LONDON UNDERGROUND SIGNALLING A HISTORY

by Piers Connor

35. COMPUTERS TAKE CONTROL

THE JUBILEE LINE

Following the pioneer computer installations for the interlockings and their associated traumas at the east end of the Piccadilly Line in 1982 and the introduction of service management computers on the Northern Line a few years later, the next step was to be a complete line upgrade with computers controlling all the interlockings, the communications links and the control room systems. The target area was the Jubilee Line and the section of the Metropolitan that ran parallel with it between Finchley Road and Wembley Park (Figure 1). While all the non-vital control functions were handled by the computers, the safety was still retained in traditional Style V interlocking frames, with air driven levers and relay interfaces with equipment on the ground. The first part of the upgrade was introduced late in 1986.

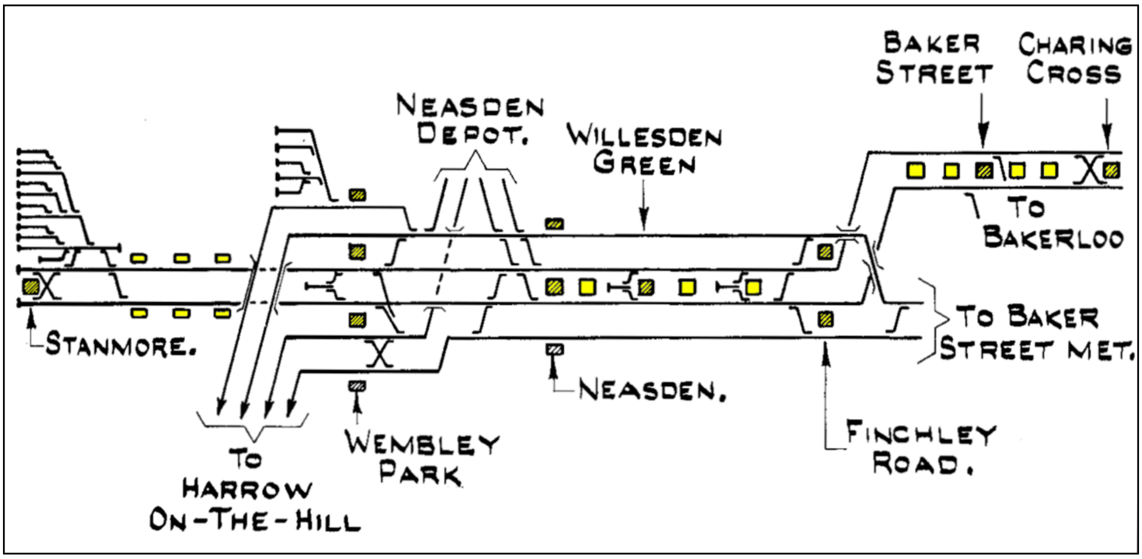

Figure 1: Track plan of the original Jubilee Line route between Charing Cross and Stanmore showing the interlockings by name and the connections to other lines. Diagram from Hooper, A (1986) Centralised Control of the Metropolitan & Jubilee Lines, Proc. IRSE 1985 – 86, pp.107-124, modified by P. Connor.

The original Jubilee Line was made up of the former Bakerloo line branch between Baker Street and Stanmore and a new extension from Baker Street, south to Charing Cross. Operation of the Bakerloo Line between Elephant & Castle and Queen's Park was separated from the Stanmore branch as a result of this but the junctions between the two were retained for stock transfer and engineering train movements. The line to Charing Cross was opened for public service on 1 May 1979 with conventional signalling, and a Style V frame with a programme machine at Charing Cross to control the reversing there. Control of Charing Cross and the Baker Street junction was transferred to special panels installed in the signal box at Finchley Road. Work then started on resignalling the route to Stanmore and designing a computer-based system for the line with a new control centre based at Baker Street. This was eventually opened on 25 October 1986 with the transfer of the Stanmore area to Baker Street and the closure of the signal box at Stanmore. Control of the rest of the route was transferred to Baker Street as follows:

30 November 1986	Baker Street to Charing Cross
18 January 1987	Baker Street to West Hampstead with closure of Finchley Road signal box
1 February 1987	Willesden Green and closure of signal box
29 March 1987	Neasden South and closure of signal box
12 April 1987	Wembley Park and closure of signal box

All the interlocking frames of the closed signal boxes were replaced by Style V frames in new Interlocking machine rooms (IMRs). The Jubilee Line resignalling of the 1980s included separating the signalling identifications for controlled areas, for example for the Neasden South area, which got a simplified layout as part of the programme, the Jubilee Line signals became 'JM' plus the lever number, while the Metropolitan signals became 'MM'. However, there was still inter running between the two lines until the late-1990s and Metropolitan Line Train Operators still learned the Jubilee route even into 2000/2001. Segregation was not only driven by the ambition to convert the line to ATO after the extension in the east was completed, but also the derailment on points at Camden Town in 2003 – the points at Finchley Road were of a similar design and were 'plain lined' which killed off any thoughts of future inter-running.

THE BAKER STREET CONTROL ROOM

The new control centre for the Jubilee Line and the adjacent section of the Metropolitan was provided at Baker Street in the former offices of the Metropolitan Line manager. The layout of the control desks was based largely on the 'Metal Mickey' installation at Earl's Court. Originally, two operating desks were provided, one for the controller but the controller (with less functionality) in a separate room. This was a deliberate break from previous policy, apparently as a result of experience at Earl's Court and Cobourg Street.

Each desk had three monitoring VDUs and two command VDUs but they were arranged in a row of five rather than the split level arrangement used at Earl's Court. All were in colour. Commands were put in using a numeric only keyboard. The monitoring VDUs could be switched to any of the interlocking sites as required but they didn't display the whole line on one screen. Each VDU had just two levels of detail – an overall view of the site and a closer view of individual areas where the user could switch the elements of the display showing track circuit names, signal and point numbers. Train numbers were also displayed but crew duty numbers were not provided. For some reason, the idea had been dropped, perhaps as they were deemed a distraction for the regulators trying to sort out the train service.

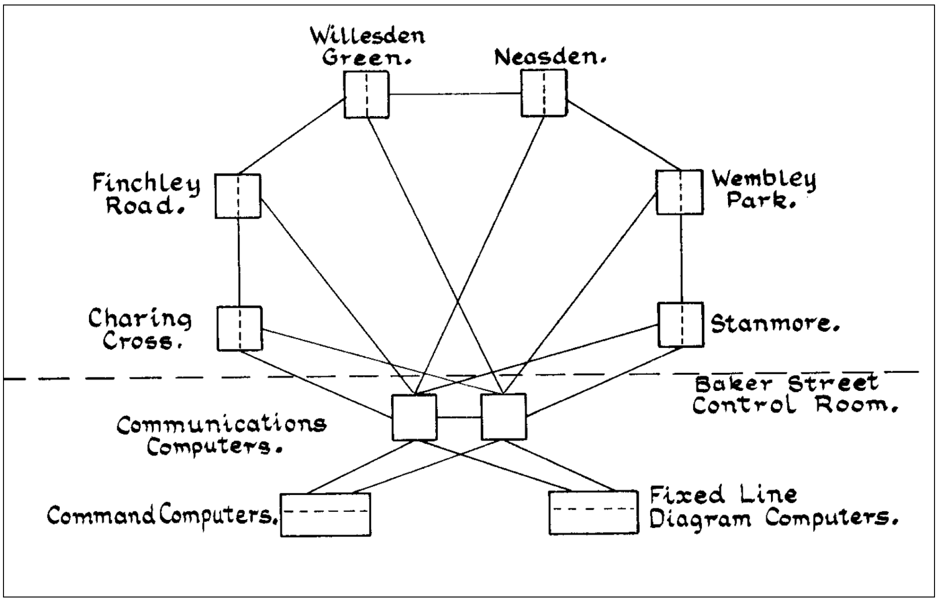

Figure 2: A schematic of the communications links between the Baker Street control room and the IMRs on the Jubilee Line when in its original form running between Stanmore and Charing Cross. The layout shows how the links were designed to cover for losses or faults by the so-called 'ring/star' configuration. A broken link could be by-passed to allow continuity of control. Also, any computer in the network can communicate with any other computer. Drawing from: Hooper, A. (1986) Centralised Control of the Metropolitan & Jubilee Lines, Proc. IRSE 1985 – 86.

There was an attempt to persuade the operating staff that they could carry out all their control functions using just the VDUs but the operators insisted that they needed a line diagram to give an overview of the whole system. Even today, with modern, large, high-definition screens available at control desks, operators persistently ask for a line overview diagram to occupy a wall in the control room, if only to demonstrate to visiting directors and politicians how big and important their control area is and to show that taxpayers' money has been well spent. Also, it does help an experienced operator to see at a glance how trains are distributed and how well, or not, the service is performing.

The command monitors displayed warnings as text messages, which could be generated from a local computer or from monitoring programs in the command computer. They were colour coded to draw attention to the most serious warnings. The information area used separate panels where they could display a list of trains in their expected order through a converging junction, plus information on their current position, their lateness and destination. The list was updated every 30 seconds. Information on an individual train, both current and historical, could also be shown.[1]

It was planned to use automatic regulation on the Jubilee Line by holding trains in platforms when a gap in the service was detected. The holding time was limited to a maximum of about 30 seconds. The holding of trains was to be arranged automatically by the control system putting a 'hold' on the starting signal. This was to be indicated to the operator on control monitors. Whether this was actually used as

[1] A more detailed description of the original Jubilee Line control system at Baker Street is provided by *Hooper, A. (1986) Centralised Control of the Metropolitan & Jubilee Lines, Proc. IRSE 1985 – 86, pp. 107-124,*

intended isn't known but, nowadays, automatic train regulation (ATR) is a part of all modern train control systems.

The resignalling and conversion to central control of the Jubilee Line was inextricably linked to the Metropolitan since, despite the separation of services, they shared the route between Finchley Road and Wembley Park and it was the original intention to turn the whole of the Met. over to central control, once the eastern extension of the Jubilee Line was completed. Actual work on getting the Met. converted was another long slow effort. It began on 26 July 1987 with the replacement of the lever frame at Baker Street signal box with a Style V frame installed in an empty room below Platform 2. This was controlled from a key panel added to the signal box. Once the transfer of the Jubilee Line was complete, control of Baker Street (Met.) was transferred to the new Baker Street control room on 12 June 1988 and the box was closed. This two-stage conversion process was the usual method of transfer of control and it was used in almost all the signalling modernisation projects on the Underground from the 1950s.

The Metropolitan transfer to central control then looked east, with a gradual transfer of control from the signal boxes at Aldgate, Farringdon and King's Cross to Baker Street Signalling Control Centre (SCC), as it had become known. As with other projects, the conversion was staged. It began on 25 January 1988 with the replacement of the Aldgate frame with a new Style V frame in a new IMR with control transferred to a push button panel installed in the signal box at Farringdon. The control panel used was the one recovered from Wembley Park after its closure the year before. Farringdon was already controlling the routes at Liverpool Street, Moorgate, Barbican and Kings Cross and control of all these areas was transferred to Baker Street in stages between July 1998 and March 2001.

THE BAKERLOO GOES CENTRAL

With the loss of the Stanmore branch to the Jubilee Line, what was left of the Bakerloo (Queen's Park to Elephant & Castle) was the next line to get central control. It was the culmination of the resignalling project started on the line in 1987 and it finally finished with the transfer of control from local signal boxes to a second new control room at Baker Street (Figure 3). This room was formerly the general administration offices for the Metropolitan Line.

Figure 3: The interior of the Bakerloo room at the Baker Street SCC in November 2009. The whole line from Queen's Park (nearest the camera) to Elephant is shown. The VDUs are arranged at the desk provided with keyboard and mouse controls. Photo: Andrew Gardiner[2].

The conversion was carried out in stages, with the first section between Queen's Park and Warwick Avenue moving to Baker Street from 6 January 1991, followed by the section down to and including Piccadilly Circus on 30 June and the final section to Elephant on 8 September. Again, local signal boxes were closed and their interlocking frames replaced by Style V frames in local IMRs.

COMPUTERISED INTERLOCKINGS

All the computer systems we've seen so far were used in the context of command and control. They were intended to provide the operators (the 'Regulators' as they were originally known) in the control centres with better real-time data, improved train service management tools and simplified

[2] https://www.flickr.com/photos/llangollen_signalman/collections/72157659373723965/

communications links to local sites. There was also a desire to improve the interface between the control rooms and the equipment in the IMRs, by reducing the number of relays and wires required to transmit commands and receive indications. Despite these improvements, the 'vital' interlocking at each site was still mechanical, usually in the form of a Style V, air operated lever frame.

By the early 1980s, programmable micro-processors had become reliable enough to be used in commercial undertakings and this allowed personal computers to be available for the public[3]. For the Underground's signal engineers, with computers established for train service control purposes, the next logical step was to see how computers could be used in a vital context like an interlocking. However, this was not to be undertaken lightly, as there was a considerable level of doubt as to how it could be achieved reliably and safely. Experience with 'Metal Mickey' on the east end of the Piccadilly Line[4] had already shown that, even in a signalling control context, computers could be more difficult to get set up reliably than conventional relays and hard wiring.

NEW SKILLS, NEW REQUIREMENTS

If computers were to work properly, they required carefully planned user requirements and accurate programming, something not easily achieved, particularly in a complex and variable environment like a railway interlocking. Those of us brought up in the electro-mechanical age are used to being able to see, feel and hear systems operating but this natural feedback is missing from both the hardware and software of a computer. Not only that but, even the most skilled and experienced signal engineer does not have the knowledge and training to write complex software for train control systems. This means that a specialist software programmer has to be employed to write the software and the user (be it the operator or the engineer), has to tell the programmer what is wanted. He (or she) has to prepare a 'User Requirements Specification' (URS) in which the programmer is provided with (hopefully) all the instructions that the computer needs to work properly. In writing this, no previous knowledge of the programmer can be assumed, since the programmer isn't a mind reader and, anyway, this maybe their first railway job. Then, the programmer has to get right the software carrying out the instructions, another possible weakness in the process. With these new vulnerabilities in the process, it became essential to introduce a checking process. This is known as verification and validation[5].

COMPUTER INTERLOCKINGS

In the mid-1980s, there were two trial micro-processor interlockings under development. One was described as Solid State Interlocking (SSI), the other was known as Vital Processor Interlocking (VPI).

SSI was installed on BR at Leamington Spa in 1985 using specially engineered equipment configured on a micro-processor. It used a 2oo3 configuration. The system was designed by British Rail in a sort of joint venture with Westinghouse and GEC/GRS.

VPI was designed independently by GEC/GRS and a trial system was installed at Northolt, again with specially engineered equipment configured on a micro-processor. This had only one micro-processor but there were two software paths through it to validate it in the event of a hardware fault. The system was run for a time in shadow mode with the existing interlocking. It suffered somewhat from electro-magnetic interference due to a current rail gap near the equipment room, but it was modified to cope with it and VPI was later used on the East London Line.

The Westinghouse CBI system used at Neasden was based on commercially available micro-processors so, unlike the early SSI and VPI systems, they didn't require to be specially engineered for railway use. Nowadays, the initials SSI and CBI are used interchangeably to mean the same thing.

VERIFICATION AND VALIDATION

Both mechanical and relay interlockings are designed on the fail-safe principle. For example, a standard Q relay should not fail in a way that causes a front contact to remain closed when power is removed. This property is used to ensure that a system made up of these relays will not go into certain unsafe states as a result of a failure. Unfortunately, a computer system cannot be designed like this because it has a wide range of possible states and this means that it is very difficult to predict what it will do as a result of a component failure. It is also difficult to ensure that the software running the programs will do

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3 After getting to use a desktop computer in Taiwan in 1984, your author's first personal computer was an Amstrad PCW8512 purchased in 1985.

4 See last month's Article No.34 'More PTI', *Underground News*.

5 A useful article on formal validation processes is available here: https://www.railengineer.co.uk/formal-methods-for-signalling-interlockings/

what the designer intended it to do and that it will do it safely. A different approach is needed if computers are to be used for safety systems like interlockings.

To get signalling software to work effectively and safely, there has to be a system of verification and validation. Validation ensures that the system requirements have been met while verification ensures that, as the end of the process, the software requirements have been met. Both these involve several internal steps during the design and testing phases. It's complex, time consuming and expensive and, despite many attempts to automate and speed up the processes, it has caused a lot of trouble in delaying projects and increasing costs; Crossrail (the Elizabeth Line) is a classic example.

Experience has shown us that, even today, new computer programs tend to be full of bugs and to behave in unexpected ways. It was a lot more difficult back in the 1980s – computing on railways was a new science then and it was clearly understood that unreliable and bug-ridden computers couldn't be tolerated in a railway safety context. It was obvious that a more cautious approach to the introduction of computer based interlocking (CBI) was needed and one way of doing this was to try out a computer driven interlocking in a non-passenger environment. It was hoped that this would allow most of the bugs to be worked out of the systems and reduce the risks of service interruptions due to safety related shutdowns. This led to a decision to install the first computer-based interlocking system at Neasden Depot, the largest passenger train depot in Britain. Before looking at what was done at Neasden, it will be useful to have a look at the issues affecting how a CBI would be designed and tested.

INTEGRITY

A number of practical methods have been developed to provide additional integrity for computer based interlockings. One common approach is the two-out-of-two arrangement, where two processors are run in parallel and their outputs are checked to see if they agree. The output is only verified if they are in agreement. Another way of doing it is to have one computer with two separate programs compiled differently and only permitting the output if both agree. Both of these methods are vulnerable to system failure if a fault causes a shutdown.

A popular approach is the two-out-of-three (2oo3) system. This is where the output from three processors is compared and at least two of them must be in agreement to get a system output. This method has additional fault tolerance, since the output is still available after the failure of a single processor and there is no reduction in the safety integrity. It was also quickly realised that better system availability could be obtained by ensuring that a faulty processor could be replaced as a unit and the processor system was designed to provide diagnostic information to help guide the maintainer. The Neasden Depot project used the 2oo3 system.[6]

NEASDEN DEPOT

The Neasden project was huge (Figure 6). The installation needed 171 track circuits, 110 point machines and 167 signals to provide a total of 388 routes[7]. Wiring in all the track circuits and signals was a mammoth task and it took over three years to complete the work. There were also 73 'Train Ready to Start' plungers, used by crews to announce to the control room operator that their train was ready for movement. These soon fell into disuse because train radio had been provided.

Figure 4: A position light shunt signal as installed in Neasden depot in 1988. The signal showed two red lights for the stop indication as seen here while proceed is a single white light with the reds extinguished. They have since been replaced with LED signals showing two white lights when 'Off". The signal number indicated the road and location, so that 251 was at the north end of 51 Road. The arrow points towards the relevant track. Note the loudspeaker mounted under the signal. These were designed to provide communication between the control room and drivers on trains. They were soon superseded by radio. Photo: TechSoc presentation 2010.

All points were converted from hand to power operation and each stabling and shed road was provided with shunt signals. The equipment was provided by Westinghouse.

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6 White, C.R. & Corrie, J.D. (1985), 'Signal Controls for Neasden Depot' *Proc. London Underground Signal Engineers Technical Society*, 1985/86.

7 Ibid.

Most of the points had air operated clamplock machines added, although there were some 4-foot air operated machines. The new shunt signals were to the standard British Rail position light design but they were modified to make the indications different for the Underground (Figure 4). They were the first such signals to appear on the Underground. They have since appeared in a few other locations around the system.

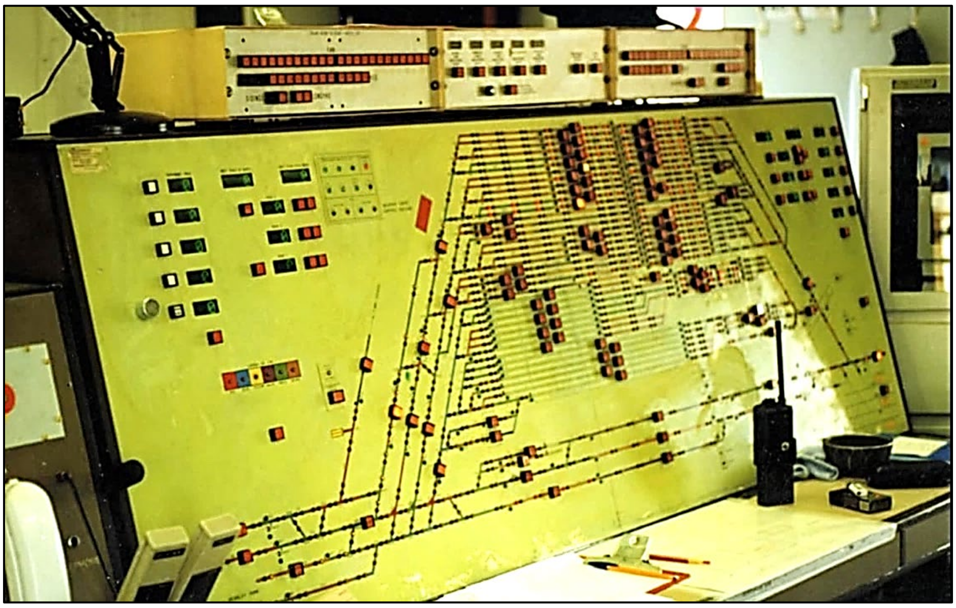
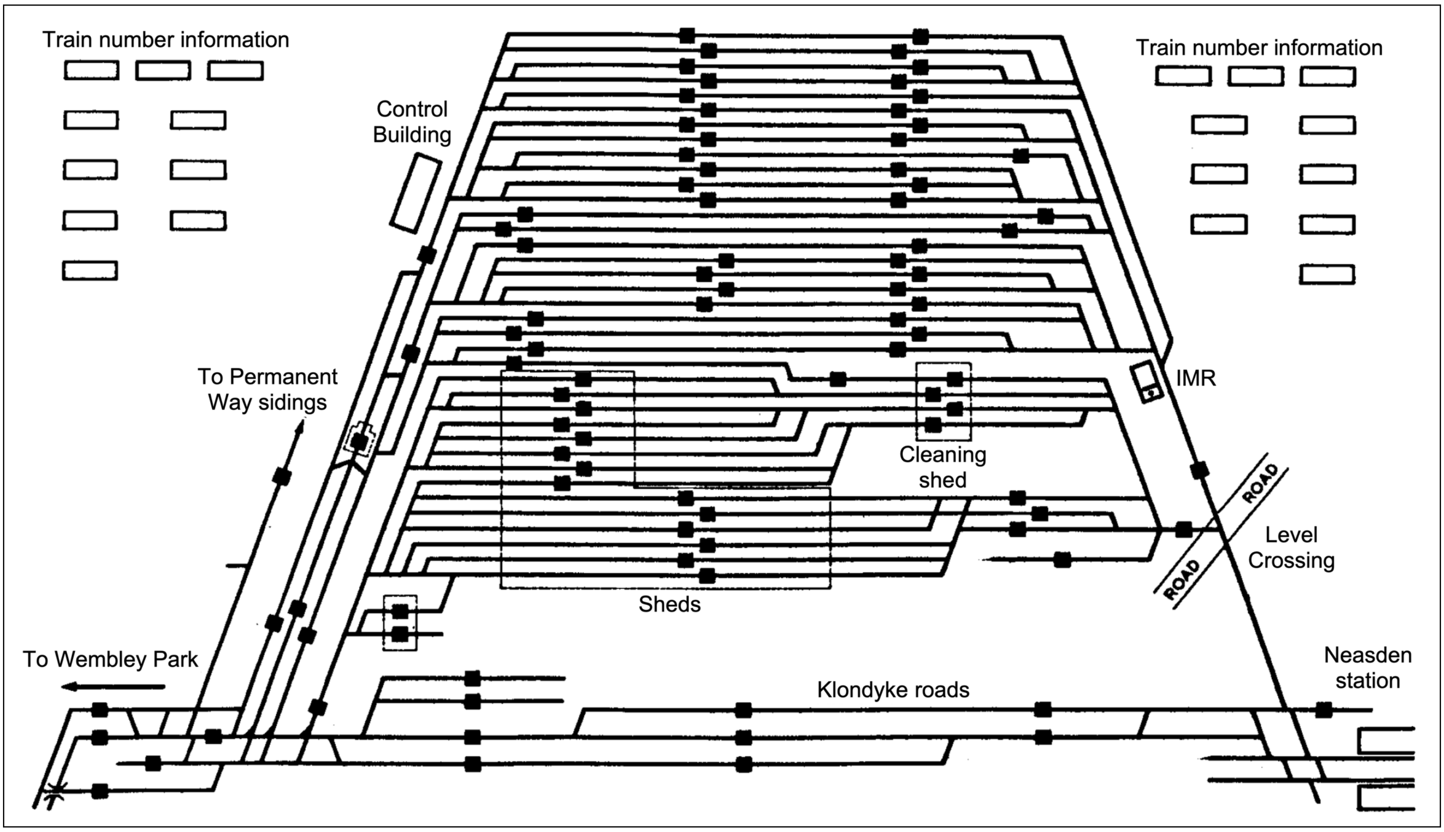


Figure 5: The original yard control panel in the TMR at Neasden Depot. The panel was designed to operate on the 'Entrance/Exit' (NX) principle. It was commissioned on 16 October 1988. Photo: Kim Rennie.

A new control tower was built containing the control panel, comms equipment and the computer based interlocking processors. The control computers were Hewlett-Packard A600s. These were the same as those installed in the Baker Street SCC but only for the fixed line diagram. They were more extensively used as site computers in the IMRs. The operators were located in a Train Movements Room (TMR) in the control tower. The main control panel (Figure 5) in the TMR was for route setting and there was an auxiliary desk for the communications equipment, which also provided the train data. There were two emergency point operating panels, one for the northern area of the yard and one for the southern to allow for direct operation of points in case of a serious computer failure. Track locking was maintained so the emergency panels also had release facilities. On the main panel, routes are set up by the operation of push buttons; the first push being automatically registered as the entrance to the route and the second as the end. Some moves could be selected in multiple to allow routes to be set from reception roads to certain stabling roads in one



operation

Figure 6: A schematic of the Neasden Depot track layout as it was for the installation of the Westinghouse CBI system in 1988. Source: White (1985).

When a train arrived, the train describer system displayed the train set number to the operator who would then select the reception road required for the train. The train was then automatically routed to the reception road where the driver was told which road the train was to be stabled on. The route from the reception road to the particular stabling road was then set by push button. The button operations were analysed by duplicated control processors and translated into point and signal commands. The commands passed to the vital computer system for the interlocking processing which then sent the output to the lineside equipment.

Apart from the desire to test CBI in a less risky environment, there were several reasons behind the decision to use Neasden Depot for this experiment. First, Neasden was a large site, with a lot of train movements both to and from the depot and around the yard. Often, it was necessary to have more than one movement going on at a time and this sometimes led to mistakes; there were a number of collisions over the years. Then, it needed staff on the ground, in all weathers, day and night, to operate the hand-worked points and advise staff where to leave their trains (Figure 7).

Figure 7: A posed photo of a Ground Shunter setting up a road in Northfields Depot (Boston end) on a cold day in March 1955. With a full depot, it is probably early in the morning, but shunters didn't have to set up roads for trains leaving the depot because the points from each road were trailing, hence the conclusion that the photo is posed. Trains were called down to the exit signal through a loudspeaker system. The shunter has his handlamp with him that he will use to signal to drivers when necessary. In the yard there are Piccadilly Line Pre-1938 (Standard) Stock, 1938 Tube Stock and District stock. Photo: LT Museum.

Drivers were supposed to stop at the entrance to a yard to get the information about where to leave the train from the shunter on the ground. This was risky, not so much for the shunter as for the train. One of the difficulties with moving trains into and out of large yards is the current rail gaps in the fans. A succession of points meant a succession of gaps and drivers have to be acutely aware of the risk of stopping a train with all the shoes "off juice". To get the train going again, you have to get out the "gap leads", plug them into the train and place the other ends onto the correct current rails. This will power up part of the train to get it moving far enough to find the nearest pair of current rails. In less risk averse days, all train crews were taught how to do this but, following the introduction of restrictions arising from the Electricity at Work Regulations 1989, it was decided that only specially trained staff could use them. Of course, there aren't that many of them and this has led to lengthy delays while a suitable person is found and brought to site.

So, stopping the train to enquire where it should be left was not recommended. Normally a green flag or a green lamp was stuck out of the shunter's cabin window. Instructions were issued on the move. "In the shed" or "Back end on" were common instructions[8] shouted to the driver as he passed. Sometimes, hand signals were used – a circular hand motion over the face to signify the wash road, one or two fingers held up to signify which end of a road to stable your train are two I remember from my time bringing trains in. Darkness and bad visibility in fog or rain brought in additional dimensions and there were occasional misunderstandings. Now, with remote point control, interlocked fixed ground signals and a central control facility, many of the issues were resolved, with the added benefits of a better

[8] "Back end on" meant you were to leave the last car outside the shed, so it was standing on current rails.

working environment for the staff. The trial CBI installation was a bonus. It is also worth mentioning here that the Westinghouse designed CBI at Neasden was the only installation of this type in Britain. British Railways stuck with SSI systems and the Underground progressed to using the Westinghouse designed Westrace interlocking system.

To be continued …