Light Rail Safety and Standards Board

Automatic Vehicle Speed Management System Trials

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Automatic Vehicle Speed Management System Trials.

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Glossary

Term/abbreviation	Description
AVSMS	Automatic Vehicle Speed Management System
LRSSB	Light Rail Safety Standard Board
IRAL	Ian Rowe Associates Ltd.
KAM	Keolis Amey Metrolink
OTMR	On Tram Monitoring Recorder
PPOS	Physical Prevention of Overspeed
RFID	Radio Frequency Identification
SIMOVE	Product name given to continuous AVSMS produced by Metro Tenerife
SR	Speed restriction

Figures

Introduction

The research detailed in this report was originally commissioned by UK Tram subsequent to the market study into Automatic Vehicle Speed Management Systems (AVSMS) following the Sandilands Tram accident in 2016.

The market study research concluded that systems available at the time fell into one of two categories. These being:

- Location specific
- Continuous

A trial of a location specific system was undertaken by London Trams, testing the EKE Sella solution, known as Physical Prevention of Overspeed (PPOS). A trial of a continuous monitoring system was also commissioned by the Light Rail Safety Standards Board (LRSSB) to provide an objective comparison of the two different approaches in order to inform the industry.

This report includes details of:

- The PPOS location specific AVSMS developed by EKE Sella and trialled at London Trams
- The SIMOVE continuous AVSMS developed by Metro Tenerife and trialled at Manchester Metrolink

PPOS System Trial

Methodology

The trial was conducted by engineers and operators from London Trams and the findings and results from the trial were communicated to IRAL over several interviews. Further technical information was obtained by IRAL as the PPOS system was integrated into the driving simulator system used by London Trams.

System Overview

The PPOS system was developed from an existing location specific system used in heavy rail. This system uses Radio Frequency Identification (RFID) tags mounted between the running rails at strategic points. These tags are passive (i.e. do not require a power supply feed) and contain information about the permitted speed for the specific upcoming location and communicates this to transponder equipment mounted below the tram. These transponders feed permitted speed information to a processing unit which also receives current speed information from the vehicle. The processing unit determines if the tram speed is in excess of the maximum tolerated speed and if so, automatically applies full-service brake bringing the vehicle to a halt.

The Tracklink III© Tag
Constructed from flame-retardant, toughened polymer and with an aluminium base, the tag is factory sealed to IP 67 and suitable for use in a variety of harsh environments.

Figure 1 - RFID Tag

System Configuration

The diagram below shows the basic configuration for each location on the network that was identified as high risk.

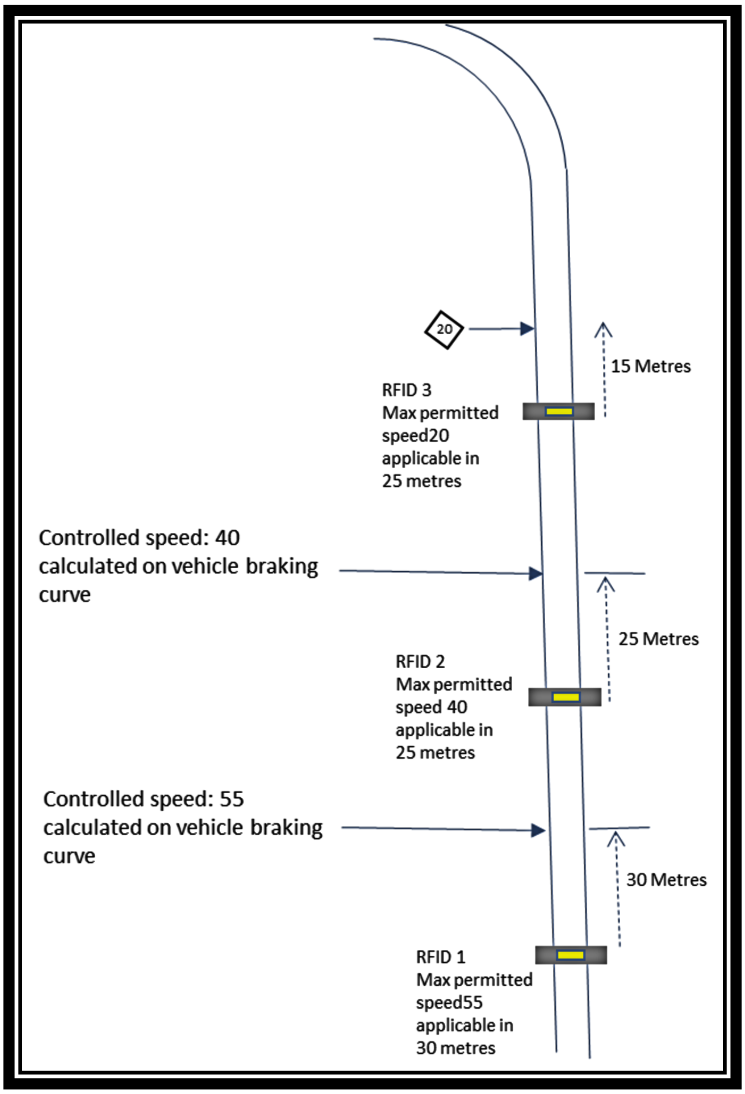

Figure 2 - Example curve protection arrangement

Each location selected for AVSMS has a series of 3 RFID Tags fitted to sleepers leading up to the protected area. In the example above, the speed restriction of 20 prior to the curve is controlled using a series of a step-down controlled speeds. These are calculated to ensure that if the vehicle speed is too high approaching the speed restriction, the vehicle will be brought to a halt before reaching the 20 speed restriction.

Note that in this example there is only one signed speed but two prior controlled speeds that are unsigned.

Each RFID Tag contains a Tag identification number as well as details of the distance ahead at which the controlled speed is to be applied. This Tag number is used to detect system integrity issues. The system is expecting each location to have 3 Tags. If, for example, the reader detects Tag 1, fails to read Tag 2 but reads Tag 3, a system integrity error is identified.

The system also includes an additional integrity layer using wheel turn information to check if the RFID Tags are detected within a set distance parameter.

Findings

As the Covid-19 pandemic restrictions precluded travel and face-to-face meetings, several telephone interviews were undertaken with Colin Matlock and James Batchelor at London Trams to establish the progress and results of the trial.

The findings are summarised as follows:

- A single transponder is fitted to each vehicle. Two vehicle types are in operation: Bombardier CR4000 and Stadler Variobahn. As transponders cannot be fitted in exactly the same position on both vehicles, the situation is managed by the system using 'offset' information programmed into the controller.
- Test Tags are installed on the exit road from the Depot so the system can be checked before vehicles enter daily service.
- In the driving cabs there is an indicator that illuminates when the PPOS system has been triggered. There are also switches to enable the driver to reset the 'trip' or override the PPOS system. In the case of a PPOS trip, the driver must gain authority from the Control Centre before resetting the system.
- The Control Room receives alarms for all brake applications and system integrity errors.
- The transponder and processing equipment require the following feeds from the tram:
    - Power source
    - Speed probes (x2)
    - Wheel turns
- The system carries Safety Integrity Level 2 (SIL2). This ensures that the system components are of suitably high quality and that the total application is implemented such that system integrity is assured.
- Drivers are trained on the functionality and operation of the PPOS system in the simulator prior to driving on the real network.
- 13 locations have been identified as 'high risk' with regard to potential vehicle overturn at speed. These locations are all on segregated track sections.

Results

The PPOS system is now fully operational. Details of the number of brake application or system integrity errors have not been disclosed, however, the following is a high-level summary of the results of the trial:

- RFID Tag breakages – Whilst the RFID Tags are designed to be robust and weatherproof, there has been some damage to installed Tags by road rail vehicles. Regular inspection is required to ensure that the Tags remain in place and are in good condition.
- Tag fitment – All 13 identified high risk locations are in segregated track sections. It is acknowledged that it would not be possible to fit these Tags in street running sections.
- System integrity – The system requires input from two independent speed probes to ascertain the vehicle speed. If the speed reading from both is different (outside a tolerance), the system identifies an integrity error and applies the brakes. This is a characteristic of the 'fail safe' nature of the system.
- Problems have been encountered with PPOS trips brought about by speed probes differentials. The causes of this are believed to be the cleanliness of the speed probes and

potential EMC noise issues. This is being addressed with increased maintenance on the speed probe system.

- Single line sections – On the network there are number of single line sections. These include the lead up to high risk curves. It has been necessary to modify the PPOS system functionality to include a directional capability such that a vehicle passing over a Tag will ignore the Tag if traveling in one direction but apply the Tag speed control when running towards the high-risk curve in the other direction. This has necessitated additional Tags to be installed at either end of the single line section. These have proven un-reliable with the tram sometimes failing to read these additional Tags. This has necessitated additional Tags being installed on adjacent sleepers to increase read reliability.
- Speed control configuration – Whilst there is a theoretical braking curve for each vehicle type, there is a natural variation in the way that drivers will approach a speed restriction. This can be dependent on track conditions and other considerations such as passenger comfort. Problems have been encountered where the brakes have been automatically applied during the 'step down' speed controls with the driver believing that the system has been over-zealous in applying the brakes.
- Diverging junctions – Whilst there are no high-risk curves immediately following a diverging junction, it is acknowledged that the system would be unable to manage this situation as there is no 'route' information considered as part of the speed control process.

SIMOVE System Trial

System Overview

The SIMOVE system is a driver advisory system that continuously monitors the tram speed, protecting every speed restriction, and is capable of requesting an application of the tram brakes. It uses both wheel turn information and GPS to operate with the safety-critical speed monitoring task based on odometer information. The system is a stand-alone system that can be retrofitted to any rolling stock type provided the necessary connections (detailed in the installation section of this report) are available.

With data from the odometer ascertaining the vehicle speed, SIMOVE can continually check that the tram is traveling at the correct speed. The GPS (using a pre-created topology map) confirms the vehicle's starting position.

GPS also identifies and double checks the location at each stop or other known GPS location in the topology map. This check ensures the vehicle is where SIMOVE expected it to be and reduces cumulative errors that may occur over a long journey.

On networks with multiple lines and routes, drivers must inform the system which route they are taking before starting the trip. SIMOVE is unable to identify that the vehicle has taken a diverging route at the time of divergence. If this occurs, the driver and Control Room are alerted to the error along with other nominated persons, and protection will cease.

Should an 'Overspeed' occur that exceeds a defined warning threshold, SIMOVE provides an audio-visual alert along with a visual alert on the in-cab dedicated screen. If the speed exceeds the braking threshold, SIMOVE requests a brake application and brings the vehicle to a halt. In both instances of minor or significant overspeed, an SMS alert is sent in real-time to the Control Room and other nominated persons.

Figure 3 - Speed control logic

If the driver takes heed of the warning and reduces the vehicle speed to a tolerable level, the journey can continue. If a brake application is applied, the driver must acknowledge the on-screen warning before the brakes are released. The journey can only then continue.

All warnings or brake applications are logged in real-time to the SIMOVE system 'Back Office'. This data gathering allows a detailed analysis of the journey, providing information about the driver, location, and details of any 'event' allowing further analysis of the error type.

The type of brake applied will depend on the connections available on individual rolling stock types. In the Manchester trial, the full-service brake was utilised as a hard-wired connection was available. Where this is not the case, the hazard brake loop could be used.

It may be possible to link the SIMOVE system with existing route setting equipment, but for the trial the system was implemented as standalone. Further integration would require the cooperation of the rolling stock manufacturer or other sub-system suppliers.

Any synchronisation location can be entered into the topology map. This means that other locations where the vehicle is normally pulled to a halt can be used to provide GPS verification thus improving overall system accuracy. This could include crossovers or sidings between stops.

SIMOVE is not SIL rated. This however is not considered critical as the system does not compromise the braking system as it is not integrated with this sub-system.

The SIMOVE system offers several additional benefits (discussed later in this report) due to the large amount of detailed information gathered.

Trial Design and Methodology

The trial was designed to objectively assess the efficacy, usability, and suitability of the SIMOVE system. This included:

- Understanding all aspects of the installation and set-up requirements of the on-board systems.
- The creation and maintenance of the line topology file.
- Assessment of system accuracy and whether any inaccuracies could affect safety performance.
- Testing of the system for reliability and robustness to ensure each speed restriction was reliably detected by the system.
- Identification of any shortfalls due to the approach used for testing and any residual risks that remain unknown.

The SIMOVE system was fitted to both A and B cabs on a single M5000 vehicle number 3113. The Rochdale to East Didsbury line was selected for the trial as it is the longest route on the Metrolink system with significantly differing distances between tram stops. The total distance is 22.87 miles.

This line contains a good mix of fast segregated and slower shared city centre running with heavily built-up areas and rural areas to test system performance. There are a total of 253 speed restriction changes on this line.

The agreed trial period was for three months, however, due to the COVID19 pandemic, the system could not be un-installed so vehicle speed compliance monitoring until August 2020.

The trial chronology is shown in the table below.

Activity	Date	Note
First on-site vehicle survey and agreement of project plan and scope	14th to 16th October 2019	Engineers from Metro Tenerife (MT) travelled to Manchester and worked with IRAL consultants
Installation design and topology	17th October to 10th November 2019	MT engineers created detailed installation design and initial topology file from track alignment and speed restriction location data
Fitting of equipment to vehicle 3113 and initial system test	11th to 14th November 2019	MT engineers installed equipment to vehicle 3113 Including connection to degraded driving mode input
Transport for Greater Manchester (TfGM) Safety Review Committee (SRC) approval	6th December 2019	IRAL presented proposed trial and gained permission to run test vehicle in service but with screen switched off (i.e. no driver feedback due to concerns of distraction) and no connection to the brake system
Final temporary installation and topology adjustment and verification	16th to 19th December 2019	Engineers from MT and IRAL consultants
Semi-permanent installation complete	20th April 2020	KAM Technicians/IRAL consultants
Running trial commences	21st April 2020	The test vehicle was allocated to the Rochdale to East Didsbury line and has run in service on this route as much as possible
Accuracy verification exercise	7th May 2020	The test vehicle was run 'non-stop' from EDD to SWR and back to ascertain accuracy when no GPS positioning was available.
Completion of trial	12 June 2020	The trial was completed. The equipment has remained on the vehicle as MT engineers are currently unable to travel to the UK. The equipment is still operational and being monitored.

Table 1 - Trial timescales

Installation

SIMOVE operates in both A and B cabs as a stand-alone system. It is necessary however for the cab systems to communicate with each other. This communication can be achieved using 4G wireless but a wired connection using an ethernet cable is preferred.

During the installation design phase, it was discovered that on the M5000 vehicle the B cab uses a feed from the OTMR to display speed information. The delays in data arrival associated with this arrangement would have resulted in significant inaccuracies in the AVSMS when driven from the B cab. It was therefore decided to install an ethernet cable between both cabs enabling accurate real time speed information to be used by both SIMOVE processors and to eliminate any reliability issues there may have been with wireless connection.

The SIMOVE system requires connection to the vehicle to operate. These are:

- Connection to the odometer
- Connection to the 24v power supply
- Connection to the vehicles earth or ground
- Connection to the cab active signal

* Connection to the chosen brake system or loop

These connections should be available in all rolling stock types.

The diagram below shows a basic installation:

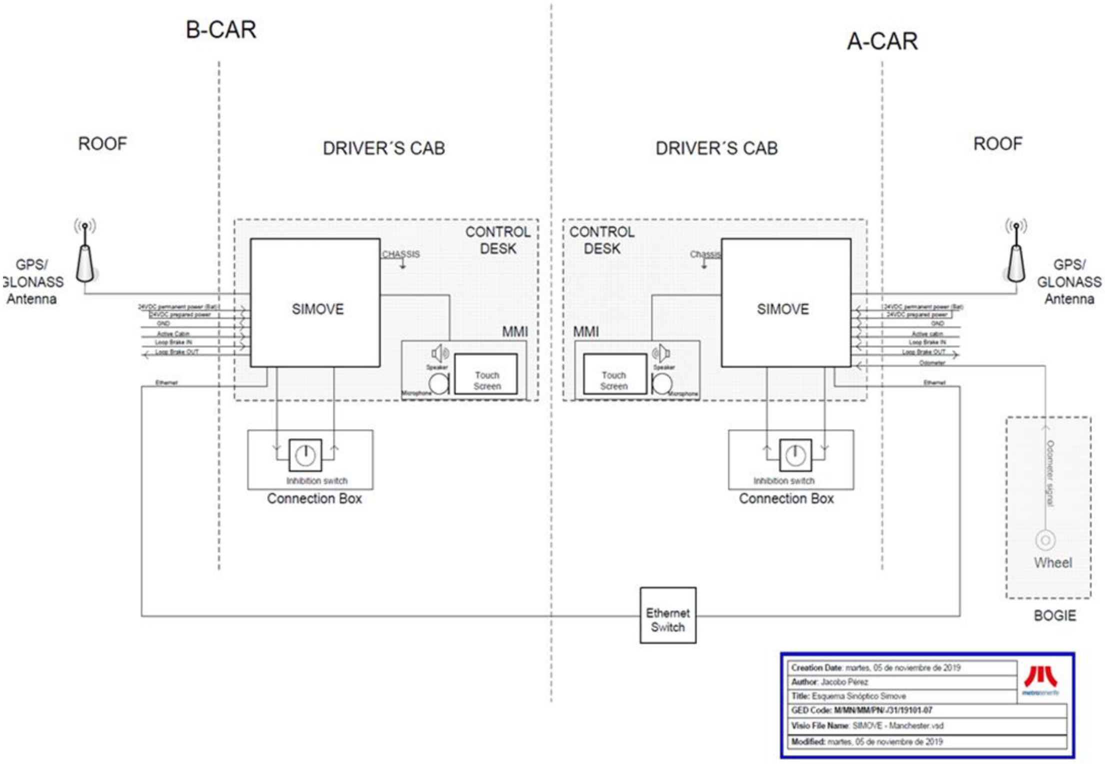

Figure 4 - SIMOVE system vehicle schematic

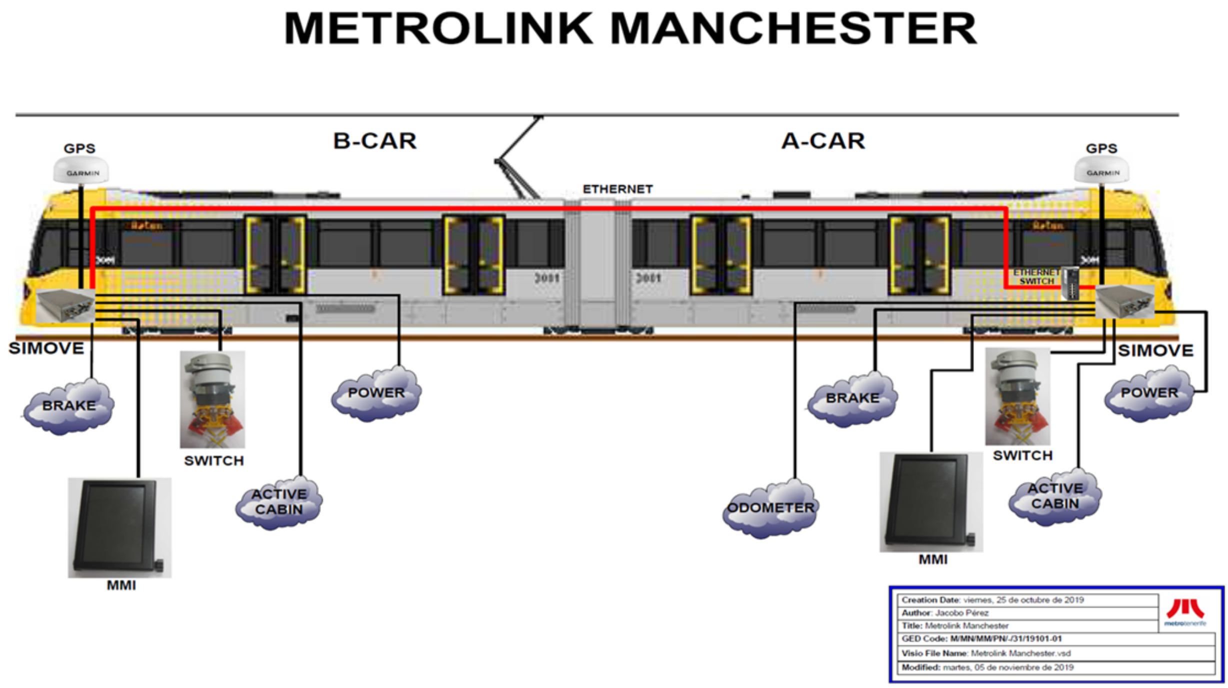

Figure 5 - SIMOVE vehicle system placement

The brake connection used is dependent on what is available on different vehicle types.

Most 2nd generation vehicles use a 'brake loop' system connected to the braking system. This is normally used to automatically apply the brakes in the case of a safety critical event such as doors being opened when the vehicle is in motion. This brake loop could have been used for the trial, but it was decided to use the hard-wired full-service brake input which is used in the case of degraded operation.

It was necessary to install a dedicated GPS antenna mounted on the roof at each end of the vehicle. This was used to accurately determine vehicle position at pre-defined synchronisation locations. It is recommended to install these directly above the driving seat position but, if this is not possible, the SIMOVE software can correct any offset.

The figure below shows the Bombardier M5000 installation, including GPS antenna dimensions. This was fitted below the height of existing equipment to avoid the need for re-gauging.

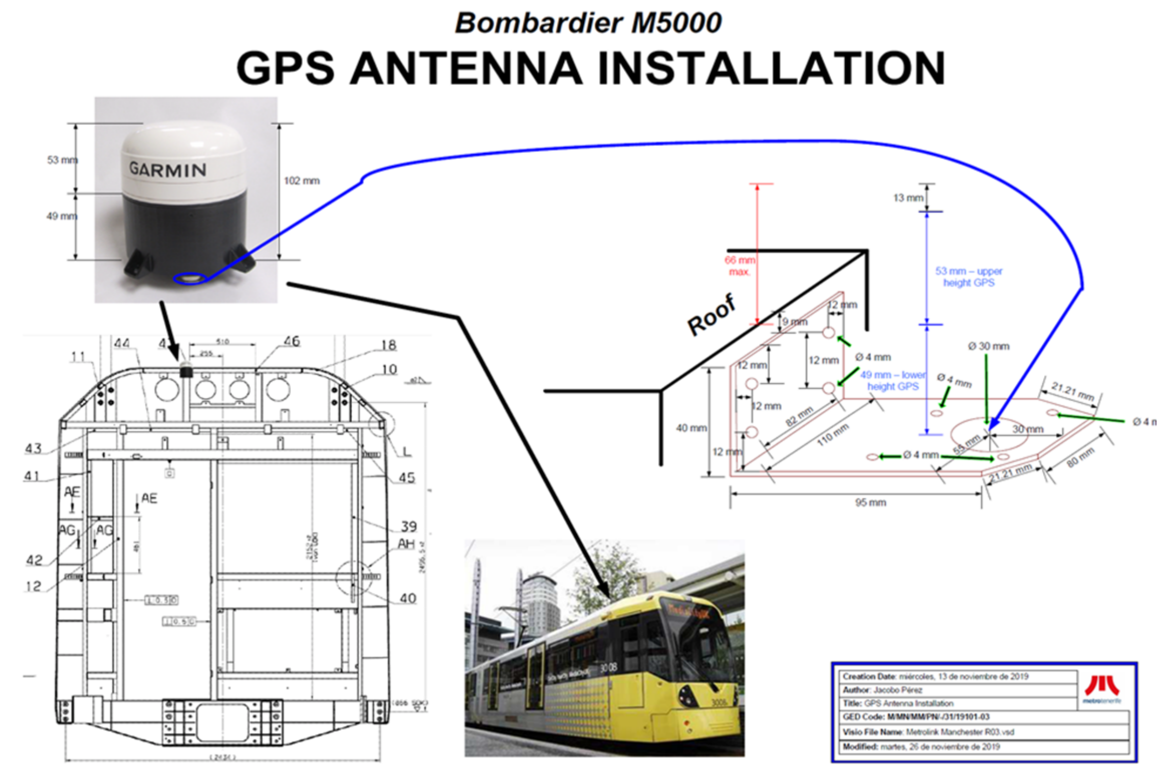

Figure 6 - Antenna placement

A small in-cab touch screen was installed in a position where it would be visible to the driver but clear of any other equipment and not easily banged or knocked as the driver carries out normal duties. This screen should ideally be positioned no further than 1.5 metres from the SIMOVE computer. Both the ruggedised computer and screen are reasonably small and light and were easily mounted in the M5000 cabs.

The system does require the in-cab screen to operate. Having this screen does however deliver significant benefits as without it the driver is unaware of any overspeed and cannot correct behaviour prior to an intervention.

The screen was turned off during most of the trial to eliminate any potential risks of driver distraction. However, the screen was switched on during specific tests and also to verify system accuracy during set up.

It should be noted that a basic Human Factors assessment including driver feedback suggests that having the screen switched on during normal operation is unlikely to cause significant distraction in the driving task.

During installation, verification of overall system integrity was carried out. Testing was carried out with another unmodified M5000 coupled to V3113. On-Tram Monitoring Recorder (OTMR) readings were taken from both. These readings were compared to ensure that the connection of the SIMOVE system had not affected the OTMR data on the test vehicle. This exercise concluded that OTMR records from both vehicles were identical, and no interference was caused by the SIMOVE equipment to either cab speedometer or OTMR.

Controlled testing of SIMOVE's ability to apply the brakes for excessive overspeed was also carried out on Trafford Depot. This was achieved using a specially created depot-specific topology map with artificially low speed restrictions. SIMOVE reliably detected the tram's speed and gave warnings or applied the brakes as expected.

The images below show the SIMOVE computer and interface touch screen in a temporary location. This provides an indication of equipment size.

Figure 7 - User interface placement

During the vehicle installation, SIMOVE personnel created a topology map of the Rochdale to East Didsbury line. This process took around three days to complete using specialist GPS survey equipment.

A GPS location must be taken at each point to be identified as "known location" such as a tram stop. A co-ordinate map is produced with GPS ‘pins’ at 2 metre intervals. An example of a partially built topology map is shown below.

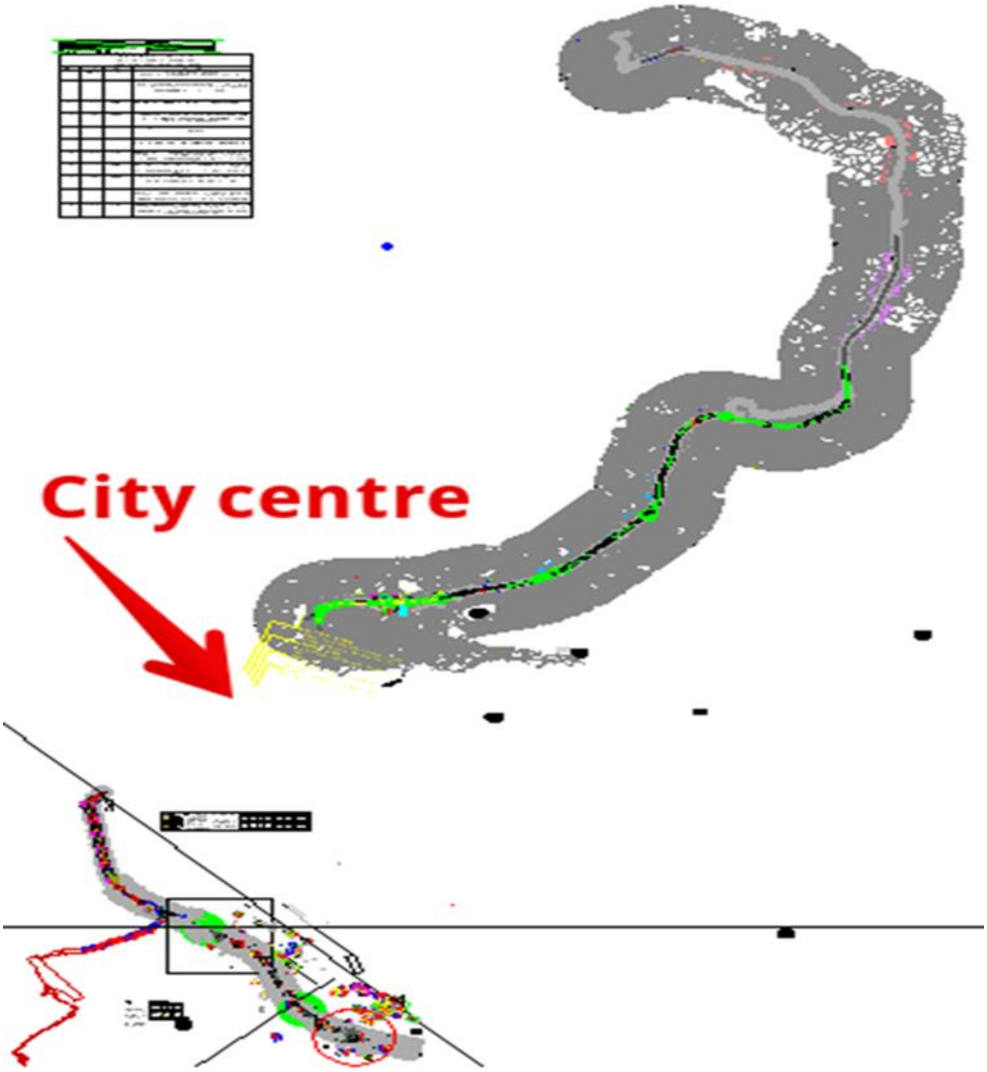

Figure 8 - Trial route coverage

Once the topology map had been constructed, several runs were needed on the line to refine the speed board positions and ensure the map was as accurate as possible. Adjustments were made between each trip. The topology construction and checking are likely to be the most time-consuming part of the initial set up and installation. The accuracy of the system depends heavily on this task.

During depot testing, an issue was discovered with the installation. Using the degraded full-service brake connection, when SIMOVE activated and the vehicle stopped, the tram would detect a fault as the vehicle appears to be taking power and braking simultaneously. This generates a fault which is displayed on the fault display unit specifying a Traction Brake Controller failure. The vehicle requires a battery reset to clear the fault. KAM engineers believe that this could be overcome by the vehicle manufacturer with a modification to the traction package. This would not have been an issue if the emergency brake loop had been used.

Operational Trial and Findings

During the trial, the SIMOVE system was closely monitored with real time alerts and via the 'Back Office' suite. This ensured trips were being recorded accurately and any warnings or 'would be' brake applications reported were understood. The SIMOVE cab screen was disabled so no warnings or messages were shown so driver interaction was not required. Warnings were still recorded and the 'Back Office' was notified as normal.

The SIMOVE system behaved reliably with consistent accuracy during the trial. A significant amount of data has been collected and verified and there have been no false positive errors. Any errors detected were investigated. These were all found to be operational issues such as the trial vehicle being re-routed onto a line that is not in the trial scope and speed restriction changes that were made after completion of the topology file and prior to the commencement of the field trial.

Errors caused by changing these speed restrictions were corrected by amending the topology file within a few days of trial commencement. Once these errors were addressed the system performed very reliably with no loss of service or failures throughout the trial.

Due to the implementation of an emergency timetable, as a result of the Covid-19 pandemic, the vehicle was also running permanently coupled with another vehicle. This meant that trips could only be recorded in one direction. Overspeed events appeared to have been accurately recorded and at the time detailed analysis was carried out approximately 540 runs had been recorded since the trial began with an average of 2.96 overspeed events per trip. It is important to note that these events are based on a tighter, more exact criteria than those used for speed restriction compliance monitoring by the operator using OTMR records.

The accuracy of warnings given was verified by sample testing a number of events from different trips on different days against the OTMR data downloaded from the vehicle. As OTMR data capture is triggered by events and not by variation in speed or frequent 'heart beat' logging, this was not a straightforward comparison. However, as the example below shows, it was possible to verify at a matching cumulative distance the speed shown by SIMOVE and accuracy of the warning matching the OTMR data.

SIMOVE is also able to graphically plot the trips using a "KML" file type recorded at the end of each trip. Google Earth or similar mapping software can be used to display location and vehicle acceleration characteristics along with other details. This enables efficient analysis and understanding of overspeed occurrences. It significantly reduced the time taken and improved the quality and accuracy of information compared to using OTMR data.

Doors Open Si 1	Doors Open Si 2	Em Pan Down	Door Em Actioned	Direction A	Direction B	Line V>400v	POS Master C	Speed KPH	Distance (Meters)	Cum Distance (Metres)	Stop To Stop Distance	Actual Speed MPH	Mapped Speed limits	Speed Over /Under	Speeding Violation +10%?	Speeding Violation +10% +2mph?	Speeding Violation?	Speed Ov %
0	0	0	0	0	1	1	-5	50	19.98	8123.04	2659.43	31.1	50	-18.9				-38%
0	0	0	0	0	1	1	-1	50	12.46	8135.5	2671.89	31.1	30	1.1				4%
0	0	0	0	0	1	1	-1	48	60.98	8196.48	2732.87	29.8	30	-0.2				-1%
0	0	0	0	0	1	1	-23	45	31.31	8227.79	2764.18	28.0	30	-2.0				-7%
0	0	0	0	0	1	1	-23	42	24.28	8252.07	2788.46	26.1	30	-3.9				-13%
0	0	0	0	0	1	1	-34	39	22.58	8274.65	2811.04	24.2	30	-5.8				-19%
0	0	0	0	0	1	1	-56	36	13.57	8288.22	2824.61	22.4	30	-7.6				-25%
0	0	0	0	0	1	1	-71	33	9.54	8297.76	2834.15	20.5	30	-9.5				-32%
0	0	0	0	0	1	1	-74	30	6.96	8304.72	2841.11	18.6	30	-11.4				-38%
0	0	0	0	0	1	1	-74	29	2.46	8307.18	2843.57	18.0	30	-12.0				-40%
0	0	0	0	0	1	1	-74	28	2.35	8309.53	2845.92	17.4	30	-12.6				-42%
0	0	0	0	0	1	1	-67	27	2.26	8311.79	2848.18	16.8	30	-13.2				-44%
0	0	0	0	0	1	1	-67	26	1.47	8313.26	2849.65	16.2	30	-13.8				-46%
0	0	0	0	0	1	1	-67	25	2.12	8315.38	2851.77	15.5	30	-14.5				-48%
0	0	0	0	0	1	1	-63	24	2.05	8317.43	2853.82	14.9	30	-15.1				-50%
0	0	0	0	0	1	1	-52	23	1.96	8319.39	2855.78	14.3	30	-15.7				-52%
0	0	0	0	0	1	1	-30	22	2.51	8321.9	2858.29	13.7	30	-16.3				-54%
0	0	0	0	0	1	1	-5	21	3	8324.9	2861.29	13.0	10	3.0	YES	YES		30%
0	0	0	0	0	1	1	-1	20	6.91	8331.81	2868.2	12.4	10	2.4	YES			24%
0	0	0	0	0	1	1	-1	20	1.7	8333.51	2869.9	12.4	10	2.4	YES			24%
0	0	0	0	0	1	1	0	19	9.29	8342.8	2879.19	11.8	10	1.8	YES			18%
0	0	0	0	0	1	1	0	18	17.88	8360.68	2897.07	11.2	10	1.2	YES			12%
0	0	0	0	0	1	1	0	17	15.41	8376.09	2912.48	10.6	10	0.6				6%

Figure 9 - System data display

Cumulative errors caused by wheel slip/slide are corrected using GPS location synchronisation at tram stops and other defined synchronisation points. Errors that may accrue if trams do not stop at defined positions are dependent on the accuracy of the wheel radius information from the odometer. For the trial, SIMOVE engineers have calculated that cumulative error is likely to be in the order of 2 metres per 3kms

To test for cumulative errors if a tram was non-stopping, test runs were carried out where GPS synchronisation was inhibited i.e. tram non-stopping at platforms. During this test, a distance of 4459 metres was travelled in this mode with no detectable change in accuracy of speed limit enforcement.

This would also be the case if the GPS signal was lost. However, SIMOVE includes the facility to inhibit the automatic braking functionality if GPS synchronisation is not attained within a defined parameter. The system will continue to record trip data and give warnings to the driver.

In order to protect routes where there is a diverging junction from a common corridor, drivers must select a route at the start of the journey. If the driver fails to do this, incorrect warnings and/or brake applications are possible. When the tram arrives at the next known GPS location, the discrepancy in geographical position is detected by the system, and the driver/Control Centre are alerted.

During the trial only one scenario was discovered where SIMOVE would be unable to offer protection due to GPS inaccuracy. Areas on the same route where trams run in the same direction on parallel lines but with different speed limits are not able to have different limits applied.

The example below shows this issue.

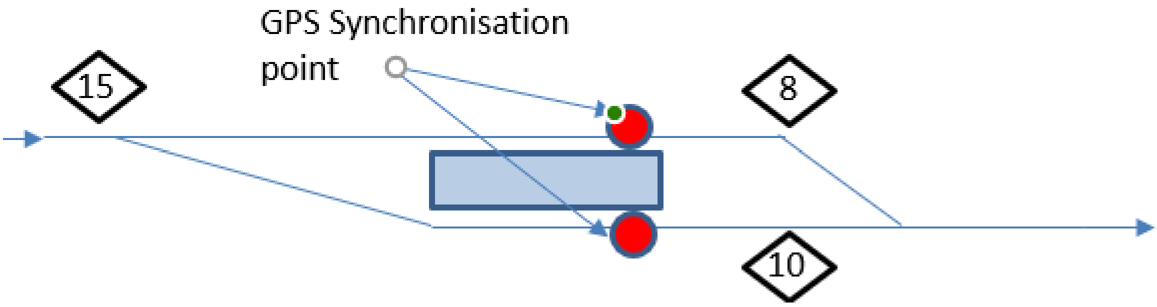

Figure 10 - Diverging junction layout

In this example SIMOVE, due to the inaccuracy of commercial GPS, the system is unable to reliably ascertain which platform the vehicle has arrived at. It is therefore not possible to control the different speed restrictions leaving the platform. In this case the lower of the speed restrictions would need to be implemented when leaving either platform to overcome the inaccuracy.

Conclusions

Both approaches to AVSMS appear to deliver good efficacy for monitoring and controlling speed at high-risk locations. The SIMOVE continuous approach has the advantage of having the ability to control every speed restriction on the network whereas it is unlikely to be practical, or even feasible, to do the same with the location specific approach.

The SIMOVE continuous approach relies on newer technology whereas the PPOS location specific approach uses technology that is already well established in the heavy rail sector and this has the benefit of carrying a safety integrity rating level.

The trial has however concluded that the reliability and accuracy of the SIMOVE continuous monitoring system was very good with no malfunction or system accuracy issues detected during the whole field trial.

The SIMOVE continuous system also delivers supplementary benefits such as collection and analysis of speed data for all trips and real-time capture of overspeed occurrences at all speed restrictions. This significantly improves the required speed monitoring process for any operator. It removes the requirement to perform random OTMR downloads and analysis to perform speed compliance monitoring as all overspeed occurrences are detected and reported by the system (i.e. 100% sample).