

Signal Design and Installation on Toronto Transit Commission's Sheppard Line

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Signal Design and Installation on Toronto Transit Commission's Sheppard Subway Line

On November 22, 2002, the Toronto Transit Commission (TTC) opened the newly constructed Sheppard Subway Line. The \$934 million (CAN) line which consists of 13 km of signalled track and five new stations. Three interlockings control movements over the line. Each interlocking is controlled by a series of vital processors. The system includes 127 signals, 135 trainstops 19 switch machines, zone control panel, two local control panels, maintenance panels, extensive modifications to an existing vital relay based interlocking and interfaces with a control office (currently under test).

This paper will describe how the Sheppard Subway project team designed, installed, tested and commissioned the \$20 million signalling system while ensuring the project was completed on time and within budget and to the highest quality standard.

The paper will:

- Provide an overview of the entire project;
- Detail the composite of the project team;
- Detail the block design process;
- Describe the new signalling features implemented such as:
 - Vital Field blocking,
 - Reverse traffic capability;
- Describe system architecture such as the following:
 - Vital processor configuration,
 - PLC interfaces,
 - Redundancy,
 - Tunnel barrier door interfaces,
 - Remote and local maintenance terminal capabilities;
- Describe the following processes:
 - Procurement,
 - System assurance process,
 - Signal construction and coordination with other systems,
 - Testing & commissioning.

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1. INTRODUCTION

The purpose of this paper is to describe the Sheppard Subway Project and detail some of innovations in project management and signal design. It will also focus on the installation process.

The new line location in reference to existing network is shown in Figure 1.

2. BACKGROUND

The Sheppard Subway project is a new 6.4 km rapid transit subway line built largely underground along Sheppard Avenue in the City of Toronto, Ontario, Canada. It is the first new subway line in Toronto in 36 years. Stretching from Yonge Street to Don Mills Road the new subway was constructed using tunnel boring machines and included five passenger stations and Wye connections to the existing Yonge Subway line providing access to existing rolling stock.

Toronto's newest subway line, the \$1 billion (all costs are in Canadian dollars) Sheppard Subway, opened on time and on budget. It is anticipated that this new line will carry over 15 million passengers per year.

The origins of the Sheppard Line can be traced back to the early 1980s when a variety of government and Toronto Transit Commission (TTC) sponsored studies recommended reducing the pressure on the downtown core by encouraging development at other urban nodes in the city. In 1991, the ambitious "Let's Move" program included construction of seven new rail transit lines. The Delcan/Hatch joint venture won the international competition for the Program Management of this \$7 billion undertaking. In 1994, engineering and construction of four projects, totaling \$2.5 billion, was approved and the initiative was renamed the "Rapid Transit

Expansion Program” (RTEP). Due to fiscal restraints within the provincial government in 1996, only the Sheppard Subway continued.

Program Management of the subway was undertaken by an integrated team of approximately 75% Delcan Hatch consultant staff (in association with O’Brien-Kreitzberg & Associates Inc. and Parsons Transportation) and 25% TTC staff. At the inception of the “Let’s Move” program in 1991, use of an integrated team for major capital projects was uncommon. The Sheppard Subway project’s success has led to this innovative approach becoming a model for many large transit initiatives around the world.

Design and construction contracts were executed for station construction, tunnel boring and the supply and installation of systems including track, train control, traction power, communications and ventilation. In total, there were over 50 design and construction contracts covering the following:

- Fixed Facilities: stations, tunnels, bridges,
- Operating Systems: track, power, CCTV, radio, fibre optic, SCADA, signals, elevators, ventilation, etc.

These were supplemented by approximately 200 contracts and purchase orders, for the following:

- Material/equipment supplies,
- Professional Services, Geotechnical, Construction Supervision, etc.,
- Third Party Agencies, Roads, Power, Gas, Telephones, Traffic Lights.

Perhaps the biggest challenge for the new line was the interconnection of the new Sheppard Line with the existing Yonge Line. The work included building the new Sheppard-Yonge Station above the existing Sheppard Station, as well as connecting the new tunnels to the existing tunnels, while at all times keeping the existing Yonge Subway Line operational. The new station features side platforms; however, a center platform was also constructed for future use when warranted by increased passenger service. Construction costs of Sheppard-Yonge Station were in excess of \$100 million. Each of the other stations, while smaller in scope, has their own distinctive designs, public art and architectural features, in addition to their own project requirements.

Tunnel Boring Machines (TBM) that not only excavated and removed the earth but also installed reinforced concrete liner rings for earth stabilization, bored the twin 5.2 metre inside-diameter tunnels, which are 13 metres apart. Located east of Leslie Station is the 60-metre long Don River Bridge — a totally enclosed concrete structure was built to be completely watertight and able to withstand the highest water levels.

There were many other individual contracts ranging in cost from the thousands to the millions.

Over and above the various construction contracts, the Sheppard Subway project included the requirement to make the system fully operational. This included testing, commissioning, rail activation, and startup operations of the facilities and systems. Associated with these activities was the provision of training and documentation (drawings and O&M manuals) for the TTC Operating Departments. The Sheppard Subway was safety certified using the APTA guidelines. Occupancy Permits from the Fire and Building Departments were also obtained. The Sheppard team also provided warranty administration and assisted the TTC Operating Departments with

mobilization. Another key component for startup was to familiarize all Emergency Response Agencies with the system.

Sheppard Subway employs a number of new technologies for operation, control and monitoring of trains that are largely invisible to passengers. These include such elements as fibre-optic backbone communications between stations and the Transit Control Centre; subway antenna system for radio communications in tunnels and stations; microprocessor-based interlocking control for the signal system; and Programmable Logic Controllers (PLC) for traction power, emergency ventilation and station security systems.

The signal system on the existing subway, the oldest of which entered service in 1954, is relay-based. Communications between interlockings is vital relay based and uses traditional multi-conductor signal cable and are single broke. All required vital timing functions are performed by either mechanical of electronic timers.

The new signal system consists of three new interlockings. They are Don Mills, Bayview, and Yonge. Limits of each are shown in Figure 2. For the first time, TTC implemented redundant Vital Microprocessor Interlocking Controller System (VMICS). The implementation on the Sheppard line required a mixture of VMICSSs and vital relays. Serial links (Fiber Optic) provided vital communication between interlockings. Where possible all vital timing functions were performed in VMICS. A more detailed description of architecture is provided in "TYPE OF SYSTEM INSTALLED" section of this paper.

3. COMPOSITE OF SIGNALLING TEAM

Management of the signals portion of the project was carried out by Delcan Hatch JV staff in association with staff from the Commission's Signal/Electrical/Communications (S/E/C) department, reporting to the Deputy Project Manager – Systems.

The JV team performed the following tasks and prepared relevant material for; Request for Information documentation, Preliminary Engineering, Specifications, Pre-qualification process, Contractual Agreements, and the evaluation and selection process.

System design and review was responsibility of TTC Signals Engineering. The detailed design was performed by GE Global Transportation Solutions – Global Signalling (GETS-GS) group. 360 Networks, a Subcontractor to GETS-GS and TTC Signal Maintenance Department carried out installation.

The work was performed under the direct supervision of the Commission's Chief Project Manager, Sheppard Subway, who reported directly to the Commission's General Manager, Engineering and Construction.

4. TYPE OF SYSTEM INSTALLED

4.1 General

Signaling on the Sheppard line is a fixed block, three-aspect system. The aspects relay route and block information. The wayside signals are a combination of controlled and automatic signals with numerous sections of speed enforcement (Grade and Station timing). Red signal enforcement is achieved by the installation of mechanical trainstops.

The interlocking signals and associated equipment are controlled by redundant vital processors and programmable logic controllers through traditional cable mounted on messenger wire.

Automatic signals are generally controlled by vital relays located within close proximity of equipment. See Figure 3 for Typical Interlocking Configuration.

Requests can be initiated from TTC's Transit Control Central, Zone (located at Yonge interlocking) or Local control. All panels can monitor indications.

In order to match technologies, the changes to existing Sheppard interlocking were performed with vital relays.

4.2 Equipment

Components supplied and/or installed and the associated company are as follows:

- Vital Microprocessor-based Interlocking Control System (VMICS) – GE Transportation Systems Global Signalling (GETS-GS),
- Programmable Logic Controllers (PLCs) – Allen-Bradley (A-B),
- Single Rail AC Track Circuits – Union Switch and Signal (US&S),
- 127 - Colour-Light Signals – US&S,
- 19 – 110 VDC switch Machines – GEC ALSTOM,
- 135 - Trainstops – US&S,
- Vital Relays – US&S,
- Wheel Detectors – Honeywell,
- Mosaic Panels – Entech.

4.3 Special Features of the Sheppard Subway Line Signal System

Numerous new features are provided by the system. Most of which meet today's operational, safety or service reliability requirements. The incorporation of most of the new features was relatively easy. This is largely due to the fact we took advantage of technology, e.g., Vital software logic and state of the art communication system.

The following list summarizes some of the features that were designed into the Sheppard Subway Signal System.

- a) **Failed train recovery:** In the event of a disabled train on the line, it is necessary to couple up with a following train and push the disabled train to a non-service area. Since the line is operated with four-car trains, the system must be able to accommodate eight-car trains under failure conditions. This is straightforward at in-line stations, and in the west tail track the structure is designed to accommodate an eight-car train. However, at Don Mills the locations of signals had to be specifically established to accommodate eight cars due to the reduced tail tracks length at Don Mills.
- b) **Fibre Optic Communication Links:** A fully redundant fibre optic "ring" network was furnished on the Sheppard Line for all data communication needs. The signal system vital and non-vital data links between interlockings utilize the fibre system, along with many other operating systems such as: radio, SCADA, CCTV, PA, Intercom. The fibre technology has proven to be highly reliable.
- c) **Six-car train alarm:** The Sheppard Stations are finished for four-car train operation, but the station structures are long enough to accommodate six-car trains in the future. The signal system is designed to be "convertible" to six-car train operation in the future, by relocating several signals. Since the other lines all operate with six-car trains, there is a risk that a six-car train will inadvertently be routed onto the Sheppard Line. To eliminate this risk, the track circuits on both the east and west Wyes are configured to check train length. If a six-car train

enters the Wye (detected by three consecutive tracks being occupied simultaneously), an alarm is sounded at Transit Control and appropriate action is taken.

- d) **Double Break Circuits:** Historically, TTC has used single break circuit design for the majority of vital circuits. For the Sheppard Line, double break circuitry was utilized for all vital line circuits. This provides an additional level of protection against false energy picking a vital relay, and is in compliance with AREMA recommended practice.
- e) **Stuck Key-By Lever Detection:** Interlocking signals with manual call on are equipped with key-by levers approximately ten feet ahead of the signal. When a red/red/yellow aspect is displayed, the Train Operator is required to press the key-by lever to drive off the trip arm. Once the trip arm is clear, the train can proceed in accordance with the rule. In the older areas of the subway, there is a risk that these key-by levers may “stick” in the operated position. Regular maintenance schedules are designed to minimize this risk. However, on the Sheppard Line, a design improvement was introduced to check the key-by lever in the “off” position before a call on signal can be initiated. Also, activation of the key-by lever is indicated on the signal control panel, to identify immediately a lever that may be “stuck”.
- f) **Platform Blind Timing:** In the older areas of the subway, train speed through stations is governed by rule. On the Sheppard Line, train speed through station platforms is enforced by grade timing, except that no lunar white aspect is displayed (hence the name “blind timing”). The leaving signal will not clear to a proceed aspect unless a predetermined time period has elapsed with the train on the platform track circuit. This limits maximum attainable speeds downstream from the station and ensures that safe braking distances are not compromised by a high speed run through the station.
- g) **Signal Annunciator Panels:** All Sheppard Line relay rooms are equipped with a detailed annunciator panel display of all signal functions within the interlocking territory. This feature is very helpful to Maintenance staff during troubleshooting activities, as they now have a

clear depiction of the state of the entire signal system. It was also proven useful during system testing.

- h) **Special Signals:** Due to the high safety catwalk in tunnel areas, it was not possible to install standard interlocking signals in several areas where an interlocking signal was required for reverse traffic operation. Instead, special interlocking signals were installed with a reduced number of aspects. These signals function the same as standard interlocking signals, with the only difference being the appearance to the Train Operator. The reduction in aspects was achieved by eliminating the route aspects (outer home signals only) and by using a single yellow aspect for both “proceed” and “call on” indications. An Operating Rule Book revision was required.
- i) **Vital Field Blocking:** Historically, TTC has utilized special tags or collars on signal levers when signal equipment is placed out of service. These devices used on signal control panels served as a reminder to operating staff of unusual conditions in the field. On the Sheppard Line, for the first time, we incorporated blocking functions within the interlocking control circuits in the field. Three types of blocks are available from zone or auxiliary panels: these are signal, switch and exit blocks. Blocking is applied by pressing the appropriate BLOCK lever and then pressing the lever of the device to be blocked. A steady blue indication confirms that the desired block is applied. Blocks are removed by again pressing the appropriate BLOCK lever, and then pulling the lever of the device to be released. A blocked device cannot be cleared or moved by any means as long as it remains blocked. The blocking logic resides in the vital portion of the interlocking logic.
- j) **Tunnel Barrier Doors:** The Sheppard Line includes several barrier doors required for the emergency ventilation system. In some circumstances, the doors are closed in order to control air flow in a fire/smoke emergency. To minimize the risk of a train contacting a door, interlocking circuitry is provided between the signal system and the door control system. The objective of the interlocking circuits is to ensure that red aspects are displayed on signals

approaching barrier doors that are not in the fully raised position, and to prevent door closure in the path of an approaching train. A request to close the door results in the affected signals being put to stop, and starts a timer within the door controller. The doors are permitted to close if after one minute if there is no train within the approach limits to the door. If there is a train near the doors, the doors can still be closed if motion sensors at the door confirm that the doorway is not obstructed. A local operation feature is also provided at each door in the event that remote operation is not available.

- k) **Reverse Traffic:** The majority of the original TTC subway is signalled for single direction travel only. Reverse traffic signalling was only provided in very limited areas where a specific operational need was identified. On the Sheppard Line, a limited reverse traffic capability has been provided. This capability allows for single track operation between interlockings in the event of a blockage on one track. A total of 13 additional signals were provided in order to achieve a limited reverse traffic capability, which safely supports signalled operation in the reverse traffic at low speeds. The achievable headway is constrained by the relatively wide spacing between crossovers and the low operating speeds, but the facility has already proven useful in the first six months of operation. It is expected that greater use of the feature will occur in future years as operating confidence grows, and as maintenance activities inevitably increase with the age of the infrastructure.

5. BLOCK DESIGN PROCESS

Block design was an iterative process, which took approximately six months to complete. It incorporates train data, operations criteria, track and structural data.

The operations criteria for Sheppard train service are as follows:

- Maximum speed: 80 kmph,
- Minimum headway: 120 s,

- Station dwell times at intermediate stations: 30 s at all stations,
- Station dwell times at terminal stations: 30 s minimum,
- Coast level: 5%,
- Maximum number of cars per train: 4 for the Sheppard Line,
- Safe braking distance: includes 35% safety factor,
- Double block overlap: to ensure at least two trainstops are in the tripping position behind a train,
- Reverse traffic layout: based on the normal direction layout

TTC used a computer simulation tool to assist in block design. The process is as follows:

- Input all track and structural data such as gradient, curve, and special track information,
- Define station and end of track information,
- Input operations criteria,
- Determine interlocking signal locations,
- Determine automatic signal locations,
- Determine signal overlap,
- Incorporate speed control (Grade Time Signals) to limit maximum attainable speeds on long stretches of straight track,
- Incorporate Station Timing to ensure trains approaching a station at a reduced speed are kept closer together.

While considering all above points, the design also ensured tracks circuits and signals were kept to a minimum.

In addition to balancing all items above, signal sightlines were reviewed. The ultimate goal was to ensure maximum viewing time for operators. In many cases, other wayside equipment had to be relocated.

6. SYSTEM ARCHITECTURE

As previously described, the Sheppard Subway signal system is composed of three control locations: Yonge¹, Bayview and Don Mills (refer to Figure 2). At each location, the Vital Microprocessor Interlocking Control Systems (VMICS) interfaces to several ancillary systems (e.g., communications) as well as to adjacent VMICSs (refer to Figure 4). A VMICS is composed of pair of redundant "Controllers" and a pair of redundant "Programmable Logic Controllers" (PLC) (refer to Figure 5).

GETS-GS had previously provided "cold" normal/standby VHLC systems but selected a "warm" architecture for the Sheppard Subway so that the "offline" components of the system could be exercised and any failure could be annunciated and therefore corrected before it was needed. In this "warm" architecture, standby VHLCs are fully operational but not energizing any outputs.

The design of the VHLC's Vital, General-Purpose Output (VGPO) allows the outputs from the normal and standby VHLCs to be wired in parallel without the need for transfer relays. Due to long distances from the relay room to some of controlled signals and the requirement to isolate Vital Lamp Outputs between normal and standby VHLCs, as well as the desire by the TTC for a consistent signal lighting scheme, signal lighting uses relays driven by VGPOs rather than Vital Lamp Outputs.

¹ Due to the amount of I/O, Yonge was implemented as two interlockings – East and West – each with its own VMICS.

The application logic on both the normal and standby VHLCs is identical and two inputs are used to establish each Controller's identity ("A" or "B"). Normally, failover to the standby system is automatic based on "health" but it can be initiated manually from the annunciator panel located in the relay room or remotely from the Central Office Signal System (CSS) at the Transit Control Centre. It is also possible to prevent failover – in essence "locking out" the standby system. Following a failover, the standby VHLCs assume control of the interlocking from a "safe" state (i.e., all signals are stop, switches locked, blocks applied).

The serial communication links are also redundant and are switched through a highly reliable and highly available crossover switch (refer to Figure 6). Bits in the appropriate serial messages indicate to the other device if the VHLC is online and configure its communication links accordingly.

Allen-Bradley (A-B) SLC 500™ Programmable Logic Controllers (PLCs) in a masked redundant configuration are used to accommodate the large amount of panel I/O and to provide the local/zone levels of control (refer to Figure 7). The VHLC and PLC communicate to one another over an RS-232 serial link. Custom firmware on the A-B BASIC-T module was developed to support the GETS-GS Local Control Panel protocol. The PLCs allow the relatively small amount of panel I/O supported by the VHLC to drive the annunciator, local and zone panels. The Remote I/O (RIO) in the local and zone control panels is redundant while that in the annunciator panel is non-redundant.

The VHLC determines if control is from central or a panel and the PLC determines if control is from the local or zone panel.

The Bayview and Don Mills PLCs communicate via redundant Ethernet LANs with the Yonge PLCs, which, in addition to driving the Yonge annunciator and local control panel, drive the zone control panel.

During the project, the VHLC was upgraded to provide Field Programmable Timers, which permits authorized signal personnel to modify a vital timer value within limits defined in the application limits. The setting is adjusted using a laptop computer attached to a new diagnostic port on the Vital Logic Processor (VLP) module. All modifications to the timer value are logged.

The VHLC was also modified to process the time synchronization messages added to the DataTrain VIII code system protocol. Through this message, it is possible to synchronize the real-time clocks of all VHLCs.

At the start of the project, a System Description Document (SysDD) was created to describe each of the major components of the signal system and define its functionality. As previously noted, there were separate procurements for the signals, switches and trainstops and contracts for the communications system, SCADA and other ancillary systems as well as an ongoing project for a new Transit Control System. The SysDD defined the signal system interface to this equipment and other systems.

Within GETS-GS, the SysDD acted as a "design handbook" for the system and application engineers. The SysDD was a living document and was continually updated as the design progressed and system requirements were refined, expanded or clarified.

7. PROCESS

7.1 Request For Information

Prior to Procurement of VMICS, the TTC issued an industry wide Request for Information (RFI) document. This was largely to ensure current technology could meet TTC's policy for new technology. The RFI stated that any new product must have been in service for a minimum of two years on a similar North American property. The RFI would also provide a mechanism to ensure performance requirements could be met by industry and was used to prequalify vendors.

7.2 Procurement

It was determined that TTC Signals Engineering would perform all preliminary design work, block design and engineering support during construction and testing. In addition, TTC Signals Maintenance would install all wayside equipment. This being the case a strategy for splitting up the contracts was developed.

The contracting strategy therefore consisted of four external contracts and two Internal Work Authorizations (IWA) for TTC Signals Engineering and Maintenance departments. The use of TTC forces by the Project Team was unique. The IWAs provided a mechanism to use internal forces in a role, which would be generally provided by a contractor. It proved to be key in ensuring the system was designed and built as per customer requirements.

The contracts splits, duration and cost were as follows:

- Preliminary Design, Engineering support, Testing and Commission Support - IWA - TTC Signals Eng. Jan. 1997 - Dec. 2002 (Approximately \$2.3 million),
- Design, Supply and Install Signal System - GETS-GS, May 99 - Dec. 02 (Approximately \$12 million),
- Supply of Trainstops - US &S, May. 99 - May 01 (Approximately \$2.0 million),

- Supply of Switch Machines - GEC Alstom, May 99 - Jan. 01 (Approximately \$600 K),
- Supply of Signals and Miscellaneous Material - US &S Nov. 99 - Feb. 04 (Approximately \$1.3 million),
- Wayside Signal Equipment Installation - IWA - TTC Signals Maintenance Feb. 00 - Feb. 02, (Approximately \$1.9 million).

With the exception of trainstops, all contracts were awarded through TTC Materials & Procurement on competitive price. Trainstops were supplied through single source procurement since US&S is the only TTC-approved trainstop vendor to the TTC due to the requirement for an external trainstop circuit controller (VCC).

The separate supply contracts allowed TTC to select specific technologies and allowed material to be on hand for preparatory work required by TTC. This work included pre-wiring of trainstops, thus maximizing use of restricted access to track level.

8. SIGNAL CONSTRUCTION AND INSTALLATION

8.1 Safety

Both the Signal Contractor (GETS-GS) and TTC Signals Maintenance were required to submit their Health, Safety and Environmental programs, which were then reviewed by the Sheppard Subway Safety Department and the Systems Resident Site Superintendent. In addition to their Health, Safety and Environmental programs, Operational Instructions for Hi-Rail Vehicle use were also provided.

The Systems Resident Superintendent ensured the "Constructor" requirements under Ontario Occupational Health and Safety Act were met. The Act requires one body to be responsible for a given area within a large construction site. It lists duties and the Constructor responsibilities,

which includes site safety and the assurance that contractors were separated by time and/or space. Contractor coordination meetings were held with various contractors throughout the installation process. Weekly systems Site coordination meetings were also held. The constructor for the signal work would routinely be assigned one trainway between interlockings, while the station contractor remained the constructor within station limits.

Safety notices were placed on operating equipment, such as switch machines and trainstops during signal testing phases. Other contractors were advised of signal testing via Safety Notices.

Procedures for moving Hi-Rail vehicles and train operation during signals testing were also implemented.

8.2 General

The installation of equipment was split into two segments. The Signal Contractor supplied and installed all equipment starting in the relay room and up to and including the wayside cases. TTC Signal Maintenance installed all wayside equipment. This included trainstops, track circuits, switch machine, signals, Grade Time signs and cable between wayside equipment and instruments cases.

One of the most difficult tasks was the daily coordination of on Site activities. Numerous other contractors, such as station contractors, trackwork, SCADA, traction power, and communications contractors were competing for time and space. To ensure all parties worked efficiently the project management team held weekly and some time daily coordination meetings with contractors.

Communications with personnel in tunnels and stations also proved to be difficult. The inability to directly contact someone within the tunnel impacted both contractors and the project team. The earliest practical establishment of a communication system on future projects would benefit all.

During the first stages of construction, five (5) drop shafts were built. This allowed the signal contractors to lower all the necessary vehicles, equipment and supplies required for the installation and testing of the signal system to track level. Vehicles lowered consisted of a diesel Hi-Rail truck, a diesel motor car, a tag along small trailer to carry small items and three (3) trailers equipped to carry huge cable reels in order to distribute the long cable runs throughout the system. All diesel engines were equipped with scrubbers and were monitored by TTC Health & Safety committee for emission compliance.

Special ventilation was not required due to the drop shaft and station openings.

8.3 Construction and Installation

TTC Signals Engineering reviewed all designs prior to construction. This started with conceptual designs, then proceeded to 30% and critical design stages. They also approved all submittals.

The VMICS components were unfamiliar territory to the Project Team. Clarifications were, therefore, required to understand the GETS-GS VHLC product line. This resulted in longer-than-anticipated submittal reviews. Perhaps future submittals to the TTC of new product lines could be preceded by a presentation to familiarize those involved, which would in turn assist in expediting the submittal review process.

The installation work commenced on July 2000 and was completed November 2002. It was divided into four areas, Don Mills, Bayview, Yonge East and Yonge West. All work commenced from the east and worked towards the west. It required great coordination and cooperation. It was proven to be very successful. Listed below is a very brief description of events.

The hi-rail truck used by the Signal Contractor was outfitted with a sliding deck. The sliding deck provided the ability to slide the work surface adjacent to tunnel walls. This was proven to be a great asset during messenger wire and cable installation.

All instrument cases and relay racks were built at GETS-GS Warrensburg, Missouri facility. Prior to shipment all equipment was Factory Acceptance Tested (FAT) by GETS-GS test personnel. The relay room equipment was also tested by TTC prior to shipping.

The Auxiliary, Annunciator and Zone Control, panels were built by Entech in Florida and shipped to the GETS-GS Warrensburg facility. They were integrated with the rest of the system and Factory Acceptance Tested (FAT) by GETS-GS and TTC personnel. Once FAT was complete, the panels were shipped to the site.

The first order of business on site by the Signal Contractor was the installation of messenger wire. Messenger wire clips were fastened to walls on uni-strut or by direct fixation. The messenger wire was then hung up and tensioned.

Next came the installation of cable. The cable was provided on numbered spools. Each spool was pre-cut for specific runs. Cable wasn't hung until cable for a complete area was paid out. An area included the distance between the relay room and the end of an interlocking.

Once ready, the cable was lifted to the messenger wire. This was achieved by using hi-rail truck sliding deck extended to the wall. The truck was also outfitted with a wheel, which could be adjusted to messenger wire height. Once ready the truck would simply drive slowly as the labor crew fastened the cable to messenger wire.

After the cable was hung, the instruments cases were installed. The instruments cases were placed on platforms within circular tunnels and on concrete plinths within box structure. Cables were then terminated and meggered.

Vital Microprocessor Interlocking Control Systems (VMICS) and associated relay racks were installed. This involved inter-rack wiring, bell check and circuit breakdown. All cables were meggered prior to installation and after termination. Associated power equipment was also installed and tested.

Interlocking to interlocking and numerous other communications required for the signal system were performed via the fiber optic network (provided by others). This required an interface point in the communications room.

The Signal Contractor also had to interface with other equipment supplied by others, such as; power, transfer switches, inverters, tunnel barrier doors and fire alarms.

TTC forces also used a high rail truck for mobility. They were responsible for hookup and post installation check out for equipment installed by them. TTC forces attempted to be either in front or behind the Signal Contractor when performing work on site.

All phases of the installation work were done under the watchful eye of an Signal Inspector. The Signal Inspector documented progress and ongoing deficiencies, and ensured conduits and cable mounting locations were preserved for the Signal system. He also assisted with coordination of all contractors.

Once the system was installed, it was handed over to GETS-GS Field Testing group.

8.4 Systems Assurance Process

For the implementation of Sheppard Subway, TTC developed a systems assurance process based on APTA guidelines for all critical systems. The systems assurance activities for the signal system are outlined below:

- An internal review of the signalling design standards,
- A specification that the Signalling Contractor was contractually responsible for ensuring that all equipment such as trainstops, switch machines, signals, etc. were correctly and properly integrated, and that the system is safe,
- A documentation package from the Signalling Contractor with an analysis of the safety, in addition to numerical reliability, availability and maintainability requirements; and
- A reliability demonstration test by the Signalling Contractor. This test shall be considered to be passed when the equipment supplied and installed meets the required MTBF, MTBSF and availability requirements within a test period of six months of successive revenue service.

The systems assurance analyses and other safety assurance documentation were provided by the Signalling Contractor. The documentation addressed theoretical hazards, which could occur due to failure of the signal system, including trainstops, switch machines, fibre optics, track

circuits, etc. The documentation also provided recommendations as to the most appropriate means of mitigating these theoretical hazards, including hardware and software design requirements imposed on the Signalling Contractor, as well as training and operating disciplines.

Much of the systems assurance analyses also addressed items common to existing TTC signal systems.

The reliability demonstration test period start coincided with opening day, which was November 22, 2002. To date the system has performed extremely well. Operations have stated that the opening of Sheppard Subway is the best opening of a Subway on the TTC.

In addition to these activities, final handover from the project office to TTC involved certification of each of the systems assurance activities, in addition to confirming receipt of standby parts, training, drawings, O&M manuals, and test reports.

Trainstops and switch machines were also certified as separate components.

9. TESTING AND COMMISSIONING

Testing personnel were brought on Site once construction of the signal system was far enough advanced, meaning signals, cabling, switch machines, trainstops, etc., were installed. Testing consisted of different phases of which some are listed below with a brief description of each. Each phase had certain individuals from different contractors testing; hence, the complete process consisted of quite a number of people. The project team ensured all items were tested without overlap.

9.1 Post Installation Check Out (PICO)

Each location was checked visually and electrically for proper installation. Then, one at a time, each element within the location was energized and tested for correct operation. This work was performed by the Signalling Contractor and TTC Signals Engineering. For example, switch machines were checked for correct mechanical installation. Fuses were then installed. The switch was then requested to a position. Voltages to motor and detector circuits were verified locally. The status of the switch was checked to ensure it matched requested position in the relay room. Two testers at each wayside location and three testers within the relay room performed this work. This exercise took about six months to complete.

9.2 Systems Tests

Once all locations were verified to operate correctly, the interlocking system was then tested as a system. The required testing personnel were stationed at numerous wayside locations within the relay room and at the Auxiliary Control Panel. The Signalling Contractor's senior Test Engineer led this testing.

The Test Engineer was stationed at the Auxiliary Control Panel and/or the Zone Control Panel. He used standard test procedures, which had been reviewed and approved by the TTC. Various elements of testing were also witnessed by TTC Signal Engineering Department.

After each interlocking successfully passed tests, the complete system (all three interlockings) were integrated and tested as a whole system.

The System Testing required large amounts of designated track time. Coordination of the construction and testing activities was scheduled around signal testing requirements.

Testers communicated with two-way radios, PBX phones and hard-wired self-powered test phones. The test crews consisted of approximately 15 people who worked 12-hour shifts and worked 10 days on and 4 days off. Testers located in the train way were rotated frequently, thus minimizing boredom.

9.3 Principle Testing

Principle testing was under the jurisdiction of TTC personnel. The TTC Test Engineer's duties were to subject the panel and the field equipment to all tests necessary to ensure that the system was following the design set forth in the signalling contract, and to predict if changes to the software program needed to be initiated.

Comparisons of the existing operating lines were made to operating characteristics and recommendations were made as to what changes would have to be considered, in order to have uniform functionality across all lines. This testing was the cause of many changes to the software provided.

Once the TTC Engineer completed his checks, a deficiency list was handed to the responsible contractor and arrangements were made to incorporate changes to the software program as deemed required.

This activity took much longer than the schedule provided. It revealed numerous items that had to be dealt with. The early addressing of outstanding items prior to revenue service ensured system would act in an expected way, ensuring enhanced reliability of system. An interlocking such as Don Mills requires at least one month for principles testing.

9.4 Regression Testing

Basically, the same testing as above in the Principle Testing section is applied. The main purpose for this test is to ensure that the requested and agreed upon changes to the original or preceding release of software have been implemented and ensures no new faults are introduced by changes. It also ensures system works as intended and that correct operating characteristics have been obtained. This test was performed and documented by TTC Signals Engineering.

Should more items of concern surface while this procedure is being processed, another stage of Regression Testing may have to occur. These testing periods would go on until the integrity of the system at that Interlocking and of the system as a whole is ensured.

All regression testing was performed by TTC Signals Engineering.

This activity took much longer than the schedule provided. An interlocking as large as Don Mills requires at least a week for each level of regression testing.

9.5 Brake Testing

Brake testing was another step in the process to ensure the system was ready for operation. This test required an operable signal system, and a train of sufficient length and of different weights, to verify that braking distances between signals was sufficient under varied speeds to attain safe controlled stops to be made and separation of trains to be maintained.

This was an exhausting experience, as every signal had to be checked at the different variables and this took considerable time, perseverance and calculations by all those taking part in the

exercise. Flat wheels on the train seemed to be the order of the day. Several times, due to this condition, trains were exchanged so as not to completely destroy the wheels.

9.6 Marker Tests

Again, a train was used to gauge the correct placement of throttle control markers. This test utilized the same type of philosophy as the above under Braking Tests, with the difference being to place markers in order to obtain the most comfortable deceleration process in order to stop at the platforms and as guides to accelerate due to inclines/declines of the track.

Once proper throttle positions were decided upon, the markers were attached at eye level and at the desired locations throughout the system, in order to maintain correct speeds.

9.7 Running Tests

As the running tests were required to be under operating conditions, authority was required and given by the TTC Signals Engineering for operation of a single train for this purpose. Authority was again required and given to run five trains. This was a simple task of running the five trains on signal indications with spacing as set forth from the Zone Control Panel (Operation Test Center), which was under the guidance of TTC Operations.

10. SUMMARY

The opening of the Sheppard line was deemed to be the best opening of and Subway System in the history of the TTC. This was largely due to cooperation and dedication of all team members. This includes, Sheppard Subway Team, TTC Signals Engineering, TTC Signals Maintenance, TTC Operations and all the Contractors. The items below summarize our success:

- The approach of using integrated teams worked very well. Team members strived to deliver a system meeting the TTC needs while ensuring the system was built on time and within schedule.
- The TTC was involved from beginning, and hence knew what they were getting.
- TTC's involvement during all aspects ensured they were familiar with the system being provided, thus reducing training and familiarization at system handover.

10.1 Lessons Learned

Below is a list of a few key lessons learned that will be implemented on future projects:

- Manufacturers/suppliers to provide up-front familiarization training to ensure those involved have a level of understanding of both the new technology and the proposed system,
- Ensure the schedule indicates sufficient time for Principles Testing. An interlocking the size of Don Mills should a month schedule,
- Ensure schedule indicates some level of Regression Testing,
- Establish as soon as possible, a multi channel communication network that can be used from tunnels and stations and has outside phone line connection capability for use by the project team and contractors. This would improve both safety and on site production.

11. ACKNOWLEDGEMENTS

Toronto Transit Commission.

12. REFERENCES

Sheppard Line Signal Block Layout Design - SL 01 R1- June 30, 2003

Sheppard Subway - Close out Report -

13. TABLES, FIGURES, ETC.

Listing of tables and figures, etc.

Drawing	
Figure 1	TTC Subway / RT Route Map
Figure 2	Overview of Sheppard Line
Figure 3	Typical Interlocking Configuration
Figure 4	High level block diagram of Sheppard Subway Signal System showing external interfaces
Figure 5	Block diagram of typical Vital Interlocking Microprocessor-Based Interlocking Controller (VMICS)
Figure 6	Block diagram of VHLC subsystem showing serial links
Figure 7	Block diagram of panel subsystem



Figure 1: TTC Subway / RT Route Map

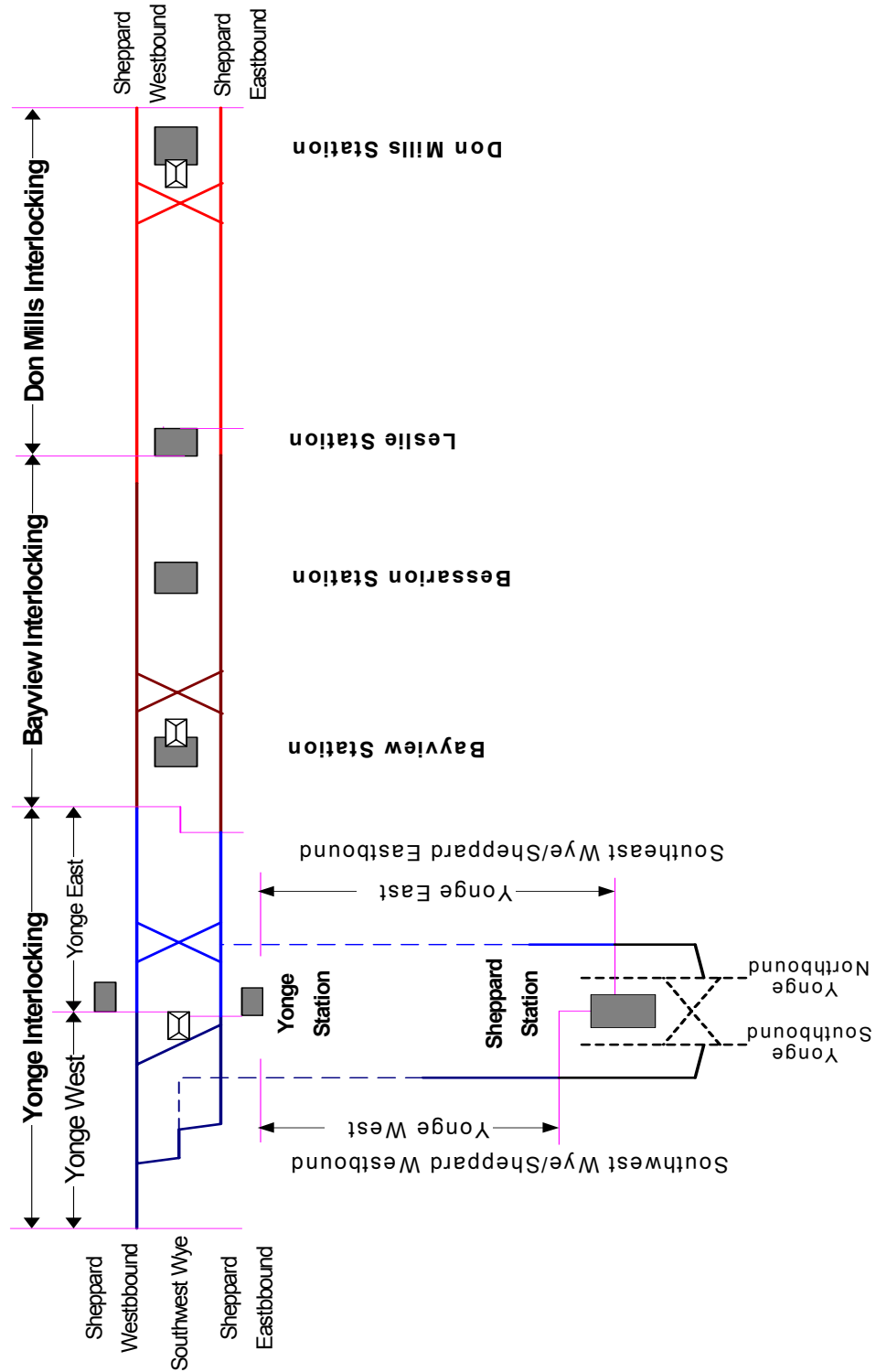


Figure 2: Overview of Sheppard Line

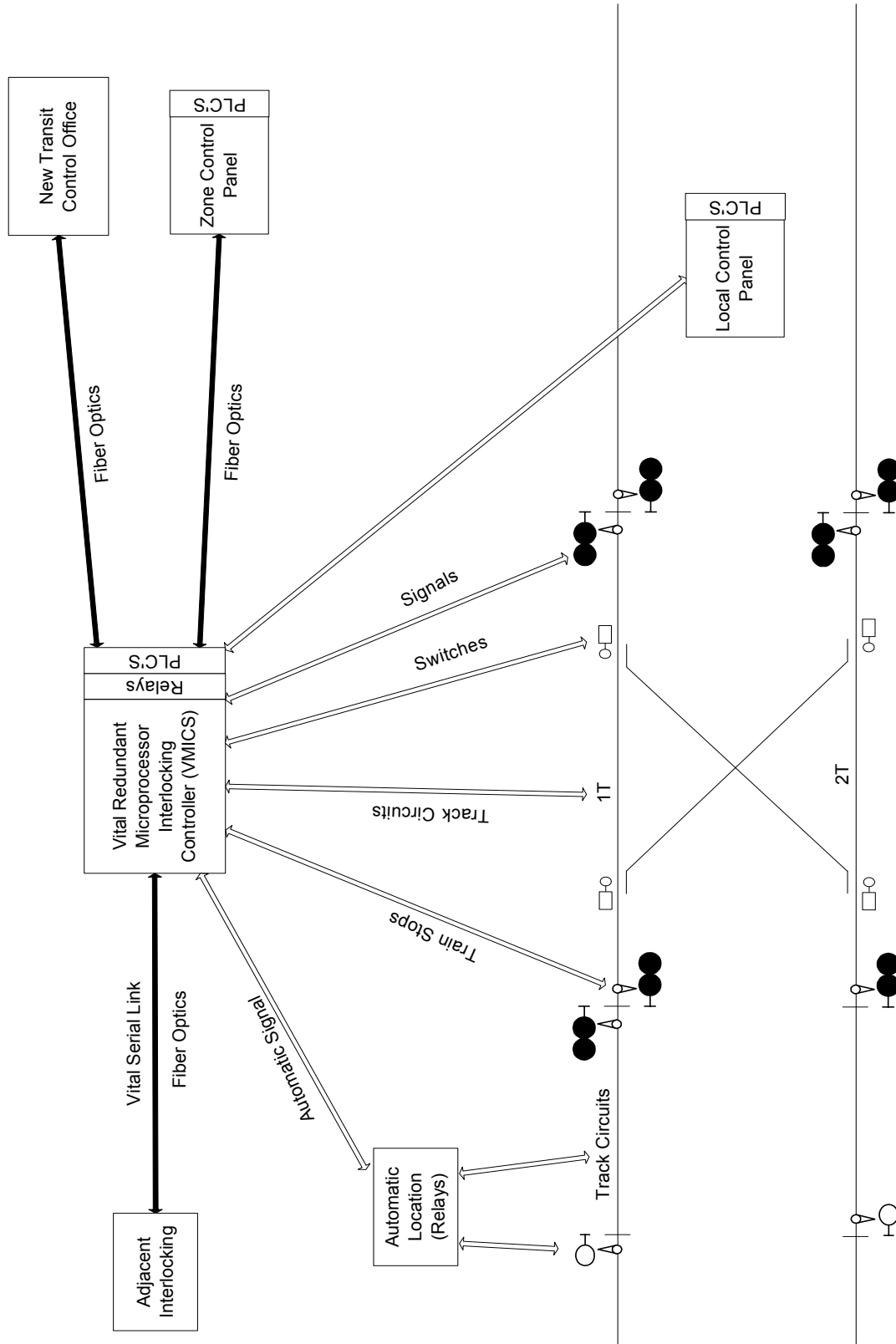


Figure 3: Typical Interlocking Configuration

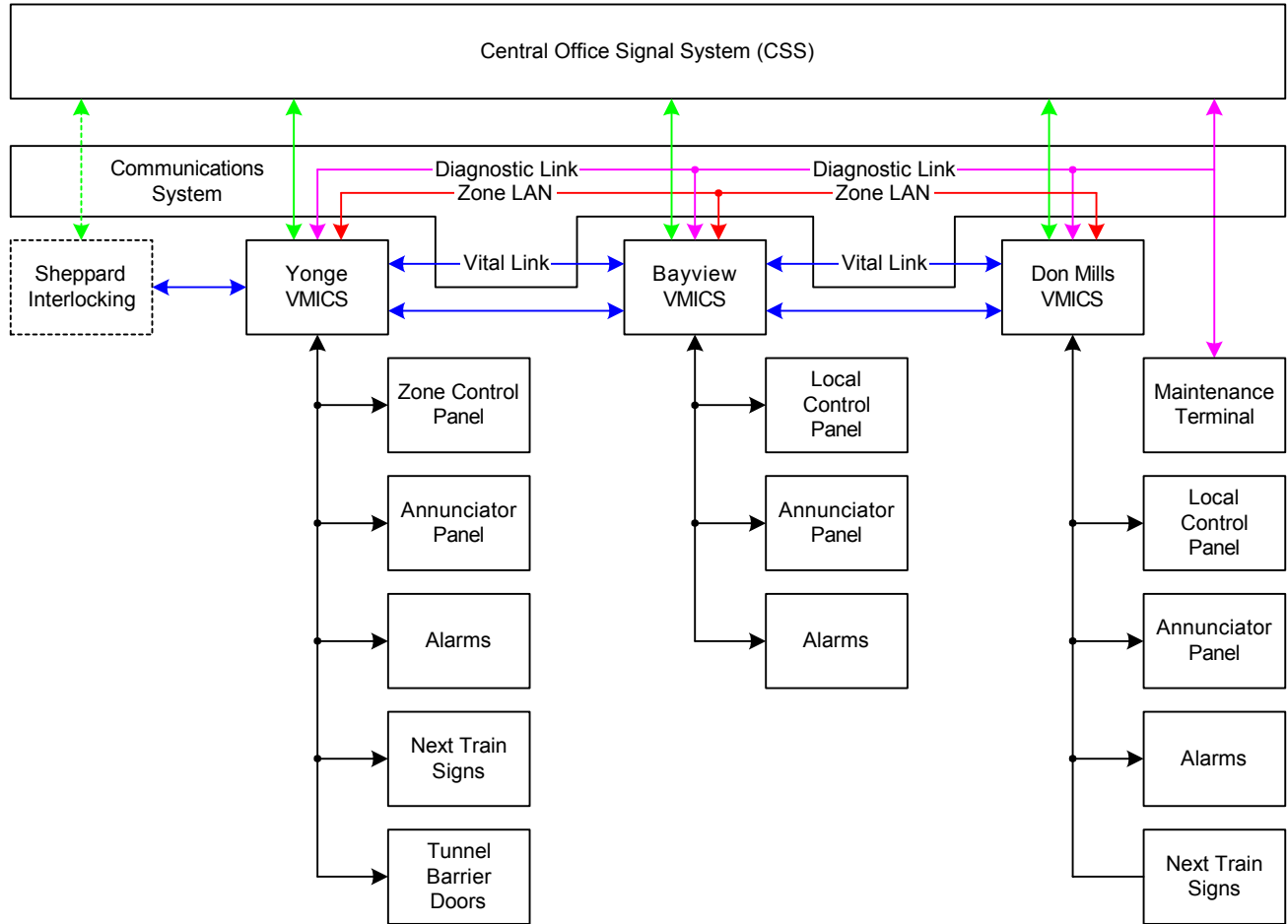


Figure 4: High level block diagram of Sheppard Subway Signal System showing external interfaces.

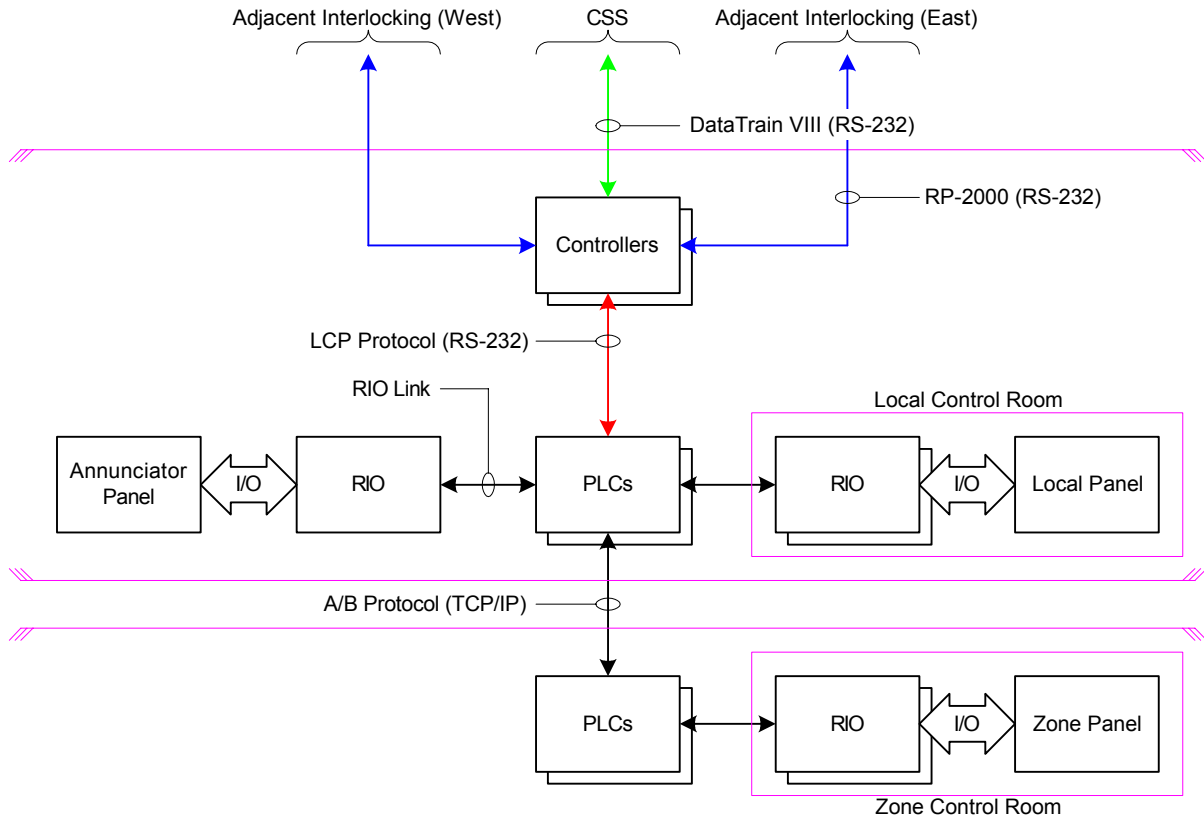


Figure 5: Block diagram of typical Vital Interlocking Microprocessor-Based Interlocking Controller (VMICS).

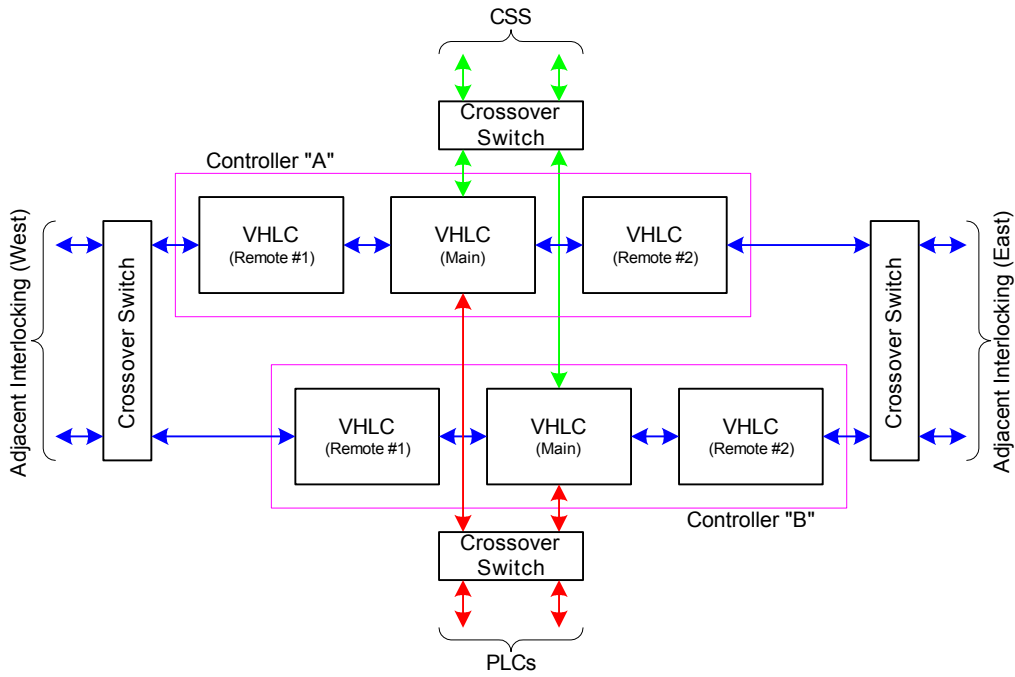


Figure 6: Block diagram of VHLC subsystem showing serial links.

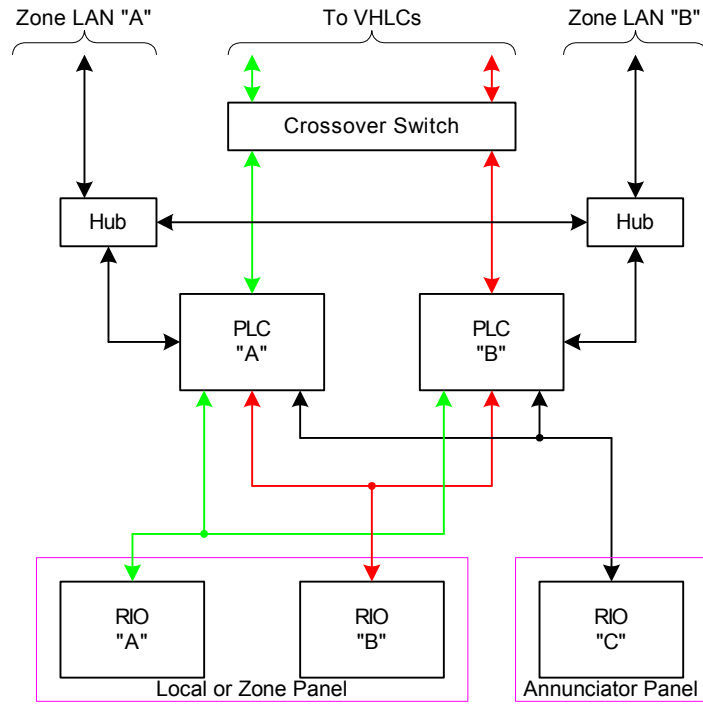


Figure 7: Block diagram of panel subsystem.