



INTEROPERABILITY OF ATC SYSTEMS, Hong Kong MTR EXPERIENCES

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SUMMARY

Metro systems in general are a self contained rail network. They have their own signalling systems and allow cross line train movements to facilitate operational flexibility. For younger metro systems they normally automated their operations and installed with the latest Automatic Train Control (ATC) system. Whenever they upgrade their signalling system to a new system or extend the network there are always two technical issues to address, the service level during the changeover period and system interoperability between the new system and the existing system. This paper presents the approaches adopted by Mass Transit Railway Corporation in addressing these issues in its ATC system replacement project and extending its network to Tseung Kwan O new town with a fully compatible ATC system from a different signalling equipment supplier.

1 INTRODUCTION

Hong Kong Mass Transit Railway Corporation (MTR) is a young railway. It commenced its operations 25 years ago. It was equipped with the latest ATC system available at the time. This ATC system was based on fixed block speed code control, a fully automated system only leaving door operation and starting the train in the hands of the train operator. Communication to the onboard equipment from trackside was accomplished through inductively coupled amplitude modulated signals using the rail as a transmission medium. At points and crossings transmission was based on loop running along the rail web. These modulated signals contained the speed code commands to control train movement and were conditioned by the interlocking code selection circuits based on track occupancy. By 1985 three railway lines were completed and the connection between Kwun Tong Line and Island Line through East Harbour Crossing was put into operational service in 1989. All these railway lines used the same ATC system. There was no limitation on stocks exchanges and cross line movements.

2 OPERATIONAL NEED FOR HIGHER CAPACITY ATC SYSTEM

In the late 80, the economy in Hong Kong was growing at a tremendous rate. The railway had to keep up with the pace of passenger growth and expand and upgrade

its network to meet the increasing passenger demands on efficient and fast transportation. In 1990, the Passenger Train Performance Working Group requested that studies be conducted into methods of improving service headways on Island Line and Tsuen Wan Line by enhancing or replacing the ATC systems. In order to investigate the feasibility of increasing the passenger carrying capacity, train service headway studies on all three lines Tsuen Wan Line (TWL), Island Line (ILS) and Kwun Tong Line (KTL) were conducted. The results showed that the passenger carrying capacity of the fixed block signalling system could be modified to provide 32 train paths an hour by adopting a pseudo moving block technique. However, it was noted that this would stretch the system to its maximum capacity allowing little margin, about 10 seconds, for operational disturbances and recovery after periods of disruption. Further enhancement would only be possible by replacing the fixed block system with a new generation Automatic Train Control system.

3 ASSESSMENT OF ATC SYSTEMS

The MTR carried 2.4 million passengers a day in mid 90. It accounted for approximately 25% of the total trips made in the Territory. In addition to this it has achieved a very high service standard. There was considerable demand on the MTRC to maintain this exceptionally high standard. People in Hong Kong live at a very fast pace and there is a lack of tolerance by the general public to even

minor delays on the Mass Transit Railway. When the new ATC system is phased in it needs to maintain its passenger carrying capacity and be transparent to the passengers. In considering the criticality of a major change to a safety critical and service critical metro network, MTR decided to adopt a new approach to ensure the system chosen met the performance requirements and there was no service interruption to train service during changeover. A pretender study was conducted to identify critical areas of the project. In this study it comprised five main studies: Safety Audit; Adaptation Study; Reliability and Maintenance Study; Operational Impact Study and the Performance Study. During the studies four systems were identified as suitable for the replacement of the fixed block ATC system. They were offered by Westinghouse Brakes & Signals (WBS), SEL Canada (SEL), Siemens and GEC-Alsthom.

WBS offered Westrace Fixed Block Brake Assured ATC system which was based on track codes operating principle. The system was at the final stage of development at the time of tender. It was compatible with the Fixed Block system in service and code transmission was based on FS2500 track circuit or cable loop. Migration to the new ATC system would require dual fitting of trackside equipment and complete replacement of 50Hz track circuit and CVCM track circuit with FS2500 track circuit. New ATC trains could be introduced one by one as they were converted.

SEL Canada offered Seltrac ATC system which was a communication based moving block system. Track to train and train to track transmission was based on loop. Train control rested with the Vehicle Control Centre and there was no intelligence on the Vehicle On-board Controller unit. This system did not permit mixed train operation and any non communicating train running in the control area would paralyse the system. Changeover to new ATC system could only commence when dual fitting of both trackside and onboard systems was complete.

Siemens offered LZB 700 ATC system. In this system track to train data transmission was based on FTGS track circuit which acted as a train detection device as well as data transmission medium. Migration to the new ATC system would need completely dual fitting of both new and in service trackside and onboard equipment before it could commence.

GEC Alsthom offered SACEM ATC system. It was designed as an overlay system with onboard intelligence. It operated based on stopping points and permitted various types of trains to be operated on the same track. Transmission could be rail feed or loop feed of various configurations. Migration to the new system would only need overlaying of transmission loop on the in service ATC system. New ATC trains could be introduced into service as soon as they were converted.

However, it was noted that none of these systems were backward compatible with the fixed block ATC system in service on the railway. The critical issues to be considered were then minimum modifications to the then existing equipment, easy system implementation and adaptability of the system. A system which could permit mixed train operations and not necessary interoperable with the Fixed Block ATC system was acceptable. After a detailed assessment and taking into account the impact that might have on railway operations, system performance, cost and implementation approach, GEC Alsthom SACEM system was chosen and the ATC Replacement contract was awarded in January 1994.

4 SACEM ATC SYSTEM DEVELOPMENT

The SACEM ATC system is a French product, designed to the requirements of the Paris Regional Transport Authority (RATP) as an overlay system. When conceived in the 1980's, RATP involved three contractors in the collaborative development of the system. This was to develop a system that all three contractors could implement thereby ensuring RATP had multiple suppliers. One project "RER Line A" went ahead and the system was installed in the late 1980's based on superimposed approach. Only two contractors participated in this project with one providing the trainborne equipment and the other providing the trackside equipment. RATP undertook no further projects using this technology for some years and each of the contractors moved on to other clients. To some of their clients they offered versions of the SACEM system with enhanced features. These later versions were developed in isolation and were not fully compatible with the original RATP concept.

5 MIXED TRAINS OPERATIONS DURING THE PERIOD OF

CHANGEOVER

On implementing the SACEM ATC system on the fixed block ATC system a number of options were examined. These included dual fitting of onboard systems, develop onboard system to detect the fixed block signal and overlay of the trackside transmission on the fixed block system. The first two options facilitated inter-operating trains and allowed cross-line train movements throughout the changeover period. The last one would keep the newly equipped trains captive on the line equipped with the new trackside transmission system. It was noticed that the first option required major modification of train cab to vacate space for new onboard equipment. The second option involved new development and the add-on function would only last for a couple of years before it was made redundant. On the other hand the passenger carried capacity of the fixed block system could not meet the operational demands and all railway lines would be converted to the new system in four years. After careful consideration a trackside overlaying approach was adopted. The advantages of adopting this approach were that implementation was much easier and it also allowed mixed train operations on the same track with same level of service as the fixed block system without compromising safety. In addition, this option was much more cost effective and avoided unnecessary development risk of providing a compatible fixed block system within a tight project timescale. The main disadvantages of this option were cable loops running all the way from one end of the line to the other end and large beacons placed within the 4-foot way. Damages to cable loops may occur during track maintenance if it is not properly supervised. Large object on the 4-foot poses problem of train evacuation with the detrainment ramp landing on it if the train so happens stopping just before the beacon.

6 SYSTEM INCOMPATIBILITY

In the pre-tender studies it highlighted that there were areas of incompatibility between SACEM system and the then existing fixed block ATC system. However, all these concerns were technically manageable and solutions available. They are:

- High magnitude of currents in FS2500 track circuit tuning area - this was resolved by replacing the track circuit in advance of new ATC system operation.
- Electromagnetic Interference to fixed block Automatic Train Protection (ATP)

and Automatic Train Operation (ATO) signals - by using of B0 loop track-to-train transmission it avoided using the same transmission medium, the rail, as the fixed block system. It also prevented signals being picked up by the fixed block system antenna. On the other hand device operating frequencies are chosen such that they were away from the fixed block ATP and ATO operating frequencies.

- Overlap track/s for ghost signals on Island Line - modifying the trackside software to avoid running the train into the overlap protection zone.
- Immunity to fixed block ATP/ATO signals – vertical antennae were used. It was insensitive to magnetic field generated by rail currents.
- Interference to the train radio system by beacon harmonic frequencies – increase the radio signal's signal to noise ratio.

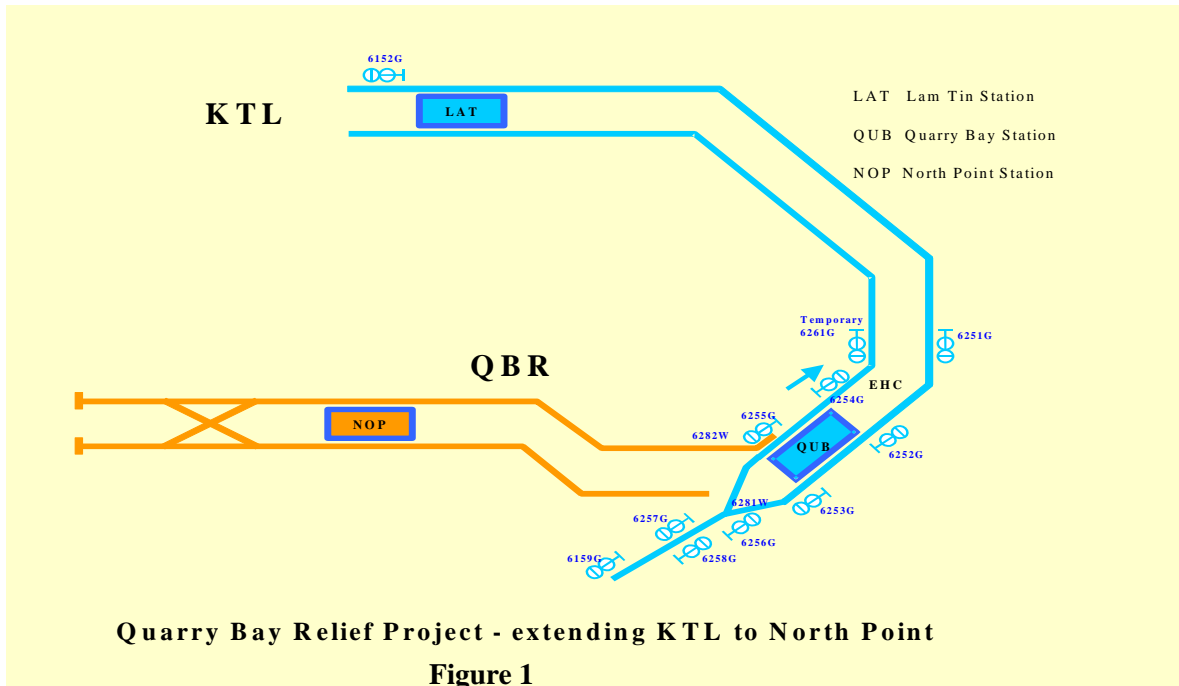
Two and a half years into the project the first SACEM equipped train was put into operational service on Tsuen Wan Line and mixed train operations was successfully introduced on the railway. There were no incompatibilities found with the fixed block ATC system and other systems such as Rolling Stock, Traction Supply, Main Control and Telecommunication systems since operation. It proved that the pre-tender studies had led to an increased understanding of the work involved by both the contractor and the MTR. Cost estimates have been much more accurate. Post contract safety management and demonstration tests were the continuation of the pre-contract studies. It ensured that the correct approaches and methodologies were used throughout. The efforts spent on pre-tender studies and post contract management was worthwhile and the project objectives were achieved.

7 REQUIREMENT OF INTER-OPERABILITY FOR THE NEW EXTENSION

In 1997 the Quarry Bay Relief Project (QBR) went ahead. The purpose of this work was to alleviate the passenger congestion at Quarry Bay station by extending the Kwun Tong Line (KTL) by one further station to North Point as shown in Figure 1. The QBR signalling contract included the provision of a fully compatible ATC system with interlocking system to the Urban Line (URL)

system. As this was a relatively small contract comprising only one new station with the connecting tunnels to the Quarry Bay Station it was awarded to the same equipment supplier through the process of contract negotiation. It was seen that as time progressed the contractor who was the sole equipment supplier was unable to provide a system in a reasonable timescale

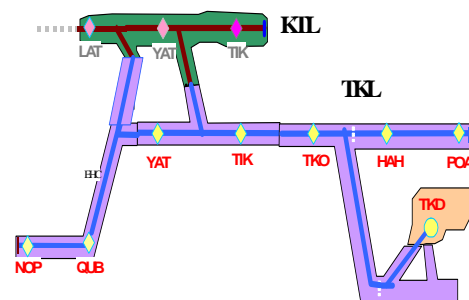
at the East Harbour Crossing and one at Lam Tin Station. Figure 2 below shows the line configuration. This therefore required an inter-operable system, which could either be a compatible system or a dual system operation configuration, allowing existing trains to move onto the new extension in a continuous uninterrupted operation. Likewise, the new rolling stock for the TKL would be required to operate on the existing



and at an acceptable cost.

lines in the same manner.

In 1996, in response to the Hong Kong Government's invitation to extend the MTR network to the new towns being developed in the eastern part of the Kowloon peninsula, the MTR put forward a technical proposal for the Tseung Kwan O extension. This new extension would stretch from a new station, Po Lam, in Tseung Kwan O new town, pass through four other new stations and connect to the existing Eastern Harbour Crossing on the Kwun Tong Line. In addition to this new line, a new branch line would divert the existing Kwun Tong Line from Lam Tin Station to the new Tiu Keng Leng station. When the decision was made in 1997 to proceed with the new Tseung Kwan O Line (TKL), it was decided to introduce competition for ATC system in order to ensure competitive prices. The MTR took this opportunity to seek alternative suppliers for the provision of the signalling system for TKL in order to reduce their dependence on a single supplier. However, this extension could not be a standalone railway line as it would connect to the existing KTL via two connections, one



8 PRE-TENDER INTER-OPERABILITY STUDIES

Underlying the operational need for an inter-operable system for this new extension there lay sophisticated technology involved in the new ATC system and the interfaces with it on both the new extension and the

existing lines. In late 1997, a working group was set up within MTR to look into the best way of achieving a practical and cost effective implementation of the signalling system on TKL. Different alternatives were looked into and four options were considered in detail. These were

- A compatible system;
- A dual system operation (both new and old systems in operation with switch over at cross system boundary);
- A completely new system;
- The same ATC system as used on the Urban Line (URL).

After detailed consideration it was decided that a compatible system would be most appropriate in terms of tendering / commercial advantages, operational consistency, project cost, system inter-operability and stock manoeuvrability. It was decided that the best way to realise these objectives and achieve the inter-operability requirements would be to return to the approach adopted by RATP when they first developed the SACEM system in the 1980's. A plan was drawn up to manage the system inter-operability issues. This included pre-tender studies and post contract award management. For the pre-tender studies, it was decided to invite all three contractors who were originally involved in the RATP project as paid consultants to the inter-operability studies. The study started in the second quarter of 1998 and was completed by the end of the third quarter of the same year. It mainly looked into the following critical components of system interoperability.

- Identify system cross compatibility elements;
- Estimate the scale of development work required;
- The risk associated with full compatibility;
- Develop outline system designs;
- Identify interface requirements with new and in-service rolling stock, and other sub-systems and equipment;
- Estimate the time-scale to deliver the complete system.

The studies concluded by the consultants confirmed that:

- A compatible system could be provided;
- New functions and interface developments could be managed within the project time-scale;
- Work could be completed as required by the TKL project schedule.

A technical specification was prepared based on the consultancy reports and the qualifications they contained. This was put out to open tender for the Tseung Kwan O Signalling Works. In June 1999 SIEMENS TRANSPORT SYSTEMS (France) - formerly MATRA TRANSPORT INTERNATIONAL MATRA came out as the winner from three tenderers. The award was based on the contractor's experience and proven capabilities in design, development, manufacture, installation, test and commissioning of similar systems. In addition to technical competence, the proposals for changeover management and the impact on train operations during the changeover, development of interfaces with other systems and the total project cost including MTR in-house costs were all taken into consideration in the tender assessment. The contract price for the work was significantly less per station and per kilometre of track than the Quarry Bay Relief Project. This massive saving in cost was proof positive that the procurement strategy was sound. On the technical aspects, the proposal showed a good understanding of the critical elements needed to achieve system cross compatibility. The following approach was adopted in the development of the new system:

- Same functional principles, based on the same application software;
- Same hardware architecture, and identical data transmission format and protocols between trainborne and trackside sub-systems;
- Same vital principles based on coded mono-processor;
- Short software development time based on B Method and using B tools to translate mathematical models into codes;
- Engineers involved in the original SACEM development would participate in the project.

9 POST-CONTRACT AWARD INTER-OPERABILITY MANAGEMENT

The post-contract award inter-operability management contains technical inter-operability demonstration tests and inter-operability analysis aspects.

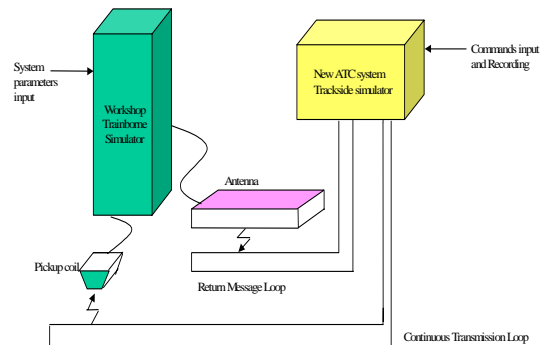
9.1 Technical Inter-Operability Management

At the pre-tender inter-operability study stage a number of assumptions were made. The fundamental building elements of the system design, both in terms of software and hardware, were assumed not to require change from the SACEM system previously introduced. The focus of the study was therefore placed on the new functions to be added to the basic SACEM ATC system as developed by RATP. After the contract was awarded, MTR engineers worked with the contractor to formulate the critical compatibility elements of the project and a detailed Inter-operability Management Plan was drawn up. Apart from the functional aspects, particular attention was placed on the ATC system design and system cross-compatibility. In this regard, a structured approach was formulated to ensure that the system compatibility issues at the physical level, data level, transportation level, presentation level and application level were all properly addressed. It was considered that proof of inter-operability should proceed in two ways, by physical and operational demonstration to prove the achievement of high level functional inter-operability and by detailed system analysis to verify sub-systems as well as low level system internal and external parameter compatibility.

9.2 Inter-operability Demonstration Tests

It was a requirement that the final acceptance of the system should include, as part of the system acceptance, a successful system inter-operability demonstration. However, to ensure efficient and timely completion of the system development, demonstration tests had to be carried out at various phases of the project to produce evidence proving that the development milestones were successfully achieved. In addition this also provided design input as early as practicable to allow correction of any compatibility issues identified. At the initial phase of the project, a series of inter-operability demonstration tests were conducted at the MTR Electronic Workshop

and on site. The test set up is shown in Figure 3. The purpose of these tests was to



Workshop Compatibility Test Setup

Figure 3

determine the compatibility of the hardware interfaces and data transmission between the URL and TKE ATC systems. The results were used as input to system design detail. In these tests, message format, communication protocols and electrical signal characteristics were collected.

Immediately after the tests it became apparent that the SACEM system as implemented by the original supplier to URL had deviated widely from the original RATP implementation and inter-operability would not easily be achieved. It was also found that information on data transmission provided in maintenance manuals by the original supplier was incorrect and did not reflect the as-built status. More importantly the safety coding for vital processes was not the same as the original RATP implementation. The issues of hardware interface and data transmission were easy to resolve but the safety coding proved a major problem to achieving system compatibility. Without the correct safety coding to ensure the safety integrity of message transmissions and data processing the system would not function. Help from the original supplier was sought but this proved difficult due to commercial consideration. To overcome this problem it was necessary for complex detailed analysis to be carried out on executable codes downloaded from the operating computer control units. Fortunately the engineers involved in the original SACEM development were familiar with the software and were able to decipher the codes downloaded from the existing system over the next two months and the project

schedule was not much affected.

After the safety codes had been successfully deciphered, the development of the application and functional software was fairly straightforward and within the control of the contractor. Further demonstration tests at the factory and on site revealed that everything was in order and all were confident that system compatibility would be achieved within the planned schedule.

9.3 Inter-Operability Analysis

The fundamental requirement of inter-operability is to permit trains equipped by one supplier to operate safely in an ATC area equipped by another supplier. This requires that messages transmitted from trackside equipment to train be identical in format, content and signal levels and for both suppliers' equipment to be capable of inter communication across the system boundaries so that seamless train operation is possible at every point on the railway line. The main objective of the inter-operability analysis was to examine the overall system functionality and system cross compatibility and to verify that the ATC system would be compatible through every aspect down to the lowest level in terms of safety and operational functionality.

The system functionality analysis mainly focused on the implementation of application and functional software. Early on in the project the MTR and the contractor's engineers worked together with the operator's input to produce the system requirement specifications. This ensured that the delivered system would perform in exactly the same way and in every aspect as the existing system. The contractor's engineers also carried out a cross-compatibility study and looked into the system parameters which were performance and safety critical. A report was produced listing all these parameters together with the operating scenarios both systems must adhere to in order to achieve safe operations with mixed stock under inter-operability. This report was put forward to MTR for cross checking with the existing system as-built parameters. Clarification on some points from the original supplier was also sought. Whenever different parameters, both internal and external to the system, were used due to system configuration or design constraints of the individual system, this information would be forwarded to system designers for detailed analysis. Design changes would be initiated where

needed to ensure safe operations and cross compatibility were achieved.

It was found that most of the critical system parameters were the same. However, the new rolling stock from a different supplier would differ from the existing stock in many respects. The weight would be heavier as it was manufactured from stainless steel and not aluminum. It would be much more powerful and would use the latest electronic traction power control system to control motoring and braking. It would accelerate much faster and maintain a high tractive effort to a higher speed. Consequently the equipment response times would differ from the existing rolling stock. All these factors would affect the dynamic behavior of the rolling stock making it impossible to use exactly the same data construction for the existing system for both types of stock. A different approach needed to be adopted on the TKL ATC system for inter-operability to be achieved. To avoid major modification of the existing system it was determined that the trackside system on the new line would be implemented in accordance with the existing design to allow existing stock to operate on the new line.

The new rolling stock would be embedded with all the new stock and ATC system characteristics so that it would only be required to pick up track related data to perform its functions, such as station stopping points, slope of the track, track boundary locations and signal position data. This meant that the new rolling stock would be capable of operating on any line on the railway network wherever the trackside related data was available, irrespective of the type of rolling stock and the ATC system installed on board.

10 IMPLEMENTATION

Implementation of the Tseung Kwan O project was in three phases. The first phase was putting in the new trackside ATC system between Lam Tin and North Point stations. The second phase was to introduce the new trains onto the existing lines and the final phase was to connect the new TKL tunnels to the KTL to achieve the final required configuration. Once tracks and overhead power lines were commissioned to the new configuration it would be irreversible. Figure 4 shows the line connection for the extension to North Point station. Well before the first changeover took place extensive tests were conducted between the new and existing trackside

systems using existing stock running on the new ATC section to prove that the existing train and new trackside systems were compatible. On the night of the changeover trains were only required to operate on the entire section to ensure everything was in order. The changeover took place in August 2001 and proved successful. Full automatic train operation was therefore available from day one.

The second phase was the introduction of the new rolling stock with the new onboard ATC system on board in February 2002. Most of the problems encountered at this stage were associated with the rolling stock interface and the new trains could operate on the URL with no major interoperability issues encountered. However, some system fine tuning was required and in some cases this necessitated loading the train to simulate the actual operational conditions on the railway in order to get the system parameters right. The third phase of the work was to connect the new TKL to the KTL. As experience had been gained in the first phase changeover, this phase went very smoothly and was successfully achieved in July 2002.

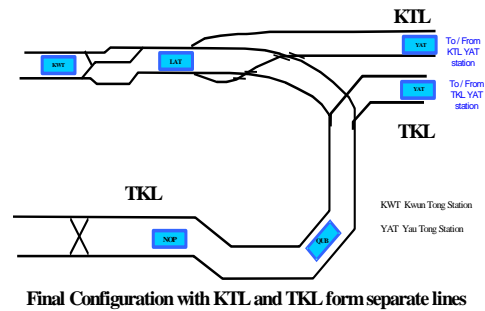


Figure 5

11 LESSONS LEARNT

Both ATC Replacement and TKL interoperable ATC projects are the first implementation of their kinds in the world and no precedence reference could be made. In both projects detailed pre-tender studies were carried out and a good understanding of the various systems and options available were the critical success factors. There were some learning points from this project, which are documented below.

- It is essential that early efforts should be made to define a clear approach to system compatibility and to prove the basic elements are correct. Some basic elements are easily overlooked, such as the hardware interface and communication protocols. These were basic to the SACEM ATC system. Problems of this kind should be identified at the compatibility study stage and should not be left unidentified until contract award.
- Critical parameters to system operations must be available. As-built information is not only essential to maintenance but also critical to system modification after a system is handed over, in particular when modification work is to be carried out by another supplier. In addition, successful demonstration of system compatibility between systems should be put in as one of the criteria of pre-tender qualification to avoid any major hiccups.
- Source codes are essential to maintenance and to the modification of a system. Every effort must be made to obtain the source code listings from the supplier. Reverse

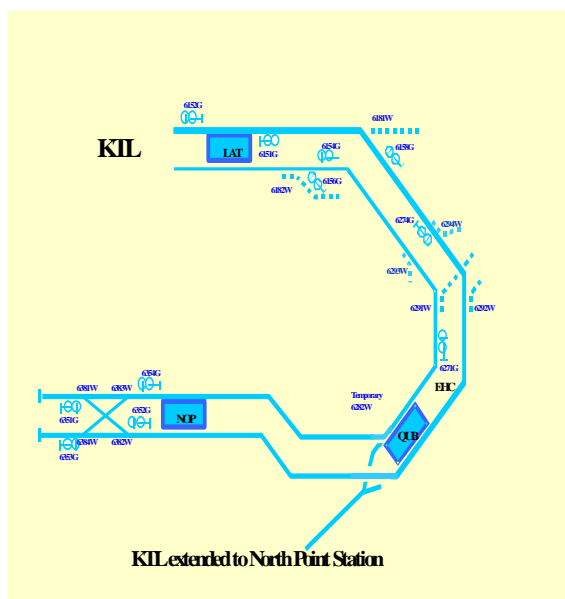


Figure 4

engineering process of the executable codes is a painful exercise particularly when it is carried out under the pressure of a very tight project schedule.

- Interface capability with other systems should not be underestimated. Some of the interfaces are service critical and may impact on operations and project cost if not properly handled.
- Early stage teamwork between client and contractor's engineers is essential. The system knowledge that can be passed on to the new contractor helps speeding up the learning curves and shorten the system development time

12 CONCLUSION

Inter-operability was achieved in the record time of two years even though the contractor had to manage the work without accurate "as built" information. This achievement was mainly due to the early system demonstration tests identifying the compatibility issues and the close collaboration between the client and contractor in resolving the problems.

As-built information is not only critical to system maintenance but also to system expansion and modification.

Introducing an alternative supplier reduces the project cost and eliminates the reliance on single suppliers when supporting a system.

Interoperability permits a high degree of operational flexibility and stock manoeuvre.

When replacing an ATC system it is better to take on a system overlaying approach. This would reduce the impact on service.

Avoid track/rail mounted equipment as far as possible to minimize equipment damage and/or service interruption.