Jubilee & Northern Upgrade Project
The Challenges of Applying a Proven Product to an Existing Metro Railway

By Andy Bourne¹ & George Clark²

As part of the Public Private Partnership, Tube Lines is upgrading the Jubilee, Northern and Piccadilly Lines to improve journey time. Tube Lines’ solution involves applying the Seltrac S-40 moving block signalling system supplied by Thales Rail Signalling Solutions. This is a product proven in metro applications, but new to the London Underground network.

This paper will explore how Tube Lines and Thales are meeting the challenges of adapting Seltrac to the LU environment and integrating it into the railway system. Areas to be covered will include signalling principles, technology adaptation, integration including electro-magnetic compatibility, migration and assurance including cross-acceptance.

LINE UPGRADE REQUIREMENTS

Under the Public-Private Partnership (PPP), London Underground (LU) has specified capacity enhancements, otherwise known as Line Upgrades, for each of its lines. These upgrades have been scheduled over a number of years, in particular on the Jubilee Line in 2009 and the Northern Line in 2011. The upgrade requirements are based on performance, that is output, and address the primary need to reduce the journey time of the passenger.

The journey time capability, measured in minutes is described by a complex formula, together with obligations to make it possible. For example, the increase in numbers of train crew to operate a higherfrequency train service leads to the need to construct additional train crew accommodation. It is not the aim of this paper to describe the model in detail, but to put the application challenge in context to give an understanding of the incentives and penalties which drive project delivery.

The journey time capability model describes a notional train service that LU must be able to operate after the upgrade. It defines one application of the technology and facilities. LU could use the same facilities to deliver a different service if they wished, but the PPP incentivises this specific solution. The service picture painted by the model allocates certain parameters to LU, such as station dwell time and service pattern.

However it also requires Tube Lines to deliver figures for:

- inter-station intervals (IRI), the time to travel from one station to the next;
- platform re-occupation time, the minimum time for one train to follow the first into a platform, traditionally known as the Run-Out/Run In (RORI);
- the number of trains to be offered for service.

This journey time capability concept results in an enhanced service capacity which is constrained either by the signalling system, in terms of headway, or by the rolling stock, in terms of the declared number of trains available for passenger service.

A scheduled journey time capability is defined, to which further benefits can be accrued from service consistency measures such as Automatic Train Operation (ATO) and from enhanced control centre features such as timetable regulation. All these extras lead to an aggregate journey time capability.

So what level of performance has LU specified? Whilst it is difficult to equate the traditional trains per hour figure to a journey time capability model, it is possible to estimate the level of enhancement based upon percentage reduction in journey time. In these terms the line upgrades equate to circa 40% enhancement on the Jubilee Line and 22% on the Northern Line.

TUBE LINES’ SOLUTION

To achieve the reduction in journey time, Tube Lines has to reduce IRI and RORI with an increase in the number of trains available for service. Whilst these are the major works, they cannot succeed without a significant number of supporting works, including the construction of over thirty new equipment rooms on the Jubilee Line and a complete new control centre building on the Northern Line. Both lines will also require additional train crew and other support facilities.

Returning to the primary incentives, Tube Lines chose a systems approach to analysing the requirements and balancing the benefits from investing in differing asset areas. Table 1 shows how each discipline contributes to the overall target for the line upgrade.

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil and Permanent Way</td>
<td>IRI reduction by localised removal of speed constraints, lifting current line (permanent) speed limits</td>
</tr>
<tr>
<td>Signalling and Train Control System</td>
<td>IRI reduction by optimising the time from door closure to train departure, and by opening the doors as soon as safely possible on station arrival. RORI reduction by means of a modern train control system with optimised/minimised block length. Service consistency by means of ATO and modern intelligent train control and regulation.</td>
</tr>
<tr>
<td>Rolling Stock</td>
<td>IRI reduction by traction performance optimisation. Fleet declared for service increased by increased overall fleet size and reliability improvements</td>
</tr>
</tbody>
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Table 1 Contribution of engineering disciplines to line upgrade
Seltrac arrived in London in the 1990s when it was commissioned into use on the Docklands Light Railway (DLR), where it controls an ever-increasing network. The specific variant approved by HM Railway Inspectorate for use on the DLR was then developed further for its first heavy rail application, in Hong Kong on the Kowloon-Canton Railway’s West Rail in 2004. It has since been applied to part of the East Rail system as well. As will be seen later in this paper the approvals gained in the UK and Hong Kong against the latest Engineering Safety Standards were a key cross acceptance benefit.

There are many technical papers published which describe the Seltrac solution for DLR, so only an overview is given here, with specific mention of developments since DLR.

The Seltrac system relies on continuous bidirectional communication between the wayside and the train. The system architecture consists of:

- a central system which includes the System Management Centre (Control System & Signaller Interface), as well as centralised Vehicle Control Centres (train protection and interlocking);
- a wayside or local level which includes the local safety processors (Station Controllers), Platform Door Controllers (Jubilee Line only), the communications loop and the axle counter system;
- a train borne level which consists of the Vehicle On-board Controller (VOCB) and associated interfaces.

The original UK application of the system on DLR led to the integration into the product of the axle counter subsystem, to ensure detection of the presence of non -communicating trains and to ensure that all detected axles were protected (if for example a train coupling failure were to occur).

The DLR application was developed further, with enhancements such as use of a dedicated fibre-optic communication system to replace much of the traditional copper communications cabling between subsystems, first applied in Hong Kong and now part of the JNUP application.

This type of transmission-based train control system is often referred to as moving block, as its primary means of train detection is reports from all trains, communicating with the central protection system (VCC) at a resolution of 6.25 m. This information is translated into a target point for the train in rear, including an allowance for braking and a safety distance. The high resolution of train location in combination with continuous brake assurance enables the safe distance between trains to be optimised to reduce the signalled headway, in particular through platforms or turn-back locations. The train tracks its own location in centimetres in order to achieve the accurate stopping required where there are platform edge doors.

**THE LONDON UNDERGROUND NETWORK**

The LU environment is unique, the railway being heavily used and having considerable history. Assets range from the signal and control systems delivered for the Millennium on the extended Jubilee Line, through to signalling systems dating back to the 1940s on the Northern Line. Although well cared-for these old systems are fragile, and so any work on them is subject to a high level of control and supervision.

**Table 2**

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Original Jubilee Line</th>
<th>Jubilee Line Extension</th>
<th>Northern Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling stock</td>
<td>96TS</td>
<td>96TS</td>
<td>95TS</td>
</tr>
<tr>
<td>Signalling power</td>
<td>125 Hz a.c.</td>
<td>50 Hz a.c.</td>
<td>125 Hz a.c.</td>
</tr>
<tr>
<td>Interlocking</td>
<td>Mechanical (shared with Bakerloo and Metropolitan Lines in places)</td>
<td>Processor based (Westrace)</td>
<td>Mechanical</td>
</tr>
<tr>
<td>Train protection</td>
<td>Trainstop</td>
<td>Trainstop</td>
<td>Trainstop</td>
</tr>
<tr>
<td>Train Detection</td>
<td>a.c. track circuit</td>
<td>Jointless Track Circuit</td>
<td>a.c. Track Circuit</td>
</tr>
<tr>
<td>Control System</td>
<td>1980s computer based, integrated with Metropolitan Line</td>
<td>1990s networked PC system</td>
<td>Bespoke programme machines with push button over-rides; shared computer based information systems</td>
</tr>
</tbody>
</table>
Whereas the technology varies greatly over the network, the basic signal system does not. LU has relied upon a fixed-block two-aspect signal system for decades. With the exception of the Victoria and Central Lines LU is a manually-driven railway with an electro-pneumatic trainstop/tripcock protection system. The basis of its system architecture has been a local interlocking, generally air driven, directing safe movements within its area using a.c. track circuits. The trains are designed so that there is always a cab at the front in the direction of travel, providing all controls direct to the driving position.

As a consequence, in general and certainly on the Jubilee and Northern Lines, the existing design principles and standards and the operational rule book rely upon the fundamental operation of fixed block train movements, that is from signal berth to signal berth.

When considering the application of a new system, albeit proven in use, to an existing railway, not only the technology and environment but also the operational history can affect the migration. This is true of both the Jubilee Line and the Northern Line, as can be seen by the infrastructure summary chart in Table 2.

LU’s historical divisional operating organisations are reflected today in the combined signalling for Metropolitan and Jubilee Line as well as the control systems for the Northern and Victoria Lines. Unfortunately the PPP prescribes individual line upgrade targets. This leads to challenges at locations such as Neasden Depot. This is not operated by Tube Lines, entry and exit are required for Metropolitan and Jubilee Line services and it is signalled by the current Jubilee Line interlockings. The resulting combination of TBTC and non-TBTC train movements over shared tracks has led to a novel development specifically to address this ‘interoperable’ area.

**SIGNALLING PRINCIPLES**

The earlier sections of this paper have shown that the transmission-based train control system differs in both concept and architecture from the existing railway. This was recognised from the commencement of design, and the JNUP project has taken a proactive approach in bringing together the supplier, LU design authorities and the LU operator to build a set of signalling principles in a working group forum.

The Signalling Principles Working Group sat throughout the concept and preliminary design phases of the project to address key technical and safety issues arising from the introduction of the TBTC technology on the Jubilee and Northern Lines. Its objective was to facilitate a joint risk mitigation approach to signalling principles applicable to the TBTC technology, including consideration of the principles involved in dual fitted and mixed mode (dual running) areas.

Application guidelines for the signalling principles were established by starting from operational scenarios (“top events”) specified in the LUL QRA, current Engineering Standards and the Works Information (TBTC contract). For each principle, the working group considered trains operating in Automatic Train Operation (ATO), Protected Manual (PM) and Restricted Manual (RM) modes, and took into account equipment failures. The scenarios led to other subsystem-specific principles such as train operation itself, and a total of 53 signal principles were defined.

Whilst many principles such as track locking are common to all signal systems, the architecture and LU degraded mode operations led to TBTC system developments, using the agreed signal principle as the prime requirement. Three specific examples are given below to illustrate the adaptation challenges which the working group faced in seeking to maintain the proven in service product whilst addressing LU’s operational and engineering concerns.

**Degraded Mode Control**

The TBTC system architecture brings many benefits in centralising its safety functions in the VCC. This is a two-out-of-three system and has been shown to have high availability, but nevertheless a failure would impact over a fifth of the Jubilee Line, potentially leaving large numbers of passengers in deep-level tube tunnels with little information available at the Control Centre.

Hence a new function which retained Control Centre indications and enabled point movement and locking was defined, to provide LU with the tools to manage what all expect to be a rare event in fact.

**Route Secure**

At DLR the movement of trains in degraded situations was based upon wayside point position indicators. This was further developed and applied to KCRC. These indications, together with basic track locking logic within the Station Controllers, enabled trains to traverse points during slow speed manual movements, confident in their position and locking.

However LU had developed a standard for the facilities to be provided by the signal system to enable train movements when either train or train detection failure had occurred. This standard facility and wayside indication, known as Route Secure, had already been applied on the Jubilee Line and other parts of the LU network. The functionality was built upon a local interlocking providing locking and indications.

However the degraded modes were different in the TBTC system, both for train failure and in the signal system architecture. The main VCC safety system provides a very similar function should a defective train need to travel through pointwork. However the same logic must be present if the VCC fails, that is for the degraded mode of operation. This led to the development of designs which could be applied at a lower level within the Station Controller, recognising when applying the principle that this subsystem would not have all the railway information that a VCC would have. Moreover the level of interlocking needed to effect Route Secure locally was such that it would constrain system performance when the system was fully functional. Hence a further principle, of locking being applied locally only under VCC failure situations, had to be developed.

**Axle Counter Reset and Restore**

Many railways have applied axle counters for train detection but previously LU had only used one in a very simple, single track arrangement. This arrangement, although it used the same axle detector head as TBTC, had a conventional arrangement of a local evaluator and reset function.

As noted above though, following the DLR application Seltrac has had its axle counter solution integrated into its central safety systems. Hence detection of noncommunicating trains relies on this subsystem. Any disturbed axle counter...
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block can be restored centrally by "sweeping the block." This enables automated restoration of the axle counter by the VCC monitoring a train through the block, but it requires the VCC system and axle counter system to correlate. That can prove difficult during engineering hours, when trolleys etcetera may be placed on and removed from the track during night works. Hence a remote immediate reset has been developed which can be used in that instance, in combination with the LU 'Line Clear/Safe' process which assures the track is clear of equipment at the end of engineering works.

Whilst the above have been defined technically in the signal principles, operational rules and associated hazard analyses are required to assure the design and ensure that mitigations are in place for identified risks, in particular for the Reset and Restore process which is essential for its implementation in the field.

TECHNOLOGY ADAPTATION

Although Seltrac is a proven product, adaptation is necessary for application on London Underground. Reasons for this adaptation include obsolescence, functionality (as discussed above) and environment, and each requires careful consideration to implement change in such a way as to preserve the essentially proven nature of the product.

The reference baseline for the JNUP system was the implementation of Seltrac on KCRC's West Rail. Obsolescence

As with any electronic based system, technology upgrade is required to avoid obsolescence. Alongside hardware upgrades, changes are made to the core software product to ensure ongoing integration with the new hardware and also to improve reliability and maintainability. Key changes for JNUP from the KCRC baseline are given in Table 3.

Functionality

Functionality changes have been made where they were necessary to meet LU and TL requirements. Table 4 shows the key changes.

Environment

The JNUP project is the first time that a transmission based signalling system has been implemented on LU and the first application to make heavy use of axle counters, so to ensure smooth migration, trials and demonstrations have been set up to give early confidence and identify any issues for resolution. Examples are given in Table 5.

<table>
<thead>
<tr>
<th>Area</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMC</td>
<td>Timetable handling, Junction Mode, Human Machine Interface, VCC commands ported to SMC, Degraded Mode Control, Data Warehouse, non-vital network and PLC, Interfaces to Existing systems</td>
</tr>
<tr>
<td>VCC</td>
<td>Remote Securing, Immediate Reset, Centralised VCCs, LU Signalling Principles</td>
</tr>
<tr>
<td>SCS</td>
<td>Remote Securing, Immediate Reset, LU Signalling Principles</td>
</tr>
<tr>
<td>VOBC</td>
<td>Interfaces to Train Management System and Incident Recorder, new Train Operator Display, Additional Supervision</td>
</tr>
</tbody>
</table>

Table 4 Differences in Seltrac functionality between KCRC and JNUP

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Location</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Contract</td>
<td>Various</td>
<td>Transmission trials on LU infrastructure</td>
</tr>
<tr>
<td>Concept Design</td>
<td>Highgate Test Facility (1 km long, 50 km/h max. speed)</td>
<td>Proof of ability to drive 96 Tube Stock in ATO at Highgate Test Facility</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Highgate Test Facility</td>
<td>EMC tests of Seltrac with 96 and 95 Tube Stock, EMC test of 95 Tube Stock signal/noise improvements, Loop layout optimisation, Passenger evacuation along track with loop in situ</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Willesden Green (Jubilee Line)</td>
<td>Advanced Demonstration (Axle Counter Trial)</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Bermondsey (Jubilee Line)</td>
<td>Advanced Demonstration (loop over slab track), Track storage with loop in situ</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Finchley Central (Northern Line)</td>
<td>Advanced Demonstration (loop over ballast and points and crossing), Proof of tamping with loop in situ</td>
</tr>
<tr>
<td>Final Design</td>
<td>Highgate Test Facility</td>
<td>EMC Testing of Seltrac with 125 Hz DEV track circuits</td>
</tr>
<tr>
<td>Implementation</td>
<td>Canons Park to Kingsbury</td>
<td>Dual Fitted Area</td>
</tr>
<tr>
<td>Implementation</td>
<td>Highgate Test Facility</td>
<td>Validated site test facility</td>
</tr>
</tbody>
</table>

Table 5 JNUP Technology Trials
INTEGRATION ISSUES

The TBTC system cannot be introduced into the railway environment in isolation. Interfaces to other systems need to be established, and it needs to be demonstrated that the signalling system can operate effectively and safely in the overall railway. For JNUP the responsibility for achieving this technically (where not explicitly given to a supplier) generally lies with Tube Lines. However London Underground also has responsibilities in the PPP contract with respect to several technical interfaces, for operational staffing and for modifying operational procedures.

System Architecture

Development of an overall system architecture early in the project is essential for understanding the overall railway system affected by the project, to drive out interface requirements and to resolve ownership of the interfaces. The architecture needs to be stable for the design to be developed without unnecessary changes.

Interfaces

The introduction of a system like TBTC necessitates interfaces to existing systems being retained (either as part of migration or in the final system) and other new systems being introduced as part of the line upgrade.

Interfaces needed to be identified and the interfacing parties established. One party is then assigned the lead role to develop and document the specification for the interface. Interfacing requirements and activities also need to be captured and programmed by both parties.

System Design Reviews

As the design evolves each contract or discipline should be holding design reviews at the appropriate phases in the design lifecycle. For TBTC this means reviews and concept design, preliminary design and final design stages.

It has also been very useful to hold System Design Reviews which sweep across the whole scope of the JNUP project alongside the TBTC reviews. This ensures that the evolving system is considered as a whole, and has been valuable in finding issues and gaps in the total system design.

Other system design reviews have been held to consider key interfaces (for example, that between the TBTC system and the rolling stock), and aspects of system behaviour which crosses multiple subsystem boundaries.

Rolling Stock

The TBTC to rolling stock interface is the most critical interface on the JNUP project. The existing ALSTOM 96 Tube Stock on the Jubilee Line and 95 Tube Stock on the Northern Line must be modified to house the train borne TBTC subsystems (for example, VOBCs) and to work with to provide Protected Manual and supervised Automatic (ATO) driving modes. There are VOBCs at both ends of the train, and either can be in control. Extensive work has been necessary on the train systems to facilitate this. Making significant changes to a working fleet has required detailed logistical planning and cooperation from fleet operations on both lines.

Communications

Along with the introduction of TBTC, communication systems are being upgraded to coincide with the upgrading of the Service Control Centre (SCC) control room on the Jubilee line at Neasden and the building of a new SCC for the Northern Line at Highgate. Facilities to be upgraded include telephony, signal post telephones, tunnel telephones, centralised public address, closed-circuit television and customer information. Extensive use is being made of the transmission capability being provided to LU through the Connect PFI. This has led to the creation of a set of interfaces managed through a joint technical group made up of Tube Lines, LU and the Connect supplier (CityLink), since Tube Lines has no direct relationship with CityLink.

Enabling Works

Significant enabling works support the introduction of the new signalling, including signalling equipment rooms and cable routes, the new SCC at Highgate, a third platform at Stanmore on the Jubilee Line, train crew accommodation, depot commissioning areas and other improvements to facilities. Each generates a set of interface requirements to be managed by the JNUP project team.

EMC

The introduction of a transmission based signalling system into an existing railway infrastructure presents a number of challenges which need be overcome alongside providing safety and legal assurances regarding the new system.

JNUP’s EMC strategy rests upon a number of key principles:

- demonstrating compliance of the Seltrac S-40 system with CENELEC EN 50121;
- generating technical construction files for final products;
- assessing the EMC threat to and from existing systems through a hazard identification process and eliminating them by function safety and other analyses, practical testing and, if required, design modification.

A number of challenges have had to be overcome along the way. In the early days of the project it was discovered through testing that the Northern Line 95 Tube Stock generates significant noise in the 36-56 kHz region used by Seltrac. Analysis and testing at the Highgate Test Facility led to an understanding of the mechanisms involved, and to a package of train modifications to reduce the noise levels to a point where a healthy signal-to-noise ratio for Seltrac could be obtained.

Further challenges were presented by the existing signalling system.

Firstly the Westinghouse PAC loops used for platform-edge door functions on the Jubilee Line operate in the same frequency band as Seltrac. This is not a problem in the final system where they are replaced, but at migration boundaries the PAC loop must be suppressed by design with Seltrac providing the same functionality.

Secondly the FS2550 jointless track circuits operate at frequencies which coincide with Seltrac. Normally the two systems can co-exist but, in the short track area between track circuits, high currents can circulate which do affect the Seltrac signal. Again this is a migration issue only and has been overcome by temporarily pinching the loops in these areas.

Thirdly it had to be demonstrated that the Seltrac loop could not adversely affect traditional 125 Hz type DEV relay track circuits. Significant analysis and testing was required, particularly concerning some of the non-linear behaviour of the DEV relays.
A final challenge has been to demonstrate that fast transients from noise sources such as traction switching, power regeneration and section gaps will not cause reliability problems with Seltrac. Again a mixture of theory, modelling and testing has been employed. To date this has showed that fast transients could theoretically affect the system, but no practical source has been encountered of sufficient duration or magnitude to affect signal bit error rates.

From the foregoing it will be seen that EMC requires significant effort and expertise for successful delivery of projects such as JNUP.

Human Factors

For LU operating a railway with moving block signalling principles represents significant changes in practices. The line upgrades also present an opportunity for LU to improve railway operations, for example by improving command and control facilities and the way they are used. JNUP has therefore made extensive use of human factors expertise to progress designs and provide assurance that they are operable.

JNUP has utilised a human factors integration approach in line with LU standards. This aims to bring human factors thinking into all aspects of the system design rather than simply to review the outcome. To this end a number of workstreams were identified for human factors engineering input, managed by a Human Factors Delivery Manager for Tube Lines. On the LU side, a User Acceptance Manager leads LU input into the process, including production of an operating concept and leading consultation with trades unions.

The production of the operating concept deserves some discussion. It is generally required early in the project to inform the system design, but at this stage of course the operator knows little about the system and how it may be used. In practice the relationship between operating concept and design has to be an iterative one during concept design.

The main areas of Human Factors input can be separated into control centre related activities (for example control room layout, lighting, acoustics, human machine interfaces) and those related to the train and wayside (train cab controls and displays, signage). Integration activities include reviewing how the overall railway operates in normal, abnormal, degraded and emergency situations.

It is the human factors area that often becomes the focus for challenges associated with changes to operating practices. On JNUP two areas stand out as significant in this respect.

Firstly a control room layout involving a circular desk arrangement has evolved, rather than the traditional class-room layout. This supports a more flexible, team-focused approach to command and control but extraordinary effort has been needed to demonstrate its operability.

A second focus has been the train operator’s display, which is the train operators’ main view of the TBTC system and hence the focus for changes in driving approaches (such as Limit of Movement Authorities and Speed Supervision), particularly for manual driving. The result of significant user input and human factors assessment is a display which is clear, concise and highly useable.

Training and Procedures

Needs for training of operators and maintainers, and for the development of new and modified operating procedures, are closely allied to human factors workstreams, and in JNUP they are managed by the same team.

Migration Issues

One of the key project challenges is to migrate to the new system whilst keeping the existing railway operational. It is not possible to close the line for extended periods so installation, testing and commissioning must be achieved in engineering hours and limited weekend closures. This constraint, along with resource logistics and the need to control project risks, leads to a staged migration of the new system.

Phased Migration

The implementation of TBTC on the Jubilee Line is being achieved in six stages.

J1 - Dual Fitted Area

This stage involves an overlay TBTC system between Canons Park and Kingsbury at the quieter, northern end of the Jubilee Line. Protection continues to be provided by the existing signalling system, but trained operators in TBTC-fitted trains can switch into TBTC mode to gain driving experience. The area also provides further technical evidence (for example, of system reliability) ahead of the migration of the final system.

J2 - Stratford to Canning Town

This is the first phase in the changeover from existing signalling to TBTC. Trains will switch into TBTC at Canning Town eastbound platform (having been tracked from Canary Wharf) and back to Tripcock Protection (TCP) mode at Canning Town westbound platform. As this is a TBTC-only area, all revenue service trains must be dual equipped to enable this section to enter service.

J3 - North Greenwich to Westminster

The extended TBTC control area includes Jubilee Line Extension stations which have platform edge doors.

J4 - Green Park to Dolls Hill

The penultimate section includes interfaces with the Bakerloo Line at Baker Street.

J5 - Neasden to Sfanmore

The final section includes interfaces to the Metropolitan Line and Neasden Depot, at Neasden and Wembley Park.

Control of the above sections is from Neasden SCC.

Post J5

Following the implementation of TBTC and hence the removal of a number of short overlaps in the old signalling system, the performance of the 96 Tube Stock can be raised and Automatic Train Operation introduced, providing the final upgrade of performance.

Installation

Installation of the new system falls into a number of zones.

In new signalling equipment rooms, installation can be achieved around the clock. In existing equipment rooms or on the railway itself installation can only be accomplished in engineering hours or closures. This means that logistic support for this work has to be strong to optimise use of the limited access.

Release of design to installation is controlled on JNUP by Installation Release.
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AUTOMATED TRAIN CONTROL
Testing and Commissioning

Testing activities commence in the factory environment, where formal validation tests and equipment tests provide sufficient confidence to release software to site and to qualify hardware for installation and energisation.

Site testing takes place in engineering hours or weekend closures on the main line, but can also take place at the validated site facilities at Highgate Test Facility for certain tests.

Site testing activities have been split into a number of “maturity levels,” building up from simple post-installation tests to full system testing involving multiple trains and ATO running.

Maturity Level 0

ML0 does not involve the use of any trains for testing. It is essentially local correspondence testing with equipment powered. It does extend to functional testing that can be conducted without trains.

Maturity Level 1

Testing at ML1 consists of hardware testing and software correspondence testing to prove satisfactory communication levels (“Datacom”) between train and control centre, and to confirm correspondence with the infrastructure (“Guideway”) data within the Seltrac system.

Maturity Level 2

ML2 addresses software functionality, system integration and compatibility. ML2 testing also includes train interfaces. The objective is to prove safe control of a train operated in Protected Manual mode and to prove all safety functions for train separation that will permit multiple train movement within the constraints of the existing fixed block signalling system.

Maturity Level 3

ML3 addresses integration, functional operational testing of the complete TBTC System, and confirms that the human machine interface is suitable for its intended application. All training will have been completed, documented and checked. On completion of ML3 testing the TBTC system will be ready for revenue service.

Maturity Level 4

ML4 adds further high level system tests to allow proving of Automatic Train Operation functionality, building on the protected manual operation in revenue service.

ASSURANCE

Assurance is now a major component of any railway project. It needs to be planned alongside physical project delivery, to ensure that evidence is available when required and that the necessary consents are in place for the project to proceed according to programme.

Philosophy

The following key principles have been adopted for the JNUP project:

- cross-acceptance of the TBTC product from its KCRC baseline using product, general application and specific application engineering safety cases;
- the use of an Independent Safety Assessor to assess the TBTC system and its interfaces;*
- the employment of Yellow Book principles for engineering safety management;
- the establishment of a System Review Panel for ‘new and novel’ assurance approvals at the Tube Lines level;
- work in accordance with Tube Lines and London Underground assurance procedures and standards.

Assurance Chain

Delivery of assurance has its own supply chain, which begins with suppliers (and their component suppliers) and flows into the Tube Lines project team. The project team provides assurance to Tube Lines asset engineers and also to the Independent Safety Assessor who works on their behalf. At this level the System Review Panel has operated to provide a formal peer-based assessment of new and novel aspects of the design. Key aspects of the design also have to be reviewed and accepted (that is, given a ‘No objection’) by London Underground Engineering Directorate.

In the early stages of the project HMRI gave final regulatory ‘No objection’ to the design under the ROTS(WPE) Regulations and indeed the Concept Design submission was endorsed in this way. With the arrival of the ROGS regulations, London Underground itself has provided regulatory approval in accordance with its Safety Management System. LU has established a Directors Assurance Review Team (known as DART) to provide a final review and ‘No objection’ of submissions from an engineering, safety and operational perspective.

As with most modern railway projects, the assurance effort on the JNUP project has been a very significant part of the overall effort.

STAKEHOLDER MANAGEMENT

A project the size of JNUP inevitably involves a large number of parties with different but legitimate interests.

Project Stakeholders

Stakeholders in JNUP include:

- Tube Lines operations; ;
- Tube Lines’ shareholders;
- Tube Lines’ financiers (represented by their technical advisor); ;
- the travelling public; ;
- trades unions;
- Businesses (such as the management at Canary Wharf); ;
- Transport for London, the Greater London Authority, local authorities and central government;
- regulators (HMRI, LFEPA, HSE).

As a project like JNUP progresses and its visibility increases, the interests of these parties need to be addressed. Some require support from Tube Lines External Communications, others are managed by the project directly. This is not a trivial demand on time, and it needs focused support. In particular the project has worked hard on the LU interface, utilising working groups as the main vehicle.
**Working Groups**

LU facing working groups have covered:
- signalling principles and application design;
- operability;
- migration;
- enabling works;
- system integration;
- software;
- safety approvals;
- training and procedures.

They operate in a non-contractual environment, to allow information exchange and permit issues to be freely discussed and resolved at working level. However once agreement is reached on matters of substance it is then formalised.

**PROJECT STATUS**

The project has now entered the application phase. The final system design reviews have been held, and installation on the Jubilee Line is well advanced. In the past three years the TBTC system has progressed from concept demonstrations on the dedicated test facility at Highgate to the completion of advanced trials of key subsystems.

The next step is the introduction of the TBTC system as an overlay on part of the existing fixed block signal system on the Jubilee Line. This “Dual fitted area” is located between Stanmore and Wembley Park at the north end of the Jubilee Line. The hardware has all been installed and the initial software delivered. System testing with trains has now begun and the system is scheduled to be introduced into operation at the end of the year.

As this paper is being drafted the testing is entering its final stage, which has three main objectives:
- to define and test the delivery and approval processes associated with commissioning the TBTC system into revenue service;
- to enable the project to gather further evidence of system operation and performance;
- to provide LU train drivers with operational experience of the TBTC system prior to full migration, complementing office and simulation based training.

Here the TBTC system will provide the driver with a fully-operational in-cab display, and will intervene should the train exceed line speed or the braking curve on approaching a red signal or other event. Whilst the existing signalling system remains the primary protection system, with trainstops and tripcocks, the TBTC system has been configured to ensure no train is given a movement authority past a signal at danger or a raised trainstop.

Acceptance criteria are well developed to enable system performance in this phase to be monitored and assured, to give a low risk of systematic faults occurring when permission is given for the full TBTC system to enter passenger service next year.

The system design for the Northern Line is also reaching its final stages now, and so the lessons learnt from the Jubilee Line are now being applied to underpin a successful application. However each LU line brings its own challenges, which here include older assets and differing depot interfaces and migrating to a new control centre as examples.

The success of this line will build upon the Jubilee Line which as this paper has shown requires careful change control in each area to manage the change. The success of this work will be seen in the level of emergent and undesirable features that arise during its application.

This project has always worked closely with its suppliers and stakeholders so that it has been best placed to manage the challenges ahead and to meet the targets it has been set.

**CONCLUSION**

The introduction of any modern train control system requires a risk-based approach, and the PPP incentivises that through its penalty regime for poor system availability or late delivery. The adoption of a proven system reduces that risk, but challenges still remain. Working with all stakeholders is important, for example to ensure that signal principles can be developed and applied without threatening reliability. A de-risking approach to migration planning through advanced trials and the off-line test railway is also vital, as are system engineering and human factors work to ensure that the people, equipment and processes work together in the field.

Proven TBTC systems also bring challenges in their application to existing lines by introducing a need to maximise the use of simulation testing and minimise site tests, something that is not an issue for green-field applications.

On an existing railway these systems demand resources for testing not seen before, relying heavily on testing with trains to assure system functionality. This requires test train drivers as well as converted trains.

JNUP has applied this risk-based approach and progressed through stages of concept proving and advanced trials. Each of them has been successful in highlighting compatibility issues, which have then been overcome to reduce the risk of introducing the system into the existing LU environment and infrastructure. The Dual fitted area stage on the Jubilee Line has brought further challenges, as overlaying a moving-block system on a fixed block is not as easy as it sounds, given that it is important not only to overlay but to mimic the existing while providing the functionality to give confidence in system operation.

2008 will see migration of the new system on to the Jubilee Line and the results of the effort to date in meeting the challenges of applying a proven product to an existing railway.

There will also be increasing activity on the Northern Line and, with the Piccadilly Line to follow, the next seven years will see the transformation of three LU lines and a new generation of signalling system, with associated operational practice and performance, providing the reductions in Journey Time that LU require.

** ACKNOWLEDGEMENTS **

Thanks are due to many colleagues in Tube Lines, Thales and London Underground who have worked hard to bring the project to its current phase of implementation.
一次難以忘懷的，不平凡的铁路旅程

2007 年 7 月，两位来自香港的退休铁路工程师（一位是轨道工程师，另一位是信号工程师）和他们的配偶，进行了一次生命中的特殊铁路之旅。这次旅行的时间选择有一种特殊的意义，它标志着青藏铁路开通一周年（正式开通运营时间—2006 年 7 月 1 日）。

为期 12 天的铁路之旅是从中国青海省的西宁市开始。前半部分的行程经由青藏公路，行程为 1947 公里，最后抵达西藏自治區的拉萨市。这次旅行花了 5 天 4 夜的时间，平均行进速度仅为 50 公里/时。在拉萨市及附近游览了几天后，他们由拉萨乘坐火车回到西宁。经由青藏铁路的行程为 1956 公里，仅用了 24 小时。

这是一次很好的旅游线路安排。在格尔木至拉萨 1142 公里的路程上，青藏铁路走向与青藏公路基本并行。沿青藏公路行进，人们很容易就可以看到众多的铁路建筑构造体，如高架桥、铁路路堤、列车车站、无线电发射站、隧道口。如果幸运，你还会看到客运、货运列车甚至工程机车。视觉敏锐的话，甚至可以看到永久冻土道床的特殊固定装置。以下是经过格尔木 2828 米至拉萨 3641 米的地点更详细的建筑构造及景色描述。

离开格尔木后不久，轨道就开始不断上升，一直到达第一座山脉—昆仑山。距格尔木 100 公里、海拔约 3800 米的地方，我们遇到第一座雄伟的铁路建筑—三岔河大桥。它是整条铁路线上最高的大桥，桥面距谷底 54.1 米。经过 4000 米的高度线，我们到达玉珠峰站。玉珠峰站海拔 4159 米，是我们所看到的第一座被积雪和冰川覆盖的昆仑山山峰。从这里开始，有 958 公里的铁轨在海拔 4000 米以上，直至拉萨。

在昆仑山脉，坐落着世界上最长的高原冻土隧道—全长 1686 米。距昆仑山隧道 50 公里处，是另一座雄伟的建筑—清水河大桥，全长 11.7 公里，是全线最长的桥。在于河上建造如此长的大桥的原因是：可减少冻土对道床的影响；同时为野生动物开辟迁徙通道。

另一山脉是风火山。穿过该山脉、全长 1338 米的风火山隧道，海拔 4905 米，是世界海拔最高的冻土隧道。下一个重要的站点具有相当重大的意义，尤其对于中国人而言。沱沱河车站是建在长江的源头，海拔 4533 米。河面上的铁路桥被称为“长江第一桥”。过了长江的源头河，铁轨来到整个旅途的最高点—唐古拉山脉。唐古拉站海拔 5068 米，是世界上海拔最高的火车站。跨越唐古拉山口的铁路最高海拔达到 5072 米，是世界海拔最高的路轨。

经过唐古拉山后，铁轨略微下降，但仍有多公里保持海拔 4500 米以上。铁轨临近一个天然湖泊—错那湖，甚至在湖边有一个车站，海拔 4594 米，海拔 4703 米的安多工务段是世界海拔最高的铁路线路维修站。

自离开格尔木后的第一个大镇是那曲，距离格尔木 818 公里，海拔 4512 米。这里的生活似乎更加“接近文明世界”，有稳定的水电供应和一家医院，可治疗严重的高原反应症。

在拉萨市近郊，铁轨线开始下降，并通过一座有三道洁白钢拱的优美大桥—拉萨河大桥。拉萨站是一个标志性的建筑，拥有各种现代化设施。中国铁道部计划拓展西藏铁路网，5 年内建成西至日喀则、东至林芝的铁路分支。

笔者很高兴与学会成员及所有读者一同分享此次搭乘世界海拔最高铁路的宝贵经验，并向他们强烈推荐这难以忘怀之旅。

作者：龍鎮邦, FIRSE, 香港
关于青藏铁路的部分技术及操作数据

总长度：
1956 公里 (西宁至格尔木 814 公里, 格尔木至拉萨 1142 公里)

竣工年份：
西宁至格尔木－1984 年, 格尔木至拉萨－2005 年 10 月

新建路段开通运营时间：
2006 年 7 月 1 日

新建路段投资总额：
250 亿元

新建路段站点总数：
45 个(其中 38 个是无人操作点)

经过海拔 4000 米以上线路长度：
958 公里

经过多年冻土区线路长度：
550 公里

翻越唐古拉山的铁路最高点海拔：
5072 米

桥梁总长度：
159.9 公里

隧道总长度：
9.5 公里

列车时速：
100-120 公里／时

拉萨站现行客车车次：

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<td>隔日</td>
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<td>隔日</td>
<td>1168 元</td>
<td>49 小时</td>
</tr>
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青藏铁路—个人经历

作者：龍鎮邦, FIRSE, 香港

[ 在之前的文章“一次特殊的铁路之旅”中，作者描述了青藏铁路的技术和操作特点。这篇文章里，他将与读者一同分享他乘火车从拉萨到西宁的 24 小时中所体会到的亲身经历。]

7 月一个晴朗的早晨，我们（妻子和我，与另一退休的铁路线路工程师和他的妻子）在拉萨酒店醒来，带着极大的热忱，踏上了期待已久的青藏铁路之旅。

我们的列车将于上午 10 时 45 分从拉萨站开出。我们 10 点前到达车站，在等车的空闲时间里观看了车站前院，并拍摄了一些照片。拉萨站是一个现代化的建筑，但具备浓郁的西藏民族风情。站内的车次显示屏引起了我的特别注意。它有 8 行，最上面的 4 行是中文简体信息，包括车次、始发站、抵达时间和是否晚点信息。底部 4 行是以藏文显示相同的内容。我想，这可能是世上唯一能显示藏文的车次显示屏。（参见照片 1）

走入候车大厅，我们注意到内部宽敞、明亮，天花板很高。楼上提供等候休息室。火车进站后开始检票后，我们越过站台上方的人行天桥，登上列车。从天桥上可以看到所有的站台和轨道。作为第一期建设阶段，该站目前有 4 条客运轨道和 2 个站台。尚有足够的空间再建设 3 条轨道和 1 个站台。

在站台上，我们见到了身穿整洁制服、面带微笑的乘务员们，他们引导我们进入正确的车厢。我们进入其中的一个软卧车厢。现在每趟列车只有 2 个软卧车厢，每个车厢容纳 32 人（8 间×4 人）。多亏我们旅行社的良好关系，我们幸运地成为这 64 人中的一员。

我们仍然有时间空余，于是沿着站台北走，去看看这列机车。它的动力车头是一对柴油机车头，编号 0061 和 0064。司机给了我们一个友好的微笑，我们毫不犹豫地告诉他：我们也是“铁路人”。列车开往重庆，但我们在中途—西宁站下车。

在隔间安顿下来后，我发现这里的设施非常齐全。每个铺位都有液晶电视、阅读灯、衣架和供氧接口。我的供氧接口有点问题，但还好它是
不断向外漏氧，即使没有插入供氧管。所以，我绝不会发生任何高原反应！（参见照片 3）

上午 10 时 45 分，火车准时开出了车站。列车开动时，我注意到邻近站台上方的一条写有中文和藏文的横幅，以庆祝青藏铁路通车一周年。

我们有许多时间去参观车厢设施。软卧车厢里的盥洗室都很干净，没有中国公厕通常带有的异味。我们走进餐车，这是很宽敞，桌椅整齐地摆放着。不过我们没有在那里用餐，因为乘务员将食物送到了隔间。我们还去看了硬卧车厢(每个隔间有 6 个床位) 和硬座车厢(2×2 的相对座位)。总体而言，整个列车相当整洁和有序。这将是我们未来 24 小时的家。

列车驶出拉萨，沿途风景在改变了。大片的草原一直延绵到远处的山脉，中间有一些小湖泊和河流，很少有人类定居的迹象。一路上我们通过了许多小站，但都没有停留。我们只是看到一些简单的单边站台、小型车站厅和设备室。我们也经常看到无线电发射站的高信号杆。

那天唯一停靠的车站是那曲，距离拉萨约 324 公里。由于该站只是停靠几分钟，我们没有被允许下车。从车窗向外望，可以看

到一个宽阔的站台，站台后是大型车站大楼和一个大面积的货运场。鲜红的高架龙门起重机自豪地驻立在阳光下，但货运场似乎很荒凉。也许它是计划在未来 50 年使用吧。（参见照片 4）

必须指出的是，在车厢内不容易看到任何的铁路构造，如高架道路、桥梁或隧道。列车经过会车线时，是唯一能看到邻近轨道的时候，而沿线却有相当多的会车线。我们乘坐的列车连续地与从反方向驰来的列火车擦身而过。忙的时候达到了一小时两次。列车平稳地通过了整条铁路线的最高点，海拔 5072 米的唐古拉山口。由于在我的铺位上方的供氧接口漏氧，我没有任何高原反应。

经过大约 10 个小时的旅程，黄昏来临。随着列车沿弯曲的轨道拐过一个大弯时，可以很清楚地看到风火山隧道口（参见照片 5）。穿过隧道后，我们靠着舒适的床，欣赏着远处山脉的绚烂夕阳，开始享受火车里的娱乐设施。上映的电影可能听起来没什么吸引力——第一频道“铁达尼号”，第二频道“哈利波特”……但在海拔 4000 米的影院，你能有更多期望吗！

午夜时分火车停在了格尔木站。从窗口望去，我们看到了一个繁忙的车站，即使是午夜时间。在该站停了约 30 分钟，大概是为了让火车的机械做修补供应吧。我睡得很好，并在六个小时后醒来，正好赶上地上行车的日出。早餐和平常一样是面条和粥。随后，我们开始准备在西宁下车。

列车于 10 时 37 分抵达西宁火车站，比预期的 24 小时到站时间提早了 8 分钟。当我们沐浴着早晨温暖的阳光，漫步在西宁车站繁忙的站台上，心中充满了对这次生命中美妙铁路之旅的回忆——一趟 23 小时 52 分钟的旅行，一个数十年的梦。
Just beyond the down platform at Crouch Hill station, on the Tottenham and Hampstead line between Gospel Oak and Tottenham in North London, is the location of our featured signal. A three aspect colour light, it is Harringay Park Junction's Down Home, worked by lever NO.3. Yes, Harringay Park Junction is one of a handful of mechanical signal boxes that survive in the London area - and is a youngster too. Dating from 1959, it has a 25 lever Railway Signal Company - Great Northern style frame, was built by the Eastern Region of British Railways and works a combination of Absolute Block and Track Circuit Block to Upper Holloway, South Tottenham and Kings Cross.

Signal No.3 acts as the junction signal directing along the main line towards Tottenham or via a single line curve to the East Coast Main Line at Harringay. One lever selects aspects for both of the two routes. Crown Hill Tunnel intervenes between the signal and the junction. The three aspect head is offset to the right of the main post whilst the position 1 junction route indicator is mounted directly on top of the main post. For the divergence the signal is slotted by Kings Cross (KC409).

(photos: JD Francis)
Happy Birthday!

Our best wishes to the following IRSE (HK Section) members.

KO KWOK KEUNG  高國強  2-Mar
LEE KIN SANG  李建生  2-Mar
CHAN TZE TSUN  陳子全  3-Mar
KWOK KING CHEUNG  郭景祥  3-Mar
SIN NGAI YUEN  冼藝源  4-Mar
LAU YING CHI  劉英慈  7-Mar
LAU YUK LEUNG  劉旭亮  12-Mar
CHI TAK FAI  池德輝  13-Mar
WONG CHUN YU  王錦宇  14-Mar
LEE KAI CHUN  李開駿  17-Mar
CHAN KIN HUNG  陳健雄  18-Mar
WONG YIU WAH  黃耀華  19-Mar
KWAN CHI HO  關志豪  22-Mar
YAM KONG  任江  25-Mar
YUEN KANG WING  袁鑑榮  27-Mar
CHENG HONG YIP  鄭康耀  27-Mar
YEUNG SIU POR  楊少波  27-Mar
HUNG HO MAN  熊浩民  29-Mar
KWOK FUNG LOK  郭逢樂  31-Mar
TAM WING HUNG  譚永鴻  31-Mar

LEE KAM KEUNG  李錦強  2-Apr
LEE YIU FAI  李耀輝  3-Apr
CHAN KWAI CHUEN  陳貴泉  5-Apr
WONG MAN HAU  黃民厚  6-Apr
MAK YAU CHEUNG  彭友祥  8-Apr
WONG MAN HEI  黃文$wp  9-Apr
LUK WAI LEUNG, GARY  陸偉良  13-Apr
CHEUNG CHUN MAN  張俊敏  14-Apr
LEUNG AH WAH  梁雅華  14-Apr
LI MAN FAI  李文輝  15-Apr
LAU HING CHUEN  劉慶泉  17-Apr
LEE KING KEUNG  李景強  18-Apr
WONG WING LIM  黃永廉  18-Apr
LI KIN MAN  李健明  19-Apr
CHOI TZE HA  蔡紫霞  19-Apr
WONG SIU TONG  黃兆榮  22-Apr
LAM TIN SANG  林天生  23-Apr
CHENG SIU PAN  鄭少斌  28-Apr
KONG TSZ FAI  江子輝  30-Apr
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Editor
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