



# STRATEGIES FOR RE-SIGNALLING METRO LINES COMPARED TO SIGNALLING NEW LINES, USING THE LONDON UNDERGROUND VICTORIA LINE AS AN EXAMPLE

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## SUMMARY

For many years the rapid worldwide expansion in urban transport systems has led to the requirement for new signalling systems to be provided for green-field sites. Entire systems have been developed with an integrated approach to civil engineering, permanent way, electrification, provision of rolling stock, signalling, train control, train supervision and operation.

Now however the emphasis is changing, and there is an increasing demand for signalling, train control and train supervision systems to upgrade existing, running, railways. These upgrades have to be carried out with minimum disruption to the railway service – often within Engineering Hours only.

Nowhere is this trend more apparent than in the Asia Pacific region.

A European example of such migration is Westinghouse Rail Systems' resignalling of the London Underground Victoria Line for Bombardier Transportation on behalf of Metronet Rail BCV. This involves the upgrade of the existing railway from the 1960s generation ATP and ATO systems to a fully featured communications based solution by 2009.

## 1 INTRODUCTION

**“Strategy”, noun, a detailed plan for achieving success in situations such as war, politics, business, industry or sport, or the skill of planning for such situations.**

The period from the late 1960s through to today has seen an enormous expansion in the number of Mass Transit systems worldwide, particularly in the rapidly growing economies of the Asia-Pacific Region. The majority of these metro systems have been constructed as completely new-build railways, allowing the adoption of integrated approaches to civil engineering, permanent way, electrification, provision of rolling stock, signalling, train control, train supervision and operation.

Contractors, Consultants and Railway Authorities have become expert in using construction management techniques in order to develop these systems in very short timescales, often incorporating and commissioning completely new forms of signalling, train control and traction technology as the projects have proceeded. The result has been a rapid expansion in system capability, and the evolution of extremely high-ridership, high performance railways.



Figure 1 - New Bombardier Rolling Stock for Victoria Line

The first generation of these railways has now matured, and has been at the vanguard of the new requirement for upgraded operation – Hong Kong being a prime example with the original code-based system being replaced by SACEM.

The trickle of railways requiring upgrades for a variety of reasons has now become a flood, and railway suppliers and authorities worldwide increasingly need to deal with the requirements of metros where signalling and train control has to be upgraded – without stopping the running railway.

## 2 DRIVERS FOR CHANGE

There are a number of prime drivers for the requirement for upgrading these existing railways. These include:

### 2.1 Performance

Many mass transit railways, particularly those in the Asia-Pacific region, have become victims of their own success, with ridership increasing beyond the original projections of the developers at the railways' inception. These railway systems offer frequent, reliable and quick transport within urban areas, and have in themselves fuelled rapid economic development, pulling in increased populations as urbanisation continues apace.

Quick fix solutions such as timetabling additional trains into the service have been successful to a degree, however doing this reduces recovery margins as Operational Headway approaches Signalling Headway, and system perturbations rapidly accelerate into significant service disruptions.

Successive generations of technology from analogue train control systems, through track-code based systems to the latest Communications Based Train Control (CBTC) systems have allowed increases in train density, although not always by as much as claimed by some manufacturers, and offer potential increases in the use of existing infrastructure.

### 2.2 Obsolescence

Railways built in the 1970s, 1980s and 1990s generally exploited each generation of new technology as it became available. For example Hong Kong MTR opened with an analogue track-based Automatic Train Protection (ATP) system and a digital Automatic Train Operation (ATO) system, Singapore Metro's North-South line followed it with a digital ATP and a digital ATO system, and more recent systems have exploited advances in computer technology to provide more and more processing power in smaller and smaller packages.

However, the design of systems using these components were not future-proof. 20 years ago processors operating at 1MHz, and with 16K Bytes of memory were seen as state of the art, whereas now the average desktop PC is operating with 1,000 times the clock speed and typically 10,000 times the memory availability.

Figure 2 shows an example of this, the Programme Machines from the 1960s which perform the local Automatic Train Supervision System functionality, which will be replaced by computer based technology under the Victoria Line project.

Components and subsystems that were readily available at the time of system design have become unavailable, and in the majority of cases no pin-compatible replacement has been developed. In an industry where microprocessors have rapidly become standard building blocks there have been

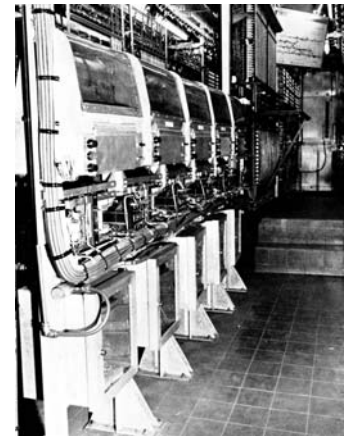


Figure 2 – Victoria Line Programme Machines - 1960s ATS Technology

additional human resource-related issues as people skilled in producing high integrity software using specific languages and components become scarce, forcing costs and therefore prices up.

Although the majority of contracts for original equipment supply did mandate a period of equipment support, typically 20 years, in many cases this period has now elapsed, and the costs of managing obsolescence – even with the most responsible and supportive of suppliers – has risen dramatically.

A clearly related issue is reliability – as parts age failure rates increase as the bathtub curve of reliability starts to enter its final stage. Not only is it more difficult to obtain spare parts to replace failed components, but staff skills change over time, resulting in increased Mean Times to Repair.

### 2.3 Changing Standards

A more subtle issue is that of changing views on requirements for Reliability, Availability, Safety and Maintainability as time progresses.

The majority of the railway community is now well aware of the CENELEC series of standards derived from IEC61508, specifically EN50126, EN50128 and EN50129, and equivalents from other markets. 20 years ago the idea of System Integrity Level was only just evolving, and requirements for Mean Time Between Wrong Side Failures were very different compared to today.

Learning lessons from other industries, particularly defence and aerospace, the railway signalling industry has rapidly gained skills in the use of microelectronics in safety critical applications. Diversity is at the heart of all current electronic interlocking and ATP technology, and high quality systems analysis and software production is very important.

Similarly higher degrees of reliability, and related to this availability and maintainability, are demanded compared to two or three decades ago. Particularly with increased ridership increasing the degree of crowding on trains – often compounded by railways operating in hostile environments – stopping trains in service is not acceptable.

In a world where delays to service can frequently result in a financial penalty from regulatory authorities, such issues can quickly add to the business case for system replacement.

## 2.4 Technology Improvements

There are a number of other well understood advantages of moving to newer technologies, these are not dealt with in depth in this paper, but they do include:

- **Reduced space envelope** – in the majority of cases, although when replacing non-duplicated systems with redundant systems this advantage may be somewhat eroded. When Computer Based Interlockings are replacing Relay Interlockings however this advantage is particularly pronounced.
- **Increased maintainability** – the provision of extensive logging and diagnostics facilities are generally a standard provision across most modern manufacturers' ranges.
- **Increased communication capability** – particularly the provision of network communication capabilities for interlockings and Control Centres, allowing for simpler and higher performance relating to passing information around the signalling and train control system.

## 3 ISSUES RELATED TO UPGRADE

Having decided that an upgrade is necessary is only the beginning of the story. There are a number of very significant issues involved in upgrading running railways, and a number of contractors have learnt these lessons through hard won experience. In the case of Westinghouse Rail Systems Ltd, experience of upgrading the London Underground Central Line, Oslo Metro and replacing the Automatic Train Supervision System of Singapore MRT, have been invaluable in planning for major upgrade projects on metros.

There are basically three options for migration which must be considered in all of these cases. Regardless of whether interlocking replacement is required, if it is necessary to upgrade from an existing ATP system to a new system, whilst retaining full protection of the railway, then there are only really three alternatives:

- Dual fit trackside so that trains fitted with either new or old ATP systems can continue to operate under full signalling protection.
- Dual fit train-carried equipment on all vehicles so that sections can be upgraded on a piecewise basis.
- Shut down the railway, or operate it under special operating rules without ATP, replace all ATP equipment.

Similar scenarios exist for Interlocking and Control System replacement.

### 3.1 'Keeping The Railway Running'

There are very few railways in the world where it is possible to carry out work whilst trains are still running. New York City Transit has up to four lines over certain sections which permits segregation of trackside work and train running – and incidentally 24 hour service! Other lines permit fully bidirectional working, allowing single line working to take place during off-peak periods. Some Northern European metros can support shut-downs for a number of weeks during summertime when ridership falls considerably.

However it is hard to imagine many of the high density Asia Pacific railways shutting completely whilst signalling and train control upgrade work is put into place. All that is therefore available is 'Engineering Hours' working, and potentially a number of short, probably weekend, shutdowns.

In many cases this equates to no more than 3 to 4 hours of 'wheels-free' access per night. It is also necessary to support normal maintenance activities during these same periods, so careful planning is necessary in order to allow the Civil and Electrification Engineers access to the railway without affecting the upgrade programme.

Furthermore it will normally be necessary to stage migration from existing signalling and train control systems to new systems. It may be possible to dual fit all of the trains prior to commissioning new train control, but this is very rare – as described in section 3.2 below. It is therefore inevitable that new and old systems must therefore either interact, or only one of them is selected. **In either case it is paramount to ensure that the work carried out cannot affect the safety or reliability of the existing railway system.**

These issues can significantly extend the time required for a signalling or train-control upgrade.

### 3.2 Space

Although rarely considered at early stages of planning upgrades, the availability of space in relay rooms, trackside and on the train is a critical

issue for the smooth migration from old to new systems.

If dual-fitting of equipment rooms is required, then space within these rooms is of critical importance. If interlockings are to be replaced, then in the majority of cases the new interlockings will be



Figure 3 - Original Victoria Line Autodriver Box Installation

smaller than those that they replace. However unless a 'blockade' approach is to be adopted, then it is normally necessary to have old and new equipment in the same location – or nearby. Even if interlocking replacement is not required, then the new ATP system has to be situated close to the existing system. Particularly on underground railways space is severely restricted. It may be possible to use temporary equipment rooms – perhaps in enclosures on platforms or other station voids, but the amount of rework required during later stageworks must clearly be minimised. Modern technology allows significant amounts of the new equipment to be located away from the old equipment – for example at street level, but there are restrictions to cable runs and so on.

If dual fitting of train carried equipment is required the problem is magnified significantly. It is inevitably difficult to find alternative locations for the additional equipment needed – indeed as Figure 3 demonstrates, space was often at a premium in original train carried installations. A number of solutions are capable of reading both old and new ATP systems, but this is rarely a cost-effective solution since, in effect, two ATP systems have to be designed, verified and validated. It is more common to seek a way of fitting both old and new equipment to trains – and this may involve fitting equipment under the vehicle, under

passenger seats, or in vestibule areas. In any case the danger is that passenger space is restricted during the migration period.

### 3.3 Flexibility Of Equipment Permitting Upgrade – Overlay Capability

The approach adopted to migration is clearly influenced by the solutions available to the supplier. As demonstrated in the Victoria Line Case Study given below, WRSL has found that the enormous flexibility of our WESTRACE interlocking product has been the key to our outstanding ability to deliver upgrades on running railways.

Vital processing and ATP systems that can take information from existing systems and pass it to new systems offer an upgrade strategy that reduces risk considerably. Existing interlockings and associated ATP can be retained until stageworks reach the point that all equipment associated with existing ATP systems can be removed.

Increasingly suppliers, including WRSL, offer CBTC systems which use radio systems which can be installed without affecting existing systems, allowing a staged upgrade to take place.

Electromagnetic Compatibility is clearly a key issue, and with a number of systems fitted to both trains and trackside, detailed victim-threat analysis is essential to avoid reductions in system reliability – or potentially even safety.

We consider that this ability to 'Overlay' new systems over existing is of critical importance to the migration process, and we also believe that having a system whereby existing systems are retained in use with a straightforward path to new equipment is essential to manage the risks associated with these major projects.

It is also WRSL's experience that the way to ensure that this flexibility can be delivered is through a modular approach to all subsystems. To that end our WESTRACE interlockings, TBS100 CBTC system and WESTCAD are all designed to be highly modular – in terms of hardware, software and data. This approach allows stageworks to be supported in a low risk, highly efficient way, with functionality being changed through simple software or hardware changes.

WRSL's familiarity with a number of different systems has demonstrated the immense advantages (in terms of both flexibility and future-proofing systems) of using a modular architecture.

In the majority of cases the flexibility of systems being provided needs to be managed in order to guarantee that at any stage of work there is a fallback situation available, so that if all work planned cannot be delivered within the

programmed timescale, the railway can be returned to the operator on time, with the required level of functionality and performance – albeit with more work required during the next work period.

### 3.4 System Assurance Issues

System Assurance is at the heart of acceptance of modern signalling system upgrades, and one of the most important elements of the project to get right. When delivering a railway to a green-field site the Safety Case need only be produced for the final solution. When delivering a railway extension then the interfaces are limited to the point of interface to the existing system – usually restricted to one physical interface. However, when delivering an upgrade to a running railway, it is necessary to maintain the validity of the Railway Safety Case at every stage of the upgrade. Any degradation in safety is completely unacceptable.

It is therefore necessary to involve the System Assurance team from the very start of the planning process. Analysis of the way in which new systems are connected to, or may interfere with, existing systems is required.

In general it is necessary to build up the Safety Case through a process of verifying and validating each step of migration - both through analysis and testing. In our experience this generally means testing of each migratory step in engineering hours running, with only one train in operation, leading up to engineering hours running with multiple trains in operation, gaining confidence in successful operation before moving on to in-service running of an increasing population of new equipment.

### 3.5 Changing Contract Models

There is also an increasing movement, especially in Europe, towards new Contracting Models including Public Private Partnerships (PPP) and Private Finance Initiatives (PFI) – an example being given in the Case Study in Section 4.

This often moves the emphasis onto measurement of performance rather than the delivery of specific technical milestones. This can significantly alter the way in which migration is delivered.

## 4 CASE STUDY – RESIGNALLING THE LONDON UNDERGROUND VICTORIA LINE

One of the prime examples of a project in which migration is critical is also one of the largest railway signalling upgrade projects undertaken to date – this being the resignalling and provision of Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) for the Victoria, Metropolitan, Hammersmith & City, Circle and District Lines of the London

Underground. Westinghouse Rail Systems Ltd has contracted to deliver these systems to Bombardier Transportation, as a significant part of Metronet's plans for the improvement of the parts of London Underground infrastructure under their control.

Whilst many contracts that WRSL has delivered before have had an element of performance related penalties contained within them, these contracts for Bombardier and Metronet reflect the wide range of penalties that Metronet Rail may incur through non-provision of availability, performance and functionality. There is therefore an added incentive for WRSL to ensure that work is carried out in such a way as to absolutely minimise disruption to service.

Experience gained from similar projects has led WRSL and its sister companies within Invensys Rail Systems to develop signalling sub-systems which are ideally suited to these upgrade projects. Prime amongst these are:

- TBS100 ATP and ATO
- WESTRACE interlockings
- And WESTCAD control centre solutions.

Each of these systems has been developed to allow a great deal of flexibility of application, whilst maintaining the highest standards of safety and availability.

### 4.1 Starting Point

The Victoria Line is currently equipped with a system which, with some modifications throughout its life, is the same as that with which it opened in 1968. Key elements are:

- Electro-pneumatic interlockings and points machines
- Simple track-code based ATP system and track loop based ATO system
- Track circuited throughout
- Programme Machines and simple control centre.

### 4.2 Final Solution

When Metronet's planned upgrades are complete, key features of the Victoria Line will include:

- New Rolling Stock supplied by Bombardier Transportation
- WESTRACE Computer Based interlockings throughout
- High capacity, high availability TBS100 train control systems including
  - Comprehensive, radio based ATP

- Full ATO for new rolling stock provided on these lines
- State-of-the Art WESTCAD Control Centres

### 4.3 Migration Strategy – ATP and ATO

Due to space limitations at the single depot for the line, at Northumberland Park in north London, it is not possible to stable both old and new fleets at the same time. Space on the trains is limited as a result of maximising passenger space, and therefore a decision was taken to fit new rolling stock with the new ATP system and ATO system, retain the existing ATP and ATO systems on the existing trains, and to dual-fit the trackside system until the last old train is removed and only new trains are in service.

This choice had to be made early on in the process how to manage this change. Options were:

- To dual fit old trains by adding the new ATP and ATO systems.
- To dual fit new trains by adding the old ATP and ATO systems.
- To dual fit the trackside so that old trains can use the old ATP and ATO, and new trains can use the new ATP and ATO.

The life-expired nature of the existing equipment made this decision quite straightforward, and as a result an overlay ATP / ATO solution was required.

#### 4.3.1 Product Solution

The product that WRSL is applying to allow this overlay migration strategy to be implemented is the Invensys Rail Systems CBTC ATP and ATO platform, TBS100. In this application signalling information related to block proceed and block



Figure 4 - One ATP Lane of TBS100 Train Carried Equipment

occupation is taken from the interlockings, and broadcast to all trains via a commercial radio system.

The same modules may be used to construct all ATP and ATO subsystems, both trackside and train-carried, resulting in enormous flexibility. TBS100 has previously been applied

extensively in Spain providing full ATP and ATO functionality on much of Madrid Metro, and part of the Barcelona Metro. TBS100 also provides Correct Side Door Enable line-wide, and Platform Edge Door functionality for the Jubilee Line Extension in London. Other projects using TBS100 include Manila and Beijing.

WESTRACE vital processing equipment is used as the enabling technology for the migration method adopted. In the overlay solution WESTRACE is installed close to the existing interlockings. It is used as a vital parallel to serial conversion medium, taking parallel outputs from the existing electro-pneumatic interlockings and converting these into serial messages to be used by the ATP Block Processor. This in turn passes a broadcast message to all trains through the radio system. A typical WESTRACE installation is shown in Figure 5, and a single lane of TBS100 in Figure 4.



Figure 5 - WESTRACE Vital Processor Technology

Communication back from the trains is used for a variety of purposes.

When all new trains have been delivered, and old trains removed, the WESTRACE is commissioned into use as a full interlocking, and the existing interlocking, ATP and ATO systems are removed.

#### 4.3.2 Migration Method

Having gained this understanding of the system solution, the way in which overlay can take place can be seen to be quite simple.

The work necessary to allow new trains to operate will be carried out in non-traffic hours. It will be necessary to carry out the following work:

In the equipment rooms:

- Install WESTRACE equipment to interface between the Interlocking Machines and the ATP system.
- Install ATP Block Processors and fixed radio equipment

Trackside:

- Install the leaky feeder radio equipment
- Install Absolute Position Reference (APR) beacons

It is possible to carry out this work in more or less any order, however in order to facilitate train testing, the first commissioning work will be carried out at the northern end of the Victoria Line in order to have a section of line close to the depot completed so that train running and integration testing can be executed as early in the process as possible. To this end much testing will be carried out on Bombardier Transportation's test track at their Derby works.

Once this initial section has been installed, tested and commissioned, work is planned to take place in such a way that the more major installations are not carried out until all simpler works are complete, as part of the risk mitigation process.

#### 4.3.3 Train Testing

Train testing will of course have to be carried out in a staged manner, in order to allow all verification and validation works to be carried out in the manner dictated by the safety approval process.

This will involve running new trains over increasingly greater areas of the railway in the following sequence:

- Train testing on the Derby Test Track
- One train in non-traffic hours.
- Multiple trains in non-traffic hours (using pre-production stock).
- One train in traffic hours.
- Multiple trains in traffic hours.

Without following this process it will not be possible to validate that the new trains and old trains, new signalling and old signalling, all work together in a safe and reliable manner. Finally the new trains are brought into passenger service.

#### 4.4 Migration Strategy – Signalling

As described above, a key part of the ATP migration involves the installation of a WESTRACE system that interfaces with the Interlocking Machine Rooms. WESTRACE is a well proven electronic interlocking system, with an outstanding record of delivery and reliability – there are currently over 1,000 WESTRACE installations in use worldwide, and a further 400 on order.

WESTRACE is completely flexible in its application. A series of modules is available which can provide a wide range of functionality. There are modules for driving relay outputs, parallel inputs, lamp outputs – specifically designed to interface with signal heads, vital and non-vital communications and so on. The systems are programmed using ladder logic in a similar way as commercial Programmable Logic Controllers (PLCs).

The strategy that has been selected is therefore to install WESTRACE systems that are capable of being upgraded during the migration phase to take over all of the functions of the existing Interlocking Machines.

The data-driven nature of WESTRACE facilitates this, since it is possible to change the overall functionality of the interlocking by a relatively simple data change, and the related testing and commissioning. The majority of testing is, in fact, carried out off-site.

The intention is therefore that at the point that the last train of 1967 stock is taken out of service, work can commence to decommission the Interlocking Machines, code selection circuitry and 1960s ATP / ATO system.

This work will be carried out over a number of weekend shutdowns, during which the WESTRACE systems will be upgraded to take full control of the railway, and then later the older equipment removed. This sounds like a huge job, but it is exactly analogous to the work carried out previously by WRSL for the upgrade of the Central Line, and the issues are well understood.

At this time, a more extensive Asset Replacement phase will also be carried out. The existing jointed track circuits will be replaced with Jointless FS2550 series track circuits, already widely in use on Underground infrastructure, and air operated point machines will be removed and replaced with electrically operated equipment. Signal heads will also be replaced with newer, low maintenance units. All of these will be commissioned at the same time to allow the completion of the signalling upgrading work.

Unlike the ATP upgrade work, this work will have to be carried out in a logical and sequential north – south fashion in order to minimise stage working, which is costly not only in time and resource, but also in terms of risk.

#### 4.5 Migration Strategy – Automatic Train Supervision

The Control Centre migration needs to be carefully phased to ensure that the new facilities and any operational changes are introduced safely and without service disruption. This work must be integrated with other elements of the overall control centre, such as train radio systems.

Installation of the new Control Centre can commence independently of the signalling installation. The Local Site Computers (LSCs) will be installed early with the WESTRACE and radio equipment. Initially the LSCs will interface to the old interlocking via the overlay WESTRACE.

Comprehensive factory testing of the Control Centre can be undertaken using system simulators

in a manner well proven during the Central Line and Singapore ATSS Upgrade projects. Correspondence testing of the installation is undertaken to prove that indications and controls are correctly mapped through to the as-built signalling.

The Control Centre can then be exercised in a limited 'Monitor' configuration with control outputs disabled. Once stability has been demonstrated, controls are enabled and an 'Over and Back' approach can then be taken to operation using the new and old Control Centres as required. At all times only one Control Centre will be controlling the railway, however, at each migration phase, progressively longer periods of operation are performed from the new Control Centre.

Once the new Control Centre is proven, the final stage of asset replacement can be undertaken with the new signalling equipment performing the full function of the interlocking. This stage enables the removal of the existing signalling and control equipment.

## **5 STRATEGIES FOR RESIGNALLING METRO LINES**

So, having discussed the drivers for change, the issues related to resignalling metro lines, and having considered a Case Study, is it possible to establish strategies for resignalling Metro lines.

It is the opinion of the authors that whilst every railway around the world is different, there are a number of common features that can facilitate the upgrade of railway signalling and train control systems. These key features include:

### **5.1 Overlay**

In order to keep the railway running, it is almost inevitable that some form of 'overlay' solution is required. In general, the movement to communications-based systems exploiting radio technology greatly assists this. WRSR has concentrated on the use of non-proprietary radio systems, and continues to do so. Being able to select any radio system from any supplier, as long as it meets basic bandwidth and protocol considerations, allows the best solution for each individual application to be selected. Whilst in some situations it may be possible to provide leaky feeder or waveguide technology, there will be other railways where such systems will not be suitable— in these situations broadcast systems can be used.

### **5.2 Modularity & Flexibility**

In order to allow for the multiple stages of such projects, it is essential to use basic building blocks of signalling and train control which are both modular and flexible. Modularity allows the

adoption of further functionality within a system as migration progresses, and flexibility in both hardware and data design is essential to ensure that every eventuality can be catered for – not least the ability to return the railway to the state it was in at the start of a commissioning period in the event of problems being encountered.

It is our particular experience that vital processor technology is the key to straightforward upgrades; WESTRACE has allowed us to make smooth migrations for a number of running railways, including the Central Line of London Underground and Oslo Metro – and it is at the heart of our work for London Underground's PPP projects. WESTRACE allows existing and new systems to co-exist in a non-intrusive way, and significantly reduces the testing overhead that would otherwise be necessary if hybrid systems were used in place of overlaid systems. The ability to choose to interface to existing interlocking technology vitally – either as a short term step on the path to full asset replacement, or as a permanent interface unit whilst interlockings which are not life expired continue in service, offers huge flexibility and significant risk reduction throughout the project lifecycle.

### **5.3 Integration of System Assurance Process**

In today's climate where Safety, quite rightly, dominates work on high density mass transit, System Assurance is a critical activity, capable of delaying system delivery purely by the inability to provide adequate proof of performance of the railway.

Following the 'V' curve laid down in the CENELEC standards is second nature to the majority of railway engineers, but this is complicated when resignalling existing lines since the interaction between existing and new railway has to be validated as being safe. The existing Safety Case has to be maintained throughout the build to guarantee the safety of the travelling public.

This is only possible if the System Assurance process is integrated fully with the design, build, install, test and operate processes. Furthermore risk may be reduced by involving client approval authorities and regulatory authorities at each stage of the project. Seeking full 'buy-in' from all of these parties is essential if a smooth, delay-free, and risk-mitigated solution is to be arrived at.

### **5.4 Flexibility of Labour and Resource Planning**

Not only is it essential that the equipment and systems to be installed are flexible, but also that the staff working on the project are appropriately skilled, flexible in their approach, and fully aware of the programme to be followed.

In terms of site work this involves detailed planning of the work to be carried out, with Method Statements agreed with the client, sub-contractors and any other parties involved well in advance of the work date. It is essential to ensure that these plans deal with contingency planning in the event of failure of any elements of installation or testing, and that detailed plans exist to return the railway to a safe operating state in a timely manner if necessary.

Schemes such as the IRSE's Licensing Scheme are useful in providing a benchmark for engineering ability and experience, and are increasingly mandated by railway authorities. In the UK for example, both Network Rail and London Underground mandate that workers dealing with Safety Critical or Mission Critical signalling and train control work hold appropriate IRSE licence categories, with appropriate logbook evidence to demonstrate relevant experience.

Management of these tasks becomes critical to the success of the entire project – the team planning the site work needs to be able to deal with situations where multiple delays occur in installation or commissioning work, to re-plan and re-programme in order to regain lost time, and to coordinate with all parties involved to ensure timely delivery.

## 6 SUMMARY AND CONCLUSIONS

In summary, the market for mass transit signalling and train control is changing from a requirement for new-build metros on green-field sites, to a requirement to resignal existing metros with state of the art signalling and train control systems.

This is particularly the case in regions like Asia-Pacific where systems installed 20 – 30 years ago have matured into densely used lines where increases in performance, safety and reliability are required – without stopping the running railway.

Problems associated with these upgrades include having to work in Engineering Hours only, with very limited wheels-free access, having to maintain contingency plans in the event of not being able to complete planned work for whatever reason, having to maintain the Railway Safety Case, and having to contend with severe space limitations on existing railways and rolling stock.

It is possible to successfully carry out upgrades of this type, WRSL, for example, has carried out such work on heavily used lines including the London Underground Central Line, with minimal disruption. Experience gained has led the company to develop highly modular and flexible system solutions, which combined with cooperative working with client companies, and comprehensive planning techniques, allow risks to be mitigated, costs to be managed, and the railway to keep running.