Applications Using Programmable Logic Controllers for MARTA’s Automatic Train Control System

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ABSTRACT
As Metropolitan Atlanta Rapid Transit Authority’s (MARTA) automatic train control (ATC) equipment ages and operational requirements evolve, pressure is exerted upon system engineering to create innovative solutions. MARTA’s ATC maintenance department and system engineering group, in cooperation with their general engineering consultant, Regional Transit Partners (RTP), has used programmable logic controllers (PLC), at a substantial cost reduction. This cost reduction originates from using the PLC instead of relay logic. This paper will illustrate the monetary and size economies, and the ease of installation of PLCs into existing relay applications that until recently was deemed too costly to attempt with relays alone.

MARTA recognized they were incurring sizable costs in time, manpower, and travel to the local train control rooms (TCR) when implementing exit prohibits. MARTA utilizes an exit prohibit to prevent train routing into work zones between interlockings, thus protecting workers on the track. The ATC department embarked on a project to control the exit prohibits remotely anywhere on the system from one of four workstations. Initial estimates revealed that use of relay equipment was impractical; therefore, MARTA explored the use of PLCs. Today, MARTA can adjust to work area changes spontaneously. This reduces MARTA’s and contractors’ loss of efficiency during non-revenue hours where time is valuable.

This paper will show MARTA’s successful use of a PLC to accomplish easily timer and counting routines not feasible with relay logic. MARTA’s success in supplementing existing relay logic will be discussed along with the use of PLCs to replace aged transistor-transistor logic (TTL) electronic equipment.

INTRODUCTION
The MARTA rail signal system is designed to permit the safe operation of trains using ATC over 100 mainline track miles at speeds up to 70 mph with design headways of 90 seconds. The combination
of safety and speed is necessary to provide marketable rapid transit service to the system’s riders. Thus, the ATC system functions involve equipment for carborne, wayside, and Central Control. An ATC system is employed to provide protection using automatic speed control with collision protection at 34 interlockings. Manual intervention is provided for the operator to control the train with minimum impact in system performance.

In 1979, MARTA began operations with a new ATC system. MARTA selected non-vital electro-mechanical relays for the subsystems requiring non-vital signal equipment, which was, at the time, deemed “state of the art.” For the automatic line supervision (ALS) functions, electro-mechanical relays were chosen for non-vital relay logic and TTL integrated circuits were employed for digital logic equipment. However, shortly after MARTA’s selection of relay logic, the train control equipment suppliers introduced microprocessor-based equipment. The microprocessor equipment reduced the size of a large relay-filled cabinet, or sometimes several cabinets, with complicated internal wiring and interconnecting cabling. Reliability for microprocessor equipment had yet to be proven; thus, MARTA adopted a “wait and see” perspective to observe the development of reliable microprocessor equipment to avoid having the system’s riders inconvenienced with service disruptions. In 1996, MARTA took the step to use non-vital microprocessor-based interlocking (NVPI) equipment at new locations. MARTA found it to be very reliable. Since then, the practice of specifying NVPI equipment has replaced the use of non-vital relays for new locations. However, to retrofit the existing all-relay control equipment could not justify the wholesale system conversion to microprocessor equipment within the estimated lifespan of the relay control equipment. Another consideration was the relay control equipment matured with few failures. Additionally, these NVPI systems are very expensive and with limited funds, MARTA could not afford to replace ALS equipment and all the non-vital interlocking relays already in service. Ironically, the non-vital relay replacement has now become cost prohibitive. The original equipment manufacturers have outsourced or eliminated the sales of the non-vital relays used on MARTA. Understandably, from the
supplier’s perspective, the emphasis is to market solid-state microprocessor equipment in the 21st century.

As this situation developed, the train control equipment was not the only equipment that aged. MARTA found that between replacing aging equipment and upgrading to new standards, such as ADA requiring tactile strips along the platform’s edge, more and more contractors required access to the trackway. MARTA had eighteen months of concrete tie replacement that required work not only during the meager amount of two hours per night of non-revenue service but also four more hours that followed the evening rush hour. MARTA found itself in the situation where the hours leading up to the end of revenue service and contractor’s work areas needed to be coordinated.

In early 2000, two incidents resulted in three fatalities from rail car accidents involving personnel working on the tracks. A complete transformation of the procedure for wayside access resulted adding flag persons who sequenced a series of colored flags to inform the train operator of the need to reduce train speed or stop to ensure the safety of workers. When a section of track between interlockings was required to be taken out of service to facilitate the work; traction power outages, track blocking, and exit prohibits were required to prevent train movement into the work area.

In the mid 1970’s when the train control system was conceptualized, functions called “route prohibits” and “exit prohibits” commands were devised. The former control originates at the Central Control facility. With a “route prohibit” implemented, if any routes were to be established that originated from the field, the route request would be cancelled immediately with a command from the Central Control computer. It was recognized immediately that this method could not ensure adequate protection of work parties in the event of computer failure or the dependability of the data transmission system between Central Control and the field location. This decision resulted in the use of the “Exit Prohibit” field function. This function was implemented exclusively in the TCR at each
local site. It was probably never conceived that this function would be exercised on a nightly basis at multiple locations.

With this change in the safety procedure, the night shift of the ATC Maintenance department was transformed into a service organization with a primary task of implementing and removing exit prohibits. This activity robbed labor resources that resulted in the suspension of periodic maintenance schedules for the ATC equipment. Logistically, the area of work covered 48 miles of track and 38 stations of the rail system within a circle with a radius of approximately 14 miles around metropolitan Atlanta requiring navigating a network of roads as shown in Figure 1. Demand for the start of revenue service required multiple exit prohibits to be removed at multiple locations simultaneously at 4 o’clock in the morning. However, there were not enough workers or vehicles to accomplish the removals and work progress suffered.

**Figure 1. System Map**

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For fiscal year 2002, the ATC Maintenance Department expended $368,225.00 for maintainers to perform exit prohibit tasks. There were more related costs including the vehicle expenses, the coordinator and manager’s expenses, and the loss of efficiency cost to the MARTA and contractors.

CONCEPT PHASE

It was recognized by the ATC maintenance department that this effort could not continue due to the resource and financial burden. ATC maintenance formulated the idea of the remote control of the exit prohibits. Analogous to the ability of clearing and canceling signals from Central Control was proposed for exit prohibits controls. “But at what cost?” was the question.

ATC maintenance called upon the MARTA’s system engineering department and its general engineering consultant, Regional Transit Partners, to team together to devise a solution. RTP is a joint venture among Parsons Brinckerhoff Quade & Douglas, Inc.; Turner Associates/Architect and Planners, Inc.; H.J. Russell & Company; and Parsons Transportation Group, Inc.

In conceptualizing the method of remotely implementing and removing exit prohibits, an increased degree for the control bit’s integrity of data transmission system (DTS) was required to remove an exit prohibit. This was not the case for the implementations of an exit prohibit command since a false control bit output from the remote terminal unit (RTU) would only be a nuisance. However, an errant control bit for the removal of an exit prohibit would result in an increased danger to a work crew. It was acknowledged that the exit prohibit was only one of multiple safety barriers for the protection of work crew. The use of flagging, portable trip stops, and traction power outages are used as methods of precautions in concert with exit prohibits. From years of observation, it was not outside the realm of possibility that the failure mode of the DTS could result in an output of multiple control bits from the RTU. First, we entertained the method of simultaneous parallel control bits, but realized that this only increased hardware requirements with a very small integrity increase with the known failure mode of a DTS failure.
Second, two control bit outputs at a discrete pulse width within a specific time period was considered. The team determined the likelihood that a DTS failure of the aforementioned type to be extremely unlikely, so we proceeded with design. Thus, the removal of an exit prohibit would have an algorithm of two sequential bits of a defined width within a specific time window. The implementation of an exit prohibit would remain the traditional one leading edge output pulse because, as mentioned previously, a failure would only result in a nuisance and not affect safety. To summarize, we wanted to maintain a traditional design with a change only to fulfill the need of increased integrity for the removal of an exit prohibit.

**ENGINEERING PHASE**

Next, the challenge to engineer the concept of using a traditional method of installing changes into a non-vital relay system presented itself. However, it quickly became evident that the exclusive use of relay logic would require a number of relays far exceeding the 10 percent vacant space within relay modules that originally was planned for minor improvements. Now we knew to investigate the use of a PLC. See Figure 2.

*Figure 2. A picture of a PLC with non-vital relays*
**What is a Programmable Logic Controller?**

A programmable logic controller (PLC) is a device that controls processes electronically. General Motors’ Hydramatic Division began development of a PLC in 1968. During the shutdown between the yearly car model changes, costly wiring and equipment modifications were required for the relay-based control system. GM specified a solid-state device with the capabilities of a computer, yet easily programmed by factory engineers and technicians.

In 1969, the first installation was an immediate success since they were built for hazardous industrial environments and their use spread to many industries. The ease of retrofitting to meet changing needs brought smiles to the faces of industrial engineers.

Industries requiring the high speed monitoring and control of a process embrace the use of a PLC. Beverage and food packaging industries use PLC in conveyor belt manipulations, container presence sensing, full level detection, and counting of product. Highway traffic signals and parking lots use PLCs for the multiple timing and counting algorithms. Pipelines, water, and wastewater facilities use PLCs for flow detection and regulation. Airport baggage handling is accomplished with PLC usage.

**Why Use a Programmable Logic Controller?**

- Vacant rack and module space to add non-vital relays was constraining for the magnitude of the modification for this particular project.

- The ease to familiarize oneself with the programming of a PLC.

- Off-the-shelf PLCs were very attractive from the cost perspective; only two or three hundred dollars. Whereas, just one non-vital relay that has been used for years on MARTA now sells for over three hundred dollars.

- The agreed upon exit prohibit algorithm required a complex logic arrangements including counters and timers that would challenge all relay logic to the extent that the hardware requirement would quickly become cost prohibitive.
• The microprocessor based interlocking control equipment is applied to installations with a considerable amount of inputs and outputs (I/O) make it more economical than the use of relay logic. PLC’s can append to a relay logic assembly inexpensively by simply inserting a compact electronic device.

• The simplicity of the installation of a PLC, see Figure 3.

![Figure 3. A close-up of the installation of two PLCs](image)

**How to select a Programmable Logic Controller**

• First, the point of interface between the PLC and the non-vital relays needed to be defined to limit the amount of wiring between the PLC, the relay module, and the DTS rack. In the case of this modification, to add the capability of remote exit prohibits, the DTS would directly output to the PLC as an input. Conversely, it was decided to output directly from the PLC to non-vital relays housed in the relay module. This minimized external wiring in numerous non-vital interlocking circuits and local control panel and Central Control indication circuits.

• The amount of spare control bits originating from the DTS unit was evaluated to verify the capability to apply and remove an exit prohibit for every controlled signal. In this case, the original spare requirement was sufficient.
• A choice of a partial list of brands and manufacturers of PLC include:
  • Allen-Bradley of Rockwell Automation
  • Modicon of SquareD
  • SIMATIC of Siemens
  • OPTO 22 of Advanced Control Solutions

• Next, the amount of inputs and outputs (I/O) were required to be defined. It was discovered that the Allen-Bradley® product used for the initial application for automatic train destination station announcements could be programmed for the exit prohibit application. Because the number of interlocking signals varies at the 34 locations, two units could be parallel configured at an interlocking with a large number of signals. Thus, the Allen-Bradley® Micrologix™ 1000 Programmable Controller was selected for its three versions of digital I/O configurations and its low cost.

How to design with a Programmable Logic Controller

• First, the Central Control workstation software was modified to add the “exit prohibit” command that would pulse the DTS to the location with a double pulse for the removal and a single pulse for the prohibiting of an exit. This was accomplished by ALSTOM Signaling as a modification to an existing contract while being managed by MARTA’s GEC, RTP. This followed RTP’s effort to define the control bit points in the array of existing controls for each interlocking location.

• Next, RTP engineers simultaneously designed the application interface circuits and learned to program the PLC. RSLogix 500™ ladder logic in the Microsoft® Windows® format allowed for a quick learning curve. What was exciting about programming was the versatility of using counters and timers from our perspective as relay logic designers. Latched outputs and bit registers simplified a complex process when using relay logic. This flexibility included easily queuing an output on the trailing edge of the second pulse.
• The ease of learning to program a PLC is that your desktop computer can be used and configured to communicate directly to a PLC. This allowed simulating inputs while the RSLogix 500™ software displays the dynamics being executed in real time, giving the necessary feedback to run and troubleshoot your program spontaneously.

• One location was selected as a prototype and the design was detailed and installed by the team of MARTA ATC maintenance, MARTA system engineering, and RTP. The results were a success. But, then the real work began.

INSTALLATION PHASE
During the months after the successful test, business cases and analysis were presented to justify the cost of a systemwide change. When the cost saving were presented and the problems of implementing and removing exit prohibits locally at the TCR continued, the following year’s budget included the funds to finish the project. Now, the invigorated team increased the scale of the project. The team was looking at 33 more interlocking locations with varying amount of signals. The limited budget required us to continue the process with the team intact rather than contracting outside resources. Even if it were financially possible, a contract would be impractical to create and time-consuming to manage. “Time and money were a’wasting.”

How to Install a Project with a Programmable Logic Controller
• Now the work turned into a production line, of sorts. RTP engineers evaluated each location’s design for the availability of empty relay space within existing relay modules and racks.

• The PLCs were procured and it was determined that the unit would be programmed with a generic program. This meant that groups of inputs and outputs were assigned to full capacity of the PLC; however, the interface would be customized for the number of signals at the
specific interlocking location. This allowed spare PLCs to be preprogrammed and stored, thus the PLC could be replaceable by technicians without customizing the software.

- With this information, RTP began designing with detailing following closely. Fortunately, the benefit of specifying spare space requirements paid off from all the previous contracts that provided the ATC equipment.

- Train control equipment that was retired from line extensions was rehabilitated and reused. This equipment was obtained due to an end of the line interlocking location acting as a terminal became an emergency crossover location. More than 150 unused and deteriorating relays and some multi-conductor cables were rehabilitated.

- As design and detailing continued, ATC Maintenance began the installation for the initial locations. ATC Maintainers began the process with a pre-programmed PLC, mounting hardware, wire, and wire tag lists.

- Any installation problems encountered by ATC Maintainers were responded to immediately by RTP Engineering to keep the work progressing.

- Once installation was completed, the testing began with a breakdown test of the TCR wiring followed by an integrated test with a workstation at the ATC maintenance office that emulated Central Control.

Within nine months, all the locations with relay logic were completely wired and tested and the five locations with non-vital microprocessors had their application software modified to include remote control of exit prohibits.

Now the commissioning of the remote control of exit prohibits was proposed to MARTA operations department. However, the implementation into the safety practices required the ATC maintenance department to continue to act as a set of check and balances. This resulted in the ATC maintenance department retaining the responsibility of controlling exit prohibits. Now, the ATC maintainer has
the versatility to control exit prohibits remotely from any of the multiple workstation locations around Atlanta. Their sole attention can be focused upon implementing and removing all exit prohibits. Whereas, previously the ATC maintainer only responded to directions from operations with a very limited viewpoint standing in front of a local control panel; now they team up to be fully involved in maintaining a safe work environment throughout the system for fellow workers and contractors.

When the project was complete, the actual cost was calculated to be $383,763.00. Prior to this project, the annual expenses estimated to implement and remove exit prohibits having maintainers travel to the TCRs was $368,225.00. This was almost a one-year payback! It was further estimated that at least one maintainer’s labor costs was saved, therefore, allowing the attention to be returned to the required and sorely needed periodic maintenance.

ANOTHER BRIEF CASE STUDY

As mentioned in the background, initially TTL integrated circuits for digital logic equipment were recommended for automatic line supervision (ALS) equipment. But recognizing the technology is far beyond its expected life, not to mention the components, MARTA maintenance discovered replacement of printed circuit boards (PCB) was impossible: repair, the only remaining option, was very expensive. Therefore, RTP engineering investigated the use of PLCs and selected the ALS Route Decoder module as a candidate to replace with a PLC. The term “module” means a 19 inch wide, 9 inch high, and 12 inch deep unit filled with almost twenty small PCBs with only a couple of components. See Figure 4. Thus far, those components are reliable, but expensive to repair. To repair two of those boards equaled the cost of a new PLC. The PLC was much smaller in size and weight as compared to the module; even though it is nicknamed “a brick” for its size only, not weight.
The route decoder does exactly what its name implies. Simply, it decodes a destination code input communicated from train to the TCR’s interlocking logic to route the train for an upstream divergent route. Of course, there are more checks required to protect against false routing. This increased in complexity the programming of the PLC.

As with the exit prohibits experience, the ease of programming and active troubleshooting the programming problems were very advantageous. With an active PLC communicating to one’s desktop computer, practice by trial and error, along with referring to a comprehensive user manual, allows for a high confidence level when commissioning the PLC in the field. Now, new instructions needed to be used rather than the simple counters and timers used with the remote control of exit prohibit programming. A series of instructions is referred to as data handling and the input of the two-digit destination code now required BCD to binary conversions and comparisons to be completed to ensure a valid output. While this routine was performed, a sequence check was made to validate train direction and input information.

Presently, a PLC, programmed as a route decoder, was operational and going through reliability demonstration testing. In the event of a failure of any original route decoder, MARTA has the ability
to replace it with a PLC rather than continue procuring expensive TTL logic chips to repair aging printed circuit boards.

![Figure 5. A picture of a Local Control Panel with a PLC below](image)

**Figure 5. A picture of a Local Control Panel with a PLC below**

We are continuing the use of PLCs by beginning an investigation using a PLC that remotely controls the full range of the functions of the Local Control Panel, Figure 5. This initiative expands our versatility of PLC by using these units that can easily be adapted into existing communication networks. This allows for a cost effective redundant system paralleling the aging Data Transmission System. In a different vein, MARTA continues to contemplate the replacement of aging non-vital ALS equipment.

**BRIEF OVERVIEW OF NON-MARTA APPLICATIONS**

The railroad and transit industry has recently discovered the value of the PLC. The vital type of PLC is being use in switch point detection by Norfolk Southern and a drawbridge control system by the P&L Railway. Transit properties, such as Chicago Transit Authority and Toronto Transit Commission, use non-vital PLC’s communication ability to use fiber instead of costly multiconductor copper cable to connect a remote control panel to the equipment facility. This allows remote control
from an adjacent station or platform supervisor’s booth. Bay Area Rapid Transit in San Francisco has a sequential occupancy detection system that uses PLCs to relay information to Central Control. New York City Transit Authority has adopted exclusively the PLC for non-vital logic applications.

CONCLUSION

The elements that brought about success for this project were:

- Vision
- Imagination
- Communication
- Innovation
- Coordination
- Tenacity

To clarify, when there was dissatisfaction that things were not working as well as they could, one person had a vision there could be a better way. It continued with communicating this vision to a team with years of experience. The team moved forward with the idea utilizing their combined experience and intelligence, respecting the talent of individuals while working cooperatively. Consequently, they were able to finish the project without any doubt of success.

When we began, all the team knew about PLCs was how to spell it, but that did not deter us from learning to use a PLC for problem solving. We found that the versatility of a PLC allows use for a multitude of applications. The project was completed with the as-built drawings being drafted by RTP and incorporated into the Book of Plans by MARTA.

ACKNOWLEDGEMENTS

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solidified into reality. We also wish to thank those technicians who worked performing the wiring for the first time with the blind faith that their labors would have results.

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