Re-signalling with communications-based train control – New York City Transit's recipe for success

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Abstract

This paper provides a status report on New York City Transit's (NYCT's) Canarsie Line Re-signalling Project which is scheduled to enter revenue service in 2004. Re-signalling an operating mass transit railway represents many challenges, particularly when introducing new computer-based and communications-based train control technologies. This paper focuses on the project and design management techniques adopted by NYCT to ensure the project would be successfully completed on schedule and within budget – NYCT's "recipe for success". The paper specifically addresses the techniques used to: understand the needs, evaluate the alternatives, develop the implementation strategy, establish the technical requirements, select the preferred system/supplier, promote a partnering philosophy with the selected supplier, finalise/freeze the system design, and plan the cut-over.
Keywords: mass transit, re-signalling, communications-based train control.

1 Background

New York City Transit is one of the most extensive and complex subway networks in the world. The first line entered service in 1904 and the NYCT rail network now comprises 22 interconnected lines with 1,100 km of track, 468 stations and over 6,000 railcars. The system operates 24 hours a day, 7 days a week, transporting on average 4.3 million passengers a day.

As part of an ongoing modernisation program, NYCT is pioneering the integration of new computer-based and communications-based technologies to enhance customer service. For example, the initial phase of a modern Automatic

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Train Supervision (ATS) system, which will provide centralised control of the rail network from a new Rail Control Centre, is scheduled to enter service in late 2004. NYCT is also modernising its existing voice communication systems and upgrading its passenger information systems, through improved Public Address and dynamic Customer Information Screens. Passenger safety and security is also being enhanced through the increased use of closed circuit television.

NYCT has also initiated a program to replace its existing fixed block, wayside signals/trip stop signal technology with state-of-the-art communications -based train control (CBTC) technology [1].

2 Understanding the needs

As with any advanced technology system, NYCT realised that one of the most critical elements in assuring the success of its signal modernisation program was to first establish a clear understanding of the operating needs and benefits to be realised by the new train control technology [2]. To this end, in the early 1990's, NYCT established an interdisciplinary task force made up of all of the users and other stakeholders who would be affected by the new train control system. This task force, with support from a consultant team (lead by Parsons in association with Booz Allen & Hamilton and ARINC, Inc.) experienced in the design and deployment of new technology train control systems, developed the key operating requirements and captured these requirements in a "concept of operations" document.

In developing such a top-level requirements document, NYCT also realised that it was important to balance the needs and expectations of the users with the capabilities and limitations of the available train control technologies. NYCT therefore actively involved potential train control system suppliers, and other transit agencies, in the development of the top level requirements and implementation strategies.

For NYCT, the key operating needs can be summarised as:

- Designing, implementing and operating the new train control system as a logical and practical evolution from current NYCT practices.
- Bringing the existing signal system into state-of-good-repair
- Enhancing the safety of train operations even in the event of train operator error, by providing continuous overspeed protection to enforce civil speed limits on curves and when moving over switches
- Increasing train throughput and passenger carrying capacity, particularly on the major trunk lines in the network
- Improving the reliability and availability of the train control system
- Providing for maximum operational flexibility, to specifically include support of mixed mode operations (equipped and unequipped trains), all under signal protection.
- Supporting both manual and automatic train operations with full automatic train protection (ATP).
- Reducing life-cycle costs

For NYCT, it was also recognised that any implementation strategy for a new train control system would need to accommodate the following constraints:

- The size of NYCT rail network is such that the implementation of a new train control system must be phased over multiple years and involve multiple contracts.
- The new train control system must support NYCT existing operating philosophy of interoperability between lines, i.e. trains that generally operate on one line within the network must be capable of safely operating on other lines within the network.
- The requirement for interoperability over multiple lines, together with the need to phase the introduction of the new train control system over multiple years also generates the need for interoperability between trainborne and wayside elements of the new train control system provided by different suppliers under different contracts, as well as the need to support mixed mode operations
- The new train control system must be capable of being introduced with minimum disruption to existing train operations on a network that operates 24 hours a day, 7 days a week.

3 Evaluating the alternatives

Having established the operating needs, the next step in NYCT's recipe for success was to establish the most appropriate train control technology to satisfy these needs.

The evolution of railway signalling for mass transit applications has involved basically four generations of train control philosophy, with each generation providing an incremental improvement in operational performance.

What can be considered the first generation of train control systems philosophy includes track circuits for train detection, with wayside signals to provide movement authority indications to train operators, and trips stops to enforce a train stop if a signal is passed at danger (intermittent ATP). With this train control philosophy, virtually all of the train control logic and equipment is located on the wayside, with trainborne equipment limited to trip stops. Train operating modes are limited to manual driving modes only and the achievable train throughput and operational flexibility is limited by the fixed-block, track circuit configuration and associated wayside signal aspects. This train control philosophy is representative of the technology currently in service at NYCT.

The second generation of train control technology is also track circuit-based, but with the wayside signals replaced by in-cab signals, providing continuous ATP through the use of speed codes transmitted to the train from the wayside. With this train control philosophy, a portion of the train control logic and equipment is transferred to the train, with equipment capable of detecting and reacting to speed codes, and displaying movement authority information (signal aspects) to the train operator. This generation of train control technology permits automatic driving modes, but train throughput and operational flexibility is still limited by the track circuit layout and the number of available speed codes.

The next evolution in train control philosophy continued the trend to provide more precise control of train movements by increasing the amount of data transmitted to the train such that the train could now be controlled to follow a specific speed/distance profile, rather than simply responding to a limited number of individual speed codes. This generation of train control technology also supports automatic driving modes, and provides for increased train throughput. However, under this train control philosophy, the limits of a train's movement authority are still determined by track circuit occupancies.

The fourth generation of train control philosophy is generally referred to as communications-based train control (CBTC). As with the previous generation of train control technology, CBTC supports automatic driving modes and controls train movements in accordance with a defined speed/distance profile. For CBTC systems, however, movement authority limits are no longer constrained by physical track circuit boundaries but are established through train position reports that can provide for "virtual block" or "moving block" control philosophies. A geographically continuous train-to-wayside and wayside-to-train RF data communications network permits the transfer of significantly more control and status information than is possible with earlier generation systems. As such, CBTC systems offer the greatest operational flexibility and can support the maximum train throughput, constrained only by the performance of the rolling stock and the limitations of the physical track alignment.

In evaluating the ability of each alternative train control philosophy to meet NYCT's operational needs, the primary evaluation criteria included performance capabilities (e.g. safety, reliability, maintainability, availability, headways, operational flexibility, etc.), the ability to implement on an operating mass transit railway, the design and implementation risks, and life cycle costs. The evaluation itself was undertaken by NYCT's interdepartmental task force, drawing on the results of an extensive consultant study and supported by industry feedback. International peer reviews were also used to validate the evaluation findings.

The alternatives evaluation concluded that CBTC technology was the most appropriate solution to NYCT requirements, offering enhanced performance, lowest life-cycle cost and minimum operational disruption during implementation.

4 Developing the implementation strategy

Having selected the most appropriate train control technology, the next step in NYCT's recipe for success was to develop a practical and realistic implementation strategy. This strategy included:

- A staged implementation driven primarily by the condition survey of the various lines
- A strategy that is closely coordinated with new car procurements, to minimise the additional costs associated with retrofitting existing trains

- A strategy that in general modernises the lower capacity branch lines first, such that when the higher capacity trunk lines are re-signalled all of the rolling stock have been equipped, thereby minimising the need for support to mixed-mode operations.

NYCT also recognised the importance of an early pilot project to not only validate the operational benefits of the new technology, but also to establish NYCT procedures and working practices applicable to this technology. The Canarsie Line was selected as the NYCT pilot project.

The Canarsie Line is a two track line, 18 km in length with 24 stations and 7 interlockings. Approximately two thirds of the line is underground. Passenger trains typically operate between the two terminal stations in both peak and off-peak periods. .

5 Establishing the technical requirements

Having selected the train control technology, and established an overall implementation strategy, the next step in NYCT's recipe for success was to develop the detailed technical requirements to support procurement of a train control system for the Canarsie Line pilot project. Again, NYCT involved all stakeholders when establishing the detailed performance, functional and design requirements for the new system.

The technical specifications developed by NYCT and its consultants focused on defining "what" functions the new system was required to perform, rather than specifying "how" these functions were to be implemented. The NYCT technical specifications placed particular emphasis on defining the operating modes required to handle the various system failure modes. In developing the technical specifications, NYCT also recognised that the CBTC system was not a "stand alone" system but was required to interface with conventional signalling equipment and other train management and customer information systems. Particular attention was therefore given to appropriately defining such interfaces in the technical specification.

Industry reviews were again utilised at key points during the development of the technical specifications to provide beneficial feedback regarding the identification of potential areas of project risk. Visits to other transit properties using similar systems and technology were also valuable to experience first hand the features of the new technology and to obtain feedback on lessons learned as well as operational and maintenance experience with the technology.

6 Selecting the preferred system/supplier

The next element in NYCT's recipe for success was to select the preferred system, and preferred system supplier, for the Canarsie Line pilot project. The Request for Proposals (RFP) for the Canarsie project was issued in October 1997 and technical proposals were received from six proposers in February 1998. In July 1998, following NYCT's evaluation of the proposals, contracts were awarded to three shortlisted suppliers for a technology demonstration test program. Installation of equipment on NYCT's test track was completed in December 1998 and the demonstration tests commenced early in 1999, running for approximately 6 months. The demonstrations included RF data communication tests, train location and speed measurement tests, tests of Automatic Train Protection (ATP) and failure management functions, and tests of other miscellaneous operational functions including equipment diagnostic provisions. From these tests, an evaluation of the proposers' Best and Final technical, management and cost proposals, and other relevant information, the train control system consider best suited for NYCT's requirements was selected for installation on the Canarsie Line.

In December 1999, a 5-year, $133 million contract for re-signalling the Canarsie Line was awarded to a Joint Venture of Siemens Transportation Systems Inc. (formerly MATRA Transports International), Union Switch & Signal, Inc. and RWKS Comstock.

7 Promoting a partnering philosophy

Having selected the most appropriate system and supplier, the next step in NYCT's recipe for success was to implement rigorous design management and project management processes using a fully integrated and co-located project team. The following implementation issues were considered particularly critical:

- Establishing realistic project schedules that draw on "lessons learned" from other similar projects.
- Adopting a structured system development process that includes a system definition phase early in the project to ensure there is a complete and common understanding between the agency and the supplier on the requirements to be implemented.
- Establishing clear requirements for an overall test and commissioning strategy, including use of prototypes, simulation tests and other facilities, to minimise actual field-testing requirements.
- Reaching early agreement between all stakeholders on the safety certification process.
- Utilising well-defined transition plans to develop and implement new operating and maintenance practices and procedures, and to operationally manage the cut-over to the new train control system.

To facilitate the timely flow of information between all project participants, NYCT introduced a Working Group concept to handle Contractor's Request for Information, and to expedite the review and approval of Contractor submittals. Each working group focused on resolving technical issues and problems within their particular technical areas. Working groups were established for overall systems design, trainborne equipment integration, data communication system definition, wayside equipment integration, control centre equipment integration, test and commissioning, safety certification, rules and procedures, and maintenance and training.

8 Finalising the system design

During the preliminary and detailed design phases of the CBTC system, NYCT and their consultants have worked closely with the Contractor to establish final system and subsystem requirements and interface specifications. This included approval of the System Functional Specifications and the Systems Design Document which froze the system functional requirements. The resulting functional requirements established the NYCT-specific adaptation requirements to the Contractor's existing service-proven system design. The CBTC system for the Canarsie Line consists of three main subsystems as shown in Figure 1:

- The Central subsystem that supervises operation over the complete line
- The Wayside subsystem, a distributed subsystem that controls individual sections of the line
- The Trainborne subsystem that determines train location, receives movement authority from the wayside, and governs train movements accordingly.

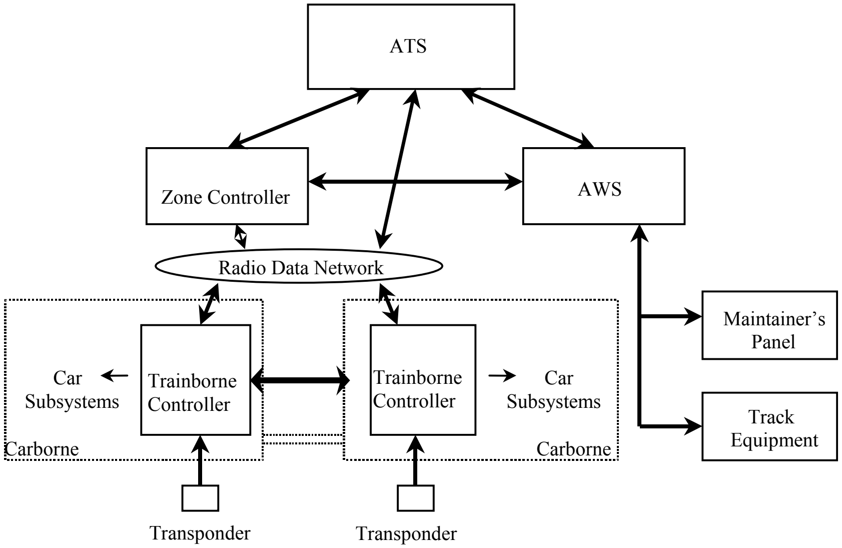

Figure 1: CBTC system architecture.

The Central Equipment is located at NYCT's Rail Control Centre (RCC) and provides the Automatic Train Supervision (ATS) functionality. These functions include all the tools, information and commands needed by dispatchers to supervise train movements, such as: line display, train tracking, trip assignments to trains, automatic routing of trains, regulation of train movements for schedule adherence and recovery from delays, and subsystem and equipment status. The

ATS subsystem can address each train to send regulation commands, such as depart from station, and to monitor train subsystem status for operational and maintenance purposes. The ATS subsystem also controls interlockings, by requesting route clearance and displaying the status of track circuits, switches, and signals, and communicates with the zone controllers to implement control actions affecting equipped trains such as blocking sections of track or setting temporary speed restrictions.

The line is broken down into multiple controlled zones including associated interlockings and radio transmission cells. Each zone is controlled by a zone controller. Zone controllers receive information from and send commands to interlockings. A zone controller also communicates with all equipped trains within its particular zone through the radio communication network. The train communicates various data to the zone controller including its location and the status of equipment on board. The zone controller in turn communicates commands and data to the train including the movement authority. The movement authority is the section of track through which the train is authorised to proceed subject to maximum speed and other limits both permanent and temporary.

Zone controllers can also detect and track unequipped trains by virtue of track circuit occupancies. The zone controller then manages a “map” of all trains (both equipped and unequipped) in its zone and is able to define movement authorities for all equipped trains.

The conventional signalling equipment, including interlockings, signals, switches, train-stops, and track circuits is collectively known as the auxiliary wayside system (AWS). For the Canarsie Line, each interlocking consists of a conventional relay-based set of equipment. The interlockings establish and maintain routes for both equipped and unequipped trains. The route requests are generated by ATS or from a local maintainer’s control panel. For CBTC equipped trains a new signal aspect (flashing green) has been created to indicate to the train operator that movement authority information is displayed onboard.

Trackside CBTC equipment consists of the track-mounted localisation transponders used to provide position fixes to equipped trains. Other trackside equipment consists of conventional signal equipment of the AWS including signals, train stops, single rail track circuits, and switch machines.

Trains are equipped with trainborne controllers that communicate with ATS, the zone controller in which the train is located, and the zone controller for the next zone into which the train is entering. Trainborne radios handle the communication between the train and the wayside. The passenger cars for the Canarsie Line are R143 cars manufactured by Kawasaki Rail Car. Trains can be configured in either 4-car or 8-car units and a complete set of trainborne CBTC equipment is provided on each 4-car unit. Provisions were designed into the cars to make them “CBTC ready” through the use of detailed mechanical, electrical, and functional interface control documents. The interfaces between CBTC and the car equipment consist of a mix of discrete wires and data networks, with train operator displays located in all driving cabs. Data communication links are also provided between 4-car units when coupled into an 8-car train.

9 Planning the cut-over

9.1 Test and commissioning

In developing a cut-over strategy for the new train control system, NYCT recognised that CBTC, unlike NYCT's existing wayside signalling/trip stop technology, requires extensive testing in the field with dedicated trains. The prerequisites for a field test typically include an equipped train with operational CBTC trainborne equipment, train operators and supervisors, fully operable CBTC wayside subsystem, and on an operating mass transit railway the need for alternative transport for passengers (buses or shuttle trains).

To minimise the field test time, significant effort was therefore put into planning for factory testing at various levels of integration. First the subsystems were tested on host hardware. This was followed by testing on the target hardware. The next stage was to connect the target hardware in the factory as close as possible to the configuration of the field, emulating missing components where necessary. For the Canarsie Line, the final in-factory system integration tests involved the central office (ATS) equipment, two adjacent zone controllers, and two trainborne controllers. The communication links between ATS, zone controllers and the trainborne equipment was achieved using actual RF communications. Emulation was used to represent the wayside signalling hardware, and the wayside network.

Once system testing has been completed in the factory, testing can begin in the field. Despite the extent of factory testing, however, problems also have to be anticipated and planned for during the early stages of field commissioning as the complexity of parameters affecting the real system operation is extensive. Field testing therefore typically starts slowly and involves extensive data gathering which must be analysed off-line back at the factory.

CBTC field testing on the Canarsie Line commenced in late 2003 and all cars will be equipped by early 2004 to support the introduction of CBTC revenue service during 2004.

9.2 Training

The introduction of CBTC technology to an organisation of the complexity and size of New York City Transit involves a significant culture change to operations and maintenance. CBTC is introducing microprocessor equipment at every layer of operations; centralised control through ATS, wayside vital computers in equipment rooms along the right of way, radio cases and antennas alongside the track, transponder equipment laid between the rails, and vital computers and complex sensors on board the trains.

Train operators for example must be trained in the new displays, the modified wayside signal aspects, and the recovery mode procedures when CBTC equipment fails. In addition to classroom training, and the use of computer aided training tools, there is no substitute for hands on training on the line itself. This can only be done after system tests are complete and will be done in off-peak periods on the line between revenue trains operating under conventional signals. With the new train control system, the Canarsie Line will now be centrally dispatched and the CBTC-ATS subsystem provides complex functions for the automated operation of the whole line. ATS training is therefore being provided on a stand alone simulator facility located within the Rail Control Centre.

In addition to train operators, dispatchers and maintainers, supervisory, management and engineering personnel also need to be trained in the new system and the overall training plan is therefore complex as the degree of understanding needed for each category of personnel varies considerably.

It must also be recognised that in addition to the technical and operational aspects of the system, staff must also be trained in the new rules and procedures that have been prepared to cover CBTC operations on the Canarsie Line.

10 Conclusions

Implementing any re-signalling project on an operating mass transit line represents significant challenges, particularly when introducing new technologies and operating practices. However, by following a logical and systematic implementation approach – an approach that is focused on risk identification and mitigation - New York City Transit is proceeding with its ambitious signal modernisation program on schedule. The first line to be equipped with CBTC – the Canarsie Line – will be entering into revenue service during 2004.

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