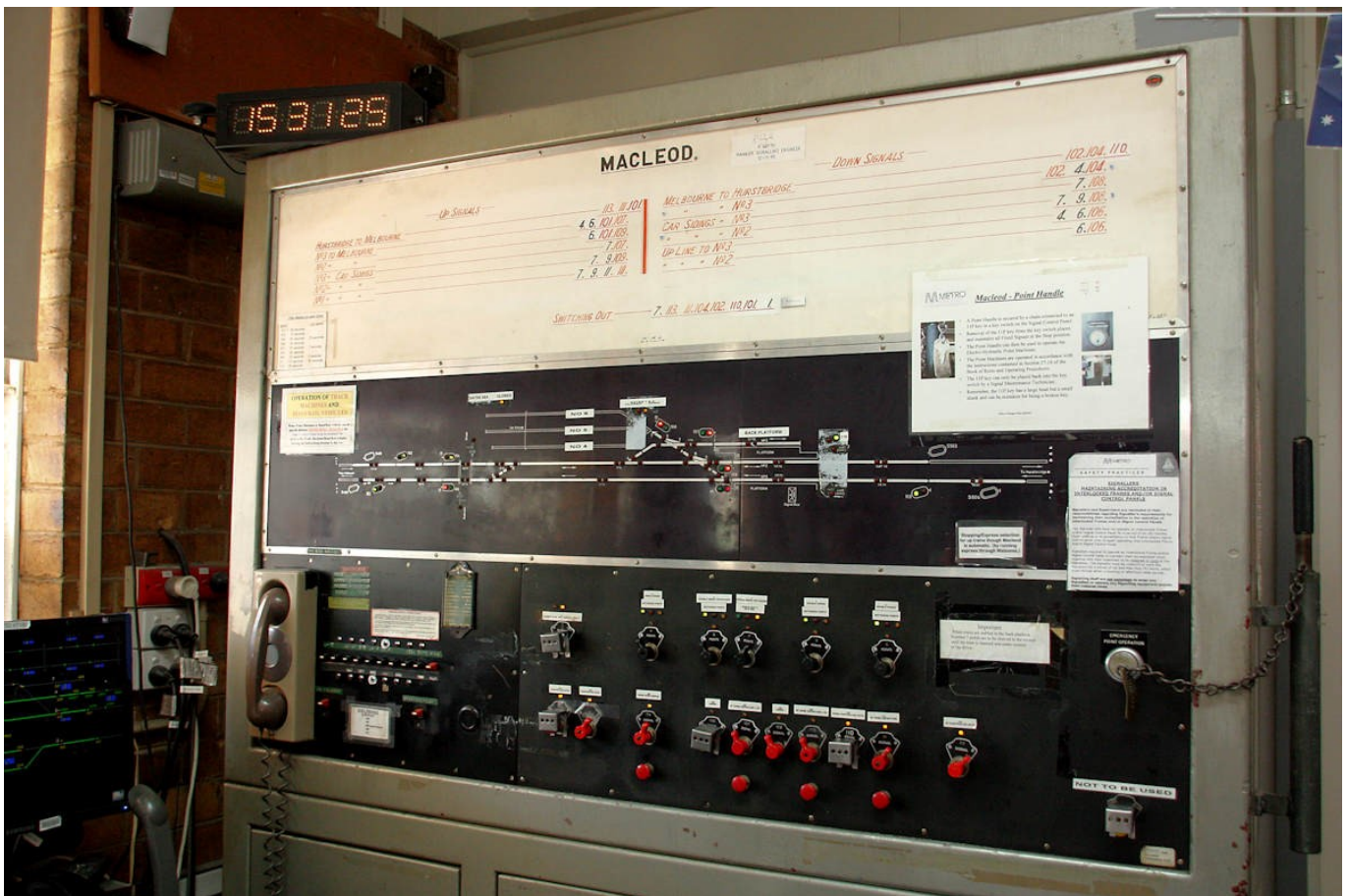


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### MINUTES OF MEETING HELD FRIDAY 16 SEPTEMBER 2016, AT THE SURREY HILLS NEIGHBOURHOOD CENTRE, 1 BEDFORD AVENUE, SURREY HILLS, VICTORIA

Present: – Noel Bamford, Wilfrid Brook, Graeme Cleak, Glenn Cumming, Graeme Dunn, Michael Formaini, Ray Gomerski, Chris Gordon, Judy Gordon, Andrew Gostling, Chris Guy, Graeme Henderson, David Jones, Keith Lambert, David Langley, Andrew McLean, Phillip Miller, Trevor Penn, Alex Ratcliffe, Laurie Savage, Rod Smith, David Stosser, Andrew Wheatland and Ray Williams.

Apologies: – Robert Bremner, Steven Dunne, Bill Johnston, Chris King, Neil Lewis, Steve Malpass, Eddie Oliver, Colin Rutledge, Brian Sherry, Frank Tybislowski and Andrew Waugh.

Visitor: – Nil.

The President, Mr. David Langley, took the chair & opened the meeting at 20:02 hours.

Minutes of the July 2016 Meeting: – Accepted as published. Laurie Savage / Alex Ratcliffe. Carried.

Business Arising: – Nil.

Correspondence: – Letter sent to David Ward at Metro Trains seeking permission for the Signal Box tour on Saturday 17 September 2016.

The invoice for the "Signalling Record" for 2015 was received from the SRSUK and payment was sent.

Letter received from AREA advising of an opportunity to apply for funding and inviting SRSV to submit a proposal.

Letter and business case sent to AREA applying for funding for a project to establish a website for SRSV and to commence scanning of documents in SRSV collection.

Ray Williams / Graeme Dunn. Carried.

Reports: – Archives. The Secretary provided an update on the matter of the lease for the rooms at Seymour. Emails sent to V/Line have not yet been answered. Dialogue continues with Victrack about accessing alternative accommodation for the archives. Any SRSV Member who can assist with sourcing a new home for the archives should contact the Secretary.

Tours. Final arrangements for the Signal Box tour in September 2016 were discussed.

General Business: – Keith Lambert provided details about various works in the Metropolitan District. A summary of the discussion follows: –

- Control of Sunshine will be transferred to Metrol on Sunday 23 October 2016. Sunshine Signal Box will be abolished.
- A four week shutdown of the Sunshine – Sunbury line will occur in October 2016 for the final stage of the grade separation works at Ginifer and St Albans.
- Signal alterations for the new railway station at Southland were discussed.

*(Front cover). On Saturday, 17 September 2016, the SRS conducted its annual signal box tour, visiting Epping, Bell, Heidelberg, and Macleod. The unilever panel at Macleod dates from 1979 when the station was resignalled as part of the duplication to Greensborough. The panel is typical of the era, with the 'pulls' at the top, the track and signal diagram in the middle, and the switches and telephone concentrator at the bottom. On the righthand end of the panel can be seen the emergency pump handle for the electro-hydraulic point machines. A 5P key is chained to the handle, and the key is normally held in a keyswitch on the panel. Removing the key secures the signals at stop. Photo Andrew Waugh*

- To allow for the construction of the new stabling sidings at Pakenham East, the boundary between Metro Trains Melbourne and V/Line at Pakenham will be moved four kilometres in the Down direction.
- The new signalling between Burnley – Camberwell is expected to be commissioned by the end of 2016. Phillip Miller reported on a video from Ansaldo STS on 'Youtube' that describes the installation of PTC on railroads in USA.

Laurie Savage discussed the current status of disused signal box buildings.

David Stosser described plans for level crossing removals on the Frankston Line.

Rod Smith asked for a description of the signalling system used on the Narrow Gauge railway at Fyansford Quarry. This led to a discussion of early single line (APB type) systems.

Graeme Henderson reported on news from New South Wales: –

- The third line between Epping – Thornleigh is now in use.
- A “turnback” road is to be commissioned at Parramatta.
- There are now very few Signal Boxes remaining in New South Wales.

Chris Gordon reported on future works on the Metro Trains Melbourne network: –

- Grade separation works at Bayswater in November 2016 will see the line closed between Ringwood – Upper Ferntree Gully.
- The signal control panel at Ringwood will be replaced by screen based equipment over the last weekend in November 2016. The interlocking will be upgraded from Westrace Mark 1 to Westrace Mark 2. Ringwood will then take control of Blackburn.
- The remote control project for Oakleigh will not go ahead. The latest proposal is for all point work at Oakleigh to be “straight railed” in 2017.

Rod Smith asked what the crossing loop at Rowsley is used for. The crossing loop is used for out-of-course crosses.

Graeme Cleak advised that a new V/Line timetable would come into use in January 2017.

Syllabus Item: – The President introduced Member Wilfrid Brook to present the Syllabus Item.

Wilfrid presented a selection of 33 images of vintage signalling equipment from Great Britain.

Wilfrid compiled the images from various visits he has made to Great Britain over the past forty years and provided a commentary to accompany the images.

Much of the signalling equipment viewed is no longer in service. Some the earliest railway signals seen were in museums when photographed in 1969.

The presentation was thoroughly enjoyed by those present at the meeting.

At the completion of the Syllabus Item, The President thanked Wilfrid for the entertainment & this was followed by acclamation from those present.

Meeting closed at 22:02 hours.

The next meeting will be on Friday 18 November, 2016 at the Surrey Hills Neighbourhood Centre, Bedford Avenue, Surrey Hill, commencing at 20:00 hours (8.00pm).

## SIGNALLING ALTERATIONS

*The following alterations were published in WN 33/16 to WN 39/16, and ETRB A circulars. The alterations have been edited to conserve space. Dates in parenthesis are the dates of publication, which may not be the date of the alterations.*

**20.06.2016 Jeparit (TON 155/16, WN 37)**

On 20.6., Points 4YHP were booked back into use.

**19.08.2016 Axle counter overlays in Metropolitan areas**

On various dates, as shown below, axle counter overlays were provided at the following level crossings in the metropolitan areas.

Station	Road	Date	Diagram	Reference
Pascoe Vale	Gaffney Street	19.08.2016	51/10	SW 245/16, WN 34
Oak Park	Devon Road	19.08.2016	51/10	SW 245/16, WN 34
Glenroy	Glenroy Road	19.08.2016	51/10	SW 245/16, WN 34
Moonee Ponds – Essendon	Park Street Buckley Street	02.09.2016?	17/15	SW 274/16, WN 36

Signal Maintenance Technicians are required to reset the axle counter sections when Road/rail vehicles on or off track at these level crossings. Circular SWP 6/16 gives instructions on dealing with failed axle counter overlay sections.

A special symbol is used on signal diagrams adjacent to the level crossing to indicate axle counter overlays on existing signal systems.

**21.08.2016 Waurn Ponds (SW 80/16, WN 33)**

On Sunday, 21.8., pedestrian gates were provided at Ghazeepore Rd (85.138 km). The gates are on the Up side of the road crossing. Diagram 26/16 (Waurn Ponds) replaced 90/14.

**22.08.2016 Vlocity Railcars on the Metro Network (SW 256/16, WN 35)**

Commencing Monday, 22.8., Vlocity are not permitted to operate on the following lines:

- North Melbourne Junction – Upfield
- Southern Cross – South Morang & Hurstbridge
- Southern Cross – Lilydale, Belgrave, Glen Waverley, & Alamein
- Caulfield – Frankston & Stony Point
- Richmond Junction – Sandringham
- Newport Junction - Williamstown
- Altona Junction – Laverton via Westona

The signalling detection characteristics of VLocity trains are monitored at test tracks at St Albans, Glenberrie, and Dandenong. V/Line must advise MTM when a VLocity train that has not been in service for more than 13 days, or which has had wheel attention, is to be operated on the metropolitan network. The performance of the track shunting during its first trip will be monitored and a decision will be made whether it is acceptable or if the train has to be removed from service. The train is also to be monitored on the second day of service.

**22.08.2016 Buckrabunyule (TON 150/16, WN 34)**

On Monday, 22.8., the siding was booked back into use for track machines. The Up end main line points have been removed, and baulks were provided in the siding at 303.330 km.

**22.08.2016 Murrumbeena (SW 249/16, WN 33)**

On Monday, 22.8., the Down platform was shortened by 9.3 metres at the Down end. The length of the platform is now 152 metres. Amend Diagram 5/12 (Carnegie – Huntingdale).

**22.08.2016 Axle counter overlays in Metropolitan areas**

On various dates, as shown below, the trap track circuit alterations were removed from the following level crossings

Station	Road	Date	Diagram	Reference
Clayton	Clayton Road	22.08.2016		SW 238/16, WN 34
Sandown Park – Noble Park	Corrigan Road Heatherton Road	24.08.2016		SW 252/16, WN 34
Sandown Park	Chandler Road	25.08.2016		SW 259/16, WN 35
Dandenong - Hallam	South Gippsland Highway Progress St	30.08.2016		SW 263/16, WN 35
Hallam	Hallam Road	31.08.2016		SW 264/16, WN 35
Narre Warren	Webb Street	01.09.2016		SW 265/16, WN 35
Beaconsfield – Officer	Station Street Brunt Road	02.09.2016		SW 266/16, WN 35

**(23.08.2016) Waurn Ponds (SW 80/16, WN 34)**

Diagram 26/16 (Waurn Ponds) replaced 90/14. The change was the provision of pedestrian gates at Ghazeepore Rd.

**(23.08.2016) Wendouree – Beaufort (SW 91/16, WN 34)**

Diagram 2/16 (Wendouree – Beaufort) replaced 22/15 as in service.

**(23.08.2016) Llanelly (SW 87/16, WN 34)**

The siding was abolished. The Up and Down end main line points have been abolished. The point levers, master key locks, derail blocks and rodded connections have been removed. TON 3/14 is cancelled. Amend Diagram 138/11 (Llanelly – Kurting).

**(23.08.2016) Inglewood (SW 87/16, WN 34)**

The siding was abolished. The Up and Down end main line points have been abolished. The point levers, master key locks, and derail blocks have been removed. TON 69/13 is cancelled.

The junction points for the Eaglehawk – Inglewood line remain, and will continue to be secured for the Dunolly line.

Amend Diagram 138/11 (Llanelly – Kurting).

- (23.08.2016) Kurting** (SW 87/16, WN 34)  
The Down end points to the siding were abolished, but the siding remains available for use as a maintenance siding. A baulk was provided at the Down end of the siding. The Down end point lever and master key lock have been removed. Amend Diagram 138/11 (Llanelly – Kurting).
- 23.08.2016 Mildura** (SW 88/16, WN 34)  
On Tuesday, 23.8., the main line points at the Down end of the platform leading to the Carriage Shed siding were abolished. The point lever, hand locking bar, derail block and rodded connection were abolished. TON 201/13 was cancelled. Amend Diagram 26/10 (Mildura – Yelta).
- 24.08.2016 Pascoe Vale** (SW 174/16, WN 31)  
On Wednesday, 24.8., the existing pedestrian emergency gates at Gaffney St were replaced by electromagnetically latched emergency gates.
- 25.08.2016 Mildura** (SW 94/16, WN 35)  
On Thursday, 25.8., pedestrian gates were commissioned at the Up end of the Mildura station platform (609.133 km). Operation of the pedestrian gates is by level crossing predictor and RFR predictor indicator boards are provided. Trains travelling at more than 50 km/h at the predictor boards may accelerate before the crossing. Amend Diagram 26/10 (Mildura – Yelta).
- 28.08.2016 Newport Workshops** (SW 223/16, WN 34)  
On Sunday, 28.8., the Driver Operated Control Units 1, 2, 3, 4, 6, & 8 were upgraded and the indicating lights replaced by brighter LEDs. Improved bells and strobe lights were installed at the Train Maintenance road crossing, and other rectification works were undertaken.  
Diagram 15/16 (Newport Workshops South Yard) replaced 53/14
- 29.08.2016 Blackburn – Nunawading** (SW 224/16, WN 34)  
On Monday, 29.8., Cottage St pedestrian crossing was temporarily closed to allow piling works. The automatic gates and fencing were removed.
- 29.08.2016 Caulfield - Oakleigh** (SW 276/16, WN 35)  
As from Monday, 29.8., Carnegie and Murrumbeena were closed to passengers to allow construction work.  
All Down trains will operate under express conditions. The stopping selection for the operation of all pedestrian and level crossings between Carnegie (progression relay for signal D387) and Oakleigh has been disabled.  
All Up trains will run under express conditions between Hughesdale and Caulfield. A temporary speed restriction has been imposed on the Up line between Hughesdale and Murrumbeena to allow time for D420 to clear before the approaching train enters Murrumbeena platform. An additional warning board will be provided at the Up end of Hughesdale platform to remind drivers of the speed restriction. The N and NS boards will be located together at the Up end of Murrumbeena station to allow trains to resume normal speed. The stopping selection at Carnegie for the operation of Koornang Road has been disabled (progression relay for signal D390).
- (30.08.2016) Newport – Werribee** (SW 255/16, WN 35)  
Vlocity, Sprinter, self powered diesel trains, and locomotive hauled trains are permitted to operate between Newport and Werribee provided Down movements operate on the East line and Up movements on the West line. Signalled movements within station limits are also permitted.  
Suburban electric trains may operate on either the East or West lines without restriction.
- (30.08.2016) Werribee – Manor Junction** (SW 254/16 & SW 95/16, WN 35)  
Due to infrequent use of the East and West Lines between Werribee and Manor Junction, the following procedures are to be followed.  
An axle counter overlay is provided to ensure the level crossing protection equipment at Werribee St operates correctly. This overlay is only provided for Down movements on the East line and Up movements on the West line. Consequently, all train movements between Werribee and Little River, including track vehicles, must be signalled via the East line (Down movements) and West line (Up movements).  
If a period of 48 hours occurs between train movements, Metro procedure L1-CHE-GDL-004 and VLine procedure TON-0400-08 will apply. Each line is to be considered separately. Monitoring the 48 hour period will be undertaken at Centrol. Before a movement is routed between Werribee and Manor Junction, the Senior Network Controller, Metrol, must confirm with the Senior Train Controller, Centrol, that the 48 hour period has not been exceeded.

Circulars SW 421/15 and 170/15 are cancelled.

- 02.09.2016 Litchfield** (TON 154/16, WN 37)  
On Friday, 2.9., the Up end points were booked out of use.
- 02.09.2016 Flemington Bridge – Royal Park** (SW 268/16, WN 35)  
On Friday, 2.9., the JAH train stop at Automatic C209 was temporarily replaced by a Siemens JAV train stop as part of the type approval process.
- (06.09.2016) Emu Loop** (SW 98/16, WN 36)  
Commencing forthwith, Emu Loop has been restored to normal use as a Trailable Point Loop. SW 117/15 was cancelled.
- 06.09.2016 Camperdown – Terang** (SW 96/16, WN 36)  
On Tuesday, 6.9., boom barriers were provided at the passive level crossing at Sandys Lane (204.973 km). The crossing is operated by a level crossing predictor. RFR level crossing predictor boards were provided. Trains travelling at more than 50 km/h at the predictor boards may accelerate before reaching the crossing. Remote monitoring equipment will be provided. Amend Diagram 30/14 (Camperdown – Terang).
- 06.09.2016 Jeparit** (TON 156/16, WN 37)  
On Tuesday, 6.9., Points 2YHP were booked out of use due to defective timbering. The intermediate Crossover 2/3YHP (between Nos 2 & 3 Roads) has been secured normal.
- 08.09.2016 Mitiamo** (TON 158/16, WN 37)  
On Thursday, 8.9., the siding was booked out of service. The points at 228.893 km and 229.609 km were secured normal.
- 09.09.2016 Elmore** (SW 99/16, WN 36)  
On Friday, 9.9., boom barriers were provided at the passive level crossing at Wakemans Road (176.631 km). The crossing will be operated by axle counters. Amend Diagram 14/14 (Epsom – Elmore).
- 12.09.2016 Minyip** (TON 161/16, WN 37)  
On Monday, 12.9., the siding was booked back into service for track machine use. Access to the siding is only available at the Up end, and the Down end points remain booked out of service.
- 12.09.2016 Reservoir** (SW 269/16, WN 35)  
On Monday, 12.9., electro-magnetically latched emergency exit gates were provided at Reservoir station pedestrian crossing and at High Street.
- 12.09.2016 Cardinia Road** (SW 278/16, WN 37)  
On Monday, 12.9., Cardinia Road carriageway was duplicated. New boom barriers and cantilever flashing light masts were provided. Automatic pedestrian gates with magnetically latched emergency exit gates were provided on both the Up and Down sides of the level crossing.  
Diagram 7/16 (Narre Warren – Pakenham) replaced 5/16.
- (13.09.2016) Ballarat & North Dynon** (SW 103/16, WN 37)  
The following instructions apply at the following locations when a fixed signal cannot be placed to proceed:
- Ballarat (Between Signals 50/52 and Signals 2/4)
  - North Dynon Broad Gauge (Between signals DYN88/DYN92 and signal DYN112)
  - North Dynon Standard Gauge (Between signals DYN90/DYN94 and signal DYN98)
- Before issuing a caution order when a fixed signal cannot be cleared, or a route line is not displayed on the VDU over all points in the required route, the Signaller must arrange for all points in the affected route to be either placed in hand operating mode and set for the required lay (if a dual control point machine), or secured by point clips (if a normal point machine). The points are to remain secured until the movement has been completed.  
SW 102/16 is cancelled.
- 20.09.2016 Tragowel** (SW 105/16, WN 38)  
On Tuesday, 20.9., boom barriers were provided at the passive level crossing at Tragowel Rd (274.225 km). Operation is by a level crossing predictor. RFR level crossing predictor boards are provided. Trains travelling at more than 50 km/h at the predictor boards may accelerate before reaching the crossing. Remote monitoring equipment is provided. Amend Diagram 54/13 (Pyramid – Kerang).
- 26.09.2016 Donald** (TON 166/16, WN 39)  
On Monday, 26.9., No 2 Road was booked out of service due to a defective point lever. The points at the Up and Down ends of No 2 Road have been secured for No 3 Road.
- 26.09.2016 Blackburn – Nunawading** (SW 224/16, WN 34)  
On Monday, 26.9., the Cottage St pedestrian crossing was returned to service.

End£

# CBTC SIGNALLING

Andrew Waugh

The Victorian government has announced that high capacity signalling will be installed on the Melbourne Metro Tunnel, extending to cover the lines out to Sydenham and Dandenong. As the project name implies, the goal of the project is to increase the line capacity of a standard double track line. This will be achieved by reducing the headway (gap) between successive trains. In practice, the Government is seeking to install CBTC signalling on the new Metro Tunnel. This article describes what a CBTC system is, how it differs from conventional signalling, and how it increases line capacity.

The article is based on a range of sources, but it particularly draws on Railway signalling and automation (Signalisation et automatismes ferroviaires), Volume 3, by Walter Schön, Guy Larraufie, Gilbert Moëns, and Jacques Poré, IRSE/La vie du Rail, 2013. An attempt has been made to illustrate CBTC concepts using details from the actual products. Unfortunately, this proved somewhat difficult as the available product descriptions are very high level. They seem to be written with the assumption that the reader is unfamiliar with CBTC systems, and needs to be convinced of its benefits. They do not give significant technical details.

## CBTC

Communications Based Train Control (CBTC) is defined by the IEEE to be a *“continuous, automatic train control system utilizing high-resolution train location determination, independent from track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and trainborne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions.”*

In essence, a CBTC system has three characteristics:

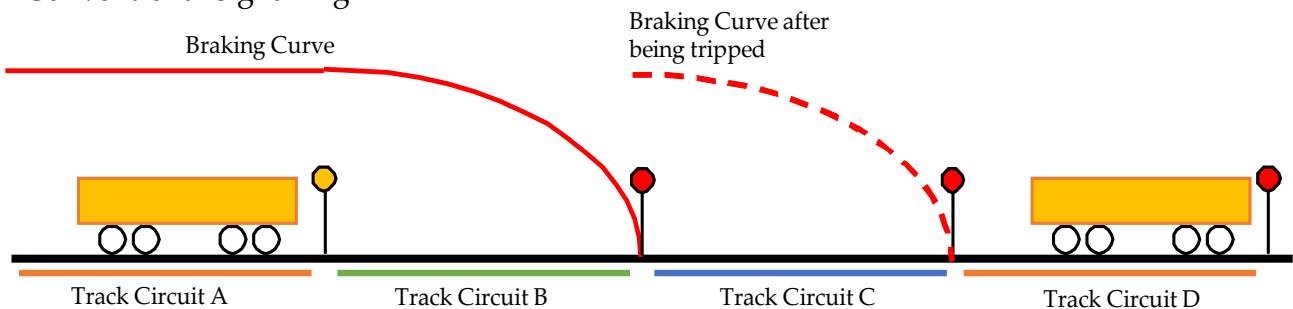
- Train location is determined by train borne equipment, not by track equipment such as track circuits or axle counters.
- Continuous communication between trains and the track side computers that issue movement authorities.
- The ability to control trains, at least to the level of Automatic Train Protection (ATP), and usually completely automatic operation of trains.

The principle of a CBTC system is illustrated in the diagram at the bottom of this page.

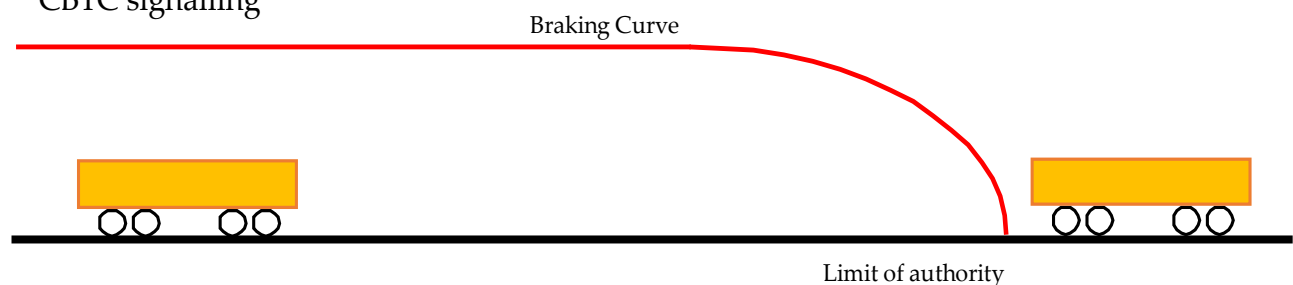
In a conventional signalling system, trains are located by track circuits (or axle counter sections). The detected location is not very precise as the track circuit is normally much longer than a train length. Movement authorities are conveyed by fixed signals driven by the track circuits. A train stop is located at each signal, and an overlap is provided beyond each signal of at least the emergency braking distance. The minimum signal spacing is related to the service braking distance. With three aspect signalling, the minimum distance between trains is somewhere between 2 and 3 times the service braking distance (it is somewhat less in 4 aspect signalling). The minimum headway in Melbourne is about 120 seconds. To achieve this headway significant trackside equipment needs to be provided – many short track circuits, trainstops, and four aspect signals.

With CBTC, the trains determine their location along the track. This position information is more accurate than when using track circuits. The position information is regularly transmitted to trackside computers. These computers use this information to issue movement authorities by radio to the individual trains. The on board computer on each train supervise the operation of the

## Conventional signalling



## CBTC signalling



train (or directly operate the train) to ensure that the movement authority is not exceeded. The minimum distance between trains is slightly over the service braking distance, and claimed headways between 75 and 90 seconds can be achieved.

Individual CBTC products implement this model in slightly different ways.

### Levels of automation

CBTC systems are primarily automated (driverless) or semi-automated. The following terminology is frequently used to describe the characteristics of such systems<sup>1</sup>.

- GoA (Grade of Automation) Level 0. No automation or protection is provided, and the driver operates the train manually in accordance with the signals and rules. In Victoria traditional mechanical signalling with double line block, electric staff, train staff & ticket, or train orders is GoA Level 0.
- GoA Level 1. The driver continues to drive the train manually, but there is supervision that the train is being operated within the movement authority. The supervision can be intermittent or continuous. The use of train stops in the electrified network and TPWS in the V/Line network are examples of GoA Level 1, as would be an ATP (automatic train protection) system such as ETCS.
- GoA Level 2. At this level, the train can operate automatically, however the train is still staffed by a driver in the lead cab. Under normal operations, the driver closes the doors, authorises the train to depart, and supervises the operation to the next station. The driver can drive the train if this is necessary or desired (e.g. to retain driver skills). This level is also known as STO or 'Semi-automated Train Operation'.
- GoA Level 3. At this level, the driver is replaced by an 'operator'. The operator is not located in the lead cab, but is normally roaming the passenger compartments. As one textbook expresses it, the driver is released to largely perform the traditional passenger related duties of a guard. The operator still closes the doors, authorises the train to depart, and supervises the passengers. If the automation fails, the operator is available to drive the train. In the event of an emergency, the operator is available at the train to assist the passengers, including, if necessary, evacuation. This level is also known as ATO or 'Automated Train Operation'.
- GoA Level 4. At the final GoA level, the train is not staffed. The difference primarily lies in passenger supervision and communication. In GoA Level 4 the central control room must be capable of responding effectively to any situation on the train, including emergency evacuation.

In Victoria, the Government has announced that the new underground stations will be equipped with platform screen doors. Ensuring that the train doors line up with

the platform doors requires accurate stopping of the train. The literature is clear that this level of consistent stopping cannot be reliably achieved by all drivers at all times. Platform screen doors consequently require some form of automatic train operation (i.e. GoA Level 2 or better).

On the other hand, drivers would still be required on any trains that extended beyond the CBTC controlled area (i.e. to Sunbury, Pakenham, or Cranbourne). Drivers would also be necessary between St Albans and Sydenham and Oakleigh and Dandenong due to the residual at-grade pedestrian crossings that will remain after the current grade separation projects have been completed. This effectively rules out GoA Level 3 or 4 operation. The Melbourne Metro is therefore likely to operate at GoA Level 2.

That CBTC systems are primarily intended to be automated or semi-automated systems is one key difference to the European Train Control System (ETCS). ETCS was developed to standardise ATP (Automatic Train Protection) systems across the European rail network, particularly on high speed lines. ETCS does not provide any form of automatic operation.

### CBTC history

The origins of CBTC systems do not lie in conventional railway signalling. Instead, they lie in the automated people mover market.

The first CBTC was SELTrac which was developed in the early 1970s by the Germany company Standard Elektrik Lorenz for a proposed maglev system known as the Kraus-Maffei Transurban automated guideway transit system. The K-M Transurban system was selected by Toronto for its proposed GO-Urban system in 1973, but prototypes showed that the maglev system was a technical failure. Instead of returning to the market to select another system, the Ontario government put together a Canadian consortium to take components of the K-M Transurban system and redesign it as a conventional steel railed railway. The result was a generic transit system named the ICTS (Intermediate Capacity Transit System). Alcatel was part of this consortium and was responsible for developing the train control system. Accordingly, it licensed the SELTrac system. ICTS pilots, including SELTrac, were eventually completed in Toronto (the Scarborough RT) in March 1985 and the Vancouver Sky Train (the Expo line) in 1986. The Sky Train was the first automated CBTC implementation. Other early SELTrac systems were the Detroit People Mover (1987), and the Disneyworld Monorail (1989). In the 1995 SELTrac was used to resignal the Docklands Light Rail in the UK – this was the first CBTC resignalling of an existing metro line. Since 2006 SELTrac has been owned by Thales. Because of its age, the SELTrac system is quite well described in the literature and examples from SELTrac will be used in this article.

The original version of the SELTrac system is considered by some to be a Transmission Based Train Control (TBTC) system as communication with the trackside computer uses an inductive loop laid along the track, rather than radios. A second difference to modern CBTC systems is that, due to the extremely limited

<sup>1</sup> The various GoA levels are defined in the IEC standard 62290-1, Urban Guided Transport Management and Command/Control Systems: Part 1 System principles and fundamental concepts.



capacity of the on train systems in the '70s and '80s, most of the processing was centralised in the track side computers. The movement authority was expressed as a 'target' location and a speed, and the on-train system merely had to drive to this speed while not overrunning the target. This centralisation of processing power was one reason why continual communication was required between the trains and the track side computers. Development of digital radio systems and more powerful computers by the turn of the century allowed the development of more sophisticated CBTC systems.

Two separate 'modern' CBTC systems were deployed almost at the same time just after the turn of the century. In February 2003, Bombardier deployed its CITYFLO 650 system in the San Francisco Airport automated people mover. Shortly afterwards, in June 2003, Alstom introduced its Urbalis system on the Singapore North East line.

Since this time CBTC systems have slowly been deployed around the world. A large number of competing products have been developed.

### **CBTC from a technical perspective**

We will now consider a CBTC system from the perspective of its technical components. We will start with how the location of a train is determined, move to consideration of the communications network used between the train and the trackside systems, and then consider the trackside side systems. We will then describe the nature of the movement authority in a CBTC system and the enforcement of the authority in the train. We will conclude with consideration of mixed mode operation – a section of line where CBTC controlled trains mix with conventional (uncontrolled) trains, and how the systems recover from failures.

It should be noted that the CBTC systems are not standardised, and each vendor implements their system slightly differently. It is not possible to run trains equipped with one vendor's CBTC on lines equipped with another vendor's CBTC. Older CBTC systems have gone through several generations of technology, and it may not be possible to interwork different CBTC generations, even though they come from the same vendor and have the same name.

This proprietary nature of CBTC is another important difference between CBTC and ETCS. ETCS allows trains from different operating companies, equipped with equipment from different vendors, to operate on the same line.

### **Location detection**

A CBTC system does not normally does not use conventional track circuits or axle counter sections to locate trains. Instead, each train calculates its position and transmits this to a trackside computer. A number of different technologies can be used to locate the train.

The original SELTrac system from Alcatel uses an inductive cable laid along the track as its primary location mechanism. Each cable covers up to 3.2 km of track and every 25 metres one wire in the cable loop is swapped to the other rail. The trackside equipment feeds a signal into

the wire and this allows the equipment on the train to detect the transpositions. Counting the number of transpositions gives the position of the train along the track to the nearest 25 metres.

More recently developed CBTC systems use balises (beacons) mounted in the track for the primary location detection instead of an inductive loop (SELTrac has also evolved to use balises). A balise is a device that transmits a short message as a train passes over it. In a CBTC system this message is the identity of the balise. The computer on each train has a table that translates this identity into a location. This approach has a number of advantages over an inductive loop. The balises are less susceptible to damage than an inductive loop (either due to track maintenance or vandalism). The message transmitted by the balise allows locations to be explicitly labelled, and it is consequently not possible to confuse two locations. Finally, there is no need to space the balises uniformly. Where balises are used with SELTrac, for example, the balises are spaced every 25 metres at congested locations or near junctions, but can be spaced up to 250 metres apart at other locations.

While balises are conceptually simple, there are complications. As an example, a CBTC system must address the problem of a train picking up a message from the wrong balise – such as a balise in an adjacent track. To minimise this risk, for example, the Eurobalise<sup>2</sup> does not continuously transmits its message, and, indeed is not connected to a power source. As a train passes over a Eurobalise, it receives RF energy from the train and uses this to transmit its message. This means that a Eurobalise only transmit its information when the train that is to receive it is actually passing over the balise.

CBTC systems use secondary location systems to provide fine grained location between the primary location points. Typical secondary location systems are odometers<sup>3</sup> and Doppler radars.

An odometer measures distance by counting the rotations of a wheel. Again, while conceptually simple, there are practical difficulties in ensuring accurate measurement. Any slip of the wheel against the rail will result in inaccuracies. For this reason, it is usual for the odometer to be mounted on an unmotored and unbraked wheel. The distance measured will depend on the wheel diameter, and it is necessary to allow for variations in wheel diameter (which will change over time as the wheel wears). Typically, this is achieved by comparing the odometer distance against a known distance. Given these sources of error, an accuracy of about plus or minus 10% can be achieved with an odometer.

As an example of the practical issues using odometers, the odometer used in the French metro system is

<sup>2</sup> Eurobalises were actually developed for ETCS, but have been adopted in several CBTC systems.

<sup>3</sup> Many references refer to this type of secondary location device as a tachometer (i.e. a device to measure the speed of rotation) rather than an odometer (i.e. a device to measure the distance travelled). In this article, I will use the term odometer as it more accurately describes the output (distance) of the system.

essentially a gear wheel. Distance is measured by counting the passage of the gear teeth past optical detectors. Each wheel has three detectors, and these are precisely spaced so that, at all times, one of the three detectors will not be blocked. This allows the system to distinguish 'no movement' from 'the detector has failed'. A circular pattern is painted on the web of the wheel. The pattern is read by another optical detector. The pattern is designed so that it gives a different sequence when the wheel is rotating clockwise and anticlockwise. This allows the system to detect the direction of the movement (and, in particular, that the train is not running backwards).

Another location determination mechanism is the use of a Doppler radar to continuously measure the speed of the train. Integrating the speed gives the distance travelled. Problems with Doppler radar include accuracy at low speeds and that the system can get confused by different track bed surfaces.

The use of GPS (or similar satellite location systems) has also been suggested as a location method. However, to achieve an accurate location fix requires at least three satellites to be in line of sight of the train. This is, of course, completely impossible within a tunnel. It also can be difficult in a built up urban environment, where cuttings, overbridges, and buildings can 'hide' the satellites.

### Footprints

Location determination is a vital function. If the train over or under estimates its progress along a track a collision is extremely likely to occur.

If a train's position estimate is in advance of its actual position, the trackside computer will release track that is still occupied by the rear of the train. This section of track could then be allocated to another train, with a consequent collision. On the other hand, if a train's position estimate is behind its actual position, the train will start to brake after it should have and is likely to overshoot its movement authority and risk colliding with a train in advance.

The problem is that location determination is not error free. While the position of a balise is known accurately<sup>4</sup>, the intermediate position determination is subject to error. In the case of an odometer, for example, systematic error will occur because the wheel does not have a fixed diameter – as it wears the distance travelled by each revolution will reduce. Spot errors will occur if the wheel slips. The consequent error in the position will increase as the train travels further.

To address this issue, the location reported is not a simple point position of the front of the train. Instead, two positions are reported: the worst case position of the front of the train (i.e. position determined plus worst case error forward), and the worst case position of the rear of the

train (i.e. position determined, minus the length of the train, minus the worst case error backward). The distance between these worst case positions is the footprint of the train. Because the error will increase as the train travels, the footprint will increase in length over time. This will, ultimately, affect the headway capacity of the line.

The footprint can be reset to the train's length whenever the train's position is known accurately – that is, at a balise (or loop transition). If a balise is missing for any reason (e.g. it has failed), the footprint will simply keep increasing until the next balise is encountered. The rate that the error increases consequently affects how far apart the balises can be located; too far and the capacity of the line is affected, particularly if a balise fails.

Because the positions of the balises are known accurately, the onboard computer system can compare the known distances between balises with the measured distance and can use this to calibrate the intermediate location system to compensate for systematic errors (such as wheel wear).

Finally, the footprint of the train is dependent on the length of the train. It is clearly necessary to ensure the integrity of the train and ensure that it has not broken in two. It appears that the standard method for doing this is to run an electrical circuit from the front of the train to the rear and back again. While this electrical circuit is complete, the train can be assumed to be complete also.

### Communications

The definition of CBTC highlights the role of communications between the train and the trackside computer. This is because the two are in constant, frequent communication. Indeed, if the communication is interrupted for a relatively short period (around 3 to 5 seconds, depending on the CBTC system), the train is brought to a stand using the emergency brake.

The development of CBTC systems has coincided with the massive change in communication systems as internet technology developed and spread. Indeed, the development of internet technology can be seen to have driven CBTC technology (as it has driven many other technologies).

The first CBTC system, SELTrac, used the inductive loop laid for location detection as an aerial for communicating between the train and the track side computers. This '80s technology had a transmission capacity of a mere 1200 bits/s to the train and half that from the train. This capacity had to be shared amongst all the trains travelling over that loop. Modern digital radios operate over a million times faster. None-the-less, this inductive loop technology has a number of advantages. The transmitters and receivers are built using discrete analog components and are easy to maintain and build.

By 2000, digital radio systems were becoming available. When the Siemens Trainguard MT system was originally deployed in January 2006 on the New York Carnarsie (L) line, for example, the product used a proprietary custom radio system. This was subsequently deployed in other Trainguard MT systems in Paris, Budapest, Barcelona, San Paulo, and Helsinki. This generation of digital radios were either developed by the

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<sup>4</sup> Assuming that the line was surveyed accurately, the location was accurately calculated and entered into the database, accurately transferred to each train, and not corrupted in memory on the train. All this is perfectly feasible, but does point out that CBTC installations are not simple.

CBTC vendor itself, or purchased from specialised radio vendors. While these systems worked well, there could be commercial problems. These proprietary radio systems often had short commercial lives as digital radio technology rapidly evolved. This was exacerbated by the tremendous development of off-the-shelf, standards based, internet technology. This internet technology was simultaneously more powerful (having a higher bitrate and more features), and far cheaper. It was also improving at a phenomenal rate.

The result was a movement in most (but not all) CBTC systems to using communication systems based on the IEEE 802.11 standard. For example, Siemens provided an 802.11b communications option for Trainguard MT by 2008.

This 802.11 standard is best known as WiFi – the common wireless system that is used to link tablets, laptops, and computers in households, shops, and offices to the internet. This communications technology has the advantage that it is extremely cheap, is continually being upgraded, has a relatively large bandwidth, and is integrated into other communications infrastructure (e.g. backhaul networks and security).

Development of communications technology has not stopped, or even slowed. CBTC vendors are beginning to offer products based on LTE, one of the technologies used in 4G mobile networks.

This illustrates one of the advantages in moving to a standards based communication system. The CBTC vendor can consider the communication system as a platform; other specialist vendors and standards bodies undertake the work to ensuring that new technologies and products can simply be plugged in to replace the old equipment.

A second advantage in considering the communications system as a platform is that it can be used for other communications needs in a metro system. These other communications needs could include passenger information systems, passenger WiFi, and live CCTV feeds from trains. In this model, the CBTC system is simply one of many applications on a train using the communications systems – and not one that uses a large amount of bandwidth.

The use of standard communications systems has one important consequence: security. This is actually a two edged sword. On one hand, the use of standard communications systems means that malicious people have easy access to knowledge about the communication system, and easy access to tools. In theory, any modern laptop or tablet could connect to the 'CBTC communications system' and receive (or send) messages. On the other hand, building a secure communications system (and then keeping it secure) is a very complex task. It is very easy, even for experienced security professionals, to inadvertently introduce security holes when developing and maintaining such systems. In using a standard communications system, CBTC vendors are building on the expertise of countless security experts, who not only designed the system, but are continually testing, refining, and evolving the systems.

In practice, the published literature from the vendors suggest that they are largely using standard security mechanisms used with 802.11. The messages exchanged between the train and the trackside are encrypted to prevent third parties from transmitting fake messages. The encryption uses standard 802.11 key management technologies such as WPA2 – which readers may be familiar with when setting up their own WiFi network.

As already mentioned, communication between the train and the trackside computers is critical; if it fails, the train is brought to a stand. It is essential, therefore, that a single failure in the communication system should not cause a communications failure.

The key aspect element of communication reliability is redundancy. In the Airlink communications system used by Trainguard MT, for example, each trackside base station is duplicated, so each train is continuously within range of two 'networks', and each train is equipped with two antennas at each end. In the SELTrac system, the base stations are located every 250 metres, but have a range of 500 metres, so that trains are always in range of two base stations. Communications redundancy extends beyond radio portion of the network; the backhaul network extending from the wireless base stations to the trackside computers must also be duplicated.

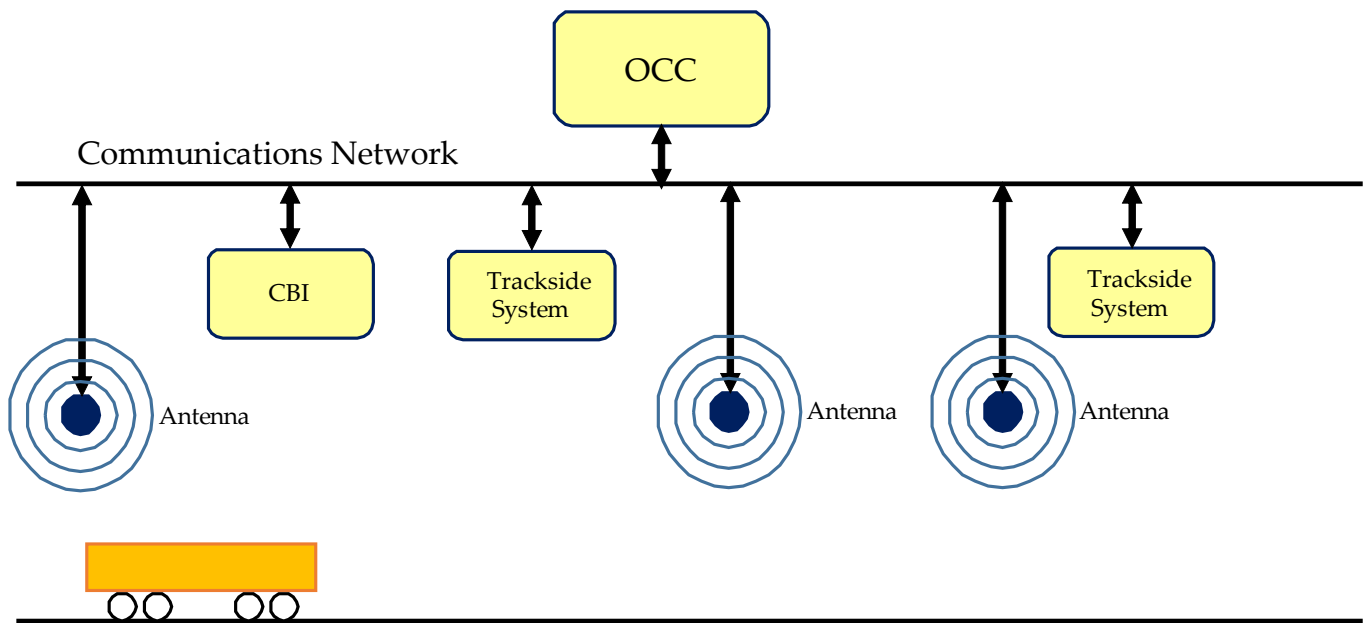
Modern OH&S requirements around working trackside, particularly in tunnels, and a desire for longer operating hours, make it difficult to provide maintenance access to trackside equipment. One advantage of CBTC over conventional signalling is a reduction in the amount of trackside equipment, and, hence the need for maintenance staff to go near the track. Unfortunately, the communications aerials and associated transmitters need to be located along the track – including in tunnels. The aerials and supporting infrastructure (routers, power supply, backhaul network connections) can be surprisingly frequent. For example, Siemens Airlink (802.11b version) has a range of 200-400 metres in tunnels, and 300-600 metres outdoors. The modern version of SELTrac is similar with a base station located every 250 metres.

### **Trackside infrastructure**

A typical CBTC trackside infrastructure is shown in the figure on the next page. It should be noted that the names of systems vary between different products.

The Operations Control Centre (OCC) supervises the operation of the network, in a similar fashion to Metrol. Usually one OCC is provided for the entire network, but occasionally separate OCCs are provided for each line. Just as in Metrol, the systems at the OCC allow the train controllers to:

- Set routes for trains (but most such systems would also support automatic route setting from a timetable)
- Block areas of track
- Control the power supply system
- Monitor stations and security systems
- Control ventilation
- Monitor fire control systems



Where automatic operation is provided (i.e. GoA Level 2 and above), the OCC can directly issue instructions to trains. For example, if delays at a station are causing the trains to bunch up, the OCC can instruct trains approaching this station to operate at a lower speed to reduce the bunching. Trains can be instructed to hold at stations, shunt, split, join, or commence a particular run.

The Trackside computers perform the vital CBTC functions for a section of line. They receive the location messages from the trains in that section, keep track of the trains, and issue movement authorities. Trackside computers must communicate with adjacent trackside computers to issue movement authorities across boundaries and to hand off responsibility for trains.

Conventional Computer Based Interlockings (CBIs) are used to perform interlocking functions. Trackside computers can only issue movement authorities up to the limit of the set route, so the CBI must inform the Trackside computer how far the route is set (indicated by a danger point which corresponds to an absolute signal in a conventional system). Having issued a movement authority over a route, the CBI must hold the route until the train has cleared it. The trackside computer must consequently inform the CBI about train locations (equivalent to track circuit occupations). Where it is necessary to cancel a route, the CBI also needs to know the position of trains so that the route can be held until the approaching train has cleared the route, or come to a stand (equivalent to approach locking).

Most Metro systems have relatively simple track layouts, and CBTC system vendors often provide the option of combining the functions of the CBI into the Trackside computers.

Alstom's recent Urbalis Fluence CBTC system has a dramatically different architecture. In this architecture, the trains are the central actors, not the Trackside computers or CBI systems. The OCC computer instructs the train as to the schedule that it is to carry out. At the appropriate time, the train checks the position of the preceding train (trains directly communicate their position amongst themselves), and then contacts the trackside computers to

request the necessary resources (sections of track, points) to set the route up to the rear of the preceding train. The trackside system checks to see if the resources are free, and, if so, allocates them to the train. Once the resources have been allocated, the train issues itself a movement authority. As the train moves forward, it releases resources that it has passed, continually checks the position of the preceding train to request new resources, and updates its movement authority.

#### Movement authorities

Movement authorities in CBTC are 'distance to go' authorities. That is, the movement authority specifies a point at which the train is clear to travel to, and a speed at which the train is authorised to travel. The 'danger point' will either be related to the end of the preceding train, or the end of the allocated route.

The diagram on the next page shows the concepts related to movement authorities in CBTC systems.

Each train is located somewhere in its footprint. Behind the footprint is a short distance known as the roll back margin. This space provides a buffer in case the train should move backwards for some reason.

The protection domain is an area in which the train can safely operate. It extends from the beginning of the roll back margin forward to a danger point. In the diagram this danger point is the beginning of the roll back margin of the preceding train, but it could be the end of a set route. Another term for the danger point is the Vital Movement Authority Limit (VMAL) – the point beyond which the train should never pass. The function of the Automatic Train Protection (ATP) system on the train is to ensure that the train never leaves the protection zone – either in advance or in the rear of the train. The CBTC system continually updates the extent of the protection zone as routes are set or the preceding train moves forward.

The operating domain is the part of the protection domain in which the train has permission to operate. The forward end of the operating domain is the target point; the point at which the train will attempt to reach and stop.

In this example, the target point (or Non-Vital Movement Authority Limit or NVMAL) is a short distance in the rear of the danger point. This distance, the collision avoidance margin, is the worst case overrun beyond the target point due to, for example, poor adhesion causing skidding. The target stopping point might not be at the far end of the protection domain. For operational reasons, the train might be required to stop before the danger point – at a platform, for example, or to turn back – and the target point of a movement authority in this case will be before the danger point.

At all times the train must never exceed the speed given by the calculated emergency braking curve. When calculating the emergency braking curve, an emergency application is considered to go through three phases: traction cut-off (during which time the speed continues to increase); coasting while the brake builds to fully applied (during which time the speed may rise or fall, depending on the gradient); and braking to a stand. The worst case scenarios are assumed for each phase. That is, maximum power applied at the point of cut-off (which may be applied in error by a failed traction system); the maximum delay in building up the brakes; and the lowest specified braking effort. Note that the guaranteed emergency braking rate assumes the worst-case adhesion. This leads to the non-obvious conclusion that the emergency braking curve is longer than the service braking curve. This is only feasible because the danger point is beyond the target point.

**Enforcement**

The ATP system on the train receives the movement authority and either operates the train to the target point within the constraints of the target speed curve, or supervises the driver in performing this task. In modern CBTC systems, this ATP functionality is similar to other automatic or supervised systems such as ETCS.

In systems where the driver can control the train, the pointy end of a CBTC system is a sophisticated speedometer in the driver’s cab. In addition to the current speed, the current speed limit is indicated and the target

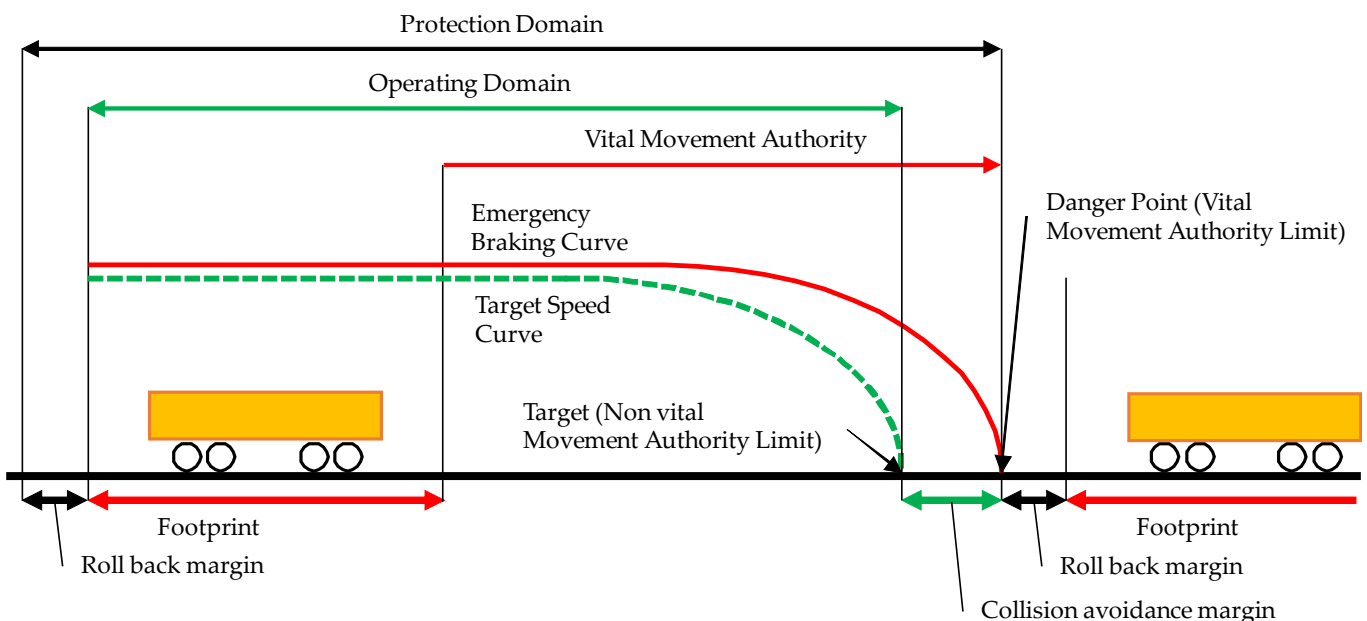
point and speed required at that point. Essentially, the driver drives the train normally, keeping the speed within the speed limit and not overrunning the movement authority.

Behind the scenes, the CBTC is continually calculating various speed curves to ensure that the train is not currently exceeding the speed limit, can slow in time for an upcoming reduction in the speed limit, and will not exceed the movement authority. Typically, three curves are calculated: the emergency braking curve (based on the worst case stopping performance and the danger point); the service braking curve (based on average stopping performance and the end of the movement authority); and a warning curve (slightly less than the service braking curve). If the driver exceeds the warning curve, the train will sound an alarm. If the driver exceeds the emergency braking curve, the emergency brakes will be immediately applied. In most systems, the train must be brought to a stand in this case.

Although the technical literature does not go into details, it appears that there is a subtle difference between CBTC systems and main line/freight ATP systems such as ETCS. CBTC systems were developed for use on metros. The trains on metros typically have very uniform braking characteristics. There is little need, therefore, for any configuration of the onboard CBTC system to take into account the type of train. This is very different to a main line system where the braking characteristics of heavy freight are completely different to a high speed passenger train, but the same locomotive could haul both on different occasions. I suspect that CBTC systems do not provide the ability to deal with different types of trains, which is why they cannot be applied to main line applications. There are CBTC like systems targeted at the freight market, but these products are not same.

**Mixed Mode working**

The discussion so far has assumed that all trains operating in the CBTC system are operating under CBTC control. Train operating under CBTC control are known as ‘communicating trains’. In Melbourne, the tracks outside



the Metro tunnels will be shared with a variety of non CBTC equipped trains (known as 'non communicating trains'). These include freight trains, V/Line trains, non CBTC equipped Metro trains, and even preserved trains. Operating a mixture of 'communicating' and 'non-communicating' trains over a line is referred to as 'mixed mode working'. Most, if not all, CBTC systems support mixed mode working. Typically this is used during the installation of a CBTC system on an existing metro line as it allows testing of the CBTC system.

Because the non-CBTC equipped trains cannot communicate their location to the trackside computers or receive movement authorities, lines operated in mixed mode have to be equipped with conventional train detection systems (e.g. track circuits or axle counters), and signals. The conventional system must be fully integrated into the CBTC system to ensure that communicating and non-communicating trains are never given conflicting authorities.

Little information is available on how this is achieved, but it appears that the CBTC system makes the footprint of a non-communicating train equal to the occupied track circuits. The protection domain will cover the footprint and extend to the end of the overlap beyond the next signal at stop.

Movement authorities will be conveyed to non-communicating trains by conventional signals driven by the CBI system under the direction of the trackside computers. CBTC equipped (communicating) trains must ignore these signals. One approach is for the signals to be normally dark (unlit) for CBTC equipped trains. The trackside computers instruct the interlocking system to light the signal and display a conventional aspect when a non CBTC equipped train needs to pass them. To indicate that the signal is not in use for a (CBTC equipped) train, rather than failed, an illuminated symbol can be provided – such as a white illuminated cross. Another solution is to provide a specific CBTC aspect – London Underground has used blue and white, for example.

### Dealing with failures

A key function of any signalling system is dealing with failures, and CBTC is no exception. There are several aspects to handling failures: how frequently failures occur; the effect of failures; and how quickly the failures can be recovered from.

Traditional signalling systems are highly distributed so that a failure (e.g. a track circuit failure) will cause a disruption, but trains will still move. Some failures, such as signalling power failure, can cause very significant disruptions.

CBTC systems are complex systems, and a total failure in a component would effectively shut down operations. For example a total radio failure in a train would mean that it disappears from the system; that train has to be brought to a stand immediately, blocking following trains until the failure is dealt with. Failure of a trackside computer, or the trackside radio in a particular area, means that the affected section of track is shut down.

It is for this reason that CBTC systems are highly redundant; if a component fails there should always be a

back-up immediately available to take over. CBTC systems are carefully designed to eliminate, as far as possible, single points of failure.

Essentially, because the effect of failures is so significant, a large effort is made to ensure that total failures of a component are rare. The reliability of installed CBTC systems shows that this approach does work.

Total failures can occur, however. Perhaps the worst failure that can occur is a failure of a trackside computer. If this occurs, the system will lose track of all trains in the affected track and it is a time consuming process to ensure that all affected trains have been identified, their location determined, and communications restored. Modern CBTC system have features designed to minimise this restart time. For example, some systems have an independent computer that keeps track of trains so that if the trackside computers fail, the identify and locations of the trains can be quickly reloaded into the trackside computer. Another solution is to provide a secondary detection system, such as axle counter sections, to ensure train detection even if the CBTC system fails. These axle counter sections can be quite long – typically station to station.

### Products

While there are numerous CBTC products, only four seem to have a significant user base. These are:

- SELTrac (Thales), with around 37 systems either operational or contracted. Some of these systems have SELTrac applied to more than one line in the system. Implementations date from 1987. The contracted SELTrac systems include the extremely large and complex London Underground Subsurface Rail.
- Urbalis (Alstom), with around 30 systems either operational or contracted. Implementations date from 2003.
- CITYFLO 650 (Bombardier), with around 23 systems either operational or contracted. Implementations date from 2003.
- TrainGuard MT (Siemens), with around 18 systems either operational or contracted. Implementations date from 2009.

It should be noted that some of these products have gone through several generations of technology.

In mid September 2016, the Government announced that two consortia have been short listed to deliver the signalling and communications systems for the Metro Tunnel:

- CPB Contractors and Bombardier Transportation
- MetroConnect, comprising John Holland, Siemens, and UGL

### Concluding remarks

The key advantage of a CBTC system is the reduced headway over a conventionally signalled line. This is achieved by knowing, relatively precisely, the exact position of each train. This allows a following train to be signalled closely to the rear of the first train. The provision of an ATP system allows the speed of the following train to be controlled so that the following train can approach the preceding train very closely. While it may appear that the improvement in headway, from say 120 seconds to 90

seconds, is relatively small, it is a cheap way to increase capacity on a line already at capacity. It is far cheaper than adding additional track in a city environment.

CBTC systems also increase safety. The Melbourne network is equipped with train stops and overlaps, but there is no supervision of speed once a trip occurs. Once or twice a decade, Melbourne has a rear end collision where the driver approaches a signal at stop in a four aspect signalling area above Medium speed, or travels too fast after tripping past a signal. So far, these collisions have not resulted in a major accident, but this is only due to luck.

The final advantage is the reduction in lineside equipment on fully CBTC lines; the track circuits, train stops, and signals are eliminated. Safety requirements make it difficult to provide trackside access to maintain this equipment; particularly in tunnels, and particularly as operating hours increase. CBTC systems concentrate the equipment in equipment rooms and on trains, both places maintenance can be easily provided. While CBTC systems do need some lineside equipment, such as aerials and balises, these are passive equipment that should not require significant maintenance.

In theory, CBTC systems operating at GoA Level 3 or 4 offer the promise of reducing staffing levels or reducing the cost of staff. In practice, this is unlikely to be achieved in Melbourne as it will be necessary to retain drivers while at grade crossings remain and the access to the line is not completely controlled.

To balance these benefits, CBTC systems have some risks.

In the Melbourne context, the greatest risk is probably the extensive use of mixed mode operation that is likely to be required. While CBTC systems do support mixed mode operation, routine mixed mode operation (i.e. outside migration and failed train working) is believed to be very rare. The only two known examples have not yet been commissioned: KCRC (Hong Kong) where MTR trains will mix with mainland Chinese trains, and a section of the London Underground SSR where LUL trains will need to work with Network Rail trains.

A second risk is that CBTC systems are proprietary. The major components of the system must be sourced from the original supplier, and must be obtainable for the expected life of the system – typically counted as 30 years. This is a major challenge for current computing and communication technology. It is possible that the CBTC system will have a relatively short life (say 10 – 20 years) before needing to be renewed. When the system is renewed, the system will be renewed from the ground up – all the equipment will be replaced.

A related issue is vendor lock-in. Selection of the initial system can be very competitive due to the number of competing vendors. However, when the initial system is extended (or applied to new lines), the operator has the hard choice of getting an incompatible system if another vendor is chosen, or paying whatever the original vendor prices their system at. It is notable that in many CBTC installations overseas, operators choose different vendors and systems for different lines. This avoids vendor lock-in, but at the cost of locking a fleet of trains to one group of lines.

## AN INCIDENT BETWEEN WINDSOR AND BALACLAVA

The National Library of Australia's Trove is a truly wonderful resource. In looking for something else, I recently came across the following 1909 regrettable incident. The incident concerned two trains in the Windsor – Balaclava block section on the night of Saturday 22 May 1909. At the time this section was worked under Sykes lock and block.

The story is told using a selection of newspaper reports. This nicely illustrates how the understanding of the incident evolved, how much information was published in the media in those days, and how difficult it was to explain railway signalling to the public. It also allows the story to be taken through to the punishment of the staff involved.

### **The Argus Wednesday 26 May 1909 p6:**

COLLISION NARROWLY AVERTED.

DRIVER'S PRESENCE OF MIND.

DEPARTMENTAL INQUIRY.

A railway collision was narrowly averted on Saturday night. Shortly after 6 o'clock, when a train, heavily laden with passengers was standing between Windsor and Balaclava, another passenger train entered the same section. The driver of the second engine, thinking the line was clear, was making good pace on his way to Balaclava when he noticed the tail lights of another train ahead. Fortunately, he applied the brakes instantly, and brought

his engine to a standstill a few yards from the guards van of the first train.

Probably none of the passengers of either train were aware of their narrow escape. After a few minutes' delay the first train proceeded on its journey mid cleared the section. The safe working of the service was then re-established. The first train left Flinders street for Sandringham at 6 15 p.m. All went well until the train passed Windsor but when about halfway between that station and Balaclava the driver noticed that the brakes had applied themselves without his applying them. Shutting off steam he stopped the engine and made an investigation. After a few minutes he discovered that the trouble could not be immediately remedied. Accordingly, he threw the Westinghouse apparatus out of gear and made preparations to use the hand brake during the remainder of the journey. In the meantime, however a second train which left Flinders-street at 6.22 p.m. had by some means been allowed to enter the same section. When the 6.22 train came thundering along on its way to Balaclava, the 6.15 was still stationary. The remarkable thing is that the driver of the second train was able to pull up in time as there is a very pronounced curve in the line between Windsor and Balaclava.

Yesterday three officers from the Railway department made an inspection of the line and the scene of the incident. They were Mr. T. Burgess, loco. superintendent,

Mr. Blazey, yard superintendent, and Mr Ballard, of the roads branch. These officers held an inquiry at Balaclava and examined the signalmen, enginemen, and guards concerned. How the two trains could have entered the same section before it was cleared is regarded as a mystery. It is stated that the signal at Windsor showed line clear to the driver of the second engine, who in such a case would naturally imagine that there was no danger of an obstacle between that station and the Balaclava signals. On the Sandringham line the ordinary block system of signalling is in use. Briefly, it may be explained that the signalling system is so designed that the danger of two trains being in one section at the same time is reduced to a minimum. For instance, the signalman at Balaclava should not give the "line clear" signal to the Windsor signalman until the train has passed out of the section between the two stations. When Windsor receives the "line clear" message he is at liberty to lower his signal and allow another train to enter the section. Exactly what occurred in the present case is not very clear but if as is stated the second train had no signals against it, it would appear that the signalling apparatus was either at fault or that there was some misunderstanding regarding a message.

The case will be thrashed out at a departmental inquiry. Meanwhile the signalmen at Windsor and Balaclava who were on duty at the time have been asked for explanations, pending an investigation. In connection with the case it is understood that further charges, involving serious allegations, will be made by the railway authorities.

**The Age, Thursday 27.5.1909 p6:**

SIGNALLING BLUNDERS.

TWO TRAINS ON A BLOCK SECTION.

With the exercise of ordinary care on the part of the railway officials there should be little danger of collisions on the suburban lines. Each line is divided into block sections, and the roads and signals are so controlled by interlocking gear that it is ordinarily impossible for two trains to traverse the one section at the same time. On certain lines, as an extra precaution, the Sykes lock and block electric system has been installed. Under this system the signalman at the beginning of a block section cannot lower the signal until that signal has been released by the signalman at the end of the section. Consequently, unless a serious blunder is made, two trains are not allowed upon the same section. Apparently someone did blunder on Saturday night, as two trains travelling towards Sandringham; came within -300 yards of each other on the section between Windsor and Balaclava which is under the control of the Sykes electric system.

According to a statement made yesterday by Mr. M'Clelland, Secretary of Railways, the 6.15 a.m. train from Flinders-street to Sandringham was pulled up outside the distance signal at Balaclava station owing, it is alleged, to a defect in the Westinghouse brake. The guard proceeded to examine the brake. and when he had completed his examination four minutes later he noticed another train — the 6.22 p.m. from Flinders-street — coming behind, having apparently received the "line clear" signal at Windsor.

The guard flashed his danger signal and it, as well as the tail lights of the train, was observed by the driver and firemen of the oncoming train, and they pulled up safely 300 yards in the rear of the guard's van. The passengers were not aware that anything had gone amiss.

A departmental inquiry is being made into the occurrence. The two signalmen, at Windsor and Balaclava have been suspended. As the signal at Windsor showed "line clear", the train crew is not held to be blameable, in fact, by keeping a sharp look out they were able to avert a serious collision. The first scrutiny of the block records in the signal boxes seemed to indicate that, both signalmen had carried out the signalling arrangements in a proper manner, but certain evidence of a suspicious character was elicited at the inquiry and resulted in the suspension of the two signalmen. It is understood that serious allegations have been made regarding the method of working the Sykes electric system. on the night in question, and it is stated that in some way the apparatus was interfered with. Some interest also attaches to the condition of the block. record books.

**The Age, Saturday 29 May 1909 p 12**

SIGNALLING BLUNDER AT BALACLAVA.

Referring to the departmental inquiry into the cause of the mistake by which two trains were allowed to enter the block section between Windsor and Balaclava on Saturday, Mr. L. M'Clelland stated last night that the signalman at Balaclava was held by the board to be chiefly to blame, and he would be charged before the statutory board. The signalman at Windsor and guard of the first train were held to be to blame to a slight extent, and would be dealt with by the heads of branches. The board found that the signalman at Balaclava had improperly manipulated the block instruments. The signalman denies that he was guilty of any improper act. Probably the statutory board will sit next week.

The regulation which the guard is alleged to have infringed is Regulation 239, which reads as follows —

Except where instructions are issued to the contrary, when a train is stopped by an accident or from any cause, unless it is efficiently protected by fixed signals, the guard must immediately go back at least 1200 yards, unless he arrive at a signal box within that distance, plainly exhibiting his hand danger signal to stop any following train, and in addition to his hand signals he must take detonators, to be used by day as well as by night, - which must be placed upon the line at distances of 400 yards, 800 yards and 1200 yards from his train; and must, also continue to exhibit his hand danger signal to stop any oncoming train.

The guard contends that he was "efficiently protected by fixed signals," inasmuch as he was on a section worked under the Sykes lock and block electric system, which, it was supposed, did not permit a signal in the rear to be lowered as long as a train was on the section.

**The Age, Friday 4 June 1909 p4**

THE SIGNALLING BLUNDER.

CHARGES AGAINST THE MEN.



Having considered the report of the inquiry board upon the blunder by which two trains were recently permitted to enter the block section between Windsor and Balaclava, the head of the branch of the department concerned has formulated charges against the two signalmen. These charges will be heard by the statutory board next week. The charges are as follows -

The signalman at Windsor is charged with misconduct in that he, it is alleged falsified the entries in the train register book at Windsor for the 6.15 p.m. train from Flinders-street to Sandringham, and the 6.22 p.m. train from Flinders-street to Brighton.

The signalman at Balaclava is charged with misconduct - (1) in allowing the 6.22 p.m. train to enter the block section between Windsor and Balaclava while that section was already occupied by the 6.15 p.m. train; (2) that he improperly manipulated the lock and block instrument at Balaclava station by, it is alleged, inserting a piece of wire and releasing the "plunger" which enabled the starting signal at Windsor to be pulled off the for the 6.22 p.m. train, which the section was already occupied by the 6.15 p.m. train and (3) that he, it is alleged, falsified the entries in the train register book at Balaclava relating to the 6.15 p.m. and the 6.22 p.m. train in order to conceal the fact that these two trains were on the same block section at the same time.

**Bendigo Advertiser Monday 7 Jun 1909 p5:**

RAILWAY SIGNALS.

A TRUSTED SYSTEM.

FOUND TO BE VULNERABLE.

In connection with, the narrowly-averted collision between two passenger trains on the railway line between Windsor and Balaclava on Saturday night, 22nd May, a disquieting discovery has been made' by the Railway Inquiry Board appointed to investigate the occurrence. It is that the Sykes lock and block system is capable of the easiest manipulation. It had previously been understood that, whilst a train was on the blocked section, no other train could pass into the section without the starting signal being at danger. But it seems (states the "Herald") that this is something of a delusion.

The outcome of the investigations has been that Signalmen Charles E. Wrench and Edward Hopper will be charged before the Railway Statutory Appeal Board with misconduct. Wrench will have to answer a charge of manipulating the lock and block instrument at Balaclava, and also a charge of having; falsified the entries in the train register book. Wrench states that he was able to work the electric lock system by means of an ordinary piece of galvanised fencing wire. He has explained why the trains got into the section together, and shown. the Inquiry Board how it was done.

It appears that, in ordinary practice, when a train leaves Windsor station and passes the starting signal there, the signal is put back to danger, and is electrically locked in that position until the tram has reached a contact point inside the home signal at Balaclava. It is not till that it is passed that it should be possible to pull off from danger the starting signal at Windsor.

The electrical apparatus controlling the system is an elaborately guarded locking gear, for which a specially-contrived key is fitted to allow of inspections. Never before, apparently, has it been known by the experts that a simple pricking action by a piece of wire on to the plunger of the locking gear could operate to release the electrical control of the signals. But this fact has now been established in a remarkably disquieting way.

To what end a wire was used at all for the purpose indicated must be ascertained at the inquiry, which should certainly be held with open doors. No secret investigation will satisfy the public

It may be added that at present the now known-to-be faulty, or, at least, vulnerable instrument is widely installed in the signal-boxes of the State railway service, and that thousands of pounds worth of the like gear is now on order for early delivery

Guard Watman, one of the officials controlling the leading train, has been reduced in rank and pay by 1/ per day. Driver E. J. Allan, was doing his duty by keeping a keen lookout, and fortunately saw the danger just in time, to avert the collision, has been censured. Why?

**The Age, Friday 18 June 1909 p6**

TRAIN SIGNALMEN.

PUNISHED FOB NEGLIGENCE.

TWO TRAINS ON ONE SECTION.

An inquiry was held yesterday by the Railway Statutory Appeal Board, consisting of Mr. C. E. Norman (chairman), Chief Engineer of Ways and Works; Mr. J. W. Hacker, Chief Accountant, and Mr. W. Phelan, employee representative, into the charges made against two signalmen in connection with the narrowly averted collision of two trains on 22nd May last between Windsor and Balaclava. The charge against Signalman Charles Edward Wrench was in effect that he had allowed the 6.22 p.m. "down" Brighton train to enter the block section between Windsor and Balaclava while the section was occupied by the 6.15 p.m. "down" train to Sandringham, and that he improperly manipulated the lock and block instrument at the Balaclava station to enable the starting signal at Windsor to be pulled off for the 6.22 p.m. "down" train while the block was occupied by the 6.15 p.m. train, he was further charged with falsifying the train register. Signalman Edward Hopper was charged with falsifying the entries. The decision of the board was that Signalman Wrench, should be dismissed, and that Signalman Hopper should be fined £6.

**The Argus, Thursday, 8 July 1909 p4**

THE AVERTED COLLISION.

DELAY IN REPORTING.

DRIVER CAUTIONED.

The circumstances in which two trains were permitted to enter the block section between Windsor and Balaclava on Saturday, May 22, caused a sensation when the facts became known. A collision was narrowly averted through the driver of the second train observing that, contrary to what should have been the case, the line was not clear. The first train, heavily laden with passengers, left Flinders-street at a quarter-past 6 p.m. for Sandringham,

and was in the section between Windsor and Balaclava when the driver noticed that the brakes had applied themselves without any action on his part. Shutting off steam, he stopped his engine to make an investigation. In the meantime the 6.22 p.m. train from Flinders-street to Sandringham had been allowed to enter the same section, and when it came along on its way to Balaclava the 6.15 train was still stationary. The driver of the second train noticed the tail lights of his train ahead and brought his engine to a standstill a few yards from the guard's van of the first train.

Impressed with the narrowness of their escape, a number of passengers proposed to give the driver of the second train a substantial token of their gratitude, but the matter was dropped in the belief that the Railway Commissioners, on inquiring into the case, would adequately recognise the services of the driver in the way of a bonus. The case has been under the consideration of the commissioners for some time. In regard to the action of the driver in stopping his engine to avert a collision, it was decided that he had merely fulfilled his duty. It is stated that he did not immediately report the occurrence to headquarters, although he wrote out a report on Sunday, the following day, and had it in his bag the next day for presentation. In these circumstances, the commissioners considered it necessary that he should be cautioned for neglect of duty in this respect.

#### **Summary and interpretation**

I would suspect that Signalmen Wrench simply used the wire to pick the lock on cabinet of the Sykes instrument at Balaclava and released the plunger.

He did this after the old, old, story. A train came unexpectedly to a stand in the section. The following train arrives at the signal box at the entry to the section, and the signalman there checks the status of the previous train. Under pressure, the signalman at the exit of section then gets confused about whether the train has left, and, not trusting his instruments, releases the block. This is the classic failure mode of accidents with Sykes instruments.

The difference between this incident and some of the well known accidents in the UK is that it appears that these Victorian instruments did not have facilities to cancel 'train on line'.

The tale illustrates the weakness of the internal investigation. There is no public, external, analysis of systematic issues underlying the incident. A couple immediately spring to mind.

First, the signal box at Balaclava was a signal bay in the Up side station building. With no elevation to see over trains, it would be very easy to doubt whether you had missed the passage of a train, particularly at night or where an Up train had blocked the view of the opposing track.

Second, the signalman at Balaclava seemed to be very quick to resort to his piece of wire. This suggests that it was not the first time he'd done this. This, in turn, suggests that the Sykes Lock and Block system was somewhat prone to rightside failures.

The references to the order of further Sykes Lock and Block gear is interesting. Shortly after this incident, the VR moved decisively away from Sykes Lock and Block and began installing track block. This used continuous track circuiting of the lines directly controlling the starting signal via a Reid's signal reverser. In the metropolitan area, this was mostly worked in conjunction with standard Winter's block. I wonder if there was a causal relationship between this incident and Sykes L&B losing favour?

Finally, I would have to suspect the driver of the second train of a cunning plan. He wrote a report on the incident the following day (Sunday), and had it in his bag when he reported for duty on Monday. If the two signalmen had managed to cover up the incident, I would bet the report would have stayed in his bag. If the incident had been found out by head office, however, he had the report to cover himself. He still got cautioned, but I suspect punishment would have been more severe if he had been caught not reporting the incident.