ENPH 479

ENGINEERING PHYSICS PROJECT LABORATORY

THE UNIVERSITY OF BRITISH COLUMBIA

PROJECT VOLTA - FEASIBILITY ANALYSIS FOR THE IMPLEMENTATION OF AN AXLE COUNTING SIGNALING SYSTEM ON AN ALLEN BRADLEY PLC

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Project 1870

Project Sponsors: SNC Lavalin & Frauscher Sensor Technologies

January 5, 2019

Executive Summary

As SNC-Lavalin looks to expand its services and presence in the western rail and transit industry, the signaling team in Vancouver is working with Frauscher Sensor Technologies to develop a new standalone product for the market. Train signaling in North America is reliable, but could be improved upon greatly. We are leveraging Frauscher's state of the art axle counter technology to create a train signaling system that will outperform the current signaling methods and reduce required wayside equipment and maintenance.

There is extensive infrastructure and experience with Allen Bradley programmable logic controllers (PLCs) within SNC-Lavalin. Therefore it was desireable that we attempt to create a solution that utilized this technology. Our main goal in this phase of Project Volta was to determine the feasibility of interfacing the Frauscher equipment with such a PLC. Two subsections were investigated: the ability to communicate information from the Frauscher systems to the PLC, and the design of an interlocking for testing the communication.

The communication between the Frauscher equipment and the PLC has been broken into two sub-processes. Information through the Frauscher protocol is read through a socket and decoded with an iOS app. The status of track sections and axle counts are displayed on a UI and recorded in a database. Communicating this information to the PLC is still in progress.

We developed a program for a mock interlocking of a main line and two sidings. This program runs on the PLC hardware and only requires the inputs from the Frauscher equipment. With further progress in the communication subsection, we will test in real time the functionality of this system.

In the summer of 2019, we want to have a prototype that can be implemented as a ghost signaling system for a railyard. There are several possible locations for this test build such as the Canada Line storage yard and the Rocky Mountaineer storage yard. This system will perform signaling duties in parallel with the current system without actually controlling train movement.

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INTRODUCTION

Who are the Sponsors?

SNC-Lavalin is a multinational engineering company involved in various disciplines. The rail and transit division provides consulting services, project design and scheduling to railways all over the world. Their services, however, are non-physical. This means that they do not provide construction or other physical implementation teams. These jobs are outsourced and are provided for in their designs. The interest in this specific project is to create a product line purchasable from SNC-Lavalin. This will open up new profitable avenues for the company in the future.

Frauscher Sensor Technologies is a high tech sensor developer for the railway industry. With large success in the european market, they are seeking to break into the North American market and demonstrate the impact their products can have in safe and efficient railroads. Their interest in the project is to develop that recognition with SNC-Lavalin.

Background

Railroad signaling systems are all based off the same idea. We must know the location of all trains on the railroad. A simple enough concept, however when we think about it in terms of the scale of railroads across the planet it becomes infinitely more complex. The idea of a track circuit beautifully simplifies the processing power required to monitor a railway. With this design, we can parcel the railroad into sections of arbitrary length. With heavier traffic areas, we create more track sections and with lower traffic we can spread the track sections out and reduce the necessary infrastructure.

With this method, we give up the ability to perfectly fit trains together as a string of vehicles would do on the road. However we gain safety. Trains are unable to perform the same maneuvers as smaller vehicles and thus we must maintain safe distances between them at all times. Referring to figure 1, we also notice the fail-safe property of the track section. If the track relay is not energized, we assume the presence of a train in the section - which is the safest assumption to make. A train cannot enter a track section if the section is *occupied*.

The track circuit idea spans the entire rail and transit industry. The implementations are what differentiate methods. In North America there are two alternative train detection

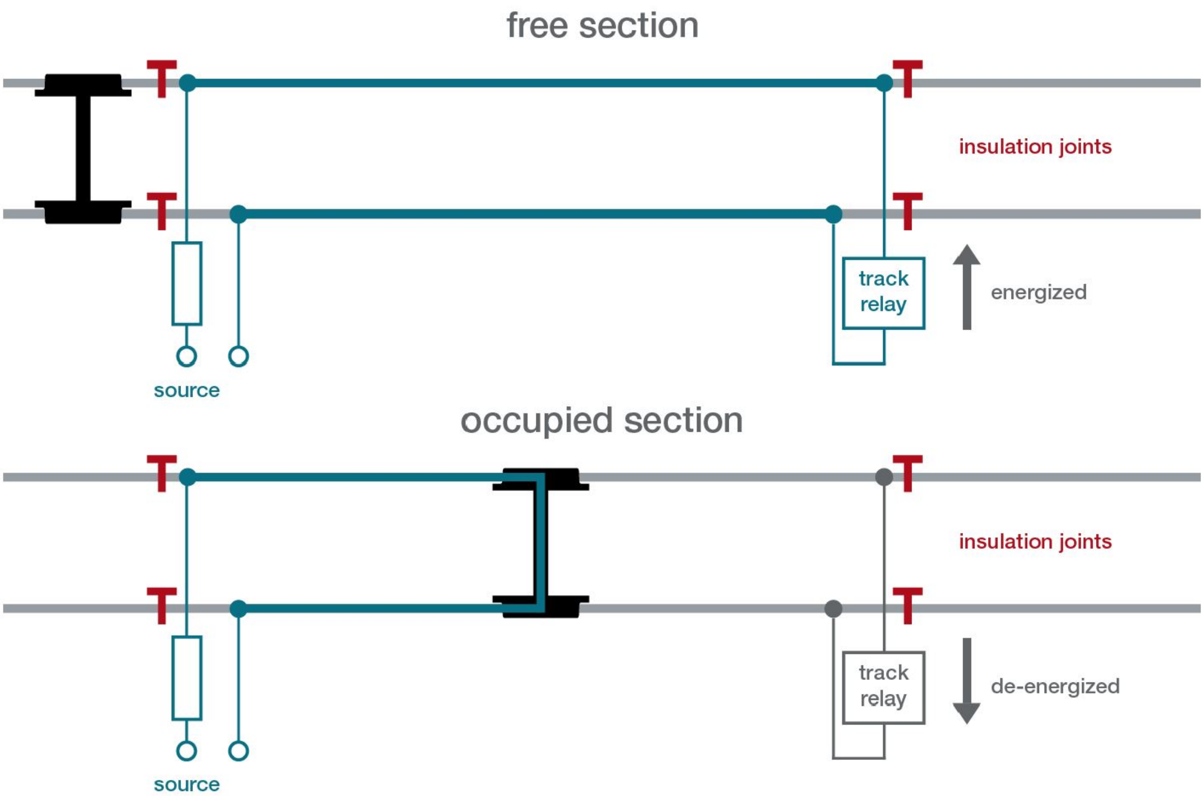


Figure 1: Concept for a track relay monitored track circuit. In the above track, the train axle has not entered the track section and the track relay is picked up. This demonstrates the absence of a train in the section. In the lower track, a train axle has entered the track section and shorted the track relay. This de-energizes the track relay demonstrating the presence of a train.

methods to axle counting worth noting: track relays and phase shifting. Track relays are implemented in the exact way figure 1 displays them. A potential is placed between the rails and a relay monitors this potential. Phase shifting is a bit more involved. Two cables run parallel to the track and transmit information to a train. At a specified interval, the cables will cross causing a 180 degree phase shift in the transmitted data. The train can then determine how far it has moved based on the number of phase shifts observed.

Track relays are a suitable solution for large railways with a low traffic density. We can cover kilometers of track with one relay and minimize the system complexity. However, this requires a proportional amount of wiring to the track length covered. Phase shifting is appropriate for light rail transit systems in busy cities like Vancouver. We create a *moving* track section about each train that can be as short as tens of meters. However, this is an unsuitable approach for large scale railways. Axle counting is a happy medium between these two systems. Using a mechanism that counts in or out train axles, we can determine the occupancy of a track section. The modularity of Frauscher's system allows the sensors to be densely packed together or spread widely. They also chain together to reduce required wiring and can hook up to communication hubs along the railroad. A general comparison is shown in table 1.

method	**Axle Counting**	**Track Relays**	**Phase Shifting**
best performance	mixed densities	low density (heavy rail)	large density (LRT)
relative cost	moderate	cheap	expensive

Table 1: Comparison of train detection methods prominent in North America. Their strengths and costs in broad terms.

Objectives and Report Breakdown

Our goal is to determine the feasibility of implementing an axle counting system in various rail and transit environments using an Allen Bradley PLC as the controller. In this respect there are two main factors that we want to understand before investing in this venture. Namely, we want to know the relative difficulty of interfacing the Frauscher equipment with the PLC as opposed to other logic controllers. This is due to the experience SNC-Lavalin already has with this system. We also want to know how expensive implementing this solution will be.

The underlying feature to our entire discussion is safety. Any design decision we make in the rail and transit industry must be to preserve safety on the railroad. We have chosen to prototype for a railyard due to the reduced human factors. There are no passengers in the yard, but there are workers. With this in mind, throughout the document I will note critical components to the design and their fail-safe status.

In the following discussion, I will walk through all the components in figure 2. This figure represents the project architecture and how our design interfaces with the physical track and the Frauscher equipment. The parts in blue and green represent the communications and interlocking components of our design, respectively. I will then discuss the tests we performed with the system and the results.

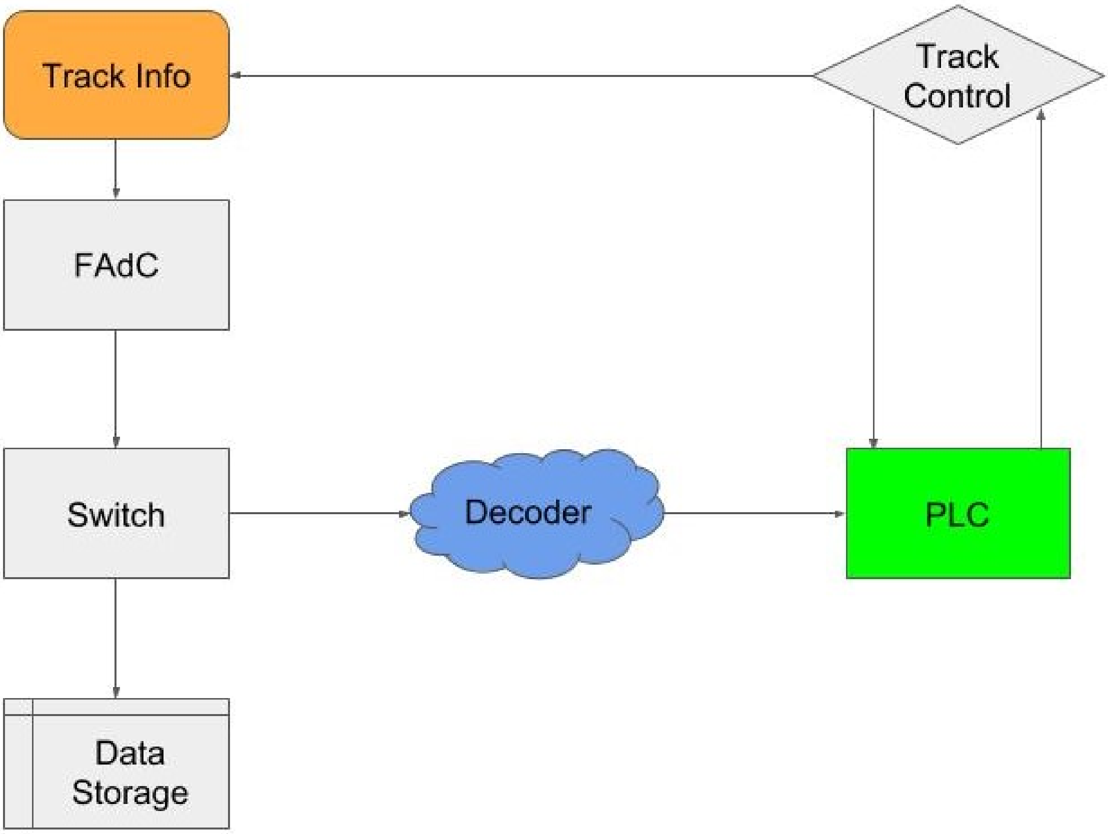


Figure 2: Block diagram for Project Volta. Track info is obtained from the axle counters in the chosen topology. This raw data is processed by the Frauscher Advanced Counter (FAdC) and the data stream is split with a network switch. The data is stored for redundancy and testing as well as decoded by our iOS app. The data is reformatted into a protocol understandable by the PLC. The PLC uses the information from the axle counters as well as from track control (switches, aspects, etc.) to control the interlocking.

Discussion

Track Info

For the feasibility study, we have chosen the topology shown in figure 3. This provides a suitable framework in which to test the prototype. With several routes for trains to take and be stored in, we can test safety scenarios similar to those which would occur in a railyard.

The double siding topology contains four switches, eight aspects and eight axle counters. There are two switches in the red section and two in the yellow section where the track

Figure 3: Railway topology for Project Volta testing. This consists of a main line ZP1-ZP2-ZP7-ZP8, and two sidings ZP1-ZP3-ZP6-ZP8 and ZP1-ZP4-ZP5-ZP8. Each colored section is a track section and train crossings are detected by the axle counters (ZPx).

diverges. The eastbound aspects are positioned at the entrance to the red section and at all three entrances to the yellow section. Similarly, westbound aspects are positioned at the entrance to the yellow section and at all three entrances to the red section.

The control and monitoring for the switches and aspects is performed through the track control subsection. The axle counters are monitored by the Frauscher Advanced Counter (FAdC), which is the next block in the system sequence. These counters detect the traversing of a train axle and can determine direction, velocity and wheel diameter among other diagnostics of interest. We can see an example of the mounting of one of Frauscher's sensors in figure 4.

Figure 4: Frauscher RSR 110 axle counter. Using a rail claw, the sensor is positioned close to the rail and uses the disturbance in its magnetic field by train wheels to detect crossings.

With these systems in place we can safely divide the topology into the colored sections shown in figure 3. Each axle counter monitors traversings between the neighboring track sections. The layout of the railway topology and how we control it sets up the reason for which this study is necessary. Had we used track relays, each track section's occupancy status would be monitored through the track control subsection. By introducing the new train detection method we must interface it with the systems that control the rest of the track equipment.

Frauscher Advanced Counter

The FAdC is a computer that is custom designed for specific projects by Frauscher. Ours was programmed for the figure 3 topology and its backplane has eight axle counter inputs. Each input is tied directly to a specific position on the railroad. These systems can be reprogrammed but are not meant to be.

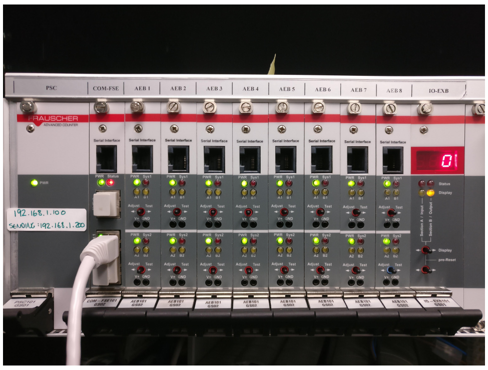


Figure 5: Frauscher Advanced Counter (FAdC) programmed for project Volta. It consists of (left to right) a power supply, communication board, eight evaluation boards (AEBs) and an I/O extension board. Individual track section counts can be monitored via the display on the right for testing purposes. Each board can host a single sensor and evaluate two track sections. Data from each AEB can be individually sampled via Ethernet hookup.

There are two toggles on each AEB corresponding to the two track sections it is evaluating. These toggles can be used to induce axle counts in each section using the sequences shown in figure 6. We were supplied with two real axle counters, therefore we were able to use a mixture of physical crossings and simulated crossings to perform tests.

For our purposes, we are only interested in the occupancy status of each track section. This information is obtained from the communication board and is SIL4 vital which means that it is fail-safe. The occupancy status - among other diagnostics - is fed to a network switch which splits the data stream for the downstream system components. The first is a data storage unit the Frauscher Diagnostic System (FDS). The FDS stores the data from the FAdC in xml format. This is useful because we were able to perform a series of traversings and store the information on the FDS, then look through the data and replicate the same conditions on the PLC. As our communications system progresses this was a useful tool to get testing started.

FAdC Toggle Cheat Sheet				
←	Toggle Left			
→	Toggle Right			
○	Release Toggle			
Sim. Traversing (Sys 1 > Sys 2)				
Top	→		○	
Bottom		→		○
Sim. Traversing (Sys 2 > Sys 1)				
Top		→		○
Bottom	→		○	
Set Coding				
Top	←	→		
Bottom			←	→
Voltage Adjustment				
Top	←	○	→	○
Bottom	←	○	→	○
Reset A1 Section (AEB)				
Top	←		○	
Bottom		→	○	
Reset A2 Section (AEB)				
Top	→		○	
Bottom		←	○	
Reset A1 Section (IO-EXB)				
Top	←	○		
Bottom	←	○		
Reset A2 Section (IO-EXB)				
Top	→	○		
Bottom	→	○		

Figure 6: Toggle sequences for changing the status of track sections evaluated on the AEB.

Decoder/Communications

The necessity for the decoder and communications subsystem derives from the usable protocols with the FAdC. By default, the system uses the Frauscher Safe Ethernet (FSE) protocol. There are several other protocols that the FAdC can support, unfortunately none of them are suitable for the Allen Bradley PLC. With help from Frauscher, we were able to deconstruct and understand the bitstream coming from the FAdC.

As we said earlier, we are only interested in the occupancy status for track sections. This information is stored in two bits at specific locations in the stream. First we need the direction of travel across the sensor and the detection of a train crossing. Using a custom iOS app, we read the FSE message through a socket and parse through it for these bits. We translate this into occupancy statuses for each track section and display it on a GUI. In order to relay this information to the PLC we still require some more hardware and research. We can see the app interface in figure 7.

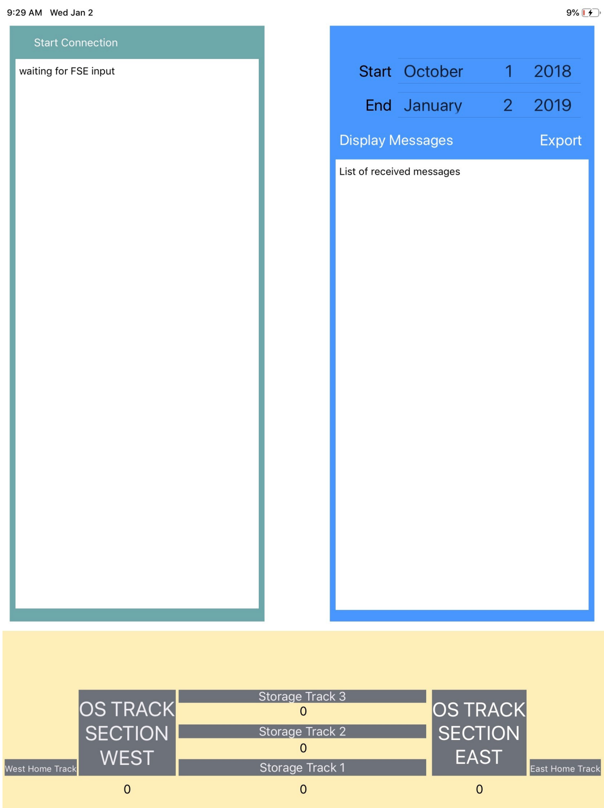
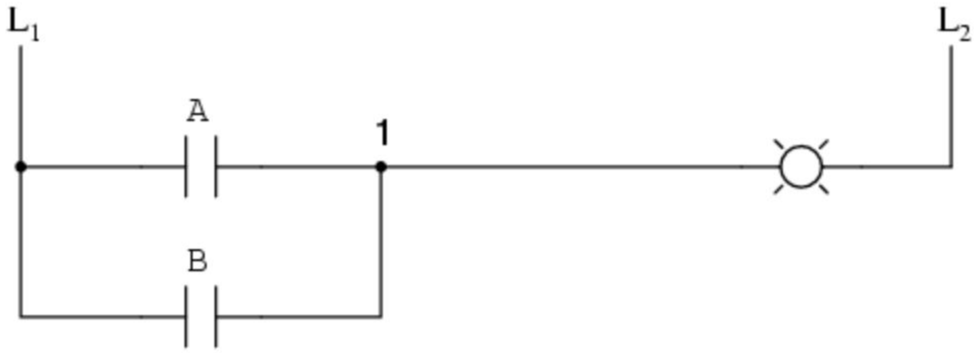


Figure 7: Screenshot of the GUI for the iOS app. Axle counts are shown below for the respective track sections and can be induced after connecting to the FAdC.

Programmable Logic Controller

Programmable logic controllers (PLCs) are found throughout every industry. These machines are useful in automating large processes and have been developed to interface with large manufacturers and standard communication protocols. Essentially, they work as a microcomputer and perform pre-programmed tasks. As we mentioned earlier, SNC Lavalin is experienced with the Allen Bradley brand of PLCs. This is why we have chosen to work with the Allen Bradley system.

The Allen Bradley PLC can be controlled with their programming software RSLogix 5000. The layout uses ladder logic to write programs which make automation of discrete processes extremely easy. This visual language uses ladder rungs to control logic functions as seen in figure 8. We can imagine the left side vertical line as positively charged and the right vertical line as ground. We must create a connection through an entire rung in order to energize the output variable - generally on the right side of the ladder.



A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

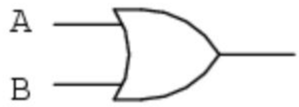


Figure 8: Ladder logic implementation for an OR gate. A and B are tied to physical inputs and when either of them are turned on the LED on the right hand side will illuminate.

The first task to tackle was to break the chosen rail topology into a system of digital circuits. We take the inputs A and B from figure 8 and tie them to the occupancy status for a specific track section. We can tie the status of each switch to an input in the program as well as any other digital information on the track. We can also tie the status of aspects and safety systems to the outputs of these rungs, and depending on the railway state the appropriate actions will be taken. An example of the program is shown in figure 9.

For example, in rung 1 in order to obtain an authorization to move a train eastbound we must satisfy several conditions. First, there must be a request from a train moving eastbound to move through the siding. Next, we must detect that the western switch is detected in either normal or reversed position. The loss of shunt timer - a safety measure we will discuss later - must be on. There must be no request to move a train westbound and the track section the eastbound train is moving into must be clear. All these considerations are controlled with this ladder. Note that we cannot route the train if the switch is not detected in either normal or reversed position. This is a fail-safe mechanism so that if the switch is left floating, no routing can be done.

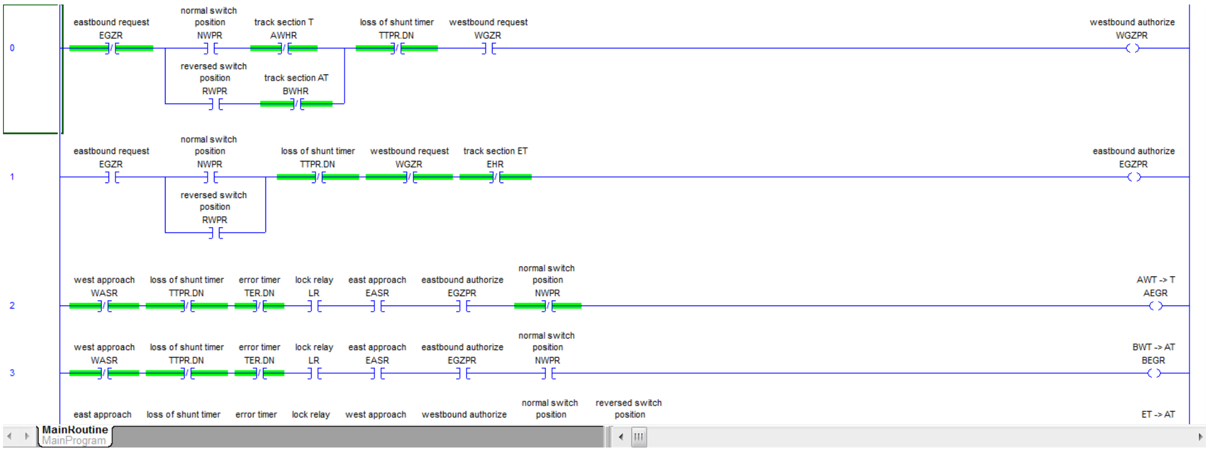


Figure 9: Several rungs from the main program. All logic functions shown on the left are tied to specific digital inputs. The symbols in green are functions that are *normally on* and have a dash through the capacitor-like symbol. All output variables are on the right hand side.

Rungs like these are used to control the authorization of moving trains, the changing of aspect colors, safety lockdowns for the railway as well as approach signals. The flow of information between the track control subsystem and the PLC provide I/O for the switches and aspects among other railway components. The input from the FAdC provides the occupancy statuses for the track section variables in our program. Without the communications subsystem fully finished, our tests were geared towards making sure that the interlocking system performed safely under all possible conditions.

Testing

Before outlining the test cases, we must understand the loss-of-shunt timer and the error timer and their purposes. The loss-of-shunt timer is a safety measure guarding against unforeseen track conditions. For example, if we were using track relays and there were some fallen leaves on the track. This would cause a loss of connection between the train wheels and the track. The loss-of-shunt timer is a 10 second timer that waits for reconnection before deaming the track section clear of a train. The error timer is a 3 minute timer that locks down the track if there are conflicting actions taken. For example if two opposing aspects are at green, this causes an unsafe scenario and the error timer will start which disallows any further action in the track until an operator can determine the issue.

We need to test that the interlocking system handles various safety scenarios properly.

These are all not fail-safe, however, as they are in software and should there be a power outage or other computer failure we cannot trust this system. These are simply tests to make sure the interlocking is working as intended. The fail-safe nature of the system comes from the FSE protocol as well as the physical implementation of the equipment.

Test	**Expected Result**	**Result**
Request to move a train East-West and vice-versa with the loss-of-shun timer energized. This simulates a train attempting to enter the railway while there is another train in the system that has recently gone undetected. 	Because we are not sure yet whether the undetected train has left the system entirely, the interlocking should not allow the routing of a train.	Success
Request to move a train East-West and vice-versa with aspects for the opposing direction at green. 	The interlocking should not allow this routing because a train coming from the opposite direction could collide with it. The train should be held until these aspects are set to red or the opposing train enters one of the sidings.	Success
Attempt to move a train through a routing with one of the switches in an incorrect position or in an undetected position. 	In our software, this should actually not be a problem. We do not make specific routes, so the software should allow this request to be authorized. The train will simply be told to move down the path the switch is set to so long as it is safe.	Success

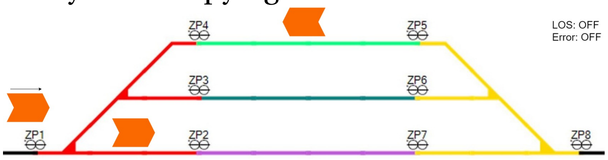
Request to move a train through the interlocking with other trains currently occupying various sections. 	Depending on the location and direction of the other trains, the interlocking will hold or allow the train to pass. In the figure, the train will not be allowed to move because there is a train in the track section it is attempting to enter (i.e. into the red section).	Success
Request to move trains from both directions through the system. 	This is okay, however the system will hold one of the trains until the other has been routed and began its traversing. Then the second will be authorized to move and they should pass each other in different sidings.	Success

Table 2: Tests performed on the interlocking software to ensure the system handles possible failures properly. A successful test creates the expected result.

Results

There two main factors we wanted to consider for the feasibility analysis: the relative difficulty and cost of implementing this idea. We have discussed much of what the project constituents are and now we must analyze whether or not the system is worthwhile pursuing further. In the following sections we will break down these two dimensions and finally make recommendations on where to go from here.

Implementation Difficulty

Individually, all components of the system shown in figure 2 work well and are easy to interact with. Over the past four months, we have had almost no difficulty in progressing with the subsystems.

First, the Frauscher system is an excellent train detection system and we have had no problems working with it. The FAdC and sensors we were supplied with were easily set up and we had the whole system up and running in about a day. This would expand to a larger system and we can imagine that setting up a Frauscher sensor network on a larger railway would be of similar difficulty in labor and hours to the competing systems.

Second, the decoder was a larger success than we initially expected. The iOS app quickly and efficiently can read and display the axle counts from the Frauscher sensors. Being able to create an app in this environment provides a lot of flexibility for future development. Unfortunately, this is not the whole picture. We are still unable to communicate from the app to the PLC. This will most likely require more hardware and more research. If a simple enough solution is to be found that can be replicated easily, then the choice of using the Allen Bradley PLC will be justified.

Last, the Allen Bradley PLC is easy to work with using the programming software RSLogix 5000. It also has the benefit that the programs are written in ladder logic which is very readable even for those without much programming knowledge. There are still competing PLCs that perform with the same relative ease, however, this would require purchasing these machines and thereby dividing the knowledge base at SNC-Lavalin from Allen Bradley only.

Relative Cost

Ideally, we will be able to solve the communication problem without the purchase of additional hardware. If this were the case, then the project would obviously recommend pursuing the interface of the Frauscher and Allen Bradley systems. However, if this were not possible and we must acquire a new piece of hardware which we can estimate to be close to $20,000. Then this purchase must reduce the amount of work required by more than that same value.

We also must consider that in expanding the project to larger railways and yards, we may require several of whatever new hardware we have purchased. If the problem can be solved in a repeatable fashion with the components we already have, then we will save a lot of capital in future deployments.

Should we pursue the avenue of purchasing a new PLC system, we will have to devote hours and finances to training employees to operate this equipment. Furthermore, Project Volta should be restarted with the new PLC and a redesign of the system architecture. This will be a large investment, however we have the benefit of the current project only costing hours. All the equipment we have used has been licensed for free and we plan to continue working with Frauscher.

Recommendations

We recommend continuing with the current state of the project. The time it will take to determine a solution to the FAdC-PLC communication issue will be minuscule in comparison to purchasing more equipment. Also, with the purchase of new equipment there will be more time required to learn the new system and how all the pieces should fall together.

With a small team devoted to this endeavor, a prototype that can be implemented on a railyard in the summer of 2019 is a reachable goal. Having this prototype will be a compelling advance in less than a year of work and will have more of an impact on the company.

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