THE JUBILEE LINE UPGRADE

by Mike Palmer

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Mike prefaced the talk by explaining how the Northern Line upgrade and Jubilee Line were similar and those who attended the Northern Line Upgrade talk several months ago would hear some similarities. Mike also explained how some of the talk would be relatively complex and different to any automatic signalling system on LU at the moment: to understand the complexity of the upgrade he would have to teach us some of the concepts behind the new system. It was also made clear to the audience that as the upgrade at time of the talk was overdue, some areas of questioning, such as details of slippage, cost, contractual relationships, would not and could not, for legal reasons, be answered.

Mike started off his career in 1982 as a railman, becoming a guard on the District Line at Acton with other well-known figures such as Colin Smith, Dave Rowe and Kim Rennie. He moved to become an Information Assistant between 1985 and 1986 where a familiar *Brian Hardy* gave him the job. He then moved to become a Line Controller on the Piccadilly, District, Jubilee Metropolitan and Bakerloo from 1986-1989, a Duty Train Manager on the Piccadilly and District between 1989-1993, and then the Duty Operations Manager for the District Line from 1993 to 1995. Following this, he then became a Service Control Manager for the Jubilee and East London lines. This included the reopening the East London Line in 1998 with a new signalling system. He then commissioned the Jubilee Line Extension signalling system and opened Stratford Market Depot control tower and Neasden Service Control Centre, which involved signalling and recruitment amongst other areas. After this had been completed in 2000 he moved to North Greenwich to manage train crews there and since 2003 he has been the Upgrade Operations Manager for the Jubilee, Northern and Piccadilly Lines, which included the 7 car upgrade and now revolves around the JNUP: the Jubilee and Northern Upgrade Project.

WHAT IS THE UPGRADE?

All the current LU upgrades are managed through the PPP contract and are journey time capability (JTC) driven. This is a hypothetical model of a typical journey based on fixed and variable factors, e.g. the walk to a platform being fixed, the wait for a train being variable, journey time while on the train being variable, etc. The central crux of the contract was that the JTC had to be reduced by around least 3 minutes. To do this, it was Tube Lines' decision on their solution to JTC, what equipment to buy and which companies to use: Tube Lines have no signalling company as a shareholder and were able to go into the marketplace for the best system for a brownfield site and meet the reduction in the JTC.

Overall, on almost any railway, it has been proven that the biggest driver for improvement in capability and capacity is signalling. There was an 'easy win' with the 7 car project as only one platform needed adjusting – Baker Street southbound, platform 7, (has a point just off the platform end which with block joints associated with the Bakerloo crossover, meant options were limited). The JLE was designed for 7 cars and older stations used to have longer stocks anyway. This added a capability increase of around 17% within a 3 week period at Christmas 2005. However, this being a "one off", any further improvements would have to be based on improvements in the signalling. To demonstrate where further gains could be made, Mike made an analogy with a Marionette puppet – some small movements on one string produce big end results and big pulls on other strings will produce almost no movement! The biggest improvement to reducing JTC is making trains go faster between stations and being able to fit in more trains onto the same system: signalling is key to this. The only exception to this in recent times has been the Waterloo & City Line where during the upgrade the existing signalling was kept but a new 'front end' control system applied – this, however, is a unique line with small numbers of trains in service at any one time.

WORK AND MODIFICATIONS TAKING PLACE FOR THE SIGNALLING UPGRADE

A third platform at Stanmore, which has been finished.

At Stratford there will shortly be a supervisory booth to facilitate stepping back. Stepping back, currently used at Brixton, Aldgate and Elephant & Castle – the driver of one train gets out at a terminal station and the driver of previous train, who is already waiting at the other end of the platform, takes the train straight out. The second driver then walks along the platform ready to take over the next incoming train. This system is used where layovers are less than 4 minutes: this will definitely be employed during the Olympics where there will be 30 trains per hour.

A new front end for the new signalling system at Neasden where the existing Service Control Centre is based.

Trackside and wayside modifications: inductive loop wiring, axle counters, etc. the use for which will be discussed in more depth later!

An increased fleet size of 63, up from the original size of 59 which was increased at the same time as 7 car.

Station equipment modifications include – providing platform emergency stop plungers and installing RTD (ready to depart) indicators: as there are no repeater signals, a different way of telling platform staff that the driver has permission to depart was needed.

Modification of depot control systems at Stratford and Neasden. Stanmore has been completely resignalled but done on a like-for-like basis, i.e. each of the 10 sidings will be resignalled with trains departing/arriving under full signalling.

Power modifications – the trains will now be able to go faster as compromised overlaps are removed. More power is thus needed. A new factor, however, is regenerative braking on the trains, which can put 790V back into the track. However, modifications were needed so that it wouldn't overload the system if all trains braked at once. As a result, the Jubilee Line now has three new substations, two track paralleling huts (where there was insufficient space for DC switching gear) and has composite rails – aluminium rail with a steel top which is better for conductivity of DC current. The power issue will be more tricky on Northern Line and a new substation at City Road, built for the Northern Line Project, but never commissioned, will be used. The main question to be solved was could more trains, all working off the same substation, get the power they need and if they all brake at the same time, would it be too much for the substation? Work to separate 'busbars' in substations where they were shared with other lines, such as the Metropolitan Line at Finchley Road, has also taken place because, to ensure that 790V going back into the sub station from Jubilee Line trains can't reach the Metropolitan Line trains which can't handle the extra voltage!

A new Alternative Line Control function. Legislation requires that each line must have somewhere other than the main control centre where it is able to control the line. Until recently, the alternative for the Northern Line was a Permanent Way cabin at Warren Street (now at Euston) if Cobourg Street needed to be evacuated. The upgrade will vastly improve on this (and will be discussed later). Mike then showed a graph showing increases in passenger capacity with the various improvements over recent and forthcoming years throughout the whole system. The Jubilee signalling upgrade, which will give a 33% increase in capability, is a big improvement in relation to some other improvements elsewhere in the system. Overall JTC will be improved by just under 4 minutes – ATP – automatic train protection – will be responsible for a little of this, a bit more by ATO – Automatic Train Operation – where the train are operated automatically (improvements being related to consistency in acceleration and braking). However, with the new signalling system, when the power is turned up, speed and therefore journey times between stations is far superior (fewer gaps between trains, etc.) and it is this gives biggest uplift. When all of these improvements are added together, the JTC model increases by just under 4 minutes.

WHAT IS THE SIGNALLING SYSTEM AND HOW DOES IT WORK?

The system is a transmission-based Train Control system (TBTC) where there is constant communication between the train and the track (as opposed to conventionally-based signalling systems where signals work on fixed blocks of track and do not communicate with the train in any way). It is based on Seltrac 40 – which is provided by Thales, a French company. This system used to be owned by Alcatel, but they were bought by Thales, who at the time didn't have their own signaling system. The system is proven and is used completely on the DLR and in Hong Kong on the Westrail and MOSrail lines, however, the Jubilee Line is the largest heavy rail application to date: Westrail is only 18 trains in the peak with a 30-minute duration from end to end. There will be 56 trains (up from 51) in the peak hours on the Jubilee, with 91 on Northern, going up to approximately 97. It is transmission based using the inductive loops situated on the tracks and is a moving block system with no signals (except for boundaries between areas using the TBTC system and areas not using it). The differences between old and new systems can be explained by thinking about a track diagram. On an old track diagram trains appear to 'jump' when they move from one block of track to another as blocks can be relatively far apart: the signalling system only knows that the train is somewhere in that block. As well, because the system is based on overlaps, trains also appear to be strange distances apart. On the new system, depending on your point of view, there are either no blocks sections, or very small ones of just over 6m per block. On the same track diagram this would then mean the trains would appear to move much more smoothly as if they were showing real-time movement. The system works on the premise that the faster the trains are going, the further they will be kept apart and conversely, the slower they go, the closer they get to each other, effectively bunching up – quite unlike existing signalling. When a train enters the station and comes to a stop, the train behind drops its speed as it gets closer until the two trains are relatively close and still safely separated: around 50-60 metres. As the first train starts to move off, the one behind it immediately begins to follow it, at a relatively low speed until it too reaches the platform. This is known as a 'safety distances'.

A diagram showing the moving block concept was then shown, demonstrating how braking reduces the speed as one train gets closer to the one in front, with an agreed safety brake rate known as the GEBR – Guaranteed Emergency Brake Rate. This style of signalling was contrasted to 'old days' where trains would always be a certain distance from the train in front and would always be a certain distance from the next station, save for some home signals which may have speeded things us slightly. Braking rates can be automatically adjusted depending on whether the train is in an open or tunnel section, the open section being more variable because of leaves on the line, rain on the rails, etc. Braking is one example of how the trains are controlled by a Vehicle Control Centre (VCCs). On the Jubilee Line there are five of these and so a train travelling from Stanmore to Stratford would pass through 5 VCC areas. These control train separation and also the interlocking at points. The different VCCs are not really related to area, but more about complexity: areas without many points, etc. will have bigger areas, however areas with points and sidings, such as Golders Green or Stratford will have much smaller geographical areas. VCCs are described as SIL4 systems – Safety Integrity Level 4 – and so are proven to be failsafe.

Inductive loops are then used to enable the VCCs to communicate with the train. The actual inductive loops used on the resignalling project were then handed round to the listening audience. The cable used is extremely thick with a relatively thin, low voltage copper coil inside. This sits in the 4-foot, equidistant between the running and power rails. Because of LU standards, the loops are a maximum of1 kilometre long, with the 2 cables crossed over every 25 metres. The cables are easily bendable and can sustain a flat-bottom rail being dropped on it from 2 metres in height, people walking on it, rain, etc. It was, however, noted that in the position that it has been laid on the tracks it makes it very easy to walk along whilst also not disrupting the workings of the wire when sleepers are removed.

Where the cables cross over at 25 metre sections, if the wheels of the train slip or slide, every time it goes over a point where the cables cross (which reverses polarity), the train knows where it is and can regain certainty of its position. Situated under both trailer cars (as there is no EMC interference there) are two aerials: a transmitting and receiving aerial, which then communicate with the inductive loop wiring. In the transmitting communications, each second the train reports its position to the VCC, whilst every 3 seconds a communication from the VCC is received giving instructions on what to do. This can be summarised like so:

1 second	train:	I'm here	
2 seconds	train:	I'm here	
3 seconds	train:	I'm here	VCC: I know you're here, do this.
4 seconds	train:	I'm here	
5 seconds	train:	I'm here	
6 seconds	train:	I'm here	VCC: I know you're here, do this.

This communication takes place constantly between the train and the track. 2 VOBC's – Vehicle on Board Controllers – actually control the movements of the train – one at each end. However, the important part of the train from the VOBC's point of view is the middle, therefore making it irrelevant which VOBC, at either end of the train, is in charge. When the system is finalised, at one point on the line the VOBC's will change over, one becoming passive, the other active to ensure they are equally exercised. However, during normal use they communicate with each other on a basic level but don't share information: the passive VOBC knows the other is working correctly or not, so that if one goes wrong, the other can take over immediately going active.

At the control system end of all of this is the SMC – System Management Centre – based at Neasden, which is a non-vital system used by controlling staff to manipulate the system to get it to do what they want it to do. The SMC is akin to an autopilot on an aeroplane – a pilot could try as hard as he could, but the computer wouldn't allow him to crash the plane. Everything discussed previously, the VOBCs, VCCs, etc. are vital, while the SMC is non-vital and essentially foolproof with regard to safety: the VOBCs/VCC will ignore or disregard any unsafe commands

WHAT HAPPENS IF SOMETHING GOES WRONG?

A level of secondary detection has also been built in, in case of equipment failure. Axle counters have been placed at each end of every platform (currently used around Chalfont & Latimer and Chesham where falling leaves can affect track circuits), across points and also at loop boundaries. If a train was to stop communicating as both VOBCs were no longer functioning, effectively becoming a NCT – non-communicating train – and so as not to lose the train off the system, axle counters will physically 'count' the train axles as it moves along the track This system then almost reverts to fixed block, with the train appearing to jump on the track diagram between axle counters.

If the VCC malfunctions, all trains under the control of that VCC will automatically emergency brake. The procedure for regaining normal working is to go over a working loop boundary. Once this is done and the two VOBCs are again verified, the train can go back into PM – protective manual mode, whereas the other alternative is to drive at 17.5kph: with this system there isn't a lot of middle ground!

IMPLEMENTATION OF THE NEW SYSTEM

Tube Line's plan was to migrate the signalling system for the Jubilee Line in 4 sections (J2-5), with a preliminary dual-fit area between Canons Park and Kingsbury, known as J1. However, the upgrade program has slipped and to save time, sections J2 and J3 were merged and were going to be migrated together, henceforth known as J23. However, this plan also slipped, meaning that J2, J3 and J4 were all merged together. The current plan is to implement Stratford to Dollis Hill in one go overnight, which from Tube Line's view deals with the program quite nicely but from an LU operational point of view makes things very difficult and fraught! When implementing the Northern Line upgrade, the plan if for it to be completed in 5 sections: Morden – Clapham Common, then the Bank branch as far as Bank, and the Charing Cross branch as far as Charing Cross itself, then through Camden, then finally the Edgware and High Barnet branches.

For the dual-fitted area, which was commissioned on 26 March 2008 and decommissioned on 18 June 2009, the Seltrac 40 equipment was overlaid on top of the existing fixed block signalling from Canons Park to Kingsbury, including the reception road No.33 of Stanmore sidings. This gave drivers practical experience of driving to the responses of the in-cab system rather than simply looking out of the cab window working from signal to signal as they were used to. It also gave Tube Lines extra information about the workings of trains, helping to iron out any software/hardware issues. Most importantly, it also gave Tube Lines assurance over the workings of the system, something LU required, especially as this was the first time it had been used on a brownfield site.

CHALLENGES

It was stressed how challenging installing the system on a brownfield site was – it had only ever before used on a greenfield brand-new site before where there is more uninterrupted time for testing, modifications, etc. When upgrading the Jubilee, week-ends, bank holidays and nights have been used for testing and installation.

(PED) Platform Edge Doors needed some modifications. At present, PAC loops are located at the front and back of a train based on the ATO equipment already installed, which uses the Westinghouse system. PAC loops talk at both cabs confirming the train has stopped within the correct area and an '*accurate stop*' sign is displayed on the driver's console, allowing the doors to open. When the train departs, both sets of doors close, the '*PED doors closed'* visual comes on, and then the pilot light then comes on, which allows the train to move off – this is quite a simple arrangement.

With the new system there is a PEDIU – Platform Edge Doors Interface Unit, which works at both ends of a train, a docking loop under the platform nosing, the inductive loop and feeds coming out, an override at Neasden (so Service Controllers can override the PEDs) and another overide in each station control room so station staff can override the PEDs where necessary. Essentially what happens now is that a train comes in, stops, '*accurate stop*' will be displayed on the console, the whole system then talks: the VOBCs communicate, through the inductive loops and the PEDIU, through to the Station Controller Subsystem up to the VCC. Once everything is verified OK, train doors open and the train doors close again. In essence, a much bigger layer of complexity just for PED doors alone!

INNOVATIONS OF THE NEW SYSTEM

The SMC – System Management Centre – the non-critical element can tweak the system in lots of ways: it can implements permanent speed restrictions, e.g. if programmed to go 30kph over a bridge, it will follow those instructions exactly when in ATO mode (when in ATP, it will advise the driver of the maximum speed accordingly!). The same also goes for temporary speed restrictions, such as Permanent Way work at a station: this can easily be put in remotely from the SMC, each train obeying those instructions. This has a huge impact on safety as it is simply not possible to overspeed.

The SMC will also set station or platform non-stopping. An added benefit is that the speed through non-stopping stations will now be much higher. At present, station starter signals and overlaps assume that a train will only ever go over a starter signal from a standstill, therefore overlaps distances reflect this: the overlap distance of a starter is very short – this can clearly be viewed at Liverpool Street heading towards Aldgate where a train will only be about 50 metres into the tunnel when the preceding train will come in at full speed. As there are now no starting signals or compromised overlaps, 5mph seemed to be much too low, however, top speed was thought to be too fast for passengers on the platform, so a speed of 30kph through non-stopping stations has been settled on. The system will also enforce code red and code amber alerts for every train to either stop at next station or to stop immediately, in the event of a security alert etc.

In addition, the train service can be regulated either through amending dwell time at a station or by amending journey time through higher or lower speeds. If the SMC wants a train to reach the next station in 2 minutes 20 seconds it can program a 20-second dwell then take exactly 2 minutes to reach the next station – the train knows it will then arrive exactly on time. Depending on the most appropriate top speed to reach the next platform in the time allotted, the dwell time can then be readjusted if necessary. This procedure is repeated for every station on every train – the SMC does not see a train as going from Stanmore to Stratford, rather from Stanmore to

Canons Park, Canons Park to Queensbury, Queensbury to Kingsbury, and so on. A similar system is in use on the DLR, sometimes there will be a 1-minute dwell before the door alarms 'ping' to tell the train captain to close the doors and depart, at other times they'll 'ping' within 5 seconds, as the SMC is trying to catch up time. Some physical parameters have to be considered though, the case in point being that at Waterloo in the morning peak, there is an absolute minimum dwell time, there's little point in setting it for 5 seconds! As an extra improvement, when the extension was built, the train weighs itself at each station so the braking is adjusted to provide consistent braking. This on how full with passengers the train is: this then has an effect on decisions on regulation as there is little point in regulating a full train, but a great deal of benefit to be gained from regulating one that is half empty.
The system is also capable of tracking movements by either train number or driver number: a driver will need to put in duty and crew numbers. All data then goes to a data warehouse where any data can be stored where necessary. There has been a need to protect this data warehouse by installing a very strong firewall between the signalling system and outside the world.

Another innovation relating to the upgrade is signage – all of the symbols are hexagonal-shaped. This was made this way to ensure there was absolute clarity in signage and allow others not directly affected by the upgrade to distinguish between Seltrac and non-Seltrac signs, for example Metropolitan Line drivers where the Metropolitan and Jubilee tracks are close to each other. Some additional signage, such as 'RM hold boards' have also been necessary, such as in the case of a non-communicating train, making it clear to the driver that he/she should not head towards critical areas, such as converging points, in RM – restricted manual mode (17.5kph) without specific authorisation from line controllers.

THE NEW SYSTEM IN ACTION

A photograph from the SMC at Neasden was then shown on its first weekend of trial operations. The photograph focussed specifically on the track diagrams, showing London Bridge, Waterloo and Westminster, with other non-operational areas shown in red. The aim at the time when the photograph was taken was to route as many trains through a specific area as possible to demonstrate a high-capacity service. Clearly visible were 5 trains between Canary Wharf and Canada Water about 80 metres apart (there were actually 6 but one was briefly a non-communicating train [NCT]). This showed the potential improvements as at present, because of the fixed block system, it is only possible to get 2 trains in the same area. Because they can communicate with each other and therefore creep, the trains effectively 'chase' each other with significantly fewer gaps: this shows how moving block is truly effective.

At Neasden, instead of there being the traditional forward-facing classroom layout, there will be a 6-desk circular design, similar to what is used in air traffic control centres. This has big advantages in communication as people managing the line can then see other people's faces more easily. A photograph of each individual work station was then shown, with a track diagram being way above head height being 2 flat-screen LED crystal, high-definition displays. There was also space allocated on each individual workstation for communications, CCTV, the connect system, telephones, etc. Differences were then highlighted between the old workstations and the new ones. Similarities were also shown between Neasden and the forthcoming Highgate centre for the Northern Line, which are both very similar to each other. This has obvious benefits in that people could then work in either centre and one will provide alternative line control function for each other: if Neasden had to be evacuated, Highgate will be able to take over relatively quickly. This is a step forward in contingency arrangements and is a similar setup to how the Channel Tunnel operates.

Photographs of the Train Operating Display – TOD – were then shown. The TOD fits exactly into the existing footprint of the Westinghouse speedometer currently in the 1995/96 stock. There was little choice to put it there as there was no other space to house it where the driver could still see it without obscuring the view from the cab window. The TOD is a vast improvement on the old speedo, which was very 1990s technology. The new TOD is LED crystal with 3 basic buttons, two to adjust brightness with the other being a maintenance button. On the TOD screen itself, there is a huge amount of information, designed to be as clear as possible and similar in ways to a conventional Satnav system on a car: on the top row of the display is the destination of the train, the train number and the status of the two VOBCs on the train (which also shows which one is currently active and which is passive), the driving mode of the train (either restricted manual, protected manual or ATO), the time and where the train currently is situated. Elsewhere on the display is the next permitted speed change, at what distance this change will become effective and the current speed of the train (shown in 1mph increments rather than the 2mph of the old Westinghouse speedo). To give an example of the TOD working in practice, a slide showed the display indicates '*at the moment the train is travelling at 20mph, but in 100m you must be travelling at 14mph*'. In ATO, the train manages this perfectly, but in ATP, if the driver is predicted to be going over the permitted speed imminently, the speed display will turn orange instead of yellow and a alert will sound, similar to the 'red alert' noise in Star Trek. At the permitted speed the train will coast and at 3kph over, emergency brake. On the TOD display on the bottom row there is also space for up to two lines of text, to show text message-style information, such as 'skip next station'. It was stressed that this does not override the normal courtesy of telling a driver via the radio, but is supplementary information. These messages are embedded in the VOBC, so it isn't possible, for instance, to say 'I love you' but it can say 'Contact Ruislip, Non-stop next station, etc.

At present, the speedometer is calibrated to show 'miles per hour' but a simple software alteration can switch all TODs to 'kilometers per hour' at some point in the future. Overall it was acknowledged that although this is a big step forward, it is also a big culture change for drivers.

OTHER INTERESTING QUIRKS

When the third platform was built at Stanmore, because of its position, the sequence was P2, then P1, then the new one – the question arose, what number should it be? Calling it platform 3, would mean the sequence would be 2, 1 and 3, which is confusing for passengers and staff alike. Engineers *hated* the idea of Platform 0, i.e. 2, 1, 0, insisting that 0 wasn't actually a number. In the end, everyone's hand was forced as Tube Lines stated that it would cost a lot of money to change all the line asset drawings and such things, which was simply too much to justify and so the sequence 2, 1, 3 was settled on. At present, the platform is finished, with all the dot matrix signage in place. The stopping points for the train on the new platform are a lot further south. This is because the new platform will only be operative once ATP comes into use. The new system allows a train to come into a terminal platform at a higher and continually supervised speed.

Through all of these changes, there is still a need to have a clear rulebook. When rewriting it, the best practice from the DLR was taken as well as other focus groups, advice given in workshops and the railway company already using Seltrac 40 in Hong Kong and DLR. Considering the amount of change which is taking place, there are only a small amount of procedures to follow – 21 in total: applying the rule in failure conditions was the foundation of the old-style rulebook and now not as many are needed. Most failures on the new system require a train to re-enter the system in case of failure and this is given the most emphasis in the new-style book. As the system has progressed and everyone has learned how to work the system better the rules have been changed slightly and so LU are currently on version 2 of the rulebook.

It was also found that a new aspect was required at migration boundaries – taking Westminster as an example, which was a migration boundary, going westbound was easy as trains were going from the Seltrac system to the traditional fixed block system, so a red and green aspect with a conventional trainstop was sufficient. However, going eastbound from fixed block to Seltrac, it wasn't possible to give a green aspect as a green essentially gives the authority to proceed to the next signal – but – there are no next signals!

It was also impossible to give no aspect, as this is one of the 16 danger signals, and a dual aspect was not permitted either, so, a new colour aspect was needed. Blue was eventually chosen, signifying a migration boundary where the switch to ATP will be made. Once the train has been checked, the communication systems are working, etc. the train has 'proved' itself, the tripcock lowers, a blue aspect is displayed (“obey in cab signalling”)and the train can enter the ATP zone. Once the entire system is finished, the tripcocks can be taken off trains as they will no longer be needed.

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