THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR982

The Transport for London Bus Safety Standard: Runaway Bus Prevention

Evaluation of Safety Measure

Kolby Pistak, Tom Hyatt, Ryan Robbins, Phil Martin, Alix Edwards

Report details

Report prepared for:	Transport for London (TfL)		
Project/customer reference:	tfl_scp_001593		
Copyright:	© TRL Limited		
Report date:	31/07/2022		
Report status/version:	Version 1.1		
Quality approval:			
Anna George (Project Manager)		Shaun Helman (Technical Reviewer)	

Disclaimer

This report has been produced by TRL Limited (TRL) under a contract with Transport for London (TfL). Any views expressed in this report are not necessarily those of Transport for London (TfL).

The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) and TCF (Totally Chlorine Free) registered.

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.1	31/07/2022	Corrections to Table 1 Added reference to TfL for latest specification in the executive summary and recommendations Appendix 6 retitled to park brake system checklist	AE	PSM & DH

Executive Summary

Bus Safety Standard (BSS)

The Bus Safety Standard (BSS) is focussed on vehicle design and safety system performance and their contribution to the Mayor of London's Transport Strategy. This sets a target to achieve zero road collision deaths involving buses in London by 2030 and zero Killed and Seriously Injured (KSI) by 2041 across the whole road network.

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.

Runaway bus prevention

Runaway bus prevention systems can be described as Driver Assist systems, designed to help the driver to avoid or mitigate the severity of incidents. In rare circumstances runaway buses can occur. These are exceptional occasions where the driver leaves their seat without properly applying the park brake and the bus subsequently rolls away. These incidents are very rare but carry a risk of very severe outcomes.

The research for this safety measure included task analysis and interviews with drivers about the extreme circumstances that might lead to a runaway incident. This analysis was used to generate a checklist of conditions whereby the bus should not roll away.

The cost-effectiveness of the runaway bus prevention system was assessed throughout this project. The technical feasibility, target population, effectiveness, fleet fitment rate and costs associated with implementing the system as a requirement of the Bus Vehicle Specification were established, whilst the cost-effectiveness and casualty saving benefits were also calculated. The system was included in the Bus Vehicle Specification in order to reduce risk of the rare, but potentially catastrophic, incidents.

The BSS will require a system of interlocks to prevent the bus rolling away if the driver leaves their seat without properly applying the park brake. The checklist is used to assess the performance of the runaway bus prevention interlocks. The performance checklist was developed to be an effective, reliable and valid tool by which the performance of a runaway prevention system can be assessed. It focuses on the outcomes of a system's functions (i.e. under what circumstances can a bus runaway), not the specifics of the engineering solution used by the system, which will allow for a range of future systems to be compared and allow for future innovation.

The checklist was applied to a single sample prevention system and though the system has been designed to be robust in that it focuses on using the root causes of runaway situations as triggers, it is possible that further refinement of the checklist could be achieved if it were tested on a wider sample of prevention systems. This may reveal other emergent scenarios that could occur which were not obvious during the initial testing however as of now it covers all known situations that could lead to a runaway bus.

Table of Contents

1 Introduction to the Bus Safety Standard (BSS)

1.1 The BSS

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

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

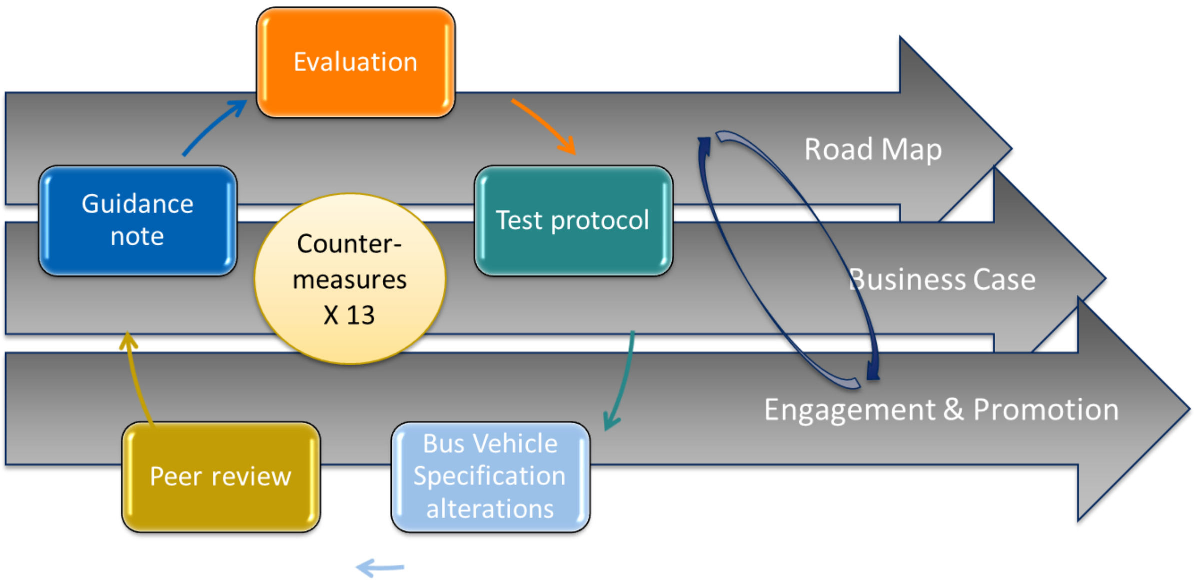


Figure 1: Summary of the BSS research programme

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.

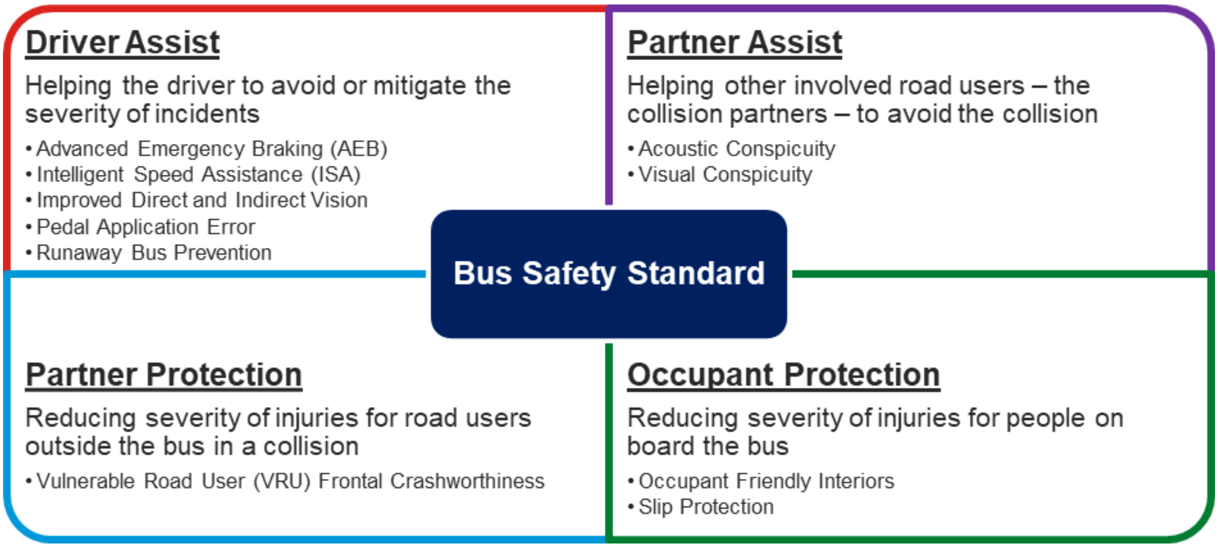


Figure 2: Bus Safety Measures

1.3 Runaway Bus Prevention

The focus of this report is on runaway bus prevention, which is a driver assistance system designed to help the drivers to avoid incidents. Runaway bus incidents occur if the driver has accidentally left the park brake off, and the bus rolls without the driver being in control. These are very rare incidents, but carry a high risk of severe outcomes.

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 The casualty problem for runaway buses

The cause of a runaway bus is a driver exiting the cab without correctly applying the park brake. The seriousness of the event can be increased should the door to the cab shut behind the driver and they do not have a key to the cab on their person, preventing them from entering the cab and resuming control.

There are numerous factors which can increase the likelihood of a driver failing to apply the brakes correctly. These include, but are not limited to:

- Distraction
- Fatigue
- Inattention
- Workload / time pressure
- Intentional violation of correct procedure

Stats 19 is the UK Department for Transport's TfL's main road casualty data source, however it is limited to public roads. Some runaway bus incidents occur in depots, so it is important to use bus operator incident data for analysis of the casualty problem resulting from runaway buses.

TfL's IRIS database collects reported incidents from Bus Operators. There is no specific field for identification of runaway bus incidents; however, there is a text description field. The keyword 'rolled' was used to identify the incidents and this returned about 950 cases. The vast majority were not runaway, but simply where the driver was in place, had released the brake and rolled forward/backwards into a vehicle, or another vehicle had rolled into the bus.

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%

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

These 950 incidents were then manually reviewed to find the ones where the driver was moving from the driving position (e.g. standing up, leaving the bus, etc.), this returned 54 cases (the characteristics of which can be seen in Appendix 5). The data shows that these events to be relatively unusual with a frequency of approximately 17 per year as shown in Figure 1.

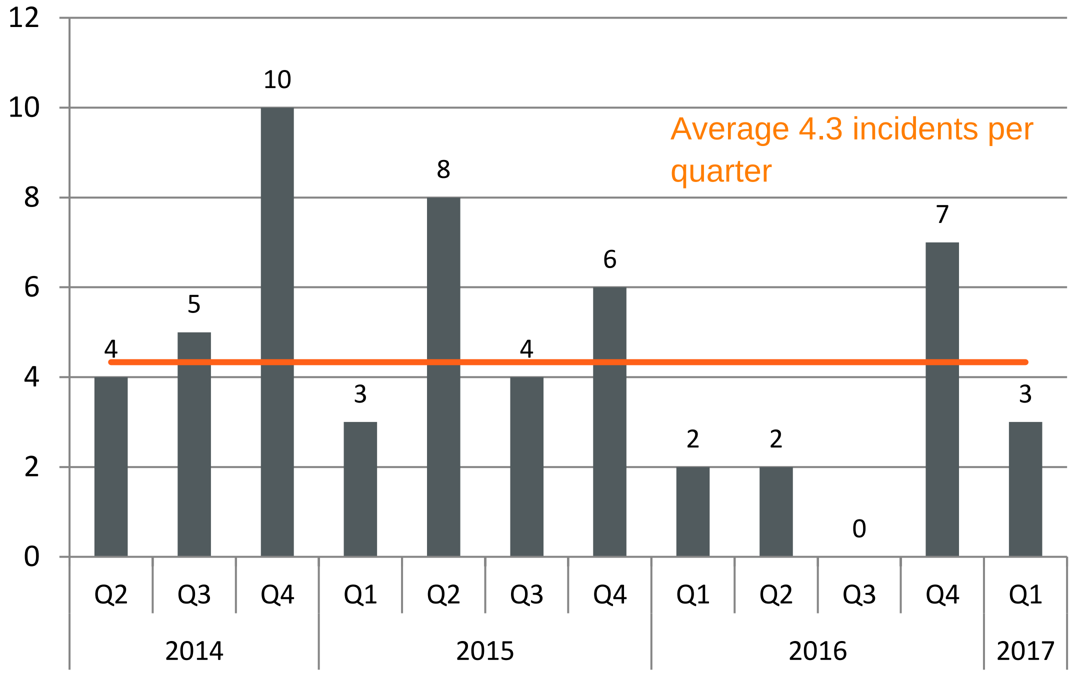


Figure 1: Runaway bus incidents reported in IRIS data (April 2014 to March 2017) reported by quarter

Of these incidents, the majority reported no bus damage (47 cases, 87%). There were three cases with major damage (6%), and four cases with minor damage (7%). There was only one case with a reported minor injury, where, during a driver changeover, the next driver fell on the floor and hurt their leg. During the time period specified in Figure 3 a and b there were no other reported injuries. These figures cover some but not nearly all incidents that occur in bus garages as that is private land, however we have been informed of these sort of incidents that have occurred in operator garages - of the 54 reported cases, 4 occurred in bus garages (7.4%). If a single runaway bus incident were to occur in a live-road situation where the driver was not able to regain control of the bus in time (whether because they either can't get back to the controls in time or can't get into the cab) it would pose a significant risk not only to pedestrians, other road users and the general local environment, but to the bus passengers as well. There is no formal reporting of runaway buses in Stats 19, so it's not possible to compare London's incidents against the rest of Great Britain.

Because of the lack of specificity in the data classification, statistical sources have proven to be of limited value in identifying the detailed circumstances of the incidents, which is important for understanding both causes and solutions. Anecdotal evidence from a variety of stakeholders reveal, going back many years there have been occurrences where buses moved while the door was open and passengers were boarding or alighting. This would either be because the park brake wasn't applied and the bus accidentally moved or because the driver started moving off without yet having closed the door and passengers still tried to get on or off. To solve this problem, the 'halt brake' was introduced. This system ensures that the brakes are automatically applied whenever the passenger doors are open. However, it has been suggested that the introduction of the halt brake has meant that some drivers have fallen out of the habit of applying the park brake at bus stops, which therefore increases the potential for runaway bus incidents. Runaway buses are not something that have so far had a massive negative impact on the bus industry, but have the potential to in the future and so in this situation a course of pre-emptive action could be considered best practise.

Examples of incidents that might occur include:

- Door entanglement: Driver stops and opens door but doesn't apply park brake (halt brake active). The driver gets out of the seat to investigate commotion at the middle door. On arrival discovers a passenger that has been trapped by the opening door. Applies the local manual door close over-ride to release the passenger, at which point the halt brake releases and the bus rolls away with driver on the vehicle but not in their seat.
- Driver exit: Driver stops, opens doors and shuts down the bus at the end of shift without applying the park brake. Driver exits the bus and closes the doors from the outside. Later on the halt brake releases and bus rolls away.
- Breakdown: The bus breaks down; bus staff try to recover the bus but it won't move. Staff conclude that the bus can't be moved because of one of the interlocks from the passenger doors is holding the vehicle in place so close the passenger door to release the brakes. The bus then start to roll towards them and they can't get back in to stop it, the bus continues to roll until it hits something or comes to a natural stop.
- During Bus Checks: At the beginning of the day the driver comes to do their check before they take the bus off the yard. The air pressure in the brakes is low so the bus brakes are engaged even if the park brake isn't. The driver turns on the bus engine not realising the park brake in the bus isn't on. While the driver is walking around doing their check of the bus the air in the brake system is increasing because the engine is on. While the driver is out of the cab conducting their vehicle checks the air in the brake system reaches the level where the brake system is released. Because the park brake was not engaged by the driver, the bus then starts to roll.

A literature search was conducted to try and establish the breadth of the problem that runaway buses potentially pose aside from the reported figures. Numerous databases were utilised and various relevant search terms were used as shown in Table 2; however, none of them resulted in any pertinent papers or studies being found. This is likely due to the rare nature of the incidents.

There are a few accounts in the media of similar incidents, the most pertinent of which is London Marylebone at which it is reported, based on eye-witness testimony and dash cam footage, that a bus rolled from Grand Central Street onto Marylebone Road without a driver in the cab. The driver managed to get back into the cab and regain control of the vehicle before there was any impact with infrastructure or other road users (Chaplain, 2017). A brief internet search also revealed similar incidents reported in Tamworth (2017), Swindon (2016) and Lisburn, Northern Ireland (2014). It should be stressed that these are reports of isolated near-miss incidents, the details of which are not reported scientifically however one might reasonably expect that, without sutiable measures being implemented sooner or later one of these types of events could be significant. Because of the way these near misses have be reported they do not provide a robust picture of likelihood of occurance however learning from near-miss events can help prevent less frequent potentially high profile runaway bus incidents.

Table 2: Relevant Literature Search Results

		Database					
		Science Direct	Taylor & Francis	CORE	BASE	Google Scholar	TRID
Search Terms	"Runaway bus"	0	0	0	0	0	0
	"bus" AND "runaway"	0	0	0	0	0	0
	"bus" AND "roll"	0	0	0	0	0	0
	"bus" AND "uncontrolled"	0	0	0	0	0	0
	"bus" AND "brakes"	0	0	0	0	0	0

One of the significant challenges of developing a method of evaluating solutions was to ensure, in the absence of substantial quantities of detailed incident data, that the solutions required would be effective in all possible permutations of driver actions and vehicle status.

3 System definition

There are two main solutions for preventing runaway buses: driver training and the use of a preventative technology.

3.1 Improving driver performance – training

Training could be used to achieve two purposes, namely improving driver use of the park brake when stationary, and educating drivers in how to respond to a runaway bus.

To improve driver performance with regards to appropriate brake use, an inspection of the current training materials and syllabus could be conducted. This would look for evidence of how drivers are instructed to use their brakes before leaving the cab, the circumstances under which they might have cause to do so, and the appropriate response to a runaway bus. The results of this task could then be used to recommend improvements to the training programme. Noted human factors expert James Reason states that there are two approaches to error management: the 'person approach' and the 'system approach'. The person approach aims to cure the fallibility of the individuals whereas the system approach aims to create systems that are robust enough to withstand any errors the operators may make; driver training would be an example of the former. The issue with taking the person approach is that by focusing on the individual origins of error it isolates unsafe acts from their system context. As a result, two important features of human error tend to be overlooked. Firstly, anyone can make an error. Secondly, far from being random, mishaps tend to fall into recurrent patterns. The same set of circumstances can provoke similar errors, regardless of the people involved. The pursuit of greater safety is seriously impeded by an approach that does not seek out and remove the error provoking properties within the system at large (Reason, 2000). This then suggests a more system focussed approach would be more effective at preventing potential run away buses as it can focus on the recurrent error patterns and circumstances which surround them.

3.2 Improving vehicle performance – technology

Technologies already exist in the market place that the manufacturers claim will eliminate the occurrence of runaway buses. An off the shelf example of a runaway bus prevention system was identified and inspected for its functionality. This system applies the brakes when the driver exits the cab and delivers an audible alert designed to make drivers aware that they are exiting the cab without the brakes being applied correctly. There are also optional alarms that just provide warning to the driver when they are exiting the cab if they have not engaged the park brake. This specific system provides both auditory and visual warning to the driver and is only silenced once the park brake is applied. This would reduce the chance of a runaway bus event occurring however it wouldn't eliminate it entirely as the system still relies on the driver to hear/ see the alert and then engage the hand brake and, as noted by Reason (2000), "humans are fallible and errors are to be expected". What this means in practice is that even thought a warning system reduces the chances of a runaway bus, there is the potential for the driver to miss the warning regardless of how loud or bright it is and to still exit the cab without the park brake being engaged. According to Reason (2000) countermeasures should be "based on the assumption that though we cannot change the human condition." In this case it is possible to remove the potential for human error entirely by identifying the conditions that cause the error (taking a system focussed approach) and then ensuring the system automatically applies the park brake (if the driver forgets) to ensure no run away incidents occur.

The sample runaway bus prevention system has been subject to VCA inspection for a N3 category tractor unit. There is a technical note in Appendix 1 that describes the implications for fitting such a third-party system to a bus braking system. It is very important the bus manufacturers and operators are aware of these implications. Fitting a third party system without the relevant approvals in place might invalidate the warranty and/or compliance of the brake system, leaving the operator exposed to unanticipated risk.

Prevention technologies could be delivered through two routes; they could be fitted by bus manufacturers at the build stage, or retrofitted to existing buses using an aftermarket system. Any retrofit system that is implemented into an air brake system must be carefully implemented in order to maintain compliance and warranty (see Appendix 1 and Appendix 3 for technical notes), and achieving this can take manufacturers some time.

An alternative is to build the logic for runaway bus prevention into an electronic park brake. The two main brake system suppliers to the commercial vehicle market are both currently developing electronic park brakes as an option. This provides the bus manufacturer an opportunity to develop the logic for all the various interlocks on the doors and brakes to implement the halt brake systems currently being offered on buses. It also provides a means for them to develop the runaway bus prevention logic directly into the bus, without having to have a third party after-market system. Since these electronic park brake systems are undergoing development it has not been feasible to test this implementation as part of this research. However, early sight of the procedure and requirements developed in this research should help to ensure that bus manufacturers can collaborate with the brake system suppliers to achieve the required performance.

4 System performance

The effectiveness of a training-based solution is difficult to predict. Given the infrequency of runaway bus incidents, and the likelihood that the present training requires drivers to use their brakes appropriately, the gains from a training-based solution may only be slight.

The trial (section 6) has indicated that it is feasible to drastically reduce the occurrence of a runaway bus through a technological solution. This could be via an aftermarket system such as the sample runaway bus prevention system, or through incorporation into new-build buses by manufacturers. It is not realistic to expect that 100% of runaway buses could be prevented because it remains possible that some extremely unusual set of circumstances and actions might combine to produce a runaway bus; however, it should be possible to prevent the vast majority of incidents and scenarios that we are currently aware of.

5 Existing standards and test procedures and their suitability for buses

TRL has previously delivered research to generate a vehicle checklist that defines functionality. For example, the In-Vehicle Information System Checklist (Stevens & Cynk, 2011) was developed by TRL and is widely applied by the motoring industry to assess the suitability of in-vehicle technologies for driver use. We applied our proven methodology for the development of scales to the creation of the performance checklist for runaway bus prevention.

6 Development testing for the BSS

The research carried out prior to the trial suggested that a training solution would be less effective than the technological solution (which can offer an intervention to prevent the incidents); therefore TfL decided not to proceed with this aspect of the research. A summary of the evaluation of driver training versus the technological solution can be seen in Table A2.1, in Appendix 2.

The research effort was focussed on the development of a performance checklist which can be used to assess the performance of any current or future runaway prevention system (Appendix 8). This will allow TfL and operators to assess the efficacy of such systems against pre-determined criteria before investment.

The development of this checklist comprised two stages. Stage 1 developed a draft checklist based on a hierarchical task analysis (HTA), direct observation of a test bus, and expert interviews. During Stage 2 this draft performance checklist was then applied to a test bus by a researcher in order to refine and finalise the checklist based on its comprehensiveness and usability. This stage 2 researcher was unaware to the project approach and aims, and how the checklist was developed, in order to provide independent review.

6.1 Stage 1 – Developing draft performance checklist

6.1.1 Purpose of test

Stage 1 was conducted to gain an understanding of the issues which relate to the occurrence of runaway buses and to use that understanding to develop a draft checklist to assess the performance of any runaway prevention system (*performance checklist*).

6.1.2 Test methodology

Firstly an HTA was conducted at TRL from the researcher's initial knowledge of bus operation and what they surmised would be reasonable procedural steps when starting and parking a bus in a yard at the beginning and end of a route. This was done in an attempt to clearly identify the different task elements that would be key to observe closely during the subsequent visit to the bus depot (Appendix 1). This guided both the initial development of the draft checklist, and was used to successfully identify areas where clarification or elaboration was required from drivers who had experience using and maintaining buses.

Secondly, a visit to a bus depot of Operator B was conducted where a bus with a sample system was inspected. During this visit the HTA was compared with direct inspection of the sample system, and input from interviews from bus drivers.

The draft checklist was developed based upon analysis of the findings gathered during the visit.

6.1.2.1 Interviews with bus drivers

Three bus drivers were interviewed. Each bus driver took part voluntarily and was interviewed away from management in a private room with the researchers to invite more open dialogue. To further this invitation of open dialogue each participant was assured all comments they made would be kept confidential. Each interview followed a standard set of questions that allowed for elaboration wherever drivers felt it was relevant. The interviews addressed three main areas:

- What they would expect from a system designed to stop runaway buses
- Places where they could see the possibility for the current safeguards against runaway buses to fail
- Any experiences they had had (either personally or anecdotally) with runaway buses in the past.

Each interview lasted between 10 and 20 minutes depending on how much each driver had to say. Prior to the start of each interview, all drivers were given the same information sheet to read and then given the same scripted explanation of what exactly the interview would entail. If participants agreed to take part, they were given a consent form to sign and the interview was recorded from that point onwards. Just to reaffirm their consent, participants were asked to verbally reiterate it on record before the interview commenced. At the end of the interview each driver was thanked for their time and reassured that all answers they had given, as well as their identities, would remain completely anonymous in all subsequent reporting.

6.1.2.2 Bus inspection

An experienced driver was present during the inspection of the bus. This was to answer any questions the researchers had about the operation of the bus in practice and what factors in their experience would activate the system. The researchers applied the HTA to explore a range of circumstances which could lead to a runaway bus (e.g. driver exiting the cab without applying any brake) to investigate how the system would respond, and to identify any gaps in the HTA. The driver was also invited to suggest circumstances where a bus might roll away.

6.1.3 Testing details

The interviews were conducted in a vacant office of Operator B. The only individuals present during the interviews were the bus driver (interviewee) and the two TRL researchers (interviewers). The inspection of the sample runaway prevention system (installed on one bus) took place in Operator B's secure bus garage parking area. An outdoor paved area was used to allow the researchers plenty of space to inspect the bus in its entirety.

The interviews were recorded for transcription. Researchers manually recorded key information that was provided throughout the interview. In addition to this, an interview schedule was followed to maintain a semi-structured framework.

The three individuals who were interviewed were drivers from Operator B's staff who volunteered their time during their break between shifts to take part in the research.

One of the also volunteered to accompany the researchers on their inspection of the bus fitted with the sample runaway bus prevention system.

Transcripts of the interview recordings were produced and a thematic analysis of responses was completed to identify relevant themes and other data pertinent to the design of the draft checklist.

During the visual inspection of the sample runaway bus prevention system notes were taken against the HTA with the purpose of guiding the design of the draft checklist.

6.1.4 Checklist generation

Following the site visit the data collected were used to draft a checklist for the assessment of any candidate runaway prevention system. This checklist was designed to allow for the reliable and objective assessment of the circumstances under which a system would succeed, or fail, to prevent the bus moving. The checklist comprised a range of vehicle state combinations into which the bus would be configured to assess whether it would roll away..

6.2 Stage 2 – Applying and refining draft performance checklist

The draft checklist was administered by a new researcher who was unfamiliar with the project. This had two aims; first to assess the quality of the checklist, and second to assess how useable it would be to someone with no prior knowledge of its application. The new researcher applied the checklist to a vehicle currently fitted with an example system to stop runaway bus incidents and examine how it worked first hand. This was to ensure that the final checklist that was subsequently developed took into account all the relevant factors that could affect such a system when implemented in a real-world situation.

This checklist comprised a number of vehicle state combinations into which the bus would be placed to assess the degree to which it would roll away.

6.2.1 Method

Following the output of Stage 1 (bus driver interviews and task/error analysis) and the development of a performance checklist, two researchers made a site visit to a bus garage in London. One researcher was there to make notes and observations on the implementation of the checklist but took no part in the actual testing; the other was there solely to undertake the testing as an individual with no prior knowledge to determine the effectiveness of the checklist. Upon arrival, the researchers spent 15 minutes confirming the combinations of bus states to be trialled and tested. The bus driver was verbally briefed.

The researcher with no prior knowledge spent the next 45 minutes working through every possible bus state configuration (with the prevention system active). During the testing it became clear there were other relevant combinations of states that hadn’t previously been considered. These combinations were added to the testing on an adhoc basis as it became clear, either through the results of other tests or from expert (driver) feedback, that they were potentially relevant to the testing or runaway situations. The testing concluded with two lists: a worked-through performance checklist and a modified checklist with additional combinations tested on the day. After the testing was completed, both researchers discussed the results and how best to formally record the testing procedure that had been conducted. This was required because of the emergent bus state combinations that only became apparent during testing. Any additional questions that were thought of were then put to the bus driver who helped with testing, and any other parties whose input was required (including the engineering and maintenance division) were contacted to discuss. Following this, the bus driver was fully debriefed with an explanation of the test purpose, and was thanked for their time.

Prior to each combination being tested the bus was reset to neutral gear, with the parkbrake on and all doors closed. The bus would then be put into the state required for the test that was being carried out; the performance indicator assessed when applying the checklist was defined as whether the bus moved from a stationary position without driver input or control. ‘Moving off from a stationary position’ was defined as uncontrolled movement, in any direction. This was assessed after each one of a list of specific combinations of pre-determined actions e.g. driver seat pressure (yes/no), driver cabin door (open/closed) etc. were set; Table 3 shows the refined performance checklist. Each state was tested three times to ensure reliability of results. The tests were conducted on ground with a slight slope (with the bus facing down-slope) to ensure if the bus was not being held stationary by any mechanisms the resulting rolling action would be obvious to the researchers. After each test the bus’s physical position on the sloped ground was reset.

6.2.2 Testing conditions

Testing was performed in a secure bus garage parking area. An outdoor paved area was used to allow the bus ample space to manoeuvre and ‘runaway’ in a safe and controlled environment.

6.2.3 Test vehicles and parts

The testing phase involved the use of an in service standard double-decker London bus fitted with an aftermarket runaway prevention system.

6.2.4 Test equipment

The only test equipment used was a copy of the draft checklist.

6.2.5 Driver and participant sample

The testing did not involve any external participants, although it was carried out using two researchers (TRL) and an experienced bus driver from Operator B. The researchers conducted the testing with the driver operating the bus (putting the vehicle into various states, instructed by the TRL researchers).

6.2.6 Data analysis methods

Notes were taken regarding the implementation of the checklist and these were used to design its final version.

6.3 Validation of checklist against current system

Testing of the performance checklist developed during Stage 1 allowed for reliable refinement and validation during Stage 2.

Initially, the bus was tested with the handbrake on, which showed no movement (as expected). Therefore, subsequent actions were performed/tested with the handbrake off. There was one key combination of states which was found to activate the sample runaway prevention system: the drivers' cab door had to be open AND there had to be no seat pressure. This was true when the engine was both on (gear: drive, neutral, reverse) and off (gear: neutral)[1]. All other combinations e.g., seat pressure + drivers' cab door open, did not activate the brakes automatically to prevent a 'runaway bus' situation (combinations including driver seat pressure present were tested in the event that the driver was in the seat and incapacitated in which case a runaway bus incident could still occur). In addition to the braking system, testing found that the bus would not roll away when the engine access or rear exit door(s) were open[2] as a result of the halt brake. The bus would also come to a controlled stop if the air brake pressure tanks fell below 6-bar.

The checklist shows a number of states for various active elements of the bus (e.g. rear door open or closed, driver sitting in seat or not). If the bus rolls in any of the specified conditions, then the test is failed, the test is passed if the bus does not roll in any of the specified conditions. This method of assessment gives rise to a simple 'pass/fail' outcome; every runaway prevention system would need to fulfil all the criteria. This list can then be used to determine if a piece of bus safety equipment designed to stop runaway buses is of sufficient quality that it could be put onto a working public bus[3].

[1] It is not possible to place vehicle in drive/reverse when engine is off.

[2] Not related to sample runaway prevention system.

[3] There is also an additional checklist to ensure that the installation of the runaway prevention system does not affect the basic function of the bus (Appendix 6)

Table 3: Runaway bus prevention system checklist

Runaway Bus Prevention			General Braking Mechanisms		Expected Outcome	Actual Outcome	Outcome match? (Yes=1, No=0)
Drive enabled (Is the bus "on"?)	**Gear**	**Seat Pressure**	**Park Brake**	**Passenger Door**			
No	Neutral	Yes	Off	Open	No roll		
No	Neutral	No	Off	Closed	No roll		
No	Neutral	Yes	Off	Closed	Roll		
Yes	Neutral	Yes	Off	Open	No roll		
Yes	Neutral	No	Off	Closed	No roll		
Yes	Neutral	Yes	Off	Closed	Roll		
Yes	Reverse	Yes	Off	Open	No roll		
Yes	Reverse	No	Off	Closed	No roll		
Yes	Reverse	Yes	Off	Closed	Roll		
Yes	Drive	Yes	Off	Open	No roll		
Yes	Drive	No	Off	Closed	No roll		
Yes	Drive	Yes	Off	Closed	Roll		
					Total		
					Required Score		12
					Outcome		

6.4 Additional functionality

It is suggested that any system implemented to prevent the occurrence of runaway buses has an auditory component. The goal would be alerting the driver that the bus was left in a vulnerable condition, and to remind them that the park brake should be applied. This is suggested as an additional warning on top of the brake intervention and not as a possible solution in isolation. This is because the alert by itself might reduce the chance of the bus being left in a condition that might allow it to roll away, but it is still reliant upon driver action and doesn't eliminate the problem. We suggest using an auditory warning instead of a visual warning, because might not be looking in the direction of the light whilst exiting or having exited the cab. An audible warning will be detectable by the driver in a greater range of positions/orientations.

The suggestion made for the audio characteristics of the sound come from an as yet unpublished report on blind spot safety systems for HGVs and are as follows: "Audible warnings shall have a minimum output of 75dBa or, where integrated in the vehicle at point of manufacture, 15dBa above ambient noise in the cab (measured 200mm forward of driver headrest at mid-point of seat fore/aft adjustment and c.25 degrees seat back angle) with engine at cold idle" (TfL, Unpublished). We recommend using a speech warning comprising of less than 6 words, which takes less than 2 seconds to complete. The warning should cease automatically within 1 second of the park brake being manually applied by the driver (TfL, Unpublished).

7 Cost-benefit analysis

7.1 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 runaway buses prevention measure are presented in Table 4 below. Target populations were calculated for bus occupants and damage to buses (there were no recorded casualties for other road user groups). All data was abstracted from the IRIS database from the period April 2014 to March 2017. See Section 2 for further information on target population calculations.

Table 4: Estimated average annual target population in 2018 for runaway bus prevention [RUN] safety measure solution

Casualty Type	Outcome Severity				
	Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage
Bus Occupants	0	0	0.33	-	-
Damage-Only	-	-	-	1.0	1.33

7.2 Estimates of effectiveness

The overall effectiveness values estimated for all outcome severities relevant to the runaway bus prevention measure (fatal, serious and slight casualties; major and minor damage-only collisions) are presented in Table 5 below. It was assumed that compliance with the runaway prevention measure checklist will result in the elimination of all driver-error related incidents, therefore, it will be 100% effective at preventing casualties and damage caused by runaway buses. As this safety measure aims to only prevent the runaway bus collision from occurring in the first place, not mitigate its consequences, it was assumed that these overall effectiveness values would apply to the prevention of casualties only.

Table 5: Estimated overall effectiveness ranges for casualties prevented by the runaway bus prevention [RUN] safety measure solution

Casualty Type	Incidents Prevented				
	Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage
Bus Occupants	100%	100%	100%	-	-
Damage-Only	-	-	-	100%	100%

7.3 Fleet fitment and implementation timescales

Timescales were determined for both the retrofit and new build runaway bus prevention measure solution to develop fleet fitment and policy implementation roadmaps for each solution (Table 6). These timescales were determined based on stakeholder consultations with bus manufacturers for first-to-market timescales and TfL for the proposed timescales for policy implementation. Bus operators and suppliers contributed to establishing the estimates for current levels fleet fitment and expected years to full fleet fitment after implementation for each solution. Please see the associated stakeholder consultation report for further information on stakeholder feedback on fleet fitment and policy implementation timescales.

Table 6: Fleet fitment and policy implementation timescales for both the retrofit and new build runaway bus prevention [RUN] safety measure solution

Safety Measure Solution	First to Market	Date Policy Implemented	Current Fleet Penetration	Full Fleet Adoption (yrs)	
				Retrofit	New Build
Runaway Buses	2019	2021	0%	2	12

7.4 Casualty benefits

The Tables below summarise the estimated total change in the number of incidents and collisions expected in London during the period 2019-2031 by specifying the performance of new build (Table 7) and retrofit (Table 8) buses for the runaway prevention measure solution. These outcomes are then monetised to estimate the total value of these casualty reduction benefits to society.

Table 7: Estimated total change in number and value (NPV) of incidents over the 12-year analysis period (2019-2031) for the new build runaway bus prevention [RUN] safety measure solution

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
Runaway Buses	Bus Occupants	0	0	2.0-2.1	-	-	0.03-0.03
	Damage-Only	-	-	-	5.9-6.2	7.8-8.3	0.03-0.04
	Totals	**0**	**0**	**2.0-2.1**	**5.9-6.2**	**7.8-8.3**	**0.07-0.7**

Table 8: Estimated total change in number and value (NPV) of incidents over the 12-year analysis period (2019-2031) for the retrofit runaway bus prevention [RUN] safety measure solution

Safety Measure Solution	Casualty Type	Number of Incidents (n)					Value (NPV) of Incidents (£M)
		Fatal Casualties	Serious Casualties	Slight Casualties	Major Damage	Minor Damage	
Runaway Buses	Bus Occupants	0	0	3.8-4.0	-	-	0.06-0.06
	Damage-Only	-	-	-	11.4-12.0	15.1-15.9	0.07-0.07
	Totals	**0**	**0**	**3.8-4.0**	**11.4-12.0**	**15.1-15.9**	**0.13-0.13**

7.5 Cost implications

The costs of runaway bus prevention solutions as part of the bus safety standard can be divided into five key cost categories based on:

- Differences in development, manufacturing and certification costs
- Differences in implementation and installation costs
- Differences in ongoing operational costs
- Differences in insurance claims costs
- Differences in environmental and infrastructure costs

Based on the outcomes gathered from the stakeholder consultation, the cost range for a retrofit solution was estimated to be £1,300 to £2,000 per bus. The cost for a new build system was estimated as £1,050 to £1,600 per bus. If an electronic park brake were used the costs might vary, but were unavailable at the time of writing.

The costs of installing retrofit systems were estimated at £100-£480 per bus (0.5-1 person-days), normal bus training should cover driver training costs. These figures were also gained through the bus operator stakeholder consultation.

Finally, the operational costs were estimated at the bus operator stakeholder consultation to be between £200 and £400 per bus for replacement costs for new parts per year.

The annual changes in incidents may be used to estimate the changes in insurance claims costs that may be expected by implementing a compliant runaway bus prevention system across the fleet. Changes in the costs of insurance claims are highlighted below in Table 9 for new build solutions and Table 10 for retrofit solutions.

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

Please see the stakeholder consultation report for further information on both development and operational cost calculations.

Table 9: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the new build runaway bus prevention [RUN] safety measure solution (cost reductions are shown in (parentheses))

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NPV) (£M)
Runaway Buses	Change in Technology Costs	982-1,497	9.23-14.07
	Change in Implementation Costs	0	0
	Change in Operational Costs	0	0
	Change in Insurance Claims Costs	(4)-(3)	(.04)-(.03)
	Totals	**978-1,494**	**9.19-14.04**

Table 10: Estimated changes in costs per bus (NPV) and total fleet costs (NPV) over the 12-year analysis period (2019-2031) for the retrofit runaway bus prevention [RUN] safety measure solution (cost reductions are shown in (parentheses))

Safety Measure Solution	Cost Description	Cost (NPV) per bus (£)	Total Cost (NPV) (£M)
Runaway Buses	Change in Technology Costs	1,236-1,902	13.44-20.68
	Change in Implementation Costs	95-456	1.03-4.96
	Change in Operational Costs	2,040-4,080	22.18-44.37
	Change in Insurance Claims Costs	(9)-(6)	(0.09)-(0.06)
	Totals	**3,363-6,433**	**36.56-69.94**

7.6 Cost-benefit analysis outcomes

Table 11 provides estimates for the break-even costs, discounted payback period and benefit-cost ratios associated with specifying the performances of new build and retrofit buses for the runaway bus prevention solution. Both the new build and retrofit solutions were found to have a poor benefit-cost ratio.

Table 11: 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 and retrofit runaway bus prevention [RUN] safety measure solution

Safety Measure Solution	Solution Type	Break-Even Costs (NPV) (£)	Discounted Payback Period	Benefit-Cost (NPV) Ratio
Runaway Buses	New Build	7.0-7.4	2031+	**0.005-0.008**
	Retrofit	11.8-12.4	2031+	**0.002-0.004**

8 Conclusions and next steps

The cost-effectiveness of the runaway bus prevention system was assessed throughout this project. The technical feasibility, target population, effectiveness, fleet fitment rate and costs associated with implementing the system as a requirement of the Bus Vehicle Specification were established, whilst the cost-effectiveness and casualty saving benefits were also calculated. The system was included in the Bus Vehicle Specification in order to reduce risk of the rare, but potentially catastrophic, incidents.

The performance checklist was developed to be an effective, reliable and valid tool by which the performance of a runaway prevention system can be assessed. It focuses on the outcomes of a system’s functions (i.e. under what circumstances can a bus runaway), not the specifics of the engineering solution used by the system, which will allow for a range of future systems to be compared.

The checklist was applied to a single sample prevention system and though the system has been designed to be robust in that it focuses on using the root causes of runaway situations as triggers, it is possible that further refinement of the checklist could be achieved if it were tested on a wider sample of prevention systems. This may reveal other emergent scenarios that could occur which were not obvious during the initial testing however as of now it covers all known situations that could lead to a runaway bus.

It is recommended that the performance checklist developed here should be used when investing in a prevention system to demonstrate system effectiveness and, therefore, the value of the investment.

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.

It should also be mentioned that there is a chance that drivers may come to rely on the runaway prevention system and routinely forget to engage the park brake. The addition of an audible waning when the system is activated may combat that risk as drivers may view the sound as an irritant. However, TfL may need to introduce a means of monitoring handbrake application to ensure drivers are not using the system as a crutch.

References

Chaplain, C. (2017, August 21). *Shocking footage captures moment London bus careers across main road without a driver behind the wheel*. Retrieved July 20, 2018, from standard.co.uk: https://www.standard.co.uk/news/transport/london-bus-careers-out-of-control-across-main-road-a3616016.html

Department for Transport. (2018). *Accident and casualty costs (RAS60).* Department for Transport (DfT).

Department for Transport. (2018). *WebTAG Databook v1.11.* London: Department for Transport (DfT).

Reason, J. (2000, March 18). Human error: models and management. *The British Medical Journal*, 768-770.

Stevens, A., & Cynk, S. (2011). *Checklist for the assessment of in-vehicle information systems.* Transport Research Laboratory. Crowthorne: TRL. Retrieved from https://trl.co.uk/reports/MIS005

TfL. (Unpublished). *Draft TfL Standard: The test and assessment of blind spot safety systems and HGVs.* Unpublished Report.

Transport for London. (2015). *Travel in London. Report 8.* London: Transport for London (TfL).

ZF WABCO. (2005). *Systems & Components in Commercial Vehicles.* ZF WABCO.

Acknowledgements

The authors would like to acknowledge the support and input of the supplier of the sample runaway bus prevention system, as well as the support and cooperation of Operator B in provision of their bus and work space for the researchers. We also gratefully acknowledge the time and input of the drivers who participated in demonstrations and in the interviews.

Appendix 1 Implementing a third-party system into a braking system

A1.1 Compliance

Any modifications or additions to the braking systems of road vehicles need to be carefully considered to ensure continued compliance of the vehicle to the applicable requirements for braking.

Modifications to the braking system of a vehicle, such as the installation of a third-party safety system, could take place in two scenarios; pre-registration or post-registration. The requirements for each scenario in the UK market differ and are discussed below.

A1.1.1 Pre-registration braking system modifications

When a vehicle manufacturer produces a complete vehicle in a single stage and a third-party system is included in the vehicle specification and design of the braking system from the outset, this would be included within the original braking approval for that vehicle type. This is not a modification as such, but a recognised feature of the braking system. Responsibility for compliance would lie with the vehicle manufacturer. This is the easiest approach from the point of view of the purchaser of the vehicle. However, it may not be the easiest for a bus manufacturer. Most bus and HGV manufacturers will simply buy their brake system from one of only a small number of tier one suppliers who may sell the same basic system across Europe and for buses, coaches and trucks. Often in this situation the tier one supplier may get type approval for the brakes as a sub-system. This leads to significant economies of scale. Thus, it is the tier one supplier that would need to add the third party system as part of its approval. In such a situation, if the bus manufacturer modified the brake system with a third party system then they would be modifying an approved system and the considerations below would be applicable.

When a modification to the braking system of a vehicle with an approved braking system is made prior to registration the impact upon the braking type approval must be considered by the installer. The design, operation and method of installation of the modification along with its impact on the original braking system will need to be reviewed in conjunction with an Approval Authority or Technical Service to determine if the original braking type approval has been invalidated by the changes. Where this has occurred, the installer of the modification will need to provide evidence that the braking system remains compliant with the applicable braking regulation, and needs to type approve the vehicle through a multi-stage type approval which would require input from the base vehicle manufacturer. In the UK, where commercial and public service vehicle manufacturers typically use national type approval schemes, the evidence of compliance could potentially come in the form of a partial test report from the UK Approval Authority (VCA) which covers the elements of the applicable braking regulation which have been affected by the modification. Where the modification takes the form of a system which could be fitted to multiple vehicle types from a range of manufacturers, it may be possible to use a test report based on one vehicle type as evidence of compliance for other vehicle types. This would be dependent on the similarity of the vehicles and way the device is fitted. This would need to be agreed with the Approval Authority on a case by case basis and assumes that the effects of the system are purely functional as opposed to performance related. If the modification was performance related, it is likely that a new type approval for braking would be needed for each vehicle type on which the modification is intended to be installed.

Whenever a modification is made to a vehicle pre-registration, the responsibility for compliance lies with the installer. They need to follow vehicle type approval processes to ensure the vehicle satisfies all applicable regulatory requirements. Approval of the vehicle type will be required before it can be registered. Type approval for HGVs is in principle the same as for passenger cars, to receive approval a vehicle will have to meet a certain specification. What is still in the process of being agreed for HGVs (and buses) is defining what constitutes a “change” i.e. how much can change on a bus before it has to be to retest and recertify the AEB.

A1.1.2 Post-registration modification

When a modification to the braking system of a commercial or public service vehicle is made after the vehicle is registered in the UK it is the responsibility of the vehicle operator to ensure continued compliance with applicable legislation.

Where modifications to the braking system are made to a public service vehicle the submission of a Notifiabale Alteration for each vehicle must be made to the DVSA by the operator. The DVSA Notifiable Alteration to a Public Service Vehicle VTP5 process should be followed and full details of the modification declared. DVSA would expect to see evidence that the modified braking system complies with the required standards for braking. This evidence could come in the form of a test report from an Approval Authority or designated Technical Service which covers the elements of the braking system impacted by the modification and confirms compliance. It is possible to use a test report applicable to a braking system modification on one vehicle type as evidence of compliance for Notifiable Alteration submissions for other vehicle types assuming there is similarity between the vehicles and way the device is fitted. This would need to be agreed with the DVSA on a case by case basis. The sample runaway prevention system in this report used a test report from a tractor as evidence to the DVSA of its compliance, as a bus and a tractor were deemed suitably similar. In the case that this sort of system is to become a standard feature on future buses a DVSA Notifiable Alteration to a Public Service Vehicle VTP5 process would need to be followed and a test report specifically for buses would need to be compiled.

As part of the Notifiable Alteration process, DVSA may request to inspect the subject vehicle at one of their sites to verify the modification has been installed correctly and is functioning as intended. If a Notifiable Alteration submission is made for a large fleet of vehicles, only a sample of vehicles would be inspected. In the case of an accident resulting in injury where a claim is made against the bus operator liability would be passed up the supply chain i.e. the person injured would make a claim against the bus operator involved and depending whether or not the system worked as intended this may result in subsequent claims by the operator to the vehicle manufacturer and onward to the Tier-1 supplier

A1.2 Warranty

Fitting a third party braking system at the post-registration stage might invalidate the warranty of the brake system supplied at manufacture of the bus, in the case of a retrofit the warranty coverage should be checked with the brake supplier. The bus operators and contractors need to investigate this fully with their bus manufacturer to ensure that they fully understand the risk that this poses in terms of future claims. If a bus operator intends to fit a runaway prevention system to a new bus, then they should inform the bus manufacturer so that the relevant compliance (as above) and warranty can be provided. The operator should check the effect of any system which interacts with the brakes as part of their procurement procedure and work through any potential warranty and compliance issues with their supplier. The particulars of the brakes warranty will come down to terms offered by various parties involved e.g. the manufacturer to the consumer, the suppliers to the manufacturer etc. In either the case of a new build or a retrofit the warranty of the brake components are unlikely to be affected unless there was a demonstrable negative impact on the system. Brake supplier warranties consider the valve/product in isolation not the system or causes of contamination/ damage (unless a large number of failures are identified).

Appendix 2 Summary of testing research proposals

The below table was used to evaluate the feasibility of the different research options; driver training vs. a technological solution.

Table A2.1: Proposed solutions and testing plan

Solution/ System	Test description (scope of tests) – very brief	Cost elements			Timescales (to complete testing)	Solution and the proposed testing:		Notes/Comments	Feasibility
		Bus hire	Drivers	Other?		Anticipated advantages	Anticipated disadvantages		
Creation of 'performance checklist' for the assessment of runaway bus prevention systems	A systematic review (task and error analysis) of circumstances under which bus brakes are applied when stationary, and actions which require a driver to exit the cab will be conducted.	Any standard bus	Test driver only	Semi-structured interview with 6 bus drivers from at least 3 operators for task/error analysis purposes	April 2018	An understanding of the circumstances which can lead to a runaway bus This knowledge will be fundamental in designing subsequent countermeasures (either technological or training)	None	The outcomes of this review will be used to develop a performance checklist for the assessment of any runaway bus prevention system and this checklist will be applied to example systems.	High
Testing example prevention system(s)	An example system will be fitted to test vehicle(s) and subject to the performance checklist.	1 bus fitted with a prevention system	Test driver only	None	April 2018	Successful systems will Reduce/eliminate potential for drivers to fail to correctly apply brakes	Cost of system may be prohibitive to wider rollout	The outcome of this assessment will be a validation of the checklist and a benchmark test result.	High
Driver training	A review of driver training materials will identify any improvements required to maximise its effectiveness at reducing incidence of drivers exiting the cab without proper application of the brakes.	n/a	Driver trainers	Access to training syllabus	April 2018	Potentially less costly than implementing new hardware.	Reduction in driver error can be difficult to achieve, especially in low-frequency events such as runaway buses.		Low

Appendix 3 Overview of a bus brake system

The brake systems of vehicles are heavily regulated as part of ‘type approval’. The design and performance of brake systems for heavy goods vehicles, buses and coaches is regulated by UNECE Regulation 13. This defines three different braking system functions:

- Service Braking System: allows graduated control of the movement of the vehicle in all circumstances and states of load. Driver must be able to operate it without taking hands from the wheel. This is the main foot pedal operated brake system all drivers are familiar with.
- Secondary Brake: must provide a graduated ability to stop the vehicle in the event of a failure in the service brake. It can be hand or foot operated.
- Parking Brake: Makes it possible to hold the vehicle stationary on a gradient even in the absence of a driver. The working parts must be locked in position by ‘a purely mechanical device’. It can be operated by a foot or hand control and does not need to offer graduated control of the level of braking applied.

In addition to this, the regulation defines three parts of a brake system:

- Control: for example, a foot pedal or hand lever. There must be at least two separate and independent control devices
- Transmission: the combination of parts that transmits the signals and/or force or energy applied at the control to the brake
- Brake: this means the parts that develop the forces opposing movement of the vehicle. It can be a friction brake (e.g. drum or disc), or an electrical brake (e.g. use of a motor as a generator to recharge batteries), a fluid brake (e.g. a retarder), or an engine brake (e.g. where engine valves are closed to increase the engine’s resistance to vehicle motion).

In the vast majority of heavy vehicles, including large buses, the regulatory requirements for brake systems will be fulfilled by an air braking system. In such a system a compressor fills air tanks with pressurised air. It is easy to see how this works for the main service brake system. When the foot valve is pressed pressurised air is released into pipes connecting it to brake actuators at each wheel. These actuators are essentially pistons that convert the air pressure into movement of a lever that exerts force to apply a mechanical friction brake.

Secondary brake requirements are fulfilled by splitting the circuits such that if there is a failure in one circuit the second circuit can still operate at a sufficient level to stop the vehicle.

However, this system is not sufficient for a parking brake system because it would rely on the stored energy of compressed air to keep it activated, rather than being locked in place by a purely mechanical means. In short, if the park brake relied on positive air pressure then air would leak out of the system over time and eventually the park brake would release.

This problem is solved by the use, on at least one axle, of spring brake actuators as illustrated in Figure 5, below.

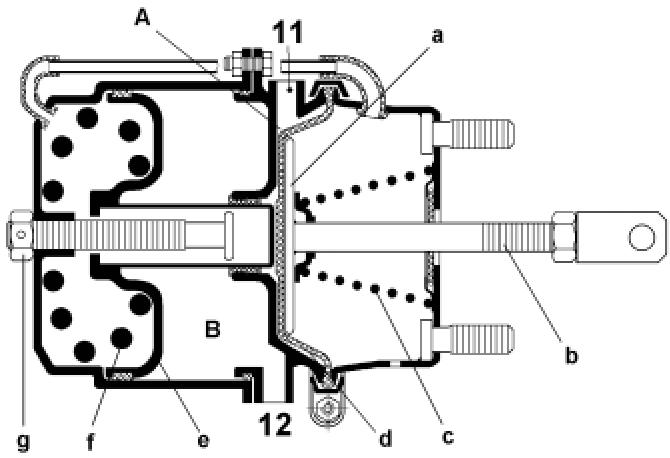


Figure 5: Schematic illustration of a spring brake actuator. Source: (ZF WABCO, 2005)

The chamber is split into two parts. The service brake is operated when pressurised air enters the right hand part at the point marked 11. This pushes the diaphragm marked (d) to the right which pushes the lever (b) to the right and applies the brakes. The area at the left of the diagram is filled with a heavy mechanical spring indicated by the black circles (f). This spring is normally held in the compressed position indicated by air pressure in the chamber to its immediate right marked B. Application of the park brake will release the air pressure in chamber B, the spring expands and the diaphragm (e) moves right and pushes the activation level (b) right.

Thus when the park brake is applied, the brakes hold the vehicle based purely on the mechanical force exerted by the spring, thus complying with regulations without interfering with the simple operation of the service brake. An added advantage of this system is that it gives additional fail-safes in the event of complete loss of air pressure, which will result in the spring brake locking the brakes on. In such a situation, if air pressure cannot be introduced to the vehicle, the vehicle cannot move. For this reason, Regulation 13 requires an auxiliary release system for the brakes to allow towing. In the example shown above, which is typical of commercially available systems, the nut and bolt marked (g) fulfil this aspect of the regulation. Tightening the nut moves the bolt to the left which will then mechanically compress the spring and allow the brakes to be released. Obviously, this should only be undertaken when the vehicle is held stationary by some other external means, e.g. wheel chocks or recovery vehicles etc., and is only intended for use in full breakdown/recovery circumstances. The Regulation permits powered auxiliary release systems but only if the energy source is different to that used by the brakes, e.g., it can’t be be operated from the same air supply such that the loss causing the problem also causes the release not to work.

One disadvantage of this approach is in the event of a failure in the park brake circuit. If for example, a pipe ruptures in the circuit supplying chamber B with pressure, then the effect is the same as applying the park brake. If the vehicle is driving normally at this time, this can be very hazardous. Vehicles behind the bus may not be expecting sudden braking for no obvious reason. In addition to this, the braking may be sufficient to lock the wheels and ABS would have no ability to prevent this. Depending on which axles affected (typically rear only), this can lead to a loss of steering control (front) and/or a spin (rear or both).

For this reason, additional regulatory requirements are in place to ensure that the air supply to the spring brake chambers is robust to failure, including the requirement that:

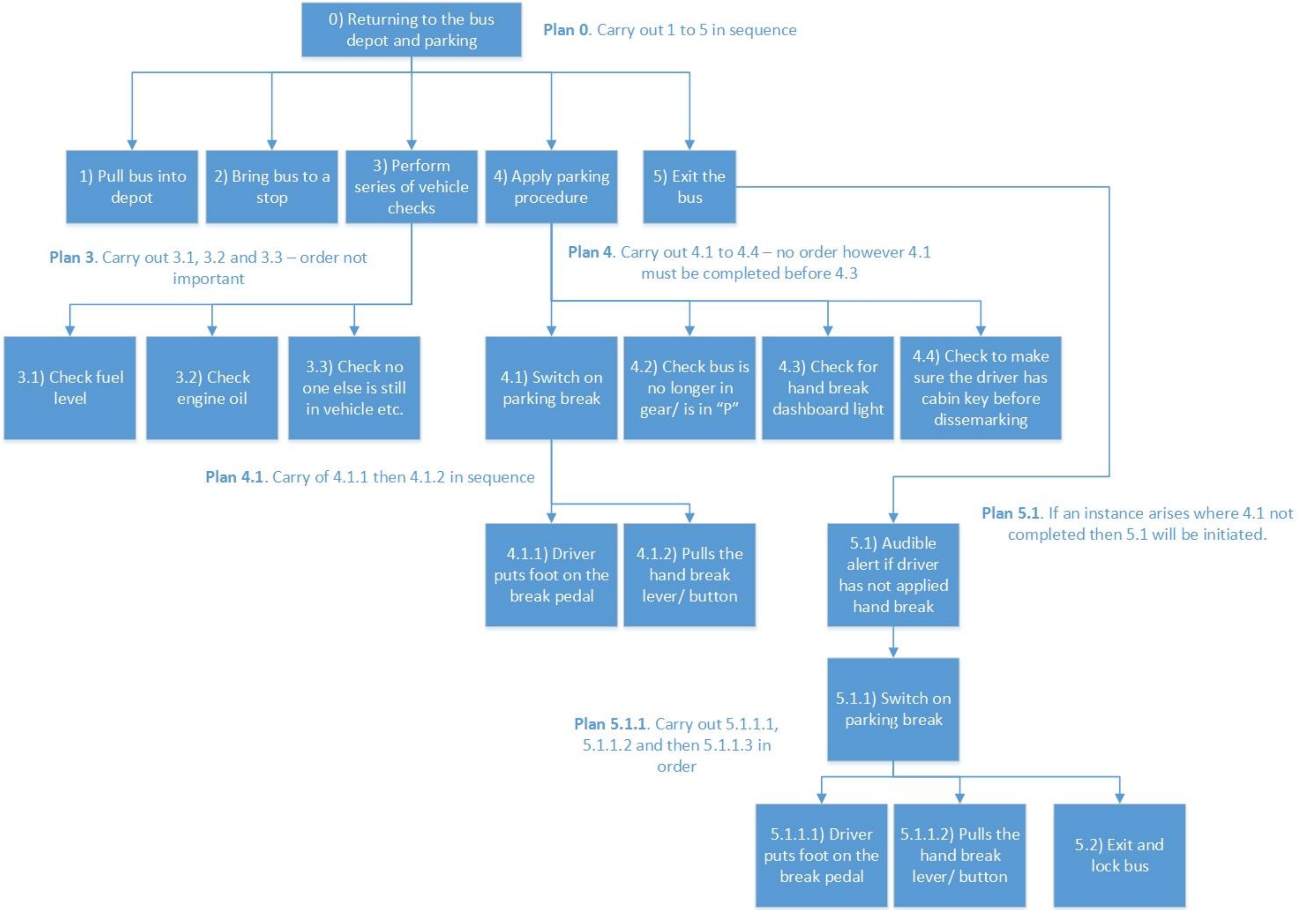
“Auxiliary equipment may only draw its energy from the feed line for the spring brake actuators under the condition that its operation, even in the event of damage to the energy source, cannot cause the energy reserve for the spring brake actuators to fall below a level from which one release of the spring brake actuators is possible.”

Although whether this requirement is strictly applicable to inter-locks to prevent runaway will depend on exact details of their implementation, it is clear that the same philosophy will be important and that operation of the system, even where generated by a fault, should not be liable to activate the brakes of the vehicle when it is in motion.

All manufacturers spoken to have stated that the ‘halt brake’ interlocks that they have applied work on the principle of applying positive pressure to the service brake system such that in the event of the most likely failure (air leak) they fail safe (no brakes applied). However, this will leave a fundamental weakness in situations where the halt brake requires vehicle electrical power and the vehicle is shut down such that the electrical power is lost, or where the halt brake is left holding the vehicle for a prolonged time and slow air leakage (an inevitable issue with all available air brake systems) will eventually result in loss of the brakes.

The use of a system that acts on the park brake circuit to release air pressure from the spring brake chambers solves those problems. However, such a system must be of a standard to ensure that a fault cannot result in air loss from that circuit and should be demonstrably compliant with type approval rules.

Appendix 4 Initial Hierarchical Task Analysis of Parking a Bus



Appendix 5 Runaway Bus Incident Stats

		No. of incident (n/54)	Percentage (%) of RaB incidents
What type of road did the incident occur on?	Dual Carriageway	2	**3.70**
	Bus Stop	3	**5.56**
	Bus Stand - On Highway	4	**7.41**
	Bus Stand - Off Highway	4	**7.41**
	Two Way (Major Road)	6	**11.11**
	Garage	4	**7.41**
	Bus Station	3	**5.56**
	NULL	24	44.44
Bus Type?	Double Decker	38	**70.37**
	Single Decker	15	**27.78**
	UNKNOWN	1	1.85
Was the bus in service or out of service?	Normal Route	38	**70.37**
	Out of service	14	**25.93**
	Other	1	**1.85**
	Unknown	1	1.85
What was the other party in the collision?	Moving vehicle	6	**11.11**
	Stationary Vehicle	36	**66.67**
	an Obstruction	2	**3.70**
	Bus Stop/ Shelter	1	**1.85**
	Other Structures	8	14.81

Appendix 6 Park Brake system checklist

Runaway Bus Prevention			General Braking Mechanisms		Break Down	Expected Outcome	Actual Outcome	Outcome match? (Yes=1, No=0)
Drive enabled (Is the bus "on"?)	Gear	Seat Pressure	Park Brake	Passenger Door	Kill Switch			
No	Neutral	Yes	Off	Closed	Disengaged	Roll		
No	Neutral	Yes	On	Closed	Disengaged	No roll		
No	**Neutral**	**No**	**Off**	**Closed**	**Engage**	**Roll**		
Yes	Neutral	Yes	Off	Closed	Disengaged	Roll		
Yes	Neutral	Yes	On	Closed	Disengaged	No roll		
Yes	**Neutral**	**No**	**Off**	**Closed**	**Engage**	**Roll**		
Yes	Reverse	Yes	Off	Closed	Disengaged	Roll		
Yes	Reverse	Yes	On	Closed	Disengaged	No roll		
Yes	**Reverse**	**No**	**Off**	**Closed**	**Engage**	**Roll**		
Yes	Drive	Yes	Off	Closed	Disengaged	Roll		
Yes	Drive	Yes	On	Closed	Disengaged	No roll		
Yes	**Drive**	**No**	**Off**	**Closed**	**Engage**	**Roll**		
						Total		
						Required Score		12
						Outcome		

Appendix 7 Runaway Bus Prevention Measure Overview

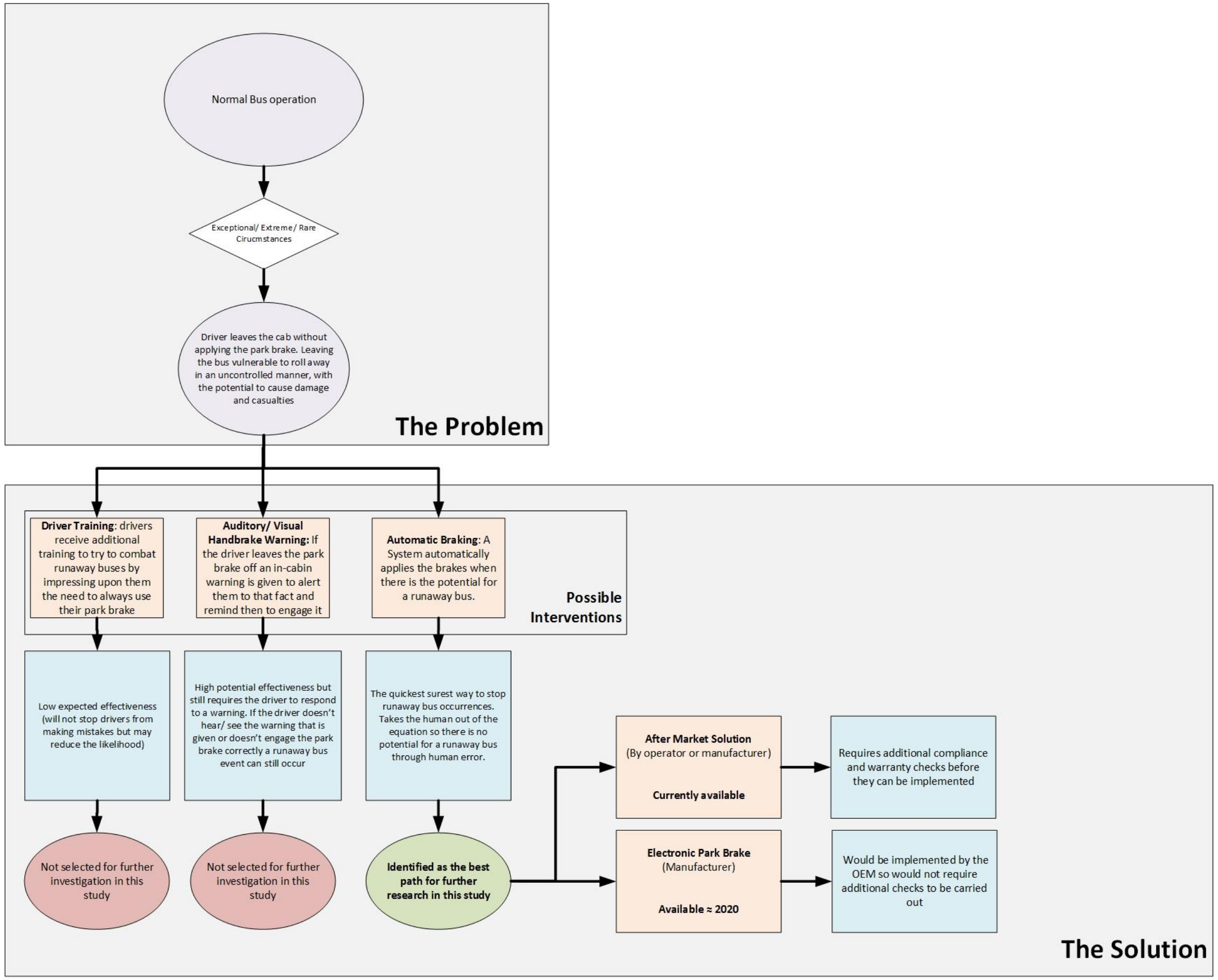


Figure 4: Runaway Bus Measure Overview

Appendix 8 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: Runaway Bus Prevention

The Bus Safety Standard (BSS) is focussed on vehicle design and safety system performance and their contribution to the Mayor of London's Transport Strategy. This sets a target to achieve zero road collision deaths involving buses in London by 2030.

All Transport for London 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, daytime 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.

Runaway bus prevention systems can be described as Driver Assist systems, designed to help the driver to avoid or mitigate the severity of incidents. In rare circumstances runaway buses can occur. These are exceptional occasions where the driver leaves their seat without properly applying the park brake and the bus subsequently rolls away. These incidents are very rare but carry a risk of very severe outcomes.

The research for this safety measure included task analysis and interviews with drivers about the extreme circumstances that might lead to a runaway incident. This analysis was used to generate a checklist of conditions whereby the bus should not roll away. The BSS will require a system of interlocks to prevent the bus rolling away if the driver leaves their seat without properly applying the park brake. The checklist is used to assess the performance of the runaway bus prevention interlocks.

Other titles from this subject area

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

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

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

ISSN 2514-9652

ISBN 978-1-913246-88-4

PPR982