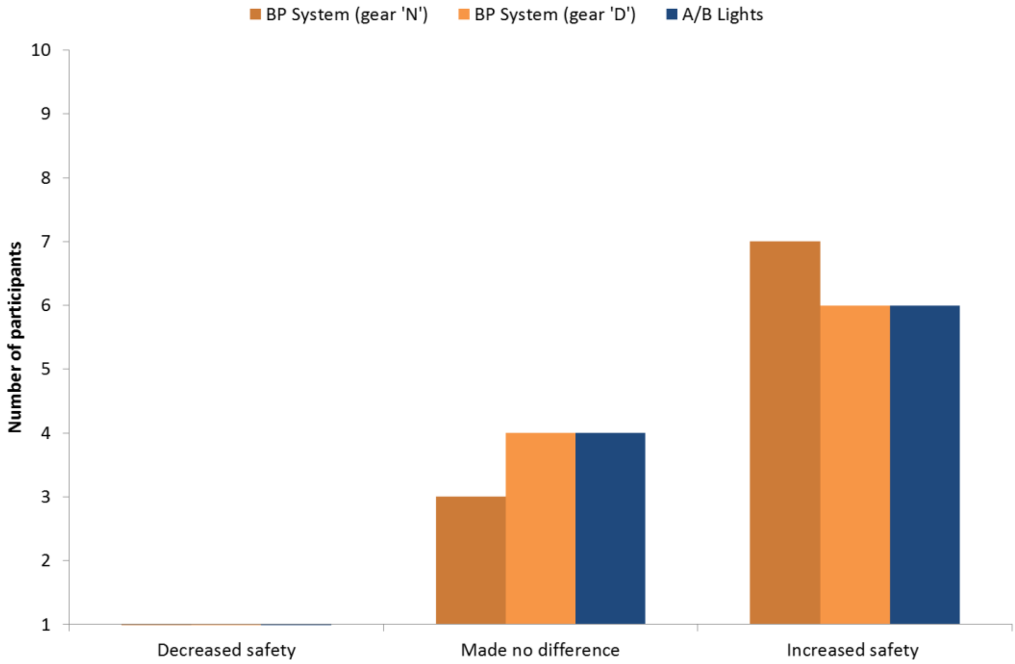

Figure 14: Perceived safety impact of both solutions

11.1.2 Perceived effectiveness of the systems

Participants found both systems to be highly and equally effective at helping them distinguish between the accelerator and brake pedals, with all median scores being above the mid-point or "moderately effective" (see Figure 15). There were no significant differences in the perceived effectiveness of the Brake Toggling system when used while setting off from gear 'N' compared to when used while setting of from gear 'D'. Similarly participants found the A/B light indicators to be roughly equally effective when used at bus stops or when the bus was at a standstill or slowly moving traffic. As a general observation, some drivers who scored low on effectiveness of the countermeasure also provided verbal comments that these scores reflected a lack of added value rather than a negative opinion. Such comments again cannot be considered as an objective measure of effectiveness.

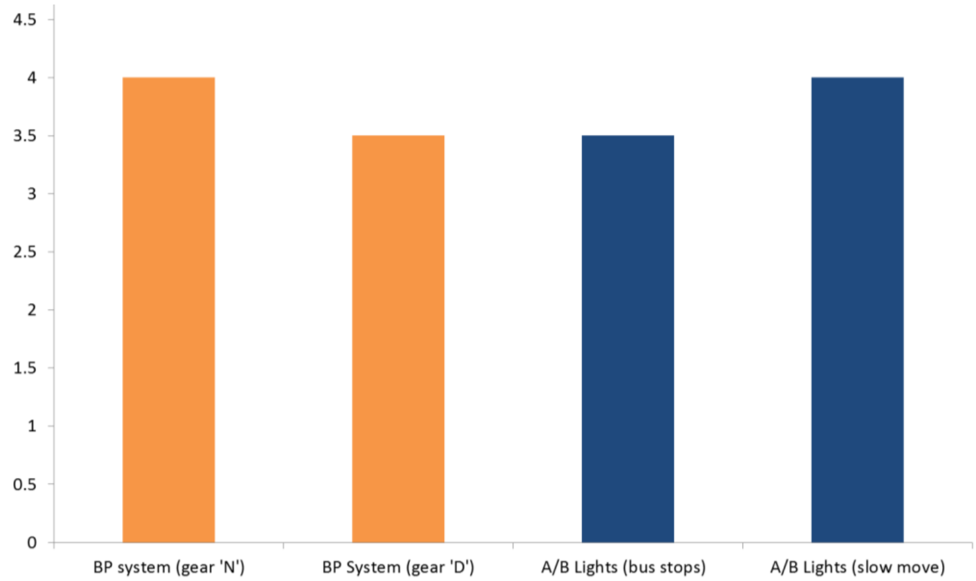

Figure 15: Median scores on perceived effectiveness of both solutions on a scale of 1(Not at all effective) to 5 (Very effective)

11.1.3 Perceived efficiency of the systems

In terms of perceived efficiency (ease of use), even though the scores for the A/B light indicators were slightly higher than those for the Brake Toggling system, this difference cannot be attributed to something other than random chance in this sample (see Figure 16). The lowest scores on perceived efficiency were associated with the use of the Brake Toggling system when setting off from gear 'N'. This however doesn't mean that the system was perceived as inefficient, with four out of 10 participants expressing neutral opinions finding the system 'neither difficult nor easy' to use.

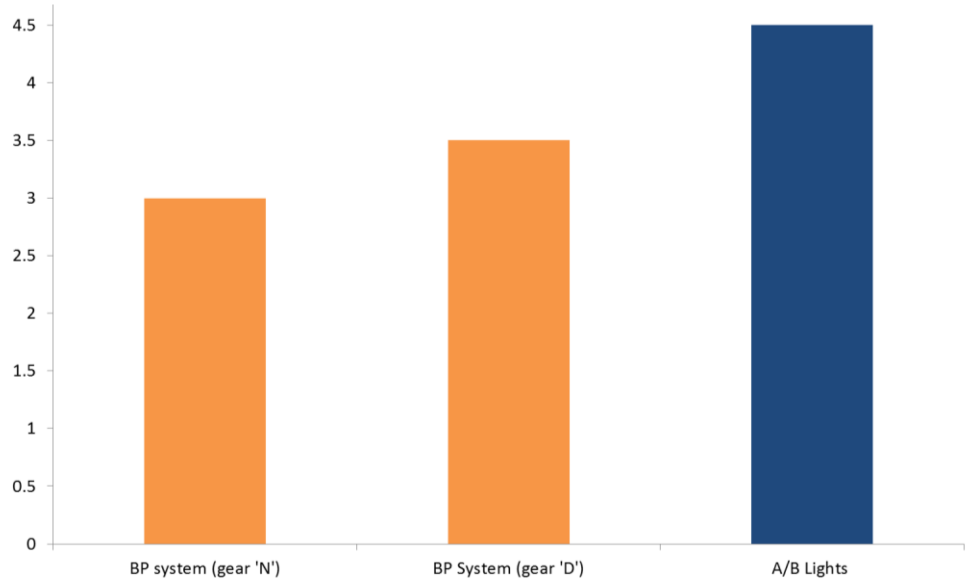

Figure 16: Median scores on perceived efficiency of both solutions on a scale of 1 (Very difficult) to 5 (Very easy)

11.1.4 Satisfaction with performance and interaction with the systems

Participants provided higher than mid-point ratings of satisfaction with the performance of both systems and with their interaction with the systems (see Figure 17). Even though the mean scores on satisfaction were lower for the Brake Toggling system when used while setting off from gear 'N', there were no statistically significant differences in satisfaction between the solutions.

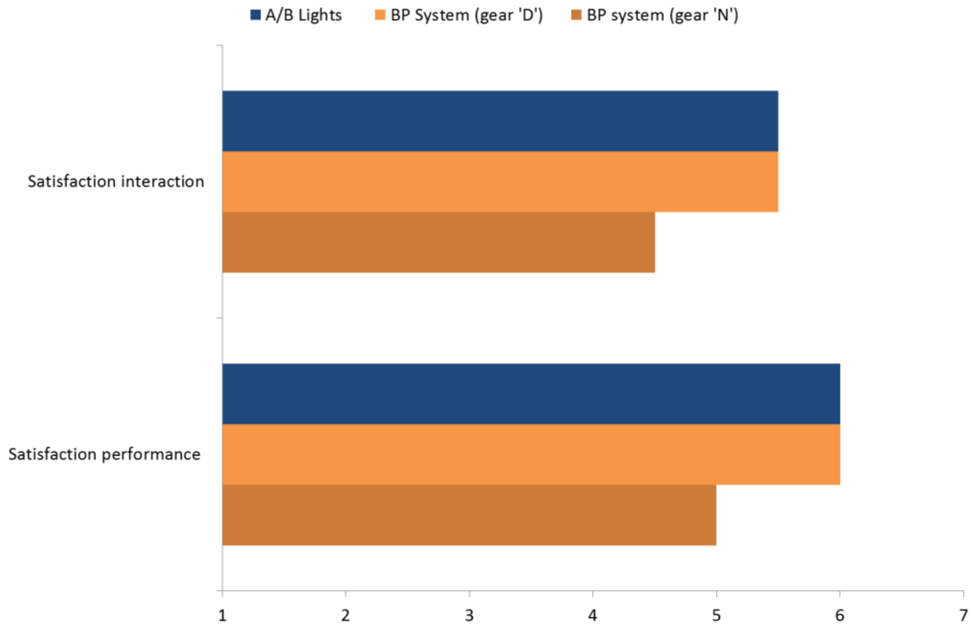

Figure 17: Median scores on satisfaction with performance and interaction with both solutions on a scale of 1 (Completely dissatisfied) to 7 (Completely satisfied)

11.1.5 Perceived intuitiveness of the systems

In terms of ease of understanding the systems (user friendliness), participants ranked the Brake Toggling system as moderately intuitive to use both when setting off from gear 'N' and when setting off from gear 'D' (see Figure 18). Slightly higher scores were attributed for intuitiveness of the A/B light indicators, although with no statistically significant differences between the ease of understanding the two solutions.

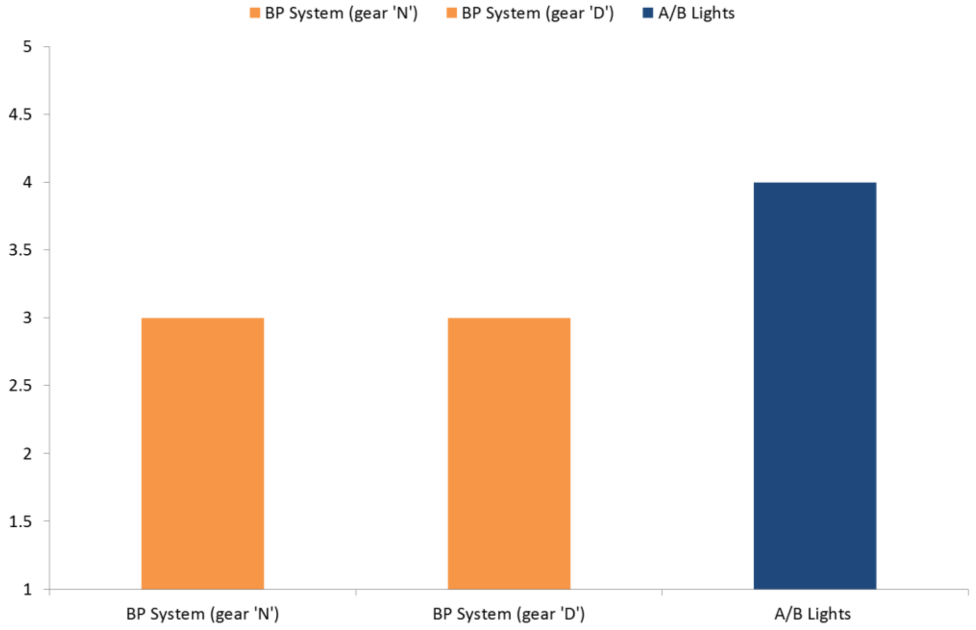

Figure 18: Median scores on perceived intuitiveness of both solutions on a scale of 1(Not at all intuitive) to 5 (Very intuitive)

Half of the participants suggested that a couple of hours of training would be enough for a driver to use the Brake Toggling system effectively; two participants advised that a day of training would be more appropriate and one participant suggested a week of training. Four out of 10 participants suggested that a couple of hours of training would be required for a driver to effectively use the A/B light indicators system; another three suggested an hour or less of training would provide sufficient proficiency and one participant was of opinion that a week of training may be necessary.

11.1.6 Perceived workload while using both systems

Overall, the reported workload was relatively low for each item of the NASA-TLX scale, noting that scores for performance are reversed so that high scores (perceived success in accomplishing the task) mean low workload.

There were statistically significant differences in terms of mental and physical demand. As can be seen in Figure 19, participants reported a higher perceived mental demand using the Brake Toggling system when setting off from gear ‘N’ compared with when setting off from gear ‘D’ ($p = .005$) and when using the A/B light indicators ($p = .005$);. This result could be related to difficulties some drivers may have experienced departing from gear ‘N’ as they have stated usually preferring to remain in gear ‘D’ while at bus stops (see Discussion). Future research could be conducted to examine whether the toggling system adds mental demand to the driving task compared to a baseline condition and accounting for differences in driving style.

Additionally, the physical demand using the A/B light indicators was significantly lower than the physical demand when using the Brake Toggling system when setting off of from gear ‘N’ ($p = .033$)

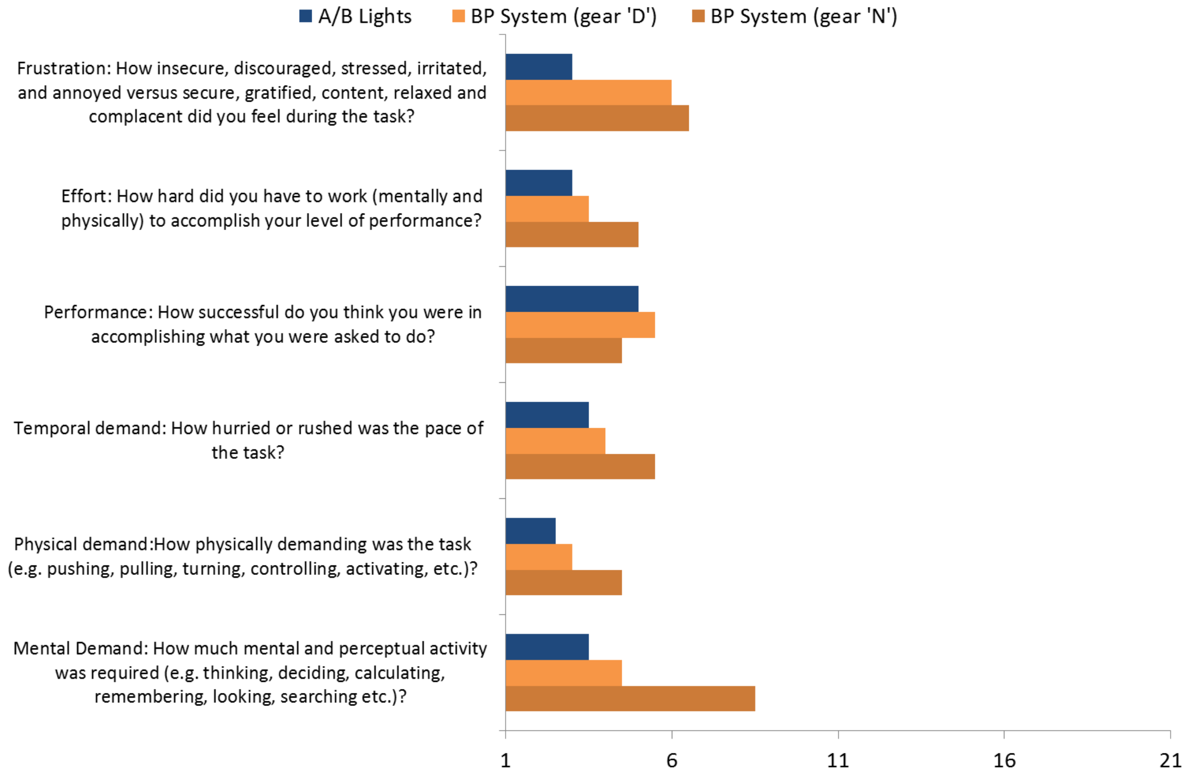

Figure 19: Median scores on the NASA-TLX scale measuring different aspects of workload when using both solutions on a scale from 1(Low workload) to 21(High workload)

11.1.7 Summary of feedback from the survey and key considerations

This section presents a summary of the main results from the survey and key considerations as per drivers' comments post-trial.

Overall, after the user trial, drivers found both systems to be equally effective and efficient at helping distinguish the brake pedal from the accelerator pedal. Clearly, according to the data on the NASA TLX scale the Brake Toggling system added mental demand to the driving task. The fact that this difference was uncovered in such a small-scale trial suggests that it will be important to understand the operational impact of any introduction of the technology.

Drivers also suggested that a short period of training will be sufficient to effectively use both of the systems. Drivers recommended different types of training for both systems (see Table 29). Table 30 and Table 31 list the perceived advantages and disadvantages according to the participants, followed by a list of suggested improvements to the systems (direct quotes from the survey are provided in these tables).

Table 29: Types of training as recommended by participants who tested the mitigation measures

Brake Toggling system	Accelerator/Brake light indicators
"Mentors could be introduced then pass the training on to other drivers. Will be more beneficial at training school for beginners or those joining the bus industry who already have their licence."	"Training stopping and starting to simulate driving in service"
"Class-room education with video before driving bus"	"Training should include introduction to the safety aspect of the added feature"
"30 min on the road out of service followed by a short period of in service observation by a mentor"	"Training should take place at daylight/darkness before service, to get used to the light"

Table 30: Perceived advantages of both systems post-trial

Brake Toggling system	Accelerator/Brake light indicators
"This will be more effective at point of training new drivers"	"It does act as a reminder of which pedal is being used"
"The brake pedal should be applied twice at all times"	"Lights showing only on the A pillar would allow to keep 'head up', not looking at your feet"
"A maximum timer allowance between pressing the brake pedal and the accelerator may be beneficial in instances where the driver is distracted (e.g. by passenger) as they are about to pull away"	"Lights showing on A pillar are easy to see"
"If the interlock is activated only when in gear 'D', this will remind the driver that gear is on"	"The system gives you an extra function to think about as well as perform"
"It made you think what pedal you were on without the need to look down at your feet."	"Helpful in driver's awareness"
"The brake pedal reminder will more likely to be effective when vehicle is in motion (frequently stops) in especially busy areas"	"Perfect visual reminder of pedal being depressed"

Table 31: Perceived disadvantages of both systems post-trial

Brake Toggling system	Accelerator/Brake light indicators
"Confusion between driving NBFL & other types of buses"	"Drivers could spend too much time looking at the dash board"
"This could become an issue when on bus stand"	"Lights only showing on A pillar – need to automatically adjust brightness to ambient light level"
"Could pose risk if driver sitting in traffic with handbrake off and foot on pedal"	"Distracting, especially at night"
"The interlock system shouldn't be activated only when in gear 'D' as the bus could roll off if doors opened and handbrake not fully on"	"It may be difficult to balance the need for bright/large lights required in sunlight with reflection problems at night"
"It will be a bit difficult to depart from the stop due to traffic volume"	"Lights on dashboard not noticeable when driving. Lights on the A pillar very distracting"
"When the bus is stopped, we always have it in D, so a little confusing to close door apply into D, press twice check green for accelerator and then move"	
"Bus didn't pull away as smoothly with this system"	
"So when in N there are other functions to perform, safety wise it's good but doing so in busy London routes will be time consuming"	
"Although my interaction with the system when in gear D was more intuitive, it still required a few times to get used to it"	

11.2 Analysis of performance data related to the speed decrease task

11.2.1 Descriptive statistics

In total 86 Bell Press Events were extracted, with half of them in standard mode and the other half in prototype mode. There were between 7 and 15 events per participant lasting from 2.24 seconds to 11.6 seconds. This means that it took participants on average 5.62 seconds to decrease speed by 5mph.

More than half of the events were triggered at a flat section of the road (n= 53, 61.6%), 23% (n= 20) while driving downhill and the smallest amount (n= 13, 15%) while driving uphill. Figure 20 below shows the average time taken to slow down according to road type. Naturally, participants took significantly longer to slow down while driving through a flat section of the route ($p < .001$) or downhill ($p < .001$) than while driving uphill. In fact, only one participant used the brake pedal to slow down while driving uphill, whereas the rest relied on the retarder. The brake was most frequently pressed when driving through flat sections of the road (see Figure 21).

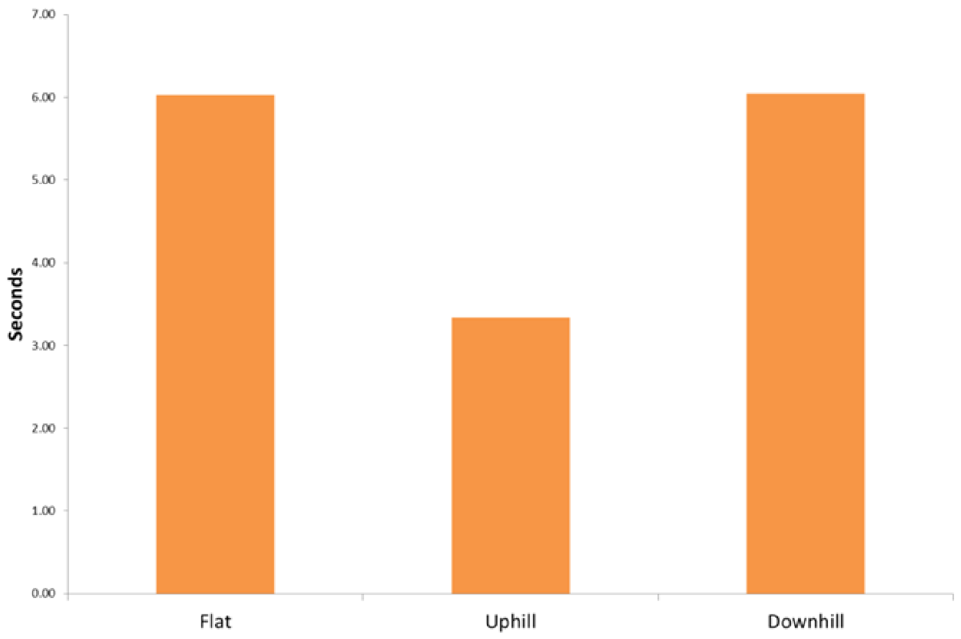

Figure 20: Average time taken to slow down by 5m/h according to road type

In most cases (95%, n= 81) the drivers' foot was on the accelerator when they heard the bus stop bell . One participant was already pressing the brake pedal and four were covering the brake pedal. As the aim of this task was to explore the time taken to move foot from the accelerator to the brake pedal, and the time taken to actually press the brake pedal after hearing the bus stop bell, the event where the participant was already braking was excluded from further analyses.

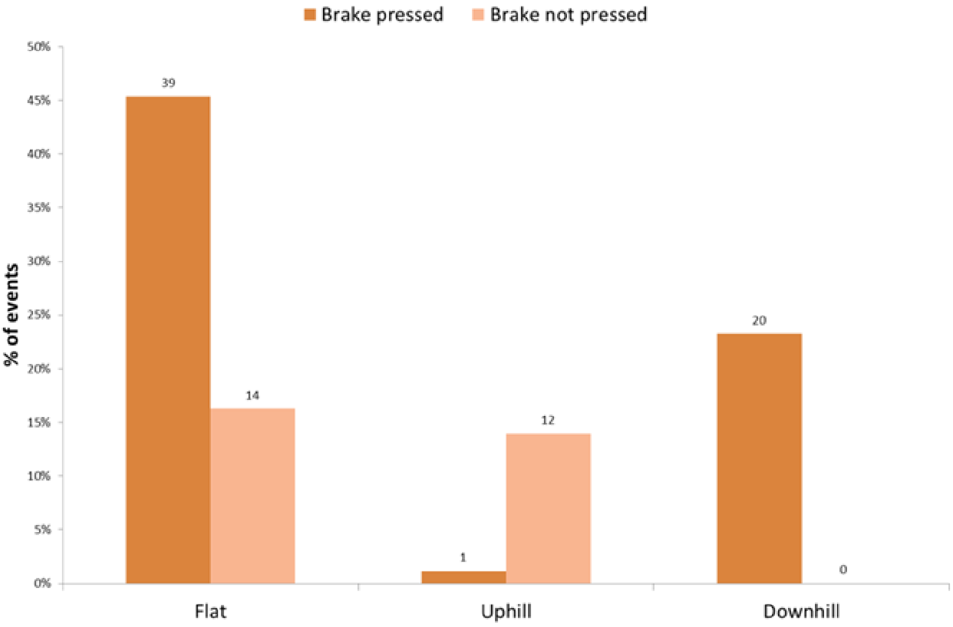

Figure 21: Use of the brake pedal (& not) to slow down according to road type

Not surprisingly all four participants whose foot was already covering the brake pedal (without pressing it) were driving downhill. During the majority of the events (86%) drivers were already pressing the accelerator when they heard the bus stop bell and more than half of them (63%) subsequently used the brake to slow down (see Figure 22). For a small number of events (n= 11) drivers were just covering the accelerator when they heard the bus stop bell and all of them subsequently used the brake to slow down.

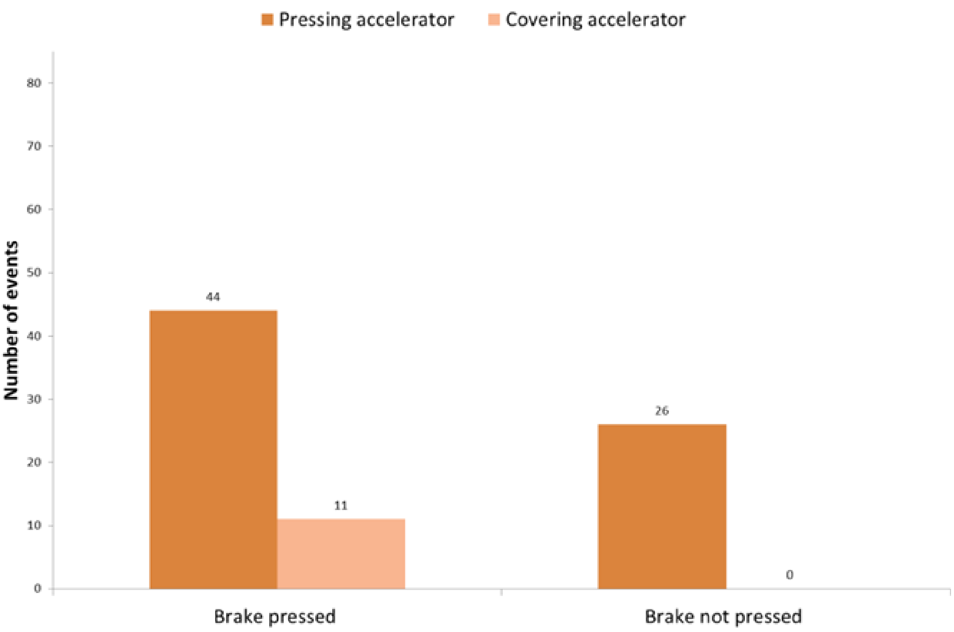

Figure 22: Use of brake pedal (& not) to decrease speed for drivers whose foot was pressing or covering the brake pedal when the bus stop bell activated

Independently of whether drivers were pressing or covering the accelerator, the large majority moved their foot to the brake after they heard the bus stop bell (see Figure 23), even though in 32% of the cases they didn't need to apply the brake to slow down (see Figure 22). Of those who were pressing the accelerator when the bus stop bell activated, only eight drivers never moved their foot to the brake pedal (see Figure 23).

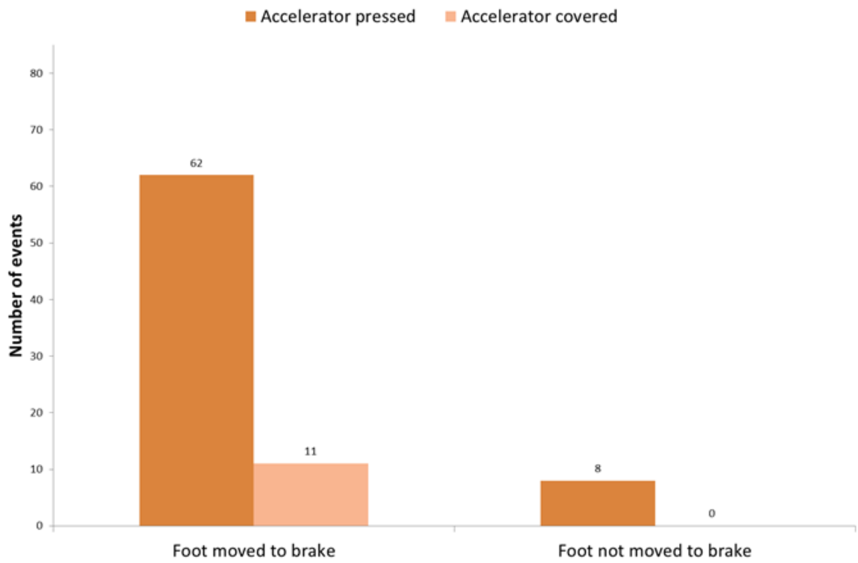

Figure 23: Foot movement after bus stop bell press according to its initial position

The descriptive statistics reported above suggest that drivers may not be likely to cover the brake pedal when driving and not applying the accelerator unless they are driving downhill. However, they do move their foot to the brake pedal when stopping or slowing down, even if they estimate that applying the brake pedal will not be necessary. Further analyses were conducted to examine whether the introduction of the solutions are likely to have an impact on drivers' foot proprioception. A summary of the results is provided in the next section.

11.2.2 Observed effect of the solutions on foot movement

To explore whether the interlock system and the brake/accelerator lights are likely to influence drivers' perception of the pedal's position, we examined differences between the following variables as illustrated in Figure 24.

- Time spent covering the accelerator
- Time taken to move foot from the accelerator to the brake pedal
- Time covering the brake before actually pressing it

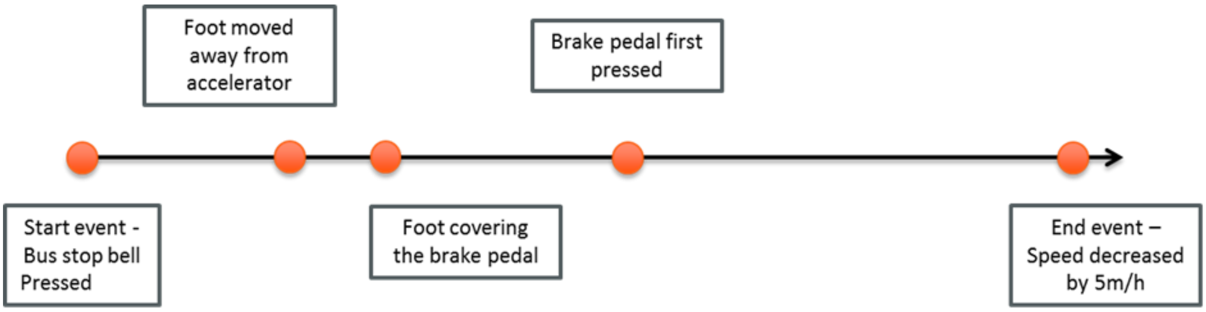

Figure 24: Illustration of the sub-tasks within the speed decrease task timeline

All of the above are likely to be influenced by the speed at which the bus was moving when the bus stop request button was pressed and by the road gradient. To account for these factors and individual differences in driving style and reaction time (e.g. some people may naturally take longer to press the brake pedal than others), we analysed the average times for each participant when:

- driving through a flat section of the road in standard mode versus in prototype mode
- driving downhill in standard mode versus in prototype mode

The events recorded while driving uphill and those where the driver was already covering the brake pedal at the activation of the bus stop bell were excluded from further analyses as these conditions imply a different driving style or preparedness.

We first examined differences in the average speed a bus was travelling when the bus stop request button was pressed in standard versus prototype modes, as this could impact the decision of how quickly to press the brake pedal. A significant difference was only found between average speed while driving through a flat section of the road in standard versus prototype mode, such that the average speed in standard mode was lower than the average speed in prototype mode (at bus stop bell press, see Table 32). This could have occurred due to random factors such as the presence of other road users using the test route or being parked on the side of the test route (at bus stops, stands). To eliminate such potential bias it is recommended that future testing procedures are carried out in controlled environment.

Table 32: Descriptive statistics of average speed at bus stop bell activation

	N	Mean speed (mph)	Std. Deviation	Minimum	Maximum
Standard Flat	8	20.43	1.21	18.67	22.08
Standard Downhill	6	21.45	4.78	13.30	27.17
Prototype Flat	8	22.62	2.07	19.50	24.84
Prototype Downhill	5	23.31	1.81	20.86	25.29

11.2.2.1 Time spent covering the accelerator

Looking at differences in the time spent covering the accelerator before moving foot to the brake pedal, the results suggest that drivers tend to move their foot faster while driving in prototype mode than while driving in standard mode. However, these differences were not statistically significant for this sample. As can be seen in Figure 25, participants took around four fifths of a second (0.79 seconds) to move their foot from the accelerator when driving in standard mode downhill, whereas when driving in prototype mode and downhill it took them on average 0.47 seconds. The same figure also shows the length of covering the accelerator in terms of percentage of the overall event time (i.e. time taken to slow down by 5mph), suggesting again that when driving downhill in prototype mode drivers spent a small proportion of time on the accelerator before moving their foot to the brake pedal.

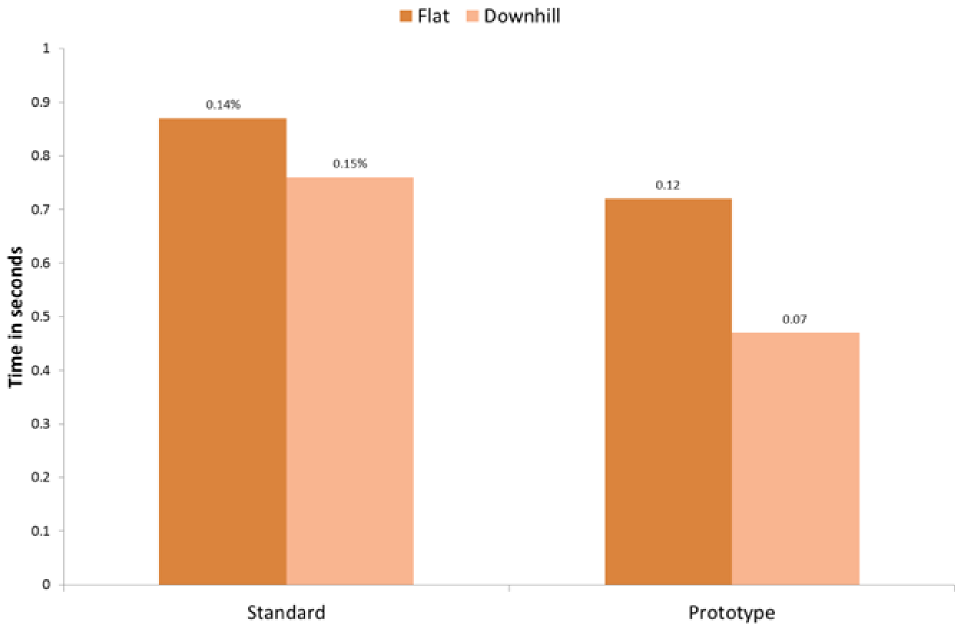

Figure 25: Period of time covering the accelerator before moving foot to the brake pedal

It is worth noting here that pedal coverage was coded manually by looking at data from the video recordings. Therefore, further research using high precision sensor technology could be conducted with a larger sample of participants to objectively measure the exact moment when drivers stop covering the pedals.

11.2.2.2 Time taken to move foot from the accelerator to the brake pedal

Analysis of the time taken to move the foot from the accelerator to the brake pedal did not show any significant differences between experimental conditions. As can be seen in Figure 26 it took drivers about one third of a second to find the brake pedal after moving their foot from the accelerator.

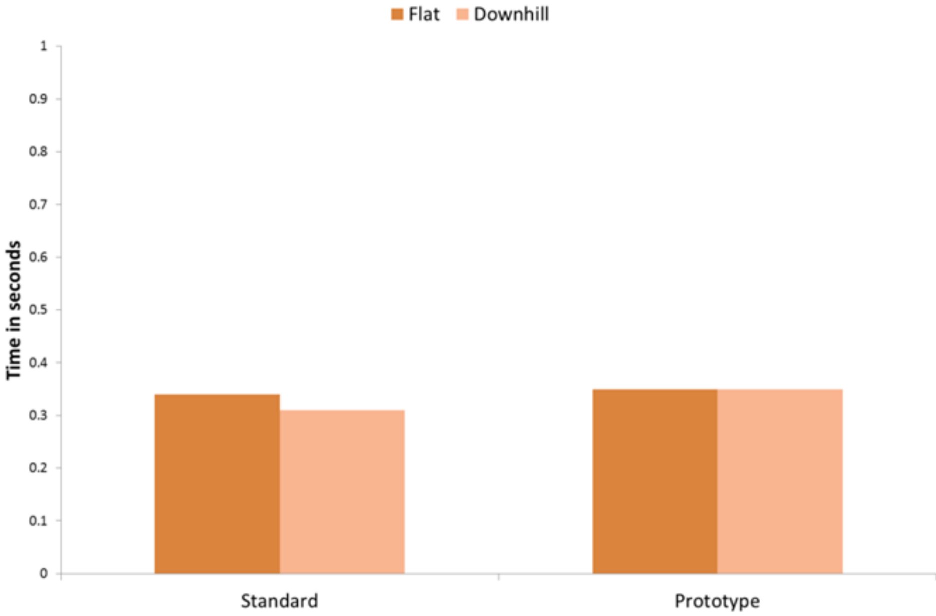

Figure 26: Average time taken to move foot from the accelerator to the brake pedal (before pressing it)

11.2.2.3 Time spent covering the brake pedal

Finally we examined the time taken after drivers' foot was covering the brake pedal before actually pressing it. Again, no statistically significant differences were found even though as can be seen in Figure 27 below, drivers apparently spent longer covering the brake before pressing it when in standard mode for both flat and downhill route sections, compared with when driving in prototype mode. The small sample size in this study need to be taken into account when considering this apparent lack of any significant difference.

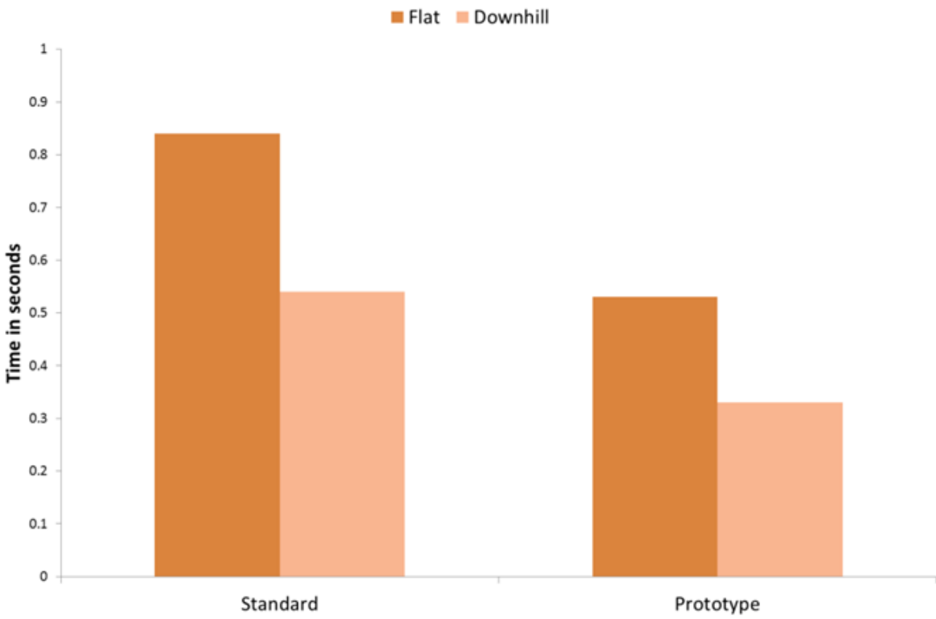

Figure 27: Average time covering brake pedal before pressing it for first time

Finally, Figure 28 provides a summary of all results which could be used as a starting point for the development of future testing procedures, although again it should be recalled that these estimates come from a very small sample. For robust estimates, a much larger sample would be required.

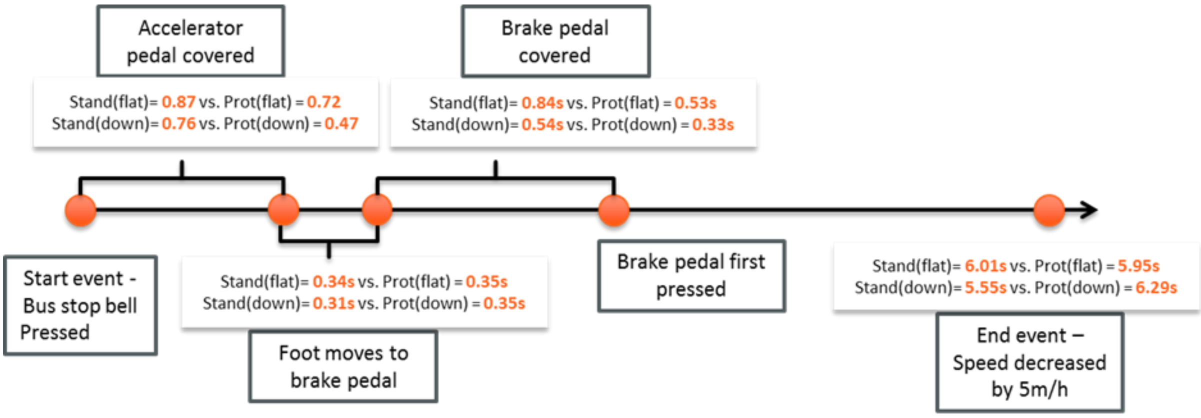

Figure 28: Summary of the average times taken to complete each sub-task of the speed decrease task according to road type in both standard and prototype mode

12 Foot Placement Observations

A potentially important observation from the user trial was the difference in how drivers positioned their foot when using the brake and accelerator pedals, and the potential impact this has on the likelihood of pedal application error incidents taking place. While some drivers placed their foot in line with the pedals, other drivers angled their foot in such a way that it was sometimes over both pedals simultaneously. This effect may be due to biomechanical differences between the drivers, experience driving buses with certain pedal layouts, as well as differences in training. Figure 29 provides an example of a driver who kept their foot positioned in-line with the pedals. Figure 30 provides an example of a driver who kept their foot positioned across the pedals.

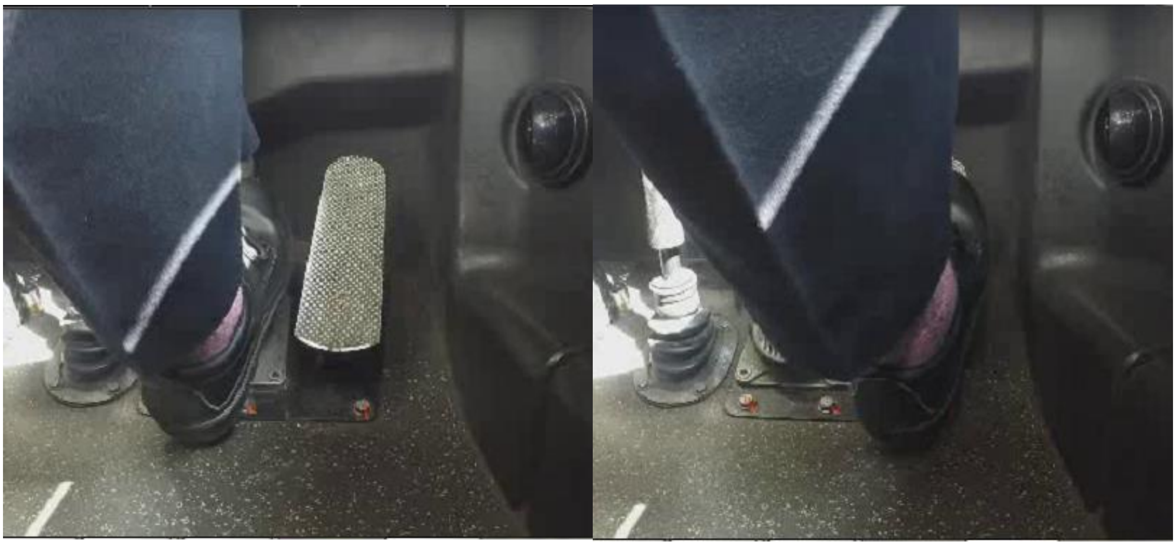

Figure 29: In line foot placement with the brake (left) and accelerator (right)

Figure 30: Angled foot placement with the brake (left) and accelerator (right)

There is the potential for increased risk of pedal application error if a driver's foot is angled across the pedals. Ergonomically, this is not an optimal position for the foot and as a result may increase the risk that the driver inadvertently presses the wrong pedal. In general, a driver having their foot in an angled position could reduce awareness of the relative location of each pedal, which in turn could lead to pedal application error. There is some evidence to suggest that a foot in transition between the two pedals (moving from one pedal to another) could be associated with higher risk of pedal error in car drivers (Wu et al. 2017). The authors argue that this position may be associated with delayed reactions in case of unexpected events creating a conflict between planned and expected actions (i.e. if a driver was planning to press the accelerator next, but an unexpected event requires them to press the brake instead). Having analysed the foot movements in naturalistic driving conditions, the same authors observed that drivers are more likely to have their foot in transition when completing complex manoeuvres (turning, parking etc.) requiring a combination of body movements. They also observed that drivers who rested their heels on the floor pan while pressing a pedal, and drivers whose back positions were not against the seat back were less likely to place their foot in transition, whereby such behaviours may help prevent pedal error.

Alternatively, angling the foot over both pedals may aid proprioception with regards to the location of the brake and accelerator pedals as it allows the driver to ‘feel’ where the pedals are, whereas a complete shift between the pedals using a straight foot will not benefit from this. This is due to the fact that it is easier for a person to tell that their foot is at an angle than where it is in space.

A further issue with an angled foot position is that it can render the accelerator heel stop – one of the main differentiators between the accelerator and brake pedal – redundant. In previous pedal application error incidents drivers failed to utilise the heel stop as their foot was angled across the accelerator pedal. This indicates the potential for an angled foot position to compromise sensory feedback from brake and accelerator pedals that can be used to differentiate between them.

Future research could be conducted to specifically test the effects of seat and foot position on reaction times while completing complex driving tasks. In the same line of thought, similarities and differences in foot and body position could be investigated among drivers who are used to driving vehicles with different spatial characteristics (i.e. bus versus car) and the extent to which the more usual driving style is applied when driving different types of vehicles. Such research would inform on the benefits of training drivers to adjust their foot and body position when driving different types of vehicles or when performing complex driving tasks.

13 Cost-benefit analysis

13.1 Target population

The annual target population in 2018 estimated for all outcome severities (fatal, serious and slight casualties; major and minor damage-only collisions) relevant to the pedal application error countermeasures are presented in Table 33 below. Target populations were considered to be equivalent between the different pedal application error solutions. Target populations were calculated for bus and car occupants, VRUs (pedestrians, cyclists and PTWs) as well as for 'damage-only' collisions as pedal application error incidents are likely to result in serious damage to property and infrastructure in addition to the risk they pose to road users. The selection of appropriate target populations was performed to include the average annual number of pedal application error incidents in London involving injury to road users and/or damage to property/infrastructure. All data was abstracted from the IRIS database for the years 2002-2017.

Table 33: Estimated average annual target population in 2018 for the pedal application error safety measure solutions

Casualty Type	Outcome Severity				
	Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage
Car Occupants	0	0	3.3	-	-
Bus Occupants	0	0	9.8	-	-
Pedestrians	0	0.3	0.3	-	-
Cyclists	0	0.2	0	-	-
PTWs	0	0.2	0	-	-
Damage-Only	-	-	-	0.7	18.3
Totals	**0**	**0.7**	**13.4**	**0.7**	**18.3**

13.2 Estimates of effectiveness

The overall effectiveness values estimated for all outcome severities relevant to the pedal application error safety measures (fatal, serious and slight casualties; minor and major damage-only collisions) are presented in Table 34. The overall effectiveness estimations are based on available evidence. Namely, Bright (2011) studied the effects of pedal application error and listed the best practices to mitigate them. Schmidt (1989) and Reinhart (1989) reported that brake toggling (requiring the driver to press the brake pedal while changing gear from stationary) reduced pedal errors by 60% in automatic cars. Trachtman, Schmidt and Young (2005) made a comparison of the different lateral and vertical spaces between the accelerator pedal, brake pedal and steering wheel axis, and cross-referenced them with a pedal error database of over

200,000 accidents, no differences in the pedal measurements of vehicles involved in accidents (when compared with their non-accident peers) were found. The following values were agreed during an internal expert workshop and verified through the stakeholder workshop. The estimations were considered to be equivalent between different casualty types and all solutions were assumed to prevent incidents only (thus all effectiveness values for casualty mitigation were assumed to be 0%).

Table 34: Estimated overall effectiveness ranges for casualties prevented for the pedal application error safety measure solutions

Safety Measure Solution	Incidents Prevented				
	Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage
Brake Toggling	40-60%	40-60%	40-60%	40-60%	40-60%
Pedals Layout Standardisation	15-35%	15-35%	15-35%	15-35%	15-35%
Improved Direct/Indirect Vision	26-36%	26-36%	26-36%	26-36%	26-36%
Accelerator/Brake Light	0-35%	0-35%	0-35%	0-35%	0-35%
Accelerator Noise Conspicuity	40-60%	40-60%	40-60%	40-60%	40-60%
Unintended Acceleration AEB	54-74%	54-74%	54-74%	54-74%	54-74%

13.3 Fleet fitment and implementation timescales

Timescales were determined for each of the pedal application error safety measure solutions in order to develop fleet fitment and policy implementation roadmaps for each solution (Table 35). Bus operators and suppliers contributed to establishing the estimates for current levels of fleet fitment and the expected number of years to achieve full fleet penetration for each solution. Specifically, stakeholder consultations contributed to detailing three phases of solution development; Prototyping, 1st Productions and then the production of more than three models. These phases reflect the development and implementation of each solution with a ‘Preference’ followed by a “Requirement” timeline:

- Preference: Refers to a best practice approach, it is not required but might gain preference in procurement. This would represent the first to market models.
- Requirement: Refers to a mandatory requirement. This would represent an ability to more widely adopt throughout the London fleet (potentially 3+ models).

It should be noted that both the pedal layout standardisation and AEB solutions are unable to be retrofitted to the current fleet of buses.

Please see the associated stakeholder consultation report for further information on the stakeholder feedback on fleet fitment and policy implementation timescales.

Table 35: Fleet fitment and policy implementation timescales for both the retrofit and new build pedal application error safety measure solutions

Safety Measure Solution	First to Market	Date Policy Implemented	Current Fleet Penetration	Full Fleet Adoption (yrs)	
				Retrofit	New Build
Brake Toggling	2019	2021	0%	1	12
Pedals Layout Standardisation	2019	2021	0%	N/A	12
Improved Direct/Indirect Vision	2020	2021	0%	2	12
Accelerator/Brake Light	2019	2019	0%	1	12
Accelerator Noise Conspicuity	2019	2021	0%	2	12
Unintended Acceleration AEB	2020	2024	0%	N/A	12

13.4 Casualty benefits

Tables below summarise the estimated total change in the number of casualties and damage expected in London during the period 2019-2031 by specifying the performance of new build buses (Table 36) and retrofitted solutions (Table 37) for each potential solution. Outcomes are then monetised to estimate the total value of these casualty reductions to society, presented in Table 36 for new build and Table 37 for retrofit.

Table 36: Estimated total change in number and value (NPV) of incidents over the 12-year analysis period (2019-2031) for the new build pedal application error safety measure solutions

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
Brake Toggling	Car Occupants	0	0	7.9-11.9	-	-	0.13-0.19
	Bus Occupants	0	0	24.3-36.5	-	-	0.39-0.58
	Pedestrians	0	0.8-1.2	0.8-1.2	-	-	0.18-0.28
	Cyclists	0	0.6-0.8	0	-	-	0.12-0.17
	PTWs	0	0.4-0.6	0	-	-	0.08-0.12
	Damage-Only	-	-	-	1.7-2.5	45.4-68.1	0.05-0.08
	Totals	**0**	**1.8-2.7**	**33.1-49.6**	**1.7-2.5**	**45.4-68.1**	**0.95-1.42**
Pedals Layout Standardisation	Car Occupants	0	0	2.8-6.6	-	-	0.05-0.11
	Bus Occupants	0	0	8.7-20.4	-	-	0.14-0.32
	Pedestrians	0	0.3-0.7	0.3-0.7	-	-	0.07-0.15
	Cyclists	0	0.2-0.5	0	-	-	0.04-0.10
	PTWs	0	0.1-0.3	0	-	-	0.03-0.07
	Damage-Only	-	-	-	0.6-1.4	16.3-38.1	0.02-0.04
	Totals	**0**	**0.6-1.5**	**11.9-27.7**	**0.6-1.4**	**16.3-38.1**	**0.34-0.79**
Improved Direct/Indirect Vision	Car Occupants	0	0	4.9-6.8	-	-	0.08-0.11
	Bus Occupants	0	0	15.2-21.0	-	-	0.24-0.33
	Pedestrians	0	0.5-0.7	0.5-0.7	-	-	0.11-0.16
	Cyclists	0	0.4-0.5	0	-	-	0.07-0.10
	PTWs	0	0.2-0.3	0	-	-	0.05-0.07
	Damage-Only	-	-	-	1.0-1.4	28.3-39.1	0.03-0.05
	Totals	**0**	**1.1-1.5**	**20.6-28.5**	**1.0-1.4**	**28.3-39.1**	**0.59-0.82**
Accelerator/BrakeLight	Car Occupants	0	0	0-7.8	-	-	0-0.12
	Bus Occupants	0	0	0-23.9	-	-	0-0.38
	Pedestrians	0	0-0.8	0-0.8	-	-	0-0.18
	Cyclists	0	0-0.5	0	-	-	0-0.11

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
	PTWs	0	0-0.4	0	-	-	0-0.08
	Damage-Only	-	-	-	0-1.6	0-44.5	0-0.05
	Totals	**0**	**0-1.7**	**0-32.5**	**0-1.6**	**0-44.5**	**0-0.93**
Accelerator Noise Conspicuity	Car Occupants	0	0	7.9-11.9	-	-	0.13-0.19
	Bus Occupants	0	0	24.3-36.5	-	-	0.39-0.58
	Pedestrians	0	0.8-1.2	0.8-1.2	-	-	0.18-0.28
	Cyclists	0	0.6-0.8	0	-	-	0.12-0.17
	PTWs	0	0.4-0.6	0	-	-	0.08-0.12
	Damage-Only	-	-	-	1.7-2.5	45.4-68.1	0.05-0.08
	Totals	**0**	**1.8-2.7**	**33.1-49.6**	**1.7-2.5**	**45.4-68.1**	**0.95-1.42**
Unintended Acceleration AEB	Car Occupants	0	0	8.1-11.1	-	-	0.13-0.18
	Bus Occupants	0	0	24.9-34.2	-	-	0.40-0.54
	Pedestrians	0	0.8-1.2	0.8-1.2	-	-	0.19-0.26
	Cyclists	0	0.6-0.8	0	-	-	0.12-0.16
	PTWs	0	0.4-0.5	0	-	-	0.08-0.11
	Damage-Only	-	-	-	1.7-2.3	46.5-63.7	0.05-0.07
	Totals	**0**	**1.8-2.5**	**33.9-46.4**	**1.7-2.3**	**46.5-63.7**	**0.97-1.33**

Table 37: Estimated total change in number and value (NPV) of incidents over the 12-year analysis period (2019-2031) for the retrofit pedal application error safety measure solutions

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
Brake Toggling	Car Occupants	0	0	16.1-24.2	-	-	0.26-0.39
	Bus Occupants	0	0	49.3-73.9	-	-	0.79-1.18
	Pedestrians	0	1.7-2.5	1.7-2.5	-	-	0.37-0.56
	Cyclists	0	1.1-1.6	0	-	-	0.22-0.34
	PTWs	0	0.8-1.2	0	-	-	0.16-0.25
	Damage-Only	-	-	-	3.3-5.0	91.9-138	0.11-0.16
	Totals	**0**	**3.5-5.3**	**67.1-101**	**3.3-5.0**	**91.9-138**	**1.92-2.88**
Pedals Layout Standardisation	Car Occupants	N/A	N/A	N/A	-	-	N/A
	Bus Occupants	N/A	N/A	N/A	-	-	N/A
	Pedestrians	N/A	N/A	N/A	-	-	N/A
	Cyclists	N/A	N/A	N/A	-	-	N/A
	PTWs	N/A	N/A	N/A	-	-	N/A
	Damage-Only	-	-	-	N/A	N/A	N/A
	Totals	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Improved Direct/Indirect Vision	Car Occupants	0	0	9.7-13.5	-	-	0.16-0.22
	Bus Occupants	0	0	29.8-41.2	-	-	0.48-0.66
	Pedestrians	0	1.0-1.4	1.0-1.4	-	-	0.23-0.31
	Cyclists	0	0	0.7-0.9	-	-	0.14-0.19
	PTWs	0	0.5-0.7	0	-	-	0.10-0.14
	Damage-Only	-	-	-	2.0-2.8	55.5-76.8	0.06-0.09
	Totals	**0**	**2.2-3.0**	**40.5-56.1**	**2.0-2.8**	**55.5-76.8**	**1.16-1.60**
Accelerator/Brake Light	Car Occupants	0	0	0-14.6	-	-	0-0.23
	Bus Occupants	0	0	0-44.4	-	-	0-0.71
	Pedestrians	0	0-1.5	0-1.5	-	-	0-0.34
	Cyclists	0	0-1.0	0	-	-	0-0.20

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
	PTWs	0	0-0.7	0	-	-	0-0.15
	Damage-Only	-	-	-	0-3.0	0-82.8	0-0.10
	Totals	**0**	**0-3.2**	**0-60.5**	**0-3.0**	**0-82.8**	**0-1.73**
Accelerator Noise Conspicuity	Car Occupants	0	0	16.1-24.2	-	-	0.26-0.39
	Bus Occupants	0	0	49.3-73.9	-	-	0.79-1.18
	Pedestrians	0	1.7-2.5	1.7-2.5	-	-	0.37-0.56
	Cyclists	0	1.1-1.6	0	-	-	0.22-0.34
	PTWs	0	0.8-1.2	0	-	-	0.16-0.25
	Damage-Only	-	-	-	3.3-5.0	91.9-138	0.11-0.16
	Totals	**0**	**3.5-5.3**	**67.1-101**	**3.3-5.0**	**91.9-138**	**1.92-2.88**
Unintended Acceleration AEB	Car Occupants	N/A	N/A	N/A	-	-	N/A
	Bus Occupants	N/A	N/A	N/A	-	-	N/A
	Pedestrians	N/A	N/A	N/A	-	-	N/A
	Cyclists	N/A	N/A	N/A	-	-	N/A
	PTWs	N/A	N/A	N/A	-	-	N/A
	Damage-Only	-	-	-	N/A	N/A	N/A
	Totals	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

13.5 Cost implications

Following a stakeholder consultation, baseline industry-wide cost ranges were established for new build and retrofitted safety measure solutions.

For each safety measure cost ranges were established for:

- Technology development, manufacture and certification costs

For BrakeToggling the estimated cost ranges were £20-60/bus for retrofit technology and neutral cost for new build. Understandably, there were no costs (neutral) associated with Pedal Layout Standardisation solution for new build. The cost ranges for technology associated with Improved Direct/Indirect Vision solutions were estimated to be lower for new built buses (£55-£960/bus) compared to retrofitted (£70-£1200/bus). Similarly, Accelerator/Brake Light could be fitted on new buses for a slightly lower price (£120-£320/bus) than if they were to be retrofitted (£150-400/bus). The cost ranges for Accelerator Noise Conspicuity measures were estimated at £420-£770/bus for retrofit and £340-£620/bus for new build, including costs for speakers to relay sound to driver in cab (£20/bus). However further research is to be conducted to confirm the need for this additional feature. The highest costs were estimated for AEB (Automatic Emergency Braking) solution, ranging between £2,000 and £4,000 per bus for new build.

- Implementation costs

In terms of implementation costs, it was suggested that normal driver training should cover driver training costs for all of the proposed solutions. For the improved Direct/Indirect vision solutions additional costs were estimated for the retrofit installation of mirrors (1 person-hour) and CMS (1-2 person-days). The installation costs for Accelerator/Brake Light were lower for retrofit installation £100-£240/bus (2-4 person-hours) compared to the costs for new build technology £120-£320). The costs for retrofit installation of Accelerator Noise Conspicuity technology were estimated at £100-£240 (2-4 person-hours).

- Operational costs

The agreed operational cost ranges account for device maintenance or replacement. Brake Toggling and Pedal Layout Standardisation were associated with neutral operational costs. The highest operational costs were associated with AEB solution (£400-£600/bus), accounting for device recalibration during its lifetime. Between £100 and £150 per bus, per year, were estimated for replacements of Accelerator Noise Conspicuity technology due to wear or damage. The operational costs for both the Accelerator/Brake Light technology and the Improved Direct/Indirect Vision technology, were estimated at £50-£140/bus/year (or 2-4 person-hours) accounting for device maintenance.

- Insurance costs

The annual changes in incidents resulting from the safety measure solutions were used to estimate the changes in the insurance claims costs that may be expected by regulating the performance of buses for each pedal application error safety measure solution.

Cost differentials resulting from environmental or infrastructure costs were not considered within the scope of this safety measure.

Cost ranges were used to calculate the associated cost per bus and fleet for new build buses (Table 38) and for retrofitted measures (Table 39) over the analysis period. Changes in the value of insurance claims are provided in parentheses to reflect a reduction in costs.

Table 38: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the new build pedal application error safety measure solutions (cost reductions are shown in (parentheses))

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NVP) (£M)
Brake Toggling	Change in Technology Costs	0	0
	Change in Implementation Costs	0	0
	Change in Operational Costs	0	0
	Change in Insurance Claims Costs	(46)-(22)	(0.43)-(0.21)
	Totals	**(46)-(22)**	**(0.43)-(0.21)**
Pedal Layout Standardisation	Change in Technology Costs	0	0
	Change in Implementation Costs	0	0
	Change in Operational Costs	0	0
	Change in Insurance Claims Costs	(26)-(8)	(0.24)-(0.07)
	Totals	**(26)-(8)**	**(0.24)-(0.07)**
Improved Direct/Indirect Vision	Change in Technology Costs	51-897	0.47-8.26
	Change in Implementation Costs	0	0
	Change in Operational Costs	291-815	2.68-7.50
	Change in Insurance Claims Costs	(27)-(14)	(0.25)-(0.13)
	Totals	**316-1698**	**2.90-15.62**
Accelerator/ Brake Lights	Change in Technology Costs	112-300	1.12-3.00
	Change in Implementation Costs	0	0
	Change in Operational Costs	315-881	3.15-8.81
	Change in Insurance Claims Costs	(29)-0	(0.29)-0
	Totals	**398-1180**	**3.98-11.80**
Accelerator Noise Conspicuity	Change in Technology Costs	318-580	2.99-5.45
	Change in Implementation Costs	0	0
	Change in Operational Costs	595-893	5.60-8.40
	Change in Insurance Claims Costs	(46)-(22)	(0.43)-(0.21)
	Totals	**868-1451**	**8.15-13.64**
Unintended Acceleration AEB	Change in Technology Costs	1866-3732	14.93-29.86
	Change in Implementation Costs	0	0
	Change in Operational Costs	2117-3176	16.94-25.41
	Change in Insurance Claims Costs	(25)-(47)	(0.38)-(0.20)
	Totals	**3936-6884**	**31.5-55.07**

Table 39: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the retrofit pedal application error safety measure solutions (cost reductions are shown in (parentheses))

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NVP) (£M)
Brake Toggling	Change in Technology & Certification Costs	19-57	0.21-0.62
	Change in Implementation Costs	0	0
	Change in Annual Operational Costs	0	0
	Change in Insurance Costs	(99)-(48)	(1.07)-(0.52)
	Totals	**(80)-10**	**(0.87)-0.10**
Pedal Layout Standardisation	Change in Technology & Certification Costs	N/A	N/A
	Change in Implementation Costs	N/A	N/A
	Change in Annual Operational Costs	N/A	N/A
	Change in Insurance Costs	N/A	N/A
	Totals	**N/A**	**N/A**
Improved Direct/Indirect Vision	Change in Technology & Certification Costs	66-1139	0.72-12.38
	Change in Implementation Costs	52-911	0.57-9.91
	Change in Annual Operational Costs	494-1383	5.37-15.03
	Change in Insurance Costs	(54)-(28)	(0.59)-(0.31)
	Totals	**559-3405**	**6.07-37.02**
Accelerator/ Brake Lights	Change in Technology & Certification Costs	143-383	1.56-4.16
	Change in Implementation Costs	96-230	1.04-2.50
	Change in Annual Operational Costs	560-1567	6.08-17.03
	Change in Insurance Costs	(60)-0	(0.65)-0
	Totals	**739-2179**	**8.03-23.69**
Accelerator Noise Conspicuity	Change in Technology & Certification Costs	401-734	4.36-7.99
	Change in Implementation Costs	95-229	1.04-2.49
	Change in Annual Operational Costs	1075-1613	11.69-17.53
	Change in Insurance Costs	(99)-(48)	(1.07)-(0.52)
	Totals	**1472-2528**	**16.01-27.49**
Unintended Acceleration AEB	Change in Technology & Certification Costs	N/A	N/A
	Change in Implementation Costs	N/A	N/A
	Change in Annual Operational Costs	N/A	N/A
	Change in Insurance Costs	N/A	N/A
	Totals	**N/A**	**N/A**

13.6 Benefit-cost analysis outcomes

Table 40 and Table 41 below provide estimates for the break-even costs, discounted payback period and benefit-cost ratios associated with each pedal application error safety measure solution for new build and retrofitted buses respectively. Positive benefit-cost ratios are highlighted in **green**, and poor benefit-cost ratios in **red**. Where the total fleet costs (NPV) were calculated to reduce (i.e. changes in insurance claims costs larger than all other costs combined), benefit-cost ratios were classified as **RoI** (return on investment) to identify safety measures likely to provide operators with a return on their investment by 2031.

Table 40: Estimated 12-year analysis period (2019-2031) break-even costs per vehicle (NPV), discounted payback periods and benefit-cost ratios (NPV) for the new build pedal application error [DIR] safety measure solutions

Safety Measure Solution	Break-Even Costs (NPV) (£)	Discounted Payback Period	Benefit-Cost (NPV) Ratio
Brake Toggling	101-151	2019-2019	**RoI**
Pedal Layout Standardisation	37-86	2019-2019	**RoI**
Improved Direct/Indirect Vision	64-89	2031+	**0.04-0.28**
Accelerator/Brake Lights	0-93	2031+	**0-0.23**
Accelerator Noise Conspicuity	101-151	2031+	**0.07-0.17**
Unintended Acceleration AEB	121-166	2031+	**0.02-0.04**

Table 41: Estimated 12-year analysis period (2019-2031) break-even costs per vehicle (NPV), discounted payback periods and benefit-cost ratios (NPV) for the retrofitted pedal application error safety measure solutions

Safety Measure Solution	Break-Even Costs (NPV) (£)	Discounted Payback Period	Benefit-Cost (NPV) Ratio
Brake Toggling	176-265	2020-2023	**18.3-RoI**
Pedal Layout Standardisation	N/A	N/A	**N/A**
Improved Direct/Indirect Vision	107-147	2031+	**0.03-0.26**
Accelerator/Brake Lights	0-159	2031+	**0-0.22**
Accelerator Noise Conspicuity	176-265	2031+	**0.07-0.18**
Unintended Acceleration AEB	N/A	N/A	**N/A**

Further information on the general approach adopted by the cost-benefit analysis may be found in 0.

14 Conclusions and Next Steps

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

14.1 Brake Toggling

Based upon the evidence reviewed, and the task analyses that underpin this short pilot study, the brake toggling solution has the potential to help improve safety. The brake toggling is designed to reduce the occurrence of pedal application error incidents by helping drivers to reinitialise their foot position and help build up muscle memory regarding the placement of the pedals. By helping bus drivers to build up a mental model of the location of the pedals the solution could help to avoid instances where a driver loses awareness of where each pedal is and therefore which pedal they are pressing. The solution was also found, in the pilot research, to be associated with relatively low levels of workload, meaning that it would be likely to have limited impact on the cognitive resources of drivers and their ability to perform driving tasks. The brake toggling solution was also found to be relatively intuitive and user friendly, which would help with its adoption amongst drivers. Previous research also supports the potential for the brake toggling system, with Wu et al. (2017) reporting that pedal application errors were more likely when drivers had previously had their foot on the accelerator rather than the brake pedal.

However, it is important to note that there are potential issues with the brake toggling solution. As it involves a change to the process of driving the bus it will require drivers to make changes to driving tasks that have become relatively ‘automated’ over time for them. As a result the introduction of such a system will require that drivers are trained on its use. A further potential issue relates to the fact that some bus drivers drive multiple routes with different buses. Requiring a driver to switch from a bus that has the brake toggling system to a bus that does not might cause confusion amongst drivers that could in turn create other, unanticipated safety issues. There is also room for improvement in terms of how intuitive and easy to understand the system is but this can likely be resolved through a more detailed training programme. On-going monitoring of the kinds of things measured in this pilot work (especially workload) within a properly designed evaluation framework would also be necessary to confirm and build upon the data collected in this small-scale pilot study.

14.2 Brake/Accelerator Light Indicator

As noted by the majority of drivers, the brake/accelerator light indicator solution is a simple and clear method for providing feedback to drivers regarding which pedal they are pressing, which could help drivers to recover from pedal application error incidents (again based on the evidence and task analyses done to underpin the pilot work). In the event of a pedal confusion incident a driver could use the light system to quickly determine that they are pressing the incorrect pedal, allowing them to quickly rectify their mistake and regain control of the bus. This solution was found to produce even lower levels of workload than the brake toggling solution in some cases, even in this small scale pilot, demonstrating that it would likely not be too taxing for drivers to use. Overall, the solution was deemed to be intuitive and user friendly by the drivers (more so than the brake toggling solution).

While there is potential for the introduction of a system of lights that indicate what pedal is being pressed to be effective, the feedback from drivers in the user trial suggests that the design may benefit from some changes. The lights on the A pillar have the potential to distract the driver, as well as posing the risk of confusing the driver when combined in the visual scene with other similar light sources such as traffic lights and brake lights. These issues would become especially problematic at night and any system of lights would need to adjust its brightness depending on the ambient lighting conditions, to avoid glare. The placement of the countermeasure on the A pillar does however have the advantage of not requiring the driver to completely look away from the road ahead. With regards to the lights on the LCD dash, a number of drivers pointed out that they struggled to see the light during daylight conditions. Drivers also stated that they used the LCD display to briefly check important safety information and using the screen to keep track of pedal usage could cause distraction by leading them to look away from the road for longer. These issues could be resolved by altering the position of the lights or by having one set of lights rather than two, and testing the usability of these options more thoroughly. A further issue with the lights is that some drivers may be colour blind, meaning that it be may be necessary to provide a further means of distinguishing the lights beyond their colour e.g. using different shapes or icons for when the brake and accelerator are being pressed.

Some manufacturers raised a concern that the drivers would ‘tune out’ the signal from the lights if it was on all the time, and giving them information that was not needed at that point in time. For example, the use of the brake pedal is not of concern, only the accelerator pedal usage is relevant. Also that the accelerator pedal indicator light is only needed at particularly high demands, to act as a warning to the driver. The specification was adjusted to require only the use of one light, and only over 80% demand from the driver. This was a pragmatic decision during a consultation meeting, since there is no specific evidence available to determine the level that should be used. There may also be benefits here for using a light that acts more like a warning of heavy accelerator usage, since it might encourage a smoother driving style overall. Using only one indicator light also simplifies the interface, and the technical implementation. If future monitoring reveals that further changes are needed, or even that more/different lights are needed then these can be implemented via the specificiation.

14.3 Other findings

One important factor to come out of the trial was the impact that driver styles and habits may have on the prototype systems tested in this trial and their effectiveness if implemented on buses. A large number of the drivers commented that they did not use gear ‘N’ when stopping at bus stops or while stopped in traffic, instead opting to remain in gear ‘D’. They also stated that this is a common practice amongst bus drivers. Any countermeasure introduced would need to be designed to be compatible with what drivers actually do, whether this is expected protocol (if this can be enforced) or not.

An important aspect of driving style that arose in the trial relates to the foot positioning behaviours of drivers, namely whether drivers tended to keep their foot in line with the pedals or tended to angle their foot across the pedals. This poses increased risk of pedal application error as it makes it easier for drivers to inadvertently press the wrong pedal, as well as compromising their awareness of where the brake and accelerator pedals are located. This practice also has the potential to limit the effectiveness of heel stops and other designs that could otherwise help drivers to distinguish between the accelerator and brake pedals. Driver training should account for differences in driver foot positioning by teaching drivers to maintain appropriate behaviour.

A further factor that arose during the testing was that some drivers would press the accelerator while the handbrake was still on, before releasing the handbrake and moving the bus. The purpose of this was to release the halt brake before releasing the handbrake in order to allow for a smoother pull away. Differences in driver behaviour are important to the implementation of systems that drivers must interact with as their effectiveness may vary between different driving styles. Different driving styles must therefore be taken into account when designing pedal application error safety systems.

A limiting factor for this trial was that the variations in the gradient of the track and the variable presence of other vehicles on the test route created substantial variation between the user trial runs, making it very challenging to draw comparisons between prototype and baseline modes. The variations in the gradient of the track meant that it was very difficult to find appropriate times to press the bus stop request button as the drivers were often covering the brake or using the vehicle's retarder/regeneration to slow the vehicle. Changes in gradient on the test track also meant that drivers may have been preparing to come off the accelerator and press the brake when the bus stop request button was pressed. The variable presence of other vehicles resulted in some of the user trial runs being clear of other vehicles whereas other runs features multiple other vehicles being present on the test route. These variations will have impacted the behaviour of the drivers. In order to fully test the effectiveness of the solutions at reducing pedal application error incidents and how drivers respond to them, further testing of the solutions is recommended with larger samples of drivers. This could involve carrying out road testing of the solutions in order to evaluate how they operate on London bus routes over entire driver shifts in different environmental conditions. This method would also allow for an exploration for how different driving styles impact on how drivers interact with the systems.

With regards to the practicality of the solutions, both the brake toggling and brake/accelerator light indicator solutions are simple in nature and have the potential to be retrofitted to buses in a relatively small amount of time and for a limited cost.

Based upon the findings of the pedal application error trial, the following conclusions and recommendations are made:

14.4 Conclusions

- Both the brake toggling and brake/accelerator light indication solutions have the potential to reduce pedal application error incidents from occurring

- Both of the solutions could be retrofitted to buses relatively quickly and cheaply
- The solutions produce relatively low levels of workload (although on-going monitoring of any deployed system would need to be undertaken to confirm this with a more robust sample)
- The brake/accelerator light indicator solution will require technical changes and further testing in order to improve its effectiveness and make sure that it does not distract drivers
- Some form of standardised training will be required to teach drivers how to use the solutions, in combination with clarity on expected protocol around gear use when stopped

14.5 Recommendations

- Carry out road testing with the brake toggling solution in order to evaluate how the system operates while used on London bus routes with a larger sample of drivers, and when expected (and unexpected) protocol around gear use is followed (unless expected protocol can be rigorously enforced)
- If the testing procedure carried out in this trial is to be repeated then it should be carried out in strictly controlled testing conditions
- Test different designs for the brake/accelerator light indicators in order to establish what the safest and most effective design is, as well as taking into account factors such as driver colour blindness:
    - Simulator-based eye tracking study to identify potential designs and distraction effects of these
    - Road testing with eye tracking to select final design
- Undertake testing in order to determine what type and the amount of training required for drivers to learn how to use the solutions safely
- Develop a standardised training programme that can be used to teach drivers how to use the solutions
- Instruct drivers of the importance of foot positioning and train them to avoid angling their foot across the brake and accelerator pedals

Finally, Table 42 provides a summary of the different solutions that might help to address the pedal application error problem. The brake toggling and brake/accelerator lights are the only measures that were evaluated in this trial. Standard pedal layout and accelerator noise conspicuity are planned. Improved visibility for the driver is covered separately in the vision measure. AEB logic for mitigation of unintended acceleration is planned for the future because it is dependent upon the successful implementation of AEB first.

Table 42: Implementation status of pedal application error safety measures in the BSS

#	Potential Solution	Error type addressed	Potential effectiveness	Status
1	**Brake Toggling**	Foot misplacement	Low	Evaluated in this trial; implemented in specification
2	**Brake / Accelerator Lights**	Late detection Recovery from error	Low	Evaluated in this trial; implemented in specification
3	**Standard pedal layout**	Foot misplacement	Low	Planning
4	**Improved direct/indirect visibility**	Foot misplacement	Medium	Evaluated as part of Direct/Indirect vision measure
5	**Accelerator noise conspicuity**	Late detection Recovery from error	Medium	Planning and partly implemented in specification
6	**AEB – Unintended Acceleration**	Recovery from error	High	Dependent upon findings of AEB trials and subsequent implementation of AEB

The measures for pedal application error that have not yet been addressed also have some associated recommendations for future research or implementation planning:

- Research is needed to support the implementation of a standardised pedal layout, which could take the form:
  - Define the problem; survey of drivers to define what they report as problems with current pedal designs, if any.
  - Technical feasibility of a standardised pedal layout between manufacturers
  - Human factors evaluation of different layouts
  - Trials to evaluate prototype layouts with drivers' input.
- Some aspects of the accelerator noise conspicuity measure have been initially specified, but there is further research needed to define:
  - Field measurements of sound levels within the driver's cab and downstairs saloon to define the baseline noise levels
  - Evaluation of whether drivers can determine the change of acceleration of the vehicle from acoustic cues
  - Development and test of a prototype
  - Evalation of driver and passenger acceptibility
- AEB as a system is not yet implemented on buses, and this will take a few more years to achieve. During this development there is an opportunity to be considering the desire for unintended acceleration detection logic to be designed in to the system. Research into the implementation on cars will be a useful input.

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Appendix 1 General cost-benefit analysis approach

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

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

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

(Equation 1)

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

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

(Equation 2)

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

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

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

(Equation 3)

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

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

Claims costs reductions for each year of the analysis period were calculated by combining average insurance claim costs (calculated from operator provided data), with the expected annual changes in incidents for each outcome severity (Equation 4). For the purposes of this report, claims reductions for fatalities was assigned a range of £35,000-45,000, seriously injured casualties assigned a range of £60,000-70,000, slightly injured casualties assigned a range of £6,000-8,000, major damage-only collisions assigned a range of £4,000-5,000 and minor damage-only collisions assigned a range of £1,000-2,000.

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

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

(Equation 4)

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

$$Break\ Even\ Cost = Monetised\ Casualty\ Reduction / Total\ Number\ of\ Buses\ Fitted$$

(Equation 5)

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

$$Benefit - Cost\ Ratio = \ Monetised\ Casualty\ Reduction / Total\ Cost$$

(Equation 6)

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

The Transport for London Bus Safety Standard: Pedal Application Error Prevention & Recovery

Abstract

Pedal application error is the process whereby a driver unintentionally presses the wrong pedal, for example pressing the accelerator pedal when itending to press the brake pedal. When a driver mistakenly presses the accelerator pedal instead of the brake pedal this can lead to an unintended acceleration of the vehicle, which has the potential to cause serious injury and damage. Although pedal application error is a rare event, the potentially severe consequences justify attempts to investigate safety solutions that can prevent pedal application error from occurring. This study involved testing two pedal application error safety systems: a brake toggling solution that was designed to prevent foot misplacement (and subsequent pedal application error) from occurring in the first place and a set of brake and accelerator lights that aimed to help drivers recover from a pedal application error event. A New Route Master type bus was fitted with the pedal application error safety solutions and tested on a test track, with driver behaviour and attitudes using the solutions compared to behaviour and attitudes when driving without the solutions. A total of ten experienced London bus drivers were tested. The results revealed that the majority of drivers believed that the solutions could help to improve safety, were highly effective and were easy to use. Analysis of workload data revealed that the solutions added minimal levels of workload to the driving tasks, indicating that the solutions are unlikely to interfere with a driver’s ability to carry out their daily driving tasks. However, due to the relatively small sample size and the rarity of pedal application error events it is hard to draw conclusions on the ability of the solutions to prevent pedal application error from occurring in the real world. It is recommended that further on-road testing be carried out on the pedal safety solutions in order to further investigate their design and understand how they can be implemented to reduce incidents.

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