Light Rail Safety and Standards Board

Driver Inattention System Trials

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Driver Inattention System Trials.

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LRSSB Report – Driver Inattention System Trials

Contents

Glossary

ASDO		Automatic Selective Door Operation
AVSM		Automatic Vehicle Speed Monitoring
CSDE		Correct Side Door Enabling
CSDO		Correct Side Door Opening
DAS		Driver Advisory System
DSD		Driver Safety Device
DSS		Driver Safety System
DVD		Driver Vigilance Device
EB		Emergency Brake
ESR		Emergency Speed Restriction
GNSS		Global Navigation Satellite System
GPS		Global Positioning System
GSM		Global System for Mobile communications
HF		Human Factors
IMU		Inertial Measurement Unit
IRAL		Ian Rowe Associates Ltd
LoS		Line of Sight
LRSSB		Light Rail Safety Standards Board
OCC		Operational Control Centre

OTMR		On Tram (or Train) Monitoring Recorder
PERCLOS		Percentage of Eyelid Closure
PGA		Programmable Gate Array
PVT		Psychomotor Vigilance Testing
RAIB		Rail Accident Investigation Branch
RFID		Radio Frequency Identification
RSSB		Rail Safety and Standards Board
SIL		Safety Integrity Level
SUT		System Under Test
TBC		Traction Brake Controller
TCMS		Train Control and Management System
TPWS		Train Protection Warning System
TRL		Technology Readiness Level
TSR		Temporary Speed Restriction
VSCS		Vehicle Supervisory Control System
WRULD		Work Related Upper Limb Disorder

Table of figures

1. Executive Summary

This report details the project commissioned by LRSSB to trial the top performing eye closure inattention systems that were identified during the previous market research project that was conducted on behalf of the UK light rail industry by UK Tram.

The report describes the methods used to test the systems and the results of those tests. The report also contains details of the practicality of installation of each system, the indicative costs associated with implementation and any other risks and benefits identified during the process.

The trial concentrated mainly on the ability of the Systems Under Test (SUT) to detect eye closure inattention and the susceptibility to 'false positive' activations.

In summary, the testing process included a total of 5740 static tests and a total of 32 hours of simulated driving (longitudinal tests). Of the four systems included in the trial process, one failed to perform reliably at all (39% Static), two were relatively more effective (85 % static/95% longitudinal and 65% static/98% longitudinal) but there was one system that outperformed all of the others (97% static and 100% longitudinal).

Following the feedback of trial performance to each participating system, one supplier, Denso, has withdrawn their permission for results obtained from their system to be published and included in this report. The results section has therefore been redacted appropriately.

Subsequent to the commissioning of this report, IRAL have been asked to add a section detailing the functionality of task monitoring systems as an alternative to address Recommendation 4 of the RAIB report. This section has been added in Appendix A of this report. A table of advantages and disadvantages of different approaches has also been included in this section as well as analysis of likelihood of habituation behaviour of resetting the device.

2. Introduction

Following the market research project carried out by Ian Rowe Associates Ltd (IRAL) in early 2019, LRSSB requested that a performance trial of the systems that achieved the highest scores during the market research should be conducted. The objective of the trial is to ascertain the viability of these systems to address Recommendation 4 of the RAIB report into the 'Overturning of a Tram at Sandilands Junction, Croydon, 9th November 2016' (Report R182017_171207_Sandilands).

The market research report concluded that inattention systems fell into one of two categories. These being:

- Fatigue detection using eye closure
- Driver task monitoring

LRSSB had requested that the top scoring fatigue detection systems from the initial research were asked to participate in a controlled trial that would determine their performance in detection of eye closure events.

Subsequent to the commissioning of this report, IRAL have been asked to add a section detailing the functionality of task monitoring systems as an alternative to address Recommendation 4 of the RAIB report. This section has been added in Appendix A of this report. A table of advantages and disadvantages of different approaches has also been included in this section.

3. Background

According to the Royal Society for the Prevention of Accidents (RoSPA), fatigue/driver falling asleep is a major causation factor in road traffic accidents.[1] This is significantly larger than road accidents caused by sudden onset illness. [2] Furthermore, the tram driver involved in the Sandilands accident in 2016 is suspected to have had a microsleep during the approach to the curve where the tram overturned and this has been identified as a root cause of the accident.

4. Scope of Study

Objectives

The objectives of this project were as follows:

- To obtain agreement from the top scoring fatigue inattention systems suppliers to participate in the trial
- To fit the equipment in a tram driving simulator
- To develop a realistic test for tram operations that can be applied identically to all participating systems
- To run the tests
- To record performance results and include in a report
- To identify indicative costings to assist in cost justification exercises used by light rail operators
- To describe the possible implementation (fitting, operation and on-going maintenance of each system)

5. Approach

Whilst the trial is mainly technical in nature, it is also important to understand the implications for the People, Process and Environment elements of the Socio-technical model (shown below). To this end the project included consideration of non-technical elements such as culture, user acceptance, data security and processing etc.

[1] According to ROSPA, fatigue/tiredness is estimated to be a causal factor in 20% of all road traffic accidents and up to 25% of all fatalities and serious injuries.
[2] Although statistics are not collected explicitly for causal factors from sudden onset illness, it is widely acknowledged that this is significantly less than 20%.

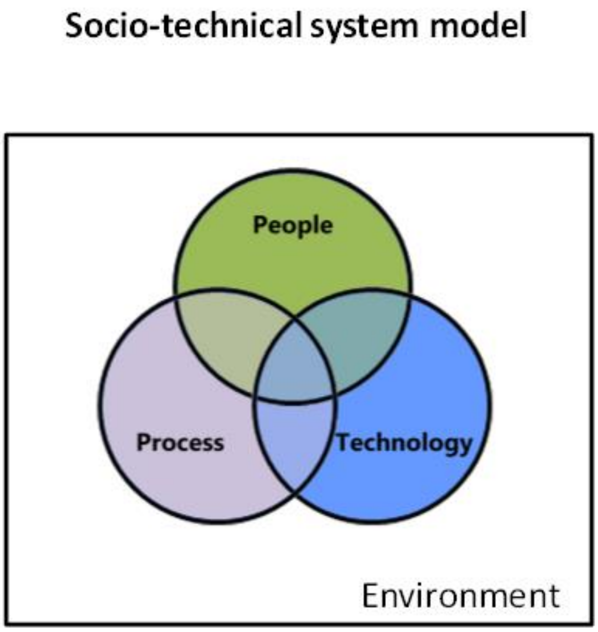


Figure 1 - Socio-technical system model approach

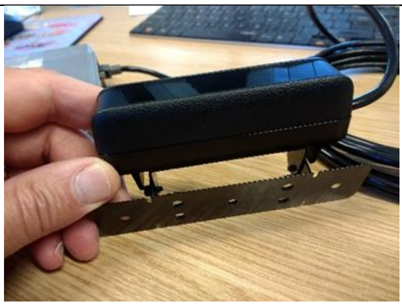
In order to provide a fair assessment of each system in the trial, a test methodology was developed that was applied identically to all systems under test and the results were recorded appropriately.

6. Systems Under Test (SUT)

The suppliers of systems with the top five highest scores from the previous research were contacted and asked if they wished to participate in the trial.

Initial responses from all five suppliers were positive. However, despite many follow up communications, one supplier failed to provide a system for the trial. The trial therefore assessed the following four systems:

Supplier	System/Description	Form
Seeing Machines	Guardian 2 Originally developed for the mining truck industry but now also in operation at London Trams. This system monitors eye closure and prompts the driver by audio alarm and seat vibration if eyes are detected closed for more than 1.5 seconds. For all activations, video footage is automatically sent to a Seeing Machines processing centre where footage is reviewed to screen out false positives. Device contains Infra-red emitter and single infra-red camera.	

Leisure Auto	LS803 Designed as an aftermarket fatigue detector for the automotive industry, this self-contained system issues voice alerts for detection fatigue and 'look away' events. The manufacturer has no presence or agents in the UK or Europe. Device contains Infra-red emitter and single infra-red camera.	
Denso	DSM Designed as an aftermarket fatigue detector for the haulage industry in Japan, this device produces voice alerts for detection of fatigue. Device contains Infra-red emitter and single infra-red camera.	
Smart Eye	Aurora XO Developed as an eye tracking system and used mostly in aviation. This system contains infra-red emitters and two infra-red cameras. The system, as supplied, provides an output for eye closure status (open, closed, non-detect).	

7. Research Objectives

The main objective of the trial was to determine the ability of each system to detect eye closure. This study was purely focused on the 'Detect' element of each device. As seen in the diagram below, in order to fully address the requirements of RAIB report Recommendation 4, it will be necessary to add/test the 'Alarm/Alert' functionality and the Intervention functionality if the system is to control the vehicle in the case of sustained eye closure.

Figure 2 - Inattention system phases

8. Methodology

The test methodology developed is described as follows:

System testing was divided into two sessions. These were:

- Static tests – Where the subject was asked to perform timed eye closures and the responses of each system was recorded
- Longitudinal tests – Where an individual wasYHI sleep deprived and then asked to drive in the tram simulator for the equivalent of a driving shift. The occurrences of eye closure and detection of the inattention system was recorded.

A number of variables were used to test the performance of each system.

Anthropometrics

Accepted norms for ergonomic assessments use body sizes between 95th percentile female and of 95th percentile male.

For this trial three subjects were recruited. Details are as follows:

Subject reference	Standing height	Percentile[3]
1	6'9"	99th percentile male
2	5'7"	45.7th percentile male
3	4'8"	>0.01 percentile female

Anthropometric and biomechanical data was used to establish the difference in the position of the head height of the maximum height driver and the minimum height driver.

The full variation was found to be between 180mm – 190mm.

[3] Based on Peoplesize 2008 database for UK population.

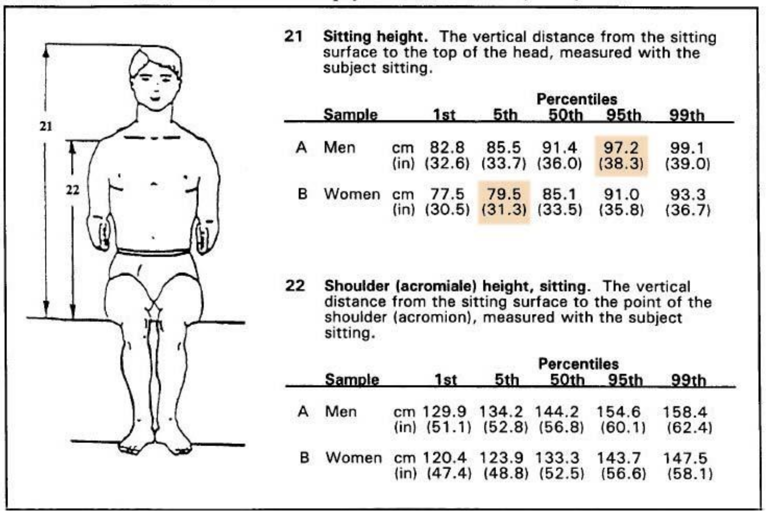


Exhibit 14.3.2.1 (continued) Static human physical characteristics (seated)

21 Sitting height. The vertical distance from the sitting surface to the top of the head, measured with the subject sitting.

	Sample		1st	5th	50th	95th	99th
A	Men	cm	82.8	85.5	91.4	97.2	99.1
		(in)	(32.6)	(33.7)	(36.0)	(38.3)	(39.0)
B	Women	cm	77.5	79.5	85.1	91.0	93.3
		(in)	(30.5)	(31.3)	(33.5)	(35.8)	(36.7)

22 Shoulder (acromiale) height, sitting. The vertical distance from the sitting surface to the point of the shoulder (acromion), measured with the subject sitting.

	Sample		1st	5th	50th	95th	99th
A	Men	cm	129.9	134.2	144.2	154.6	158.4
		(in)	(51.1)	(52.8)	(56.8)	(60.1)	(62.4)
B	Women	cm	120.4	123.9	133.3	143.7	147.5
		(in)	(47.4)	(48.8)	(52.5)	(56.6)	(58.1)

Figure 3 – Seated sizes

Figure 3 shows the relative head position with respect to seat height for the minimum and maximum sizes.

Head Position

Using the anthropometric data, the head position for the seated subjects was calculated. Figure 4 shows the positions and dimensions.

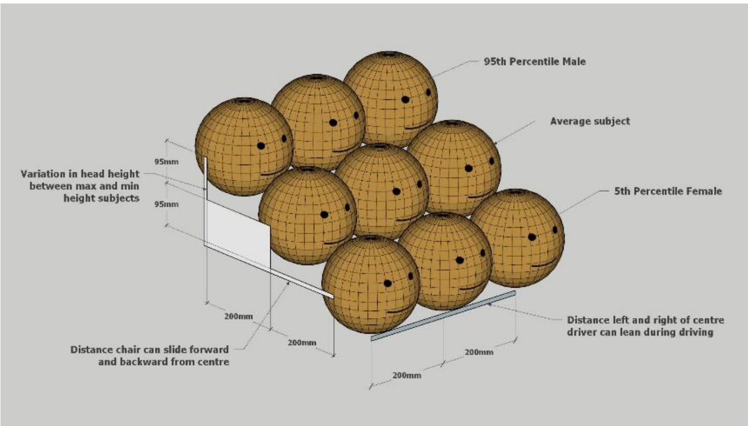


Figure 4 – Relative head position

The driver’s head position envelope was calculated by establishing the extremes of each variable.

- Driver size – 5th percentile female to 95th percentile male. This establishes the envelope height. The seat was not adjusted for height with each subject in order to maintain extreme positions
- Driving position – leaning to the furthest position left and right. This establishes the envelope width.
- Driver’s seat position – sliding the average driver’s seat to its maximum forward and rearward position. This establishes the depth of the envelope.

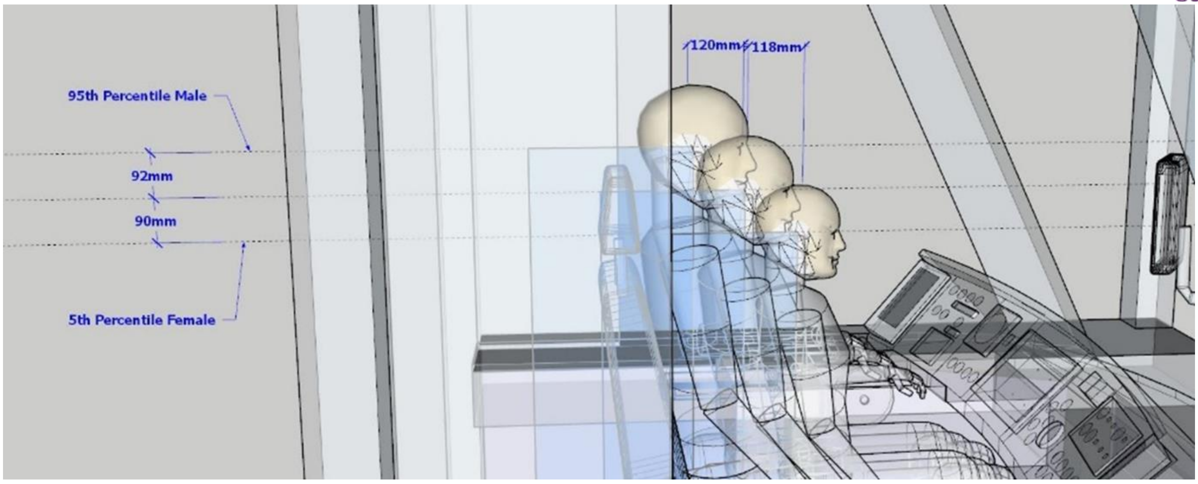


Figure 5 – Head position with respect to console

Cab Dimensions

The dimensions of three different cabs currently in use in the UK were measured and recognised when setting up the devices. The distance from an average driver's eyes to the highest point of each tram cab console was measured and an average taken from them. Figure 5 shows the measurements used for the Bombardier CR4000, CAF Urbos 3 and Stadler Variobahn vehicles.

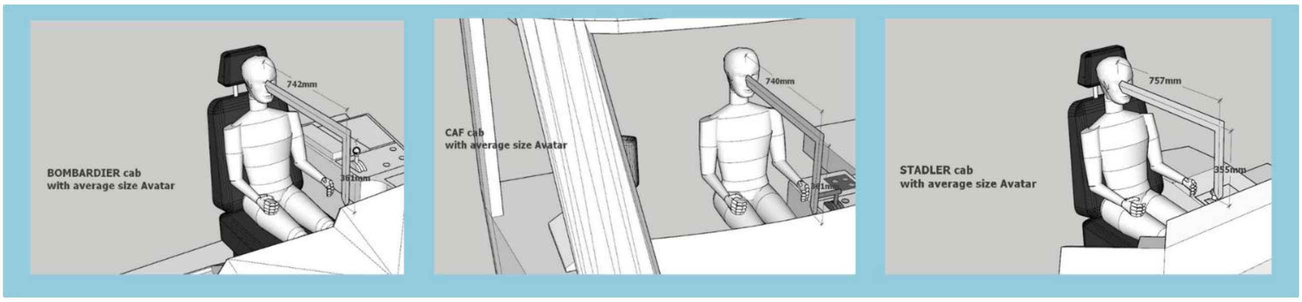


Figure 6 – Cab dimensions

Each of the devices was fixed at the same distance and position relative to the driver's viewpoint for the trial.

Eyewear

To test the effect of different eyewear on each device, a number of different spectacles/sunglasses were included in the trial.

Lenses are categorised as follows:

CATEGORY	LIGHT TRANSMISSION	WEATHER	USAGE
CATEGORY 0	81 - 100%		Indoor and cloudy weather
CATEGORY 1	44 - 80%		Low brightness
CATEGORY 2	19 - 43%		Medium brightness
CATEGORY 3	9 - 18%		Bright light Water / Snow
CATEGORY 4	3 - 8%		Extreme bright light Not for driving

Figure 7 – Categories

Following advice from an optician, Category 4 lenses were excluded from the trial as these are not recommended for driving.   It was noted that most commonly available sunglasses are Category 3. Mirrored and polarised Category 3 lenses were also added to the test.

Figure 8 – Eyewear used

As seen in Figure 8, lenses fitted in identical frames were used in the trial to eliminate any possible effects caused by different frames.

Besides glasses, tests were also conducted with contact lenses.

Figure 9 – Contact lenses

Both clear prescription and coloured prescription contact lenses were used.

Head/Face Wear

The table below shows the different head/face wear included in the trial.

Description	Example	Note
Burqa		Although it is felt that a driver wearing a Burqa would be unacceptable by most UK tram systems, this headwear was included in the trial for the sake of completeness.
Hijab		Most UK tram systems agree that there is no objection to a driver wearing a 'Hijab' or head scarf.
Face mask		Whilst it is not common in the UK to see people wearing facemasks for medical reasons or to reduce emissions inhalation, this may change over time. For the testing two different types of face mask was used.
Jewellery		As there is no common policy in the UK on drivers having facial jewellery, this test was included. As the detection systems use infrared light and infrared sensitive cameras for detection, there was concern that the presence of reflective objects on the face could 'confuse' the detection algorithms.

Test Procedures – Static

An accurately timed audio message was recorded with the following design:

Sequence	Audio Count down	Elapse time	Instruction	Pass criteria	Note
1	3 to 0	3 seconds			Lead in countdown
2			close		
3		1 second			
4			open	No eye closure detected	
5		2 seconds			
6			close		
7	1				
8			open	Eye closure detected	
9		2 seconds			
10			Close		
11	1, 2	3 seconds			
12			Open	Eye closure detected	
13		2 seconds			
14			Close		
15	1,2,3	4 seconds			
16			Open	Eye closure detected	

For each variable, the above sequence was repeated and results recorded.

This was designed to ensure consistent eye close/open performance by each subject and consistency across all subjects and observers.

Note that after Sequence No.2 there is no countdown preparation for the next 'close' instruction. This means that the actual eye closure time is likely to be very slightly shorter than the intended closure time as a countdown is used before issuing the 'open' instruction.

For each subject (tallest male, shortest female and average size person) this test was repeated with the following variables:

- Head position x 3 (central, left of centre (200mm), right of centre (200mm))
- Head rotation x 3 (directly forward, 45° to left, 45° to the right)

Each test specified above was then repeated in entirety but with different eyewear (7 types) and at two different ambient light levels in the simulator cab (1500 lumens to represent day time conditions and 10 lumens to represent night time conditions).

Forms were developed to record the results for each set of tests and a simple pass/fail marked against the expected response of the system under test.

Examples of the forms developed especially for this purpose are shown below.

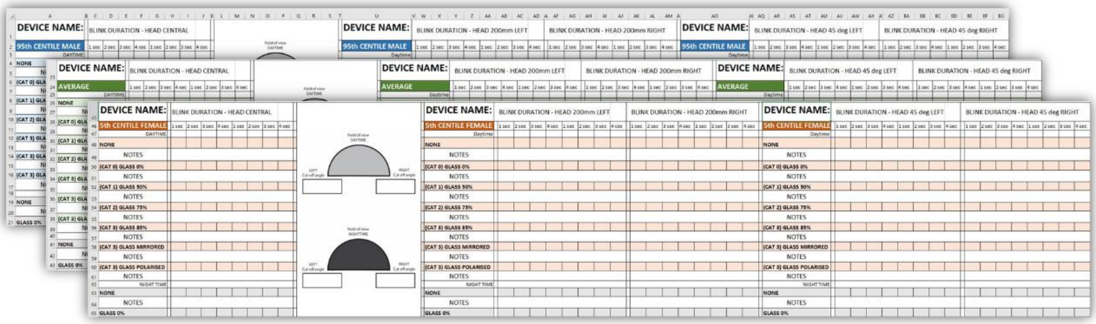


Figure 10 – Forms used for recording static blink tests

Additional tests were then performed using the average size subject but with head/face ware/jewellery and contact lens variables.

An example form, developed for recording results from these tests, is shown below.

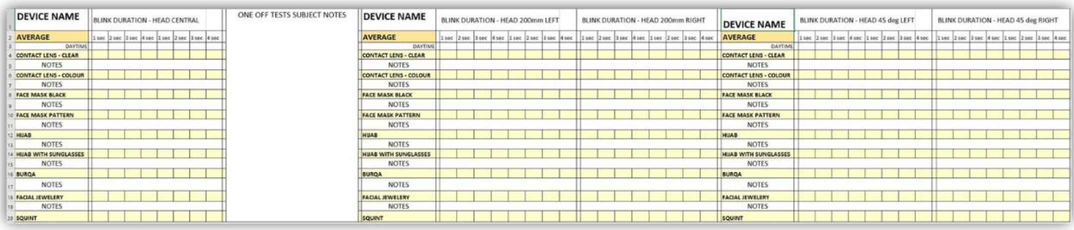


Figure 11 – Additional static tests

These tests were included to ‘stretch’ the capability of each system (e.g. covering the mouth and nose may challenge the recognition of the face and therefore is likely to fail to accurately ‘find’ the eyes).

Note that the final test in this sequence, ‘squint’ was included to simulate the driver squinting at sudden increase in light level. In this case a detection during the squint was considered as a false positive.

Test Procedures - Longitudinal

This test was designed to induce real sleep in the subject in a controlled environment that could be repeated for each device, in order to establish the relative reliability of their sleep detection systems.

Figure 12- T1 Simulator

The longitudinal tests involve a single subject driving in the T1 simulator over an eight-hour night shift, starting at 10pm and ending at 6am. The simulation was for a 'real' UK tram network that includes 31km of geo-specific environment, tram stops, signals etc. The route was driven in all directions and required the driver to stop to pick up and drop off passengers, obey all signals etc. Purposely, there were no operational scenarios triggered during this test as the objective of using the simulator was to re-create the real driving tasks as accurately as possible but with no abnormal stimulation that may decrease natural drowsiness that the driver would experience.

The subject took a 'meal break' approximately half-way through the test.

The simulator room was kept to a constant warm temperature (>20 degrees) and there were no external disturbances from the driving task.

A subject facing video camera recorded the full 8-hour session and three of the four systems under test were used during this test (one of the systems was so un-reliable during static testing that it was considered unnecessary to include this system in the longitudinal test).

After completion of the sessions, the subject facing camera footage was reviewed in detail and analysis of observed events compared with detected events from the SUT.

During the test there were a number of purposeful eye closure events that were used to ensure that the SUT was continuing to monitor.

9. Results

All details of detections, lack of detections and false positive were logged accordingly and the results are summarised in the tables and graphs below.

Static Tests

MARKS	SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
	FAILS		FAILS	FAILS
	MB TESTER		BB TESTER	MB TESTER
72	0		0	29
72	0		3	36
72	0		1	41
	MB TESTER		MB TESTER	MB TESTER
72	0		6	32
72	0		7	35
72	0		2	33
	BB TESTER		BB TESTER	MB TESTER
72	0		0	31
72	0		0	35
72	0		0	32
648	0	0	19	304
	minus head rotation	minus head rotation	minus head rotation	minus head rotation
	Minus additional tests	Minus additional tests	Minus additional tests	Minus additional tests
	100.00%	x	97.07%	53.09%

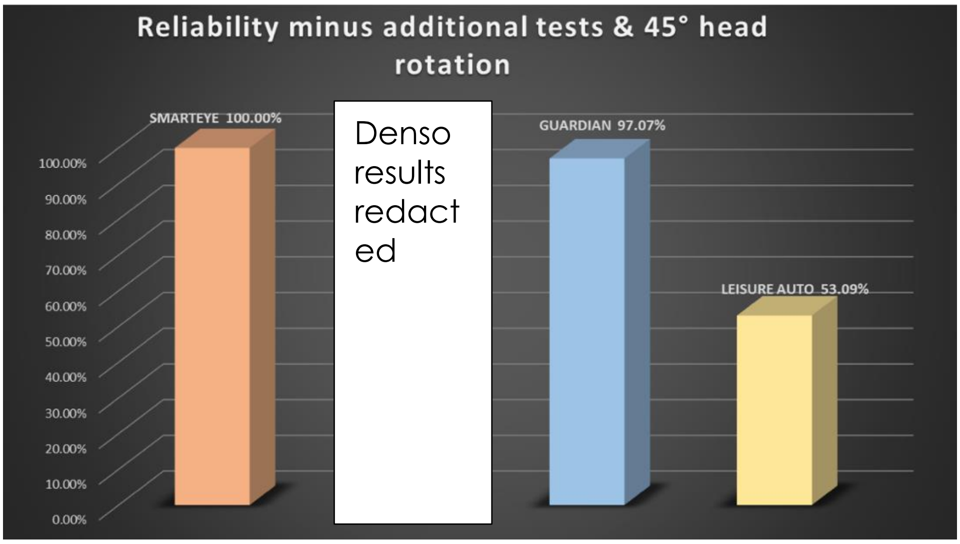


Figure 13 – Reliability results without inclusion of additional tests and head rotation

	MARKS	SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
		FAILS		FAILS	FAILS
AVERAGE		MB TESTER		BB TESTER	MB TESTER
Head central	72	0		0	29
Head to left	72	0		3	36
Head to right	72	0		1	41
Head rotated 45 deg left	72	0		27	54
Head rotated 45 deg right	72	0		9	54
99th %ILE		MB TESTER		MB TESTER	MB TESTER
Head central	72	0		6	32
Head to left	72	0		7	35
Head to right	72	0		2	33
Head rotated 45 deg left	72	0		17	54
Head rotated 45 deg right	72	0		0	54
<0.1 %ILE		BB TESTER		BB TESTER	MB TESTER
Head central	72	0		0	31
Head to left	72	0		0	35
Head to right	72	0		0	32
Head rotated 45 deg left	72	7		0	54
Head rotated 45 deg right	72	18		0	54
TOTALS	1080	25	0	72	628
		Minus additional tests	Minus additional tests	Minus additional tests	Minus additional tests
		97.69%	x	93.33%	41.85%

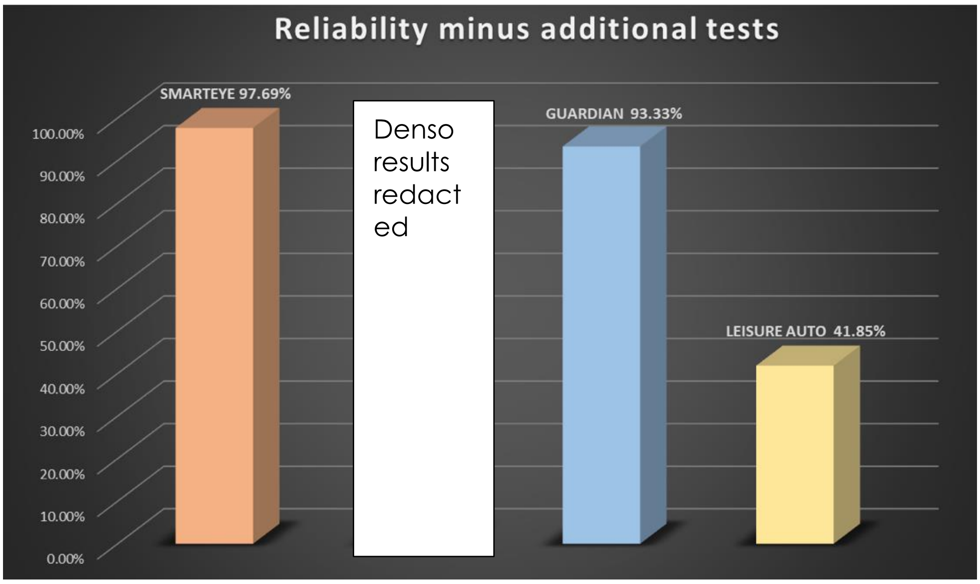


Figure 14 – Reliability results without additional tests

	MARKS	SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
		FAILS		FAILS	FAILS
AVERAGE		MB TESTER		BB TESTER	MB TESTER
Head central	72	0		0	29
Head to left	72	0		3	36
Head to right	72	0		1	41
Head rotated 45 deg left	72	0		27	54
Head rotated 45 deg right	72	0		9	54
99th %ILE		MB TESTER		MB TESTER	MB TESTER
Head central	72	0		6	32
Head to left	72	0		7	35
Head to right	72	0		2	33
Head rotated 45 deg left	72	0		17	54
Head rotated 45 deg right	72	0		0	54
<0.1 %ILE		BB TESTER		BB TESTER	MB TESTER
Head central	72	0		0	31
Head to left	72	0		0	35
Head to right	72	0		0	32
Head rotated 45 deg left	72	7		0	54
Head rotated 45 deg right	72	18		0	54
Additional Tests		MB TESTER		MB TESTER	MB TESTER
Head central	64	1		11	46
Head to left	64	8		18	46
Head to right	64	10		18	46
Head rotated 45 deg left	64	11		46	46
Head rotated 45 deg right	64	1		46	46
TOTALS	1400	56	0	211	858
		Overall Reliability	Overall Reliability	Overall Reliability	Overall Reliability
		96.00%	x	84.93%	38.71%

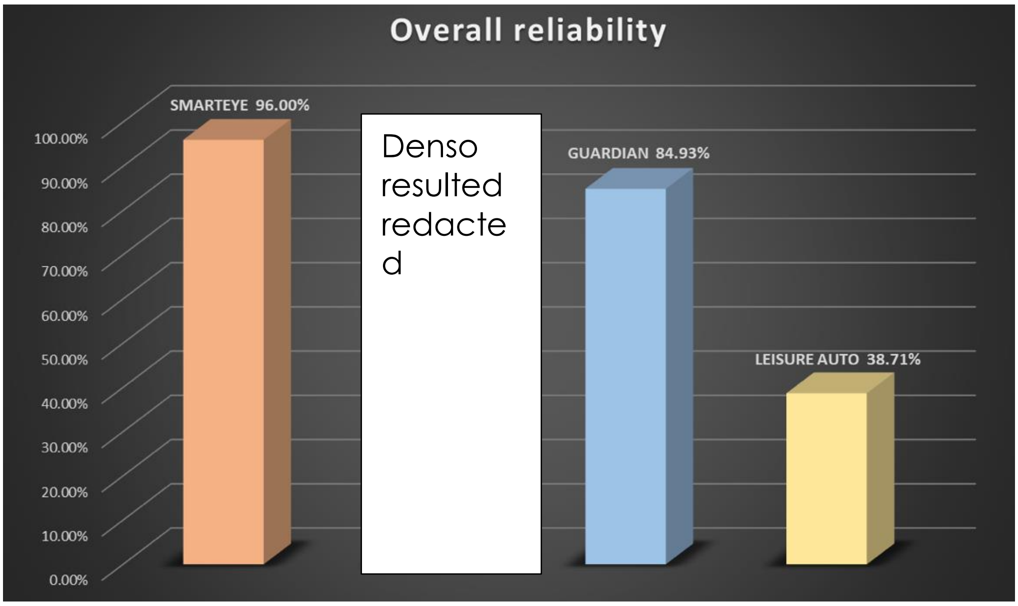


Figure 15 – Reliability results - Overall

		EYEWEAR			
		The effect of eyeware on the devices reliability (not including head rotation)			
		SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
		% pass rate			
Glasses - CAT 0 (0%)					
		100.00%	x	99.00%	48.00%
Tinted glasses - CAT 1 (50%)					
		100.00%	x	100.00%	55.00%
Sunglasses - CAT 2 (75%)					
		100.00%	x	100.00%	56.00%
Sunglasses - CAT 3 (85%)					
		100.00%	x	100.00%	46.00%
Polarised Sunglasses - CAT 3 (85%)					
		100.00%	x	100.00%	51.00%
Mirrored Sunglasses - CAT 3 (85%)					
		100.00%	x	97.00%	47.00%

Figure 16 – Reliability – Eyewear tests

	NIGHT DRIVING - less than 10 lux			
	The effect of low visible light on the devices effectiveness (not including head rotation)			
	SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
	% pass rate			
	Tests conducted only without glasses and with clear glasses			
Without Glass				
	100.00%	x	100.00%	53.00%
Glasses - CAT 0 (0%)				
	100.00%	x	100.00%	58.00%

Figure 17 0 Reliability – Low light

	ADDITIONAL TESTS			
	The effect of low visible light on the devices effectiveness (not including head rotation)			
	SMARTEYE	DENSO	GUARDIAN	LEISURE AUTO
	% pass rate			
Contact lenses - Clear				
	96.00%	x	88.00%	46.00%
Contact lenses - Coloured				
	80.00%	x	100.00%	49.00%
Face mask - Black				
	51.00%	x	0.00%	0.00%
Face mask - Patterned				
	100.00%	x	50.00%	0.00%
Hijab				
	100.00%	x	100.00%	43.00%
Hijab with sunglasses				
	100.00%	x	100.00%	51.00%
Facial jewelery				
	100.00%	x	100.00%	56.00%
Squint				
	96.00%	x	47.00%	0.00%

Figure 18 – Reliability – Additional tests

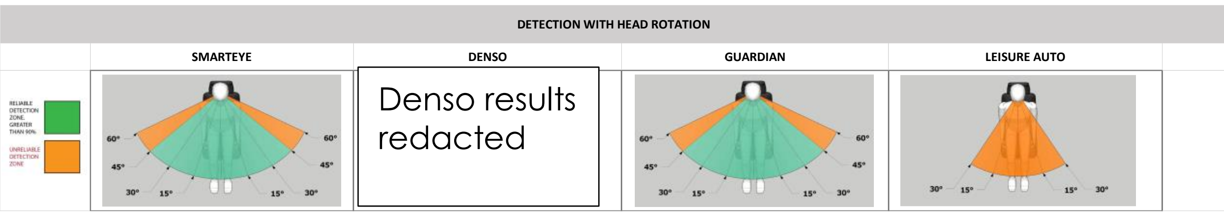


Figure 19 – Reliability – Head rotation

HEAD POSITION

SMARTEYE

	200mm LEFT OF CENTRE - Detection success rate	CENTRAL - Detection success rate	200mm RIGHT OF CENTRE - Detection success rate
Subject: Matt Baker Height: 6' 9" 99th %ILE	100%	100%	100%
Subject: Daniel Beecher Height: 5' 9" AVERAGE	100%	100%	100%
Subject: Lynn Phillips Height: 4' 8" <0.1 %ILE	100%	100%	100%

DENSO

	200mm LEFT OF CENTRE - Detection success rate	CENTRAL - Detection success rate	200mm RIGHT OF CENTRE - Detection success rate

Denso results redacted

GUARDIAN

	200mm LEFT OF CENTRE - Detection success rate	CENTRAL - Detection success rate	200mm RIGHT OF CENTRE - Detection success rate
Subject: Matt Baker Height: 6' 9" 99th %ILE	100%	100%	98%
Subject: Daniel Beecher Height: 5' 9" AVERAGE	99%	99%	97%
Subject: Lynn Phillips Height: 4' 8" <0.1 %ILE PERCENTILE	97%	100%	98%

LEISURE AUTO

	200mm LEFT OF CENTRE - Detection success rate	CENTRAL - Detection success rate	200mm RIGHT OF CENTRE - Detection success rate
Subject: Matt Baker Height: 6' 9" 95th PERCENTILE	44%	48%	40%
Subject: Daniel Beecher Height: 5' 9" AVERAGE	64%	59%	61%
Subject: Lynn Phillips Height: 4' 8" 5th PERCENTILE	73%	78%	70%

Figure 20 – Reliability – Head position

Longitudinal Tests

SMARTEYE

SUBJECT - *B.Batten*			
TIME PERIOD		CORRECT DETECTION	
TEST 1	NON DETECTION	NON SLEEP EVENT	REAL SLEEP
10:58pm to 11:46pm	0	16	52
11:46pm to 12:00am	0	2	3
1:32am to 2:22am	0	3	2
TOTALS	0	21	57
% VIGILANCE			100.00%

DENSO

Denso results redacted

GUARDIAN

SUBJECT - *B.Batten*			
TIME PERIOD		CORRECT DETECTION	
TEST 1	NON DETECTION	NON SLEEP EVENT	REAL SLEEP
10:17pm to 11:07pm	1	1	1
4:17am to 5:07am		1	
5:07am to 5:56am	1	2	1
5:56am to 6:00am		1	
TEST 2			
1:55am to 3:49am	0	0	31
TOTALS	2	5	33
% VIGILANCE			95.00%

Figure 21 – Reliability – Longitudinal tests

10. Analysis and Comment

Smart Eye

Smart Eye system performed best overall (96% Static tests, 100% Longitudinal tests). The main reason for this was its ability to function well during the additional static tests, head rotation and head position. It is unclear as to why the performance of the system when the subject was wearing a black face mask was so relatively poor and why. In contrast with the same subject wearing a patterned face mask, the performance was higher.

In the longitudinal test, Smart Eye performance was measured at 100%

Denso

The Denso system was fully tested as per the other systems in the trial. However, after being presented with the performance results obtained from their system, Denso withdrew permission to include results in this report.

Guardian

The Guardian performed well in static tests under 'normal' operation (i.e. no head rotation or additional test – 97%) but less well when head rotation and additional tests were included (85%). The main weaknesses were when the subject's mouth and nose is covered (See Fig 17).

In the longitudinal tests Guardian performance was measured at 95%.

Leisure Auto

The performance of this device overall was very inconsistent (39% for Static tests). It is suspected that this could be due to the necessary distance between the detector and the driver in a tram (bearing in mind that in cars/trucks, the dash is normally significantly closer to the driver). As this device showed poor consistency, it was decided not to conduct a longitudinal test on this device.

11. Equipment Installation

The table below details the equipment to be installed

System	Power	Detector	Processor	Additional equipment
Smart Eye	12v/24v DC	Infra-red emitter and camera	Small ruggedized computer	Configurable to customer requirements (Audio, haptic etc.)
DENSO	12v/24v DC	Infra-red emitter and camera	Small ruggedized computer	
Guardian	12v/24v DC	Infra-red emitter and camera	Small ruggedized computer	GPS, Seat vibrator
Leisure Auto	12v DC	Infra-red emitter and camera	Built-in to detector unit	GPS (optional)

Ease of Installation

All systems use a single central emitter/detector unit. All of these could be fairly easily mounted centrally directly in front of the driver.

Smart Eye and Guardian

From the emitter/detector unit a single data cable needs to be routed to the processor unit. This is a small ruggedized computer and is powered directly from the trams auxiliary power supply system (24v).

In the case of Guardian, a GPS antenna (ideally mounted on the vehicle roof) is connected to the processor. A seat vibrator unit is also fitted underneath drivers' seat. This is connected to the processor unit.

The Smart Eye system that was tested did not include any audio or other outputs. It is however understood that this system could be connected to external equipment to provide driver feedback as required.

Leisure Auto

The processor is incorporated in the emitter/detector unit and requires a single 12v DC power supply that is plugged in to the unit.

Data collection/back office

Guardian

The Guardian system is linked in real time with data centres location in the U.S.A. and Australia. When a fatigue event is detected by the in-cab system, video footage is automatically sent to one of these data centres where it is analysed by trained staff. If it is deemed that the detected event is a real fatigue event, then an alert is sent to the Operational Control Centre (OCC) of the transport operator along with video footage. Although this process happens in real time, there is an inherent lag from the detection to the time that the OCC is alerted.

This process is designed to screen out any false positive events.

All trigger data from the Guardian device is available to the operator and can be used to analyse trends such as detections on common shifts etc.

Smart Eye

The Smart Eye system records all data event information. There is however no back office functionality currently available for this device although it is understood that this could be developed.

Leisure Auto

This device has no back office capability and it does not appear feasible that one could be developed based on the current technical arrangements.

12. Indicative Costs

Each suppler has provided indicative costs for the supply of equipment. In addition, any known ongoing costs have also been estimated.

The following table contains details received from suppliers

Supplier/system	Equipment capital costs	Implementation costs/notes	Operational costs	Note
Seeing Machines/ Guardian 2	£3,400 per cab	£500 per cab or training for operators engineer - £4,500 to £7,500	£50 per vehicle per month +£40 per vehicle per month (GSM Sim card)	Minimum contract period: 36 months.
Leisure Auto/ LS803	£190 per cab	None	None	
DENSO/DSM	Information redacted	Information redacted	Information redacted	
Smart Eye/ Aurora XO	£4200 per cab	Set up for each vehicle type £17000. (One-off cost). Training for operator technicians will be included. Thereafter those technicians will fit all devices.	£5000 per vehicle per year	A partnership with a systems integrator would be required.

13. Supplier Feedback

Since the completion of the testing, all suppliers have had the opportunity to receive feedback about the methodology used and their own system's performance.

Following this feedback, further information has been established.

Smart Eye

The Smart Eye system is developed primarily as an eye tracking system. Smart Eye do however have experience with detection of drowsiness having been involved with the development of this type of system for the automotive industry.

There is still some development required for this product to be ready for the Tram industry and the costs of this have been included in the indicative prices as detailed above.

Denso

The Denso system has been developed for the road haulage market in Japan. At this time this supplier is uncertain whether there is enough volume to justify the further investment required to supply the tram/light rail industry. Subsequent to the trial Denso have withdrawn from this opportunity.

Seeing Machines (Guardian)

The results from the Guardian system highlight some weaknesses. The supplier was keen to point out that some of the failures encountered were due to the set-up of the device under test. For example, with head rotation, currently if the system losses detection of one eye, then it is programmed NOT to issue a detection warning.

The supplier has stated that the system does detect both eyes individually and it would be a minor software modification to activate an alarm on non-detection of one eye and the closure of the other.

Furthermore, the supplier has stated that new software will be available shortly to address the performance of the Guardian system when the mouth and nose is covered (e.g. face masks, burqa).

14. Conclusions

Of the four systems trialled, three performed reasonably well under, what could be considered as, normal operating conditions. The Smart Eye system scored highest overall due to its ability to function when mouth and nose is covered. It is understood that Guardian may be able to address any shortfalls in performance with updated software.

The following table contains the overall rankings

Ranking	System	Static %	Longitudinal %	Note
1	Smart Eye	96	100	
2	Guardian	85	95	
3	Leisure Auto	39	-	This system was not included in Longitudinal test

The following table contains the rankings with additional tests (such as face masks) excluded.

Ranking	System	Static %	Note
1	Smart Eye	98	
2	Guardian	93	
3	Leisure Auto	43	

15. Recommendations

From this project the following recommendations are made:

- This report is shared with all UK tram operators.
- A workshop is held with all UK tram operators to discuss this report and agree on required next phases (Alert/Alarm and Intervention).
- The tests detailed in this report should be used as a benchmark for the assessment of suitability of any alternative eye closure systems being considered to address inattention
- This report and subsequent workshop outputs are used to form a standard that can be adopted by the industry.

16. Contributors to this Project

We would like to thank all those that participated in this project.

The following table contains details of contributors;

Name	Affiliation	Role	Note
Peter Cushing	LRSSB	CEO	
James Hammett	UK Tram	MD	
Jo Allerton	IRAL	Consultant	
Steve Duckering	UK Tram	Operations Manager	
Matt Baker	Independent	Research Subject	
Ian Rowe	IRAL	Director	
Beau Batten	IRAL	Researcher	
Martin Batten	IRAL	Director	
Duncan Smith	IRAL	Consultant	
Daniel Beecher	IRAL	Research subject	
Linda Fyfe	IRAL	Research subject and Report Editor	

Lynne Philips	Independent	Research subject	
Matt Baker	Independent	Research subject	
Louis Walmsley	Nottingham Express Transit	Head of Safety	
Lea Harrison	Edinburgh Tram	MD	
Colin Kerr	Edinburgh Tram	Head of Engineering	
Tim Lewis	AECOM	Head of Rolling Stock Transportation	
Chris Lewis	South Yorkshire Supertram Limited	Head of Safety and Environment	
Bilal Mohamed	South Yorkshire Supertram Limited	Head of Engineering	
Terry South	South Yorkshire Supertram Limited	Standards, Competency and Training Manager	
Thomas Ledger	South Yorkshire Supertram Limited	Driver	
Lee Joyce	South Yorkshire Passenger Transport Executive	Asset Engineer (Light Rail).	
Christopher Hopkinson	South Yorkshire Passenger Transport Executive	Tram Concession Manager	
Graham Thornton	Keolis Amey Metrolink	Head of Rolling Stock Projects	
Chris Allen	Keolis Amey Metrolink	Driver Manager	
John McGovern	Keolis Amey Metrolink	Engineering Safety Business Partner	
Terry Cook	Transport for Greater Manchester	Signalling and Digital Engineer	
Ian Coleman	Network Rail	Principal Engineer – Asset Enhancement Team Lead	

Chris Goodlad	Office of Rail and Road	HM Principal Inspector of Railways	
Ian Raxton	Office of Rail and Road	HM Principal Inspector of Railways	
Ian McDermott	Office of Rail and Road	HM Inspector of Railways	
Gabriel Nystrom	Smart Eye	Supplier Representative	
Björn Lindahl	Smart Eye	Supplier Representative	
Solmaz Shahmehr	Smart Eye	Supplier Representative	
Alastair Protheroe	Seeing Machines	Supplier Representative	
Andrew Thorpe	Seeing Machines	Supplier Representative	
Alan Smith	Seeing Machines	Supplier Representative	
Jon Ashley	DENSO	Supplier Representative	
Daniel Vine	DENSO	Supplier Representative	

17. References

- Overturning of a tram at Sandilands junction, Croydon, 9 November 2016 Report 18/2017 December 2017. Rail Accident Investigation Branch (RAIB)
- PeopleSize. 2008, Version 2.02, Open Ergonomics Ltd.,
- Human Factors Report – UK Tram - Driver Inattention and Speed Management Project. 4th May 2019 – Ian Rowe Associates Ltd.
- Human Factors Review for Driver Vigilance Device for Midland Metro. 3rd October 2018 – Ian Rowe Associates Ltd.

Appendix A – Approaches to Inattention Protection

UK Tram systems rely mainly on 'line-of-sight' principles. With this approach the driver is responsible for driving the vehicle appropriately according to weather and light conditions, anticipating emerging hazards and driving defensively to avoid collisions. Tram vehicles are also equipped with some railway standard type devices such as the Driver Safety Device (DSD), also sometimes known as the 'Dead Man's Device. These devices are intended to protect passengers, the vehicle and other stakeholders from harm should the driver become incapacitated.

The safety devices currently used on trams in the UK fall into two categories. In this report these are defined as follows:

DSD – Where the driver holds down a sprung switch (hand or foot switch) or places a finger on a capacitance touch pad in order to take and maintain traction and braking via the Traction Brake Controller (TBC)

DVD – (Driver Vigilance Device) Where the driver needs to engage a switch to take power/brake but needs to release and re-engage within a certain pre-defined time or distance to enable the vehicle to continue driving as normal.

For both approaches, if the driver fails to engage the device appropriately, the tram will alert the driver (usually with an audio alarm) and then apply the brakes if the driver does not respond appropriately within a pre-determined time or distance travelled.

Whilst the DSD type device has been used on rail vehicles for many years it has been proven that this device may not provide adequate protection under certain human failure types. The tram overturn in Croydon in 2016 is an example. Here the driver is believed to have suffered a micro-sleep but managed to maintain a downward pressure on the DSD switch. In this case the device did not protect against the failure of the driver and this resulted in the accident.

To address Recommendation 4 of the RAIB report into the Sandilands accident, market research was implemented into available 'inattention' systems. This subsequently concluded that there appears to be two fundamental approaches to detection of inattention.

These are categorised as:

- Facial and eye closure detection
- Task monitoring

The Driver Vigilance Device falls into the 'Task Monitoring' category of inattention systems. These systems test for regular activity of the driver (e.g. by monitoring activation of controls, change in TBC position or DVD reset) and produce an alarm and then application of brakes following lack of response within a pre-determined time or distance.

The 'Task Monitoring' approach is more likely to protect against inattention than the static DSD. These devices may increase driver workload and could result in Work Related Upper Limb Disorders (WRULD's) due to repetitive operation. They can also lead to false positive activations (e.g. if the driver misses the timer alarm). As most dynamic devices fitted in the UK apply hazard brake when activated, passengers travelling in the saloon can be harmed by the sudden braking. This can be particularly serious if hazard brakes are applied at low speed.[4]

These devices are also susceptible to habituation behaviour which is where the task of resetting the device becomes either a motor response (constant resetting of the device when the hand is placed on the TBC for example) or an automatic response to the alert that can be performed sub-consciously.

There are a number of documented cases from the heavy rail sector where the habituation issue has resulted in the DVD becoming ineffective. See the DVD Reset Habituation section of this report.

From research conducted by Ian Rowe Associates Ltd. (IRAL), in the event of driver incapacitation, the configuration of the DVD is critical to balance the protection offered against collision and to minimise false positive activations which can result in injuries to customers in the saloon.

This research conducted on behalf of Midland Metro in 2018 concluded that additional workload for the driver in resetting DVD was acceptable in terms of incapacitation protection. It was also manageable by drivers if the timer expiry alarm allowed sufficient response time before applying the brakes. In this case, a 15 second expiry time and a 4 second alarm time before applying brakes was programmed. Since the change to these new settings were implemented in October 2019, no instances of false positive activations have been experienced.

The most appropriate protection against human failure resulting in inattention (and therefore inability to control the vehicle appropriately) will depend upon how the human failure manifests itself. In the case of sudden onset illness such as a Stroke, or cognitive distraction (such as daydreaming), the driver's eyes may remain open. In this case an eye closure detection system may not mitigate against this risk.

The following table describes the perceived advantages and disadvantages of each approach:

Approach	Advantages	Disadvantages
Static DSD.	No additional driver workload. May protect against sudden onset illness (depending on failure type).	May not protect against fatigue events. May not protect against sudden onset illness event.
Task monitoring (including dynamic DVD).	• May protect against fatigue and sudden onset illness failure. • May protect against cognitive distraction	• Delay in response to detection based on timer settings. • Increases driver workload. • Susceptible to false positive activations. • May lead to WRULD injuries for drivers. • Subject to possible risk of habituation behaviour
Facial / eye closure detection.	• Good performance for eye closure detection (fatigue events).	May not protect against sudden onset illness (e.g. stroke), or other

[4] A hazard brake activation in Europe recently following a false positive DSD detection resulted in the death of a customer traveling in the saloon.

	• Feedback is immediate • No impact on driver workload • Could provide insight into general fatigue amongst drivers and inform rosters etc.	inattention where driver's eyes remain open.

It should be noted that some dynamic DVD systems are more sophisticated than a simple fixed timer reset by the driver removing and replacing their thumb on a capacitance switch. Systems such as those used by Edinburgh Tram use a combination of 'time and distance travelled' with 'tasks monitored' (including TBC and foot pedal activation) to manage the device. This is designed to minimise false positive applications especially at low speed.

DVD Reset Habituation

Since initial publication of this report in 2020, further research has been conducted to understand the possible risks associated with the DVD system approach and mitigation measures available.

As discussed previously, it is possible that the constant resetting of the DVD device could become habitual. This is more likely if the response timer is set to a very low interval as this could result in a motor response or if the interval is a fixed time unaffected by operation of controls other than the specific DVD reset switch. In this case a sub-conscious auto response to the alert could be developed. In either case, DVD reset habituation is a risk that dilutes the effectiveness of the DVD approach.

To understand more about the likelihood of habituation two short studies were carried out on two UK tram networks both having DVD but with differing system set-ups.

Edinburgh Trams uses a pedal to reset the DVD. This system however also uses movement of the traction brake controller to reset the DVD. The DVD has two modes[5] but drivers are trained to use what is known as 'slow' mode. In this case the driver rests their foot on the pedal and drives. Each time the TBC moves through 25% of travel, the DVD is reset. If the tram travels for 400 metres without receiving a reset, an audio and visual alert is given. If the tram travels a further 70m without the DVD being reset by either moving the TBC or by the driver manually resetting the device using the pedal (release pedal and re-press), the full-service brakes are applied and the tram is brought to a halt.

The system uses 'fast' mode if the foot pedal is not pressed. The system works similarly to slow mode except the distance travelled before the alert is 70 metres with a further 100 metres before brakes are applied.

[5] The DVD mode is known as 'fast' if the tram is operated without the driver's foot on the pedal and slow if the drivers foot activates the pedal

Figure 22 - Edinburgh Trams DVD foot-pedal

Midland Metro trams use a single reset device for the DVD. The DVD can only be reset by the driver removing their thumb from the capacitance touch switch on the end of the traction brake controller and replacing the thumb.

If the DVD is not reset within the 15 second interval an audio alert is given. The driver then has 4 seconds to reset the device. If the device is not reset then the hazard brakes are applied and the tram is brought to a standstill.

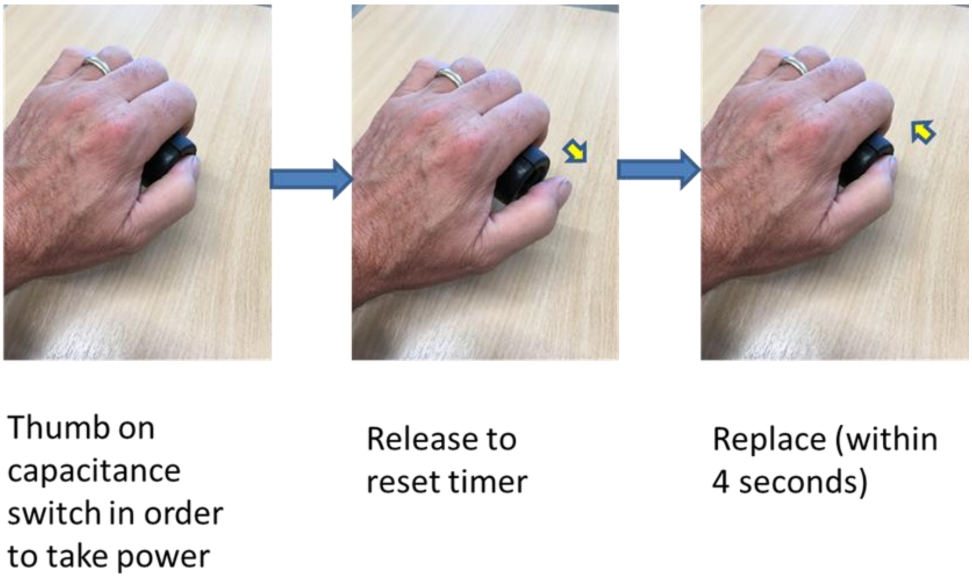


Figure 23 - Midlands Metro TBC touch switch

Downloads from the On Tram Monitoring Recorder (OTMR) were taken from random sample trips from trams at Edinburgh and Midland Metro. An analysis of manual DVD resets was undertaken to understand the frequency of manual resets required on the different systems and to establish the relative likelihood of reset habituation.

The results are summarised in the following tables:

Edinburgh Trams

Ref	Session time (Mins)	No of foot pedal resets	Average time between manual resets (mins)
Tram 256EB	120	12	10
8	7	1	7
7	139	4	34.75
6	134	1	134
5	137	1	137
4	137	4	34.25
3	137	7	19.57
2	143	20	7.15
1	150	49	3.06
255am	64	2	32
255mid	95	1	95
255pm	97	89	1.09
256am	100	6	16.67
256mid	99	6	16.5
256pm	99	1	99
260am	86	3	28.67
260mid	96	3	32
260pm	97	0	97
262am	128	5	25.6
262mid	99	6	16.5
262pm	96	35	2.74
271am	90	1	90
271mid	100	2	50

271pm	98	1	98
276am	100	2	50
276mid	101	2	50.5
276pm	99	1	99

Midland Metro

Ref	Session time (Mins)	No of resets	Profile 3-14 seconds	Profile 15+ seconds
T33 03-11-2020	73	344	199	135
T25 11-09-2020	53	401	332	52
T25 03-09-2020	70	473	309	119
17-06-2020	80	628	300	174
T20 05-10-20	73	246	106	136
T23 30-09-2020	57	360	210	113
T24 22-09-20	64	324	242	65
T27 08-08-20	72	608	626	56
T28 22-07-2020	69	587	277	124
T33 14-07-2020	73	415	212	156
T35 15-12-2020	72	149	114	13

Please note that the total number of resets include those activated after the alert timer activation and those occurring with less than 3 second gaps

DVD System Analysis

As seen in the above tables, the Edinburgh Trams reset frequency is significantly less than that required for Midlands Metro with average reset time interval being 47 minutes compared to Midland Metro requiring 4 resets per minute.

It is concluded that habituation is far more likely with the Midland Metro arrangement than with the Edinburgh Trams set-up.

The DVD protection zones for the two networks are as follows:

Network	Protection distance	Interval time	Vehicle speed	Mode
Edinburgh Trams	400 metres (fixed)	20.6 seconds (Calculated)	70kph	Slow mode
	400 metres (fixed)	144.4 Seconds (calculated)	10kph	Slow mode
	100 metres (fixed)	5.1 seconds (calculated)	70kph	Fast mode
	100 metres (fixed)	35.97 Seconds (calculated)	10kph	Fast Mode
Midland Metro	291 metres (calculated)	15 seconds (fixed)	70kph	N/A
	41 metres (calculated)	15 seconds (fixed)	10kph	N/A

Edinburgh Trams use distance as the DVD interval with Midland Metro using time. It is therefore not possible to make direct comparisons on protection zones.

Eye Closure Detection vs. Task Monitoring - Conclusions

Both approaches to driver inattention have advantages and disadvantages.

This report concludes that the state of the eye closure detection technology is generally reliable, and if implemented carefully, could have prevented the type of accident that occurred at Sandilands in 2016. Equally a properly configured Task Monitoring (DVD) system could also have prevented the accident.
For both types of systems, occurrence of false positive activations needs to be appropriately managed. This is especially important if the system intervenes and automatically applies the brakes.

As seen with the Midland Metro experience, the timing configuration is critical to manage false positive activations but it is possible to minimise these with appropriate timings and other configurable variables. Furthermore, using additional inputs from the control in the cab, such as traction brake controller, can significantly reduce the likelihood of reset habituation that could be considered as a weakness of the task monitoring approach.

In the case of eye closure detection, it is recommended that a further 'acknowledgement phase' is added to the sequence before the system automatically applies the brakes. None of the systems involved in the eye closure system trial have developed this functionality but it is anticipated that this new functionality would be feasible and could be implemented in the future.