LONDON UNDERGROUND SIGNALLING – A HISTORY

by Piers Connor

45. A ROUNDUP

IMPORTANT DEMONSTRATIONS

This is the final article in this series. When I first started researching the subject of signalling on the Underground, I had a vague idea that it might run to 15 or 20 episodes. In the end, it has run to 45 but, despite this, it has not been possible to cover all the variations of signals, signs, technology, local oddities, operational quirks and modifications that have been a part of the Underground's signalling systems over the years but it has been my intention to provide a rounded history with as much detail as reasonably possible from the information available. My objective has been to describe the unique and fascinating signalling equipment developed on the Underground over the last 160 years. In my research for the series, I've found that history can offer us a number of important demonstrations of how to do signalling projects well and, equally, how doing them less well might be avoided. We take a quick look at some of these in this final article.

A STEP CHANGE

This history has shown how the Underground gradually and sometimes painfully, moved from traditional, block telegraph signalling to electro-mechanical signalling, then to programme machines and then to micro-processor based and computer driven equipment. These steps can be seen generally as positive moves towards improved efficiency and better reliability but it has come with a price, not just in financial terms but in, in recent times, in terms of retaining skills. This was forcefully demonstrated at the time of the installation of the Central Line ATC system in the 1990s. For this project, the Underground began relying on outside contractors to design its signalling and train control equipment and to install it. It led towards the Underground having to rely on the expertise of consultants, contractors and suppliers to design and specify critical equipment. The system hung on to its traditional standards and rules and required suppliers to conform to them but it was beginning to lose its own experience and expertise.

The detailed and prescriptive 'standards' that had to be written for the step change to contractor led signalling systems was a switch from the traditional, internally-based rules and instructions used by the Underground. The standards were needed so that potential suppliers could understand what was required and how it should be designed to meet the Underground's performance requirements and safety integrity. It should not be forgotten that an operator must retain its own expertise if it is to maintain control over its safety obligations and its ability to understand that it is getting value for money.

In parallel with this change, signalling systems were now supplied in electronic "boxes" containing microprocessors or printed circuit boards (PCBs) that did a particular job but did it in a way that wasn't seen or heard. The electronic boxes were being controlled by software that got more and more complex as systems developed. Very soon, electronics became standard and software became king. As long as the inputs were correct, the outputs would (hopefully) behave as expected. If they don't, you can't use the railway's traditional oil can or hammer, you have to get the device reprogrammed by a software engineer and then uploaded as a software upgrade[1]. If it's perceived as a hardware fault, you unplug it, swap it out with a new one. What you don't need is a fitter with a screwdriver and an AVO[2]. Out on the line, real time repairs to faulty signals or point controls slowly began to become rarer but software issues and temporary loss of communications have become very common. Delays to the service have become longer.

COMPLEXITY

Another issue that was first exposed with the Central Line project was complexity. Those of us that were trained in the operation and maintenance of the Victoria Line's original 'Dell' ATO system, might have thought of it as complex and, for its day it was, but the Central Line was much more so. It had computers, so the systems had to be designed by software engineers and programmers. These are skilled people but they are people whose native language is 'code' not 'railway'. They can write the code to make the processor do what it's supposed to do but they need to know what it's supposed to do

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1 It is instructive to remember that the Thameslink Class 700 fleet was on version 37 of its train control software when the first train entered passenger service.

2 An AVO is a multimeter, used to measure voltage, current and resistance. AVO = Amps, Volts, Ohms.

first, so they need to be told, in detail. This has led to the introduction of what are known as 'user requirements' – instructions to the programmer, designer or electronics supplier so that they know what code to write or what circuit design to include in a PCB. User requirements specifications now have to be written, in some form or another, for all new projects and they have to meet the standards proscribed by the operator. The detail, quality and validity of these (or the lack of them) are often the cause of many problems.

A consequence of the development of 'standards' and 'user requirements' is that they don't always align. The complexity of modern systems means that we have lots of experts in the details of the boxes and how they are programmed but fewer and fewer people who actually see how all the boxes fit together. We've had to invent 'systems engineering' to manage them. This used to be the role of the chief engineer supported by a small cadre of trusted and experienced technical staff but nowadays, systems are too complex for one person to manage. Nowadays, we need systems engineers to pull together all the elements and make sure that they work together. The skill is to recognise the interfaces and to ensure the boxes are integrated into a system that will meet the user requirements and the engineering standards and do it reliably. It is a rare skill. There are not many railway system engineers around with the broad understanding of how train control and signalling fits together and how it interfaces with all the other systems on the railway like power supplies, earthing and bonding, communications, train systems, fire detection, station systems and information systems. To resolve this shortage, education and training, coupled with and supervised by experienced management, is essential if the railway business is to have a continuing supply of engineers and operators who understand how the railway works as a system.

WHAT ATC DID FOR THE UNDERGROUND?

London Underground has installed five different systems of Automatic Train Control (ATC) on various lines as follows:

- The original Victoria Line fixed block "Dell" system, supplied by Westinghouse.
- The Central Line Westinghouse fixed block system.
- The Victoria Line's Distance to Go-Radio (DTG-R) system.
- The Jubilee and Northern Line SelTrac S40 Transmission Based Train Control (TBTC).
- The Sub-Surface Lines SelTrac radio-based Communications Based Train Control (CBTC).

It is useful to assess some of the features for each of them and to see what lessons could be learned from the design, installation and operation of the different systems. We should also look at the benefits of ATC and take the opportunity to debunk some of the myths going around about automation.

We should not forget that the original Victoria Line system was an international pioneer. It was the first railway in the world to be designed and built with ATC as the train control system. Others had dabbled with it, notably the New York Subway, who tested an experimental system on the 42nd Street Shuttle between 1962 and 1964. A derailment on 16 April 1964 and a fire that destroyed the experimental train on 21 April 1964 ended the trial. Meanwhile, London persevered with their trials during the same period and the system became a world first and survived for over 40 years. In later years, the increasing use of microprocessors, first in control systems and then for safety systems, led to it becoming out of date but it pointed the way for train control automation around the world.

Later systems tended to go for a more centralised architecture and there was, in parallel, a gradual move towards systems that didn't require track circuits. However, Westinghouse and its successors stuck to the track circuit option for its ATC systems and it has proved reliable and capable of matching the throughput and reliability offered by so-called moving block systems like SelTrac.

SELTRAC VS WESTINGHOUSE

Whilst I might seem to have been critical of the adoption of the SelTrac system on the Underground, it would be remiss of me not to offer some of the positive aspects of the system. The most obvious is the centralised architecture. The system is driven from a central service control computer – the System Management Centre (SMC) – and the train location and command system controllers (the VCCs) all in the same place. Only locations with points have local 'Station Controller Subsystems' (SCSs) working as object controllers. The SelTrac system can also be said to have simpler cabling, with a single kilometre long loop in place of all the wiring necessary for the multitude of track circuits. Mind you, most of this advantage has been lost in London with the requirement for axle counters.

The Westinghouse based systems use a distributed architecture, having a Westrace interlocking at each station, whether it had points or not. The system also uses track circuits – a lot of them – and this requires a multitude of trackside kit, mostly passive, such as disconnection boxes. Whilst the service control is located in a central room, the distributed architecture might be seen as a disadvantage as it requires technicians to travel to locations to correct problems. This is often not required with the SelTrac system although SelTrac too has a lot of active electronic kit trackside.

The Westinghouse systems have proved rather less prone to failures than SelTrac. Whether this is a result of design, installation or maintenance variations isn't clear but, in retrospect, it is unfortunate that the Westinghouse DTG-R system wasn't installed on the subsurface lines as originally intended. It would've been up and running by now on all the parts of the system it was intended for. Dumping it has cost over five years of delay and £millions in wasted work. Whilst some might say that the use of track circuits for train detection was a retrograde step, the system has proved to be very reliable. Sadly, the system has been abandoned by Westinghouse's new owners Siemens, who have their own ATC products.

Many people see that the problem with track circuits, or axle counters, is that they require systems to be on or near the track. With more recent techniques in train positioning, using radio, it can be said that less equipment has to be on the track[3]. Well, this might be so but the radio system requires a large number of trackside pieces of kit including radio masts, repeater stations and radiating cables and we still have points and point machines. These all require maintenance at one level or another and they all require track access. So, the desire to remove equipment from the track by eliminating track circuits may not lead to as much of a reduction in track access requirements as everyone supposes. I wonder if anyone has done a rigorous analysis of this. I suspect not.

CONVERSION TROUBLES

Each of the ATC conversion projects has had its problems. Some were common, like finding the resources for staff and training, like finding the space for the additional equipment needed for control systems, both on stations and on trains; like the irritating hunting sequence of motor-brake operation as the control system tries to keep the train at the maximum speed ceiling set by the ATC system and like the changes to train dynamics that has led to additional mechanical wear on the fleets converted to ATC.

The SelTrac system installations on the Jubilee, Northern and Subsurface lines were done differently from the Victoria Line's DTG-R. Before their line signalling upgrade, the trains on all these lines operated under the traditional trainstop/tripcock signalling system, so they had to go through a conversion programme to have the equipment fitted for the new signalling system.

Each fleet had to be fully fitted before the new system on their line could be brought into operation. The switchover to the new systems had to be done in stages, like the Central Line. The boundaries between manual and automatic operation were critical and the changeovers often caused problems where the train entering the upgraded section failed to be recognised by the system. These problems still persist on the Subsurface lines and will continue to do so.

An issue for SelTrac was that the traction system used on the 1995 Tube Stock on the Northern Line is different from that used on the 1996 Tube Stock on the Jubilee. This caused a problem on the Northern Line because of electronic noise, known as the 'signal to noise ratio'. This hadn't been so much of a problem on the Jubilee. It took a series of modification trials on the Northern's 1995 Stock to get the ratio down to an acceptable level at 60% of its original level.

Once the system was in service on the Jubilee Line, it took two years to get the reliability at a reasonable level. Luckily, many of the problems were largely under control for the summer of 2012 when the Olympic Games took place. On the Northern Line, the reliability following a switchover to a new VCC area was restored to an acceptable level after about three months. Experience obtained from the Jubilee Line was used on the Northern and it showed.

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[3] As Tom Crame pointed out to me, one of the critical parts of a signalling system is knowing where the back of the train ahead is. The problems of using radio with transponders for train positioning is that the train-borne kit knows where the front of the train is, but not the back. This is not a big issue when you're running fixed length trains but it does make things more complicated when you're running a mixed fleet. Of course, you get this functionality as standard with track circuits and axle counters, albeit with a considerable tolerance.

The subsurface lines are not immune from problems either. In an incident at Earl's Court back in August 2023, the signalling system went down. There was some sort of transmission failure due to a "data switch failure" in the SCC at Hammersmith. There is no backup transmission system so everything shut down. It took almost an hour and a half to find out what was wrong and then, half an hour later, communications were restored without anyone knowing how or why. It was fortunate that the failure took place late on a Saturday night. A peak hour failure of that type would have had a much more serious impact.

LESSONS

One of the common features of almost all signalling projects (and many other engineering programmes too) is that they invariably run over time and over budget. The reasons are varied and complex but one stands out above all others – design changes. If you change the design after you have agreed it, you are asking for trouble. Changes cost time and money and, the later the change, the more it costs. The peculiar circumstances of the Public Private Partnership (PPP) on the Underground from 2002-2010, made this an even bigger problem than it should have been. For the SelTrac system, the Underground's signal engineers demanded all sorts of add-ons and extra precautions over and above what the original design had envisaged. Despite it being a tried and tested system, the Underground wanted it to be modified to comply with their traditional standards and methods of operation and this led to many modifications and software changes. It didn't help that much of the design work was sub-contracted and done in India. Also, the SelTrac engineers in Canada had their had their own language and methods that were quite different from those in London. Somebody senior from London Underground commented recently that the SelTrac engineers knew very little about train operations. Perhaps what he meant was that they knew very little about the Underground's particular train operations.

The Westinghouse work for the Victoria Line was carried out in a different way. Westinghouse knew the Underground; they had the battle scars from the Central Line conversion and the abortive work on the Jubilee Line and their system was closer to the Underground's traditional views about how signalling should work. Also, they were working on a line that had been designed for ATC from the start, rather than the older parts of the Jubilee and Northern Lines that were being converted by Alcatel.

A useful lesson for new metro systems being designed today is that we should always allow room in new construction for the future replacement of equipment. There needs to be space for the new equipment to be installed whilst retaining the old equipment that's keeping the railway running during the upgrade. This applies to all systems, particularly signalling, train control, power supplies, ventilation plant and cables. It should extend to designing a spare control floor and extra equipment rooms for the control centre.

An important lesson to be learned from the Underground's line conversions is that a conversion to a new system will not work well if the operator insists on sticking to the old rule book and old engineering standards. New train control systems need new rules and new standards. The changeover from the old system to the new system must be designed with this in mind. It may be time to get rid of things like 'route secure' and 'rail gap indicators' designed for the Underground and, instead, use the facilities provided by the suppliers.

BACKING UP

A feature of many metro operators' specifications for automated systems, particularly TBTC or CBTC systems, is a requirement for a back-up signalling system in case the main system fails. There are a number of reasons for this.

In London, the SelTrac system we've seen installed on the Jubilee, Northern and Subsurface lines has a back-up system in the form of axle counter train detection. This proved an expensive and difficult addition to a system that didn't need it. On the other hand, the Victoria Line's DTG-R system that I described last month, doesn't have a back-up. Quite why this should be so is puzzling – two different approaches by the same operator. If you have so little faith in a system that you require it to have a secondary system as a back-up when there is another system available to you that you don't think needs a back-up, why would you buy it? And then, if you do specify that your new system has to have a back-up, doesn't this mean that, if the back-up suffers a failure, it will drag down the functioning front of house system with it? Yes, it does and it has.

Then there is the question of dealing with trains that stop communicating with the system controller. SelTrac refers to them as 'Non Communicating Trains' or NCTs. Will they be lost and become a danger to other trains? Of course not. All ATC systems have protection written into the systems that protect trains lost to the control computers and they have procedures provided for recovery. The same systems can be used for non-equipped trains, although you would only expect to use these in non-traffic hours. Alternatively, you can equip your engineering trains with the ATC system, as London has done. It is actually cheaper than providing a back-up system. London, of course, has done both.

All the arguments for back-up systems are largely baseless. They cost more (often a lot more), they increase the time it takes to install and get approval, they reduce reliability, they provide very little benefit for the passengers and they remain a millstone around the operator's neck for the lifetime of the system[4].

PRICE

We should not forget about price. In this series, I have generally refrained from looking at the costs of signalling systems. This was deliberate, as it is very difficult to relate costs to the variations in real time costs over different periods of time. It is often said that things today cost more than they used to and, in many cases, it is true but, inflation aside, real costs rise with the development of modern technology and with the introduction of more and more legislation relating to contractual relationships, quality, safety and staff management. Thus, comparisons with earlier costs are largely irrelevant. Perhaps contemporary comparisons with other railways or other countries might be relevant but, even then, social, economic, legislative and cultural differences will play a part in invalidating cost comparisons. What we can do is try to get the best system for what we want it to do and get it at a fair price. However, being a publicly supported organisation, a railway is subject to certain restrictions in procurement and these do cause difficulties.

The difficulties are largely caused by the obsession inbred into many government organisations for always adopting the cheapest option in the vain belief that they are doing the right thing by saving taxpayers' money. It inevitably ends up with them often making the wrong choices. They think 'value for money' means spending as little as possible, whereas any savvy customer knows that cheap is just cheap; it is rarely the best and usually the worst option. 'Caveat emptor' (buyer beware) is not a phrase understood in public procurement circles. The story of the abandonment by London Underground of the Westinghouse DTG-R system intended for the Sub-Surface Lines, on the grounds that it was too expensive, in favour of Bombardier who offered to do the job at half the price and then couldn't complete it, clearly demonstrates the folly of looking for a cheaper substitute[5]. As I mentioned above, it ended up with £millions being wasted on abortive work and compensation payments and more than five years being added to the time needed to finish the work[6].

MYTHS AND LEGENDS

Just as in any profession, the railway signalling business has had its own scattering of myths and legends, some of which get into the mainstream media and some that get embedded into the minds of certain railway operators and managers. Perhaps one of the most infamous is the idea that the railway is only modern if it is a 'digital railway'. Quite what this means isn't always defined but it's held up as 'the way to go' for modern railway management. In today's understanding, 'digital' systems are simply microprocessor based systems to assist with service management, train control and signalling. They may, if designed with the right functionality, offer better reliability, improved data management or reduced staff costs and they may even provide better service opportunities but they are not new. Systems functioning under digital rules pre-date microprocessors and they have been in use on the railway for over 150 years[7]. They started with the adoption of the electric telegraph and continued through to electrical detection and locking and with systems like the District Railway's original electro-mechanical train describer system – a classic example of digital data storage used to provide train

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4 Thales, perhaps as a result of their experience in London, published a paper online on this subject, "Do you really need a fallback system with Communications-Based Train Control?", in which they argue against back-up systems.

5 The story is told in articles by Connor, P. (2014) 'SSL Resignalling in Trouble' *Underground News* No.625, January 2014 and 'Round Again for SSL Signalling', *Underground News* No.626, February 2014.

6 A London Assembly report of March 2016 describes the Bombardier fiasco and the losses incurred. What it significantly leaves out is any mention of the equally flawed process that led to the employment of Bombardier through the dumping of Westinghouse and that fact that it was the direct cause of even more losses of money and benefits. **https://www.london.gov.uk/sites/default/files/transport_for_londons_signal_failure.pdf**

7 According to the Cambridge Dictionary, digital means 'recording or storing information as a series of the numbers 1 and 0, to show that an [electric] signal is present or absent'.

information data[8]. There are many other examples. In effect, the ‘digital railway’ is really just the way much of the railway works and always has done.

An older myth is that track circuits are needed on a railway because they can detect broken rails. As I discussed in Article 28, this isn’t true. Broken rails are rarely detected by track circuits so, if your new ATC system doesn’t have them, it shouldn’t be a show-stopper and it certainly isn’t a reason for having a back-up system. Surprisingly, there are still railway managements around the world who cling on to this myth.

Another myth that plagues the railway is the idea that throwing more signalling at it will increase the train service. This fiction manifested itself widely in Britain when Mark Carne, as the then Chief Executive of Network Rail, announced to a surprised world in late 2014 that ETCS (the European Train Control System) would increase railway capacity by 40%[9]. Ever since, the railway has been trying to live that one down. Whatever else Mr. Carne did for Network Rail, this was not his finest hour. The reality is that, given all the right infrastructure improvements to match it, ETCS could increase capacity in some places by up to 10% but no more. After all, trains still have to stop at stations, obey speed limits and negotiate terminal track layouts. More power will be needed to drive the extra trains and the trains themselves must be capable of matching the full signalling capacity. Put into context in London, it has proved possible to increase the capacity of the Victoria Line by around 26% with better signalling, but that wouldn’t have been possible without the line being built for automatic operation in the first place and then subsequent major upgrades of the power supply, improved ventilation, new rolling stock with better capacity and performance and major upgrades to the layouts of the two terminals.

The lesson here is that, despite the temptations of modern media to offer something the punters want to hear, sound bites do not improve the railway. Only carefully considered and long-term project visions, properly designed, planned and justified socially or financially, will give the railway the improvements that it needs to survive in the 21st Century. Myths and legends do not a railway make.

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The records and photographic collections in the LT Museum, the Signalling Record Society and the Westinghouse Archive & Chippenham Museum have been valuable sources of information and confirmation. Much useful information has also found in the proceedings of the Institution of Railway Signal Engineers and their journal, IRSE News. I have also found much historical information through the online organisation **Archive.org** who have collected a huge resource of magazines, journals, articles, books and internet sites. And finally, to anyone I may have missed, my thanks also.

The End.

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8 For a full description, see Article 11 in this series, *Underground News* No.710, February 2021.

9 Reported in RAIL magazine, 24 December 2014, amongst other places.