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Movable Bridge Remote Operation Best Practices:
As Learned from CSX CMAR Automation Program

Stephen Shortridge[1], Samir Abdo, P.E.[2]

1. PCL Civil Constructors, Incorporated (PCL)
2. Henningson, Durham, and Richardson Engineering, Incorporated (HDR)

RENAISSANCE ORLANDO AT SEAWORLD
ORLANDO, FLORIDA

Program Background

Initial Objectives

In 2017, CSX initiated a construction management at risk (CMAR) program with aims of reducing labor and maintenance costs required to operate the movable bridges within their network while also improving their safety performance. These goals would be achieved by building and implementing bridge control systems and remote operation centers that allow CSX bridge operators to control multiple movable bridges from a centralized control center. In order to obtain US Coast Guard (USCG) approval for remote operation as well as ensure costs incurred as a result of incident response, train, or boat delays do not outweigh the savings, the program also laid out guidelines for improving operational reliability through structural, mechanical, and electrical upgrades.

General Approach

The scope of the automation program is to bridge-by-bridge furnish and install new equipment and machinery required to provide an improved complete functioning mechanical, electrical, and controls system capable of simplified operation from a remote control center. At the program's outset, the status of bridge operating systems across the network ranged greatly from automated controls systems installed within the past few years and nearly ready for remote operation to extremely basic manual operation systems consisting of HPUs powered by propane-fueled 20th century tractor motors and controlled via levers with very little electronics.

Figure 1: Sample Existing Operating System

Figure 2: Sample Existing Operating System

Figure 3: Sample Existing Operating System

Figure 4: Sample Existing Operating System

By the program's completion, each selected bridge will have a standardized and multiply redundant programmable logic controller (PLC) based system with touchscreen interface interlocked to ensure the control system cannot perform operation functions out of sequence, without proper feedback from required field devices, or without intentional bypass by the human operator. Each bridge will be operable from a selected centralized control center specially designed and constructed for seamless, reliable, and safe remote operation, achieved by providing the remote operator with adequate information of local information and by ensuring the bridges receive necessary or prioritized reliability improvements to the operating system and structure.

Program Team

Primary Team

The program is led by CSX's Structures Engineering Department with engineering and consulting services provided by HDR. Construction management and general contracting services are provided by PCL, who, with cooperation from CSX's own Brotherhood of Maintenance of Way Employees (BMWE), also perform the majority of structural and mechanical construction. Electrical and controls specialty subcontractors are selected project by project based on best value proposals.

Additional Stakeholders

United States Coast Guard

Requirements regarding the operation of all movable bridges spanning navigable waterways are described in Title 33, Chapter I, Subchapter J, Part 117 of the Code of Federal Regulations. Subpart 5 of the code requires that, "except as otherwise authorized…by this part, drawbridges must open promptly and fully for the passage of vessels when a request or signal to open is given…" Subpart 7 of the code requires that "…drawbridge owners must: (a) Provide the necessary draw tender(s) for the safe and prompt opening of the drawbridge [and] (b) Maintain the working machinery of the drawbridge in good operating condition…" However, Subpart 42 of the code also allows for the local USCG District Commander to authorize a drawbridge to operate under an automated system or from a remote location upon written request by the owner. As of September of 2021, the USCG reported 20 such requests from several state DOT and railroad companies under evaluation, and the numbers are only expected to increase in the foreseeable future.

To obtain this approval, the proposal must convince the USCG that the bridge will operate remotely at the same level of safety and reliability as provided by an onsite bridge tender. This is done by comprehensively addressing the following key topics:

- Condition of the Bridge Structure
- Capabilities, Condition, and Reliability of the Bridge Operating System (Local and Remote)
- Contingency Planning for Local Operations
- Emergency/Incident Response
- Maintenance Planning
- Remote Tender Operational Capacity
- Cybersecurity

Since the approval process has not yet been nationally standardized and is unique to each district, early and regular coordination with the USCG throughout preparations for remote operation is necessary for a successful process.

CSX Signals

Local and Remote Bridge Permissive

CSX's Signals Department implements the system that has the critical safety function of permitting bridge operation only when train passage is prevented, and vice versa. Per the Federal Railroad Administration (FRA) and the American Railway Engineering and Maintenance-of-Way Association (AREMA) requirements, a Signals Department permissive must be present in order to operate the bridge. The daily coordination of this permissive is managed cooperatively between the bridge operator and the train dispatcher. Locally, an operator house or room typically has a display panel showing the status of local rail signals, the position of key movable bridge components, and a switch commonly labeled "River/Rail". The operator generally cannot operate the bridge unless the switch is in the "River" position, and the dispatcher generally cannot line a train unless the switch is in the "Rail" position. In addition to the basic rules, the operator must not attempt to switch to "River" if a train has already been lined and must not attempt to switch to "Rail" if all of the key movable bridge components aren't in the correct closed and/or locked position. This functionality is similar for remote operation, but the switch is typically a digital selection on a computer. The specifics of this system may vary from movable bridges designated for vehicular or pedestrian traffic, but the overall concept is the same.

Limit Switch Indication

The Signals Department must install, maintain, and monitor separate limit switches independent from the bridge controls system. This requirement reduces the coordination required between stakeholders during construction unless major mechanical adjustments are made, or full replacements of equipment are performed. However, the redundancy of limit switch indication offers operators additional information to assist in diagnosis and troubleshooting should issues arise.

CSX Communications

Remote Bridge Control

The local bridge system must be able to communicate bridge indications and information to the remote control center and receive control commands from the remote control center. The remote PLC processor installed at the remote control center is programmed to send a command to the local bridge control system to operate the span from the remote control center, but the operating sequence is provided locally at the bridge PLC. When operating in remote, the local bridge PLC program is set up to operate via a command word from the remote processor and human machine interface (HMI). The remote processor and HMI's continuously monitor the operations at each bridge, including logging messages, alarms, and faults. All the information being supplied to the bridge PLC is replicated to the remote PLC. This communication between the two PLCs may be via fiberoptic, ethernet, satellite, cellular, or a combination of multiple connections and is implemented and managed by CSX's Communications Department.

Requests for Opening or Closing

Marine vessels may request a bridge opening using a standard very high frequency (VHF) radio. CSX's Communications Department implements a radio dispatch system that transmits communication between the remote operator and marine vessels within range of the bridge, typically using the same communication path as the PLCs. The radio dispatch system allows the remote operator to monitor and transmit radio communications from all connected bridge sites or mute selected ones as needed. Remote operators can monitor and transmit communications on CSX's standard systemwide VHF radio using the same radio dispatch system as the marine radio. Dispatchers, train conductors, hi-rail vehicles, and work crews may request a closing via this radio. A landline telephone is also available for use by marine vessels or rail-mounted vehicles. CSX employees and their contractors are also provided with the telephone number as needed.

Remote Bridge Surveillance

Strategically located Pan-Tilt-Zoom (PTZ) cameras can be used to inspect the rail, the waterway, and the rest of the site as needed to confirm safe conditions for operation. Generally, two cameras are installed at either end of the movable span and aimed back towards the center to provide intersecting views of the track, and two cameras are installed on or near the fender and aimed upstream and downstream respectively provide views of the waterway. The camera views are displayed on monitors mounted directly above the remote bridge control HMIs and can be controlled using the computer's mouse and keyboard. CSX's Communications Department implements and maintains the cameras and monitors, as well as their communications path. PCL provides assistance during construction.

CSX Facilities

Design/Preconstruction

Coordination with CSX's Facilities Department begins during preconstruction because their experience with the bridge's electrical system is vital in determining required modifications or improvements as well as identifying portions of the required construction scope that they may wish to handle. Also, the Facilities Department will take over responsibilities for electrical maintenance and troubleshooting on the bridges and at the control centers once construction is complete.

Construction

The large majority of major electrical and controls system rehabilitation work is generally performed by the specialty subcontractor, but coordination and/or assistance is needed from CSX Facilities personnel periodically throughout construction.

Progress Update

Completed (Currently Operating Remotely)

- Big Manatee River (Bradenton, FL)
- Little Manatee River (Ruskin, FL)
- Hillsborough Canal (Tampa, FL)

- Trout River (Jacksonville, FL)
- St. Johns River / Buffalo Bluff (Satsuma, FL)
- Tennessee River (New Johnsonville, TN)
- Cape Fear River (Hilton, NC)
- Mobile River (Hurricane, AL)
- Bayou Sara (Mobile, AL)
- East Pascagoula River (Pascagoula, MS)
- Biloxi Bay (Ocean Springs, MS)
- Bay St. Louis (Bay St. Louis, MS)

Completed (Ready to be Operated Remotely)

- Three Mile Creek (Mobile, AL)
- Alafia River (East Tampa, FL)
- St. Lucie Canal (Indiantown, FL)
- Schuylkill River (Philadelphia, PA)
- Appomattox River (Hopewell, VA)

Ongoing

- Chickasaw Creek (Mobile, AL)
- Curtis Creek / Marley Neck (Baltimore, MD)
- Des Plaines River (Joliet, IL)
- Tailrace Canal (Moncks Corner, SC)
- Cooper River (Cordesville, SC)
- Chef Menteur Pass (Chef Menteur, LA)

Future

- Pearl River (Ansley, MS)
- Maumee River (Toledo, OH)
- Ashley River (Charleston, SC)
- Rigolets Pass (Rigolets, LA)
- Cumberland River (Nashville, TN)
- Tennessee River Channel #1 (Bridgeport, TN)
- Green River (Spottsville, KY)
- Cape Fear River (Navassa, NC)
- St. Joseph River (St. Joseph, MI)

Best Practices Learned

With the CSX CMAR Automation Program hitting the five-year mark, there are countless stories of challenges faced and overcome. Below is a summary of some best practices learned throughout our team's experience that may help others considering similar efforts.

Preconstruction

When considering or preparing for remote operation of bridges, it is important to consult with experienced owners, consultants, and contractors to define the project goals and develop standards to be used for years to come. It is recommended to utilize the preconstruction process to iteratively develop ideas and review costs, benefits, risks, constructability, and priorities. This is especially true when multiple bridges will be involved in a network, and consistency and standardization is needed across an entire remote operation program. Success and satisfaction with the remote operation program can be diminished when mistakes, oversights, or even improvements are discovered after significant work is in place and the owner must then decide between costly rework or lost consistency.

Even after several years of refining the automation and control systems to meet our programs' goals, substantial preconstruction time is still dedicated to each individual bridge to identify, prioritize, and design necessary improvements to the structure and operating machinery and ensure reliable service. Scope decisions delayed until, or changes made during, construction can delay progress and increase costs significantly.

Our team targets the following phases:

- 30% Phase
    - Initial Scoping Site Visit
    - Develop Draft Scope Document with Rough Price Model
    - Review with Team
    - Finalize Scope Document and Rough Price Model
- 60% Phase
    - Develop Draft Design Drawings
    - Review with Team
    - Follow-Up Site Visit
    - Finalize Design Drawings and Price Model
- 90% Phase
    - Prioritize Confirming and Purchasing Long-Lead Equipment
    - Develop Draft Design Drawings
    - Review with Team
    - Finalize Design Drawings and Price Model
    - Execute Construction GMP
- 100% Phase
    - Finalize Design Drawings

Control Panels and Drives

A standardized cabinet layout reduces long-term design costs and may even allow for bulk upfront purchasing of expensive and long-lead items. Having a standard design/layout also allows for bridges to look and feel similar to the operators and maintenance team, reducing the time spent by personnel getting acquainted with bridge interface/controls whenever the need arises. This also allows for a consolidated list of key standardized spare parts to be developed and maintained per region, which reduces procurement cost and storage space while maintaining reliability.
The control system standard design consists of multiple levels of redundancy that are categorized as follows:

- Programmable Logic Controller (PLC) Based System: This system consists of two standalone central processing units (CPUs) where the logical control resides and that serve as the "brain" of the bridge. The PLCs are fully redundant and designed for one PLC to actively control the bridge while the second one is on standby which allows for seamless controls transfer should one PLC fail. These PLCs are communicating with various bridge components through two input/output (I/O) racks. The system is designed such that both racks are fully redundant, but only one rack is active at any given time. Should the active rack fail, the PLC will switch automatically to the redundant rack and be able to resume operation. A PLC based system is required for remote operation.

Figure 5: New Control Panel

- Relay Based System: The relay system is a fully standalone system where it has its own circuitry and relay logic that allows for full bridge operation in case of total PLC failure, or where local/manual troubleshooting is needed. When operating in relay mode and proper bridge conditions can be visually confirmed by a local operator, many types of faulted interlocks can be bypassed at the operator's discretion to allow continued operation. Although a relay-based backup system provides immense value during troubleshooting and PLC failures, it is labor and space intensive and is not necessary for remote operation.

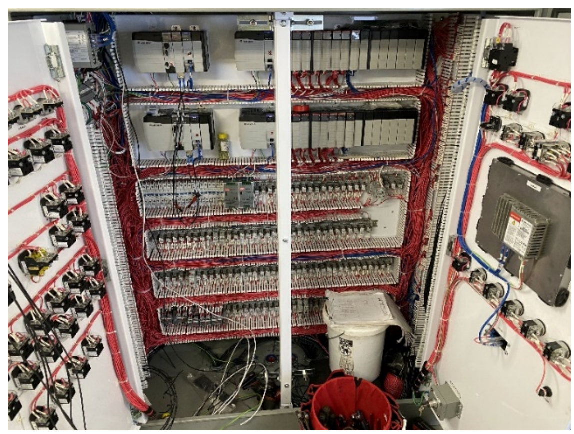

Figure 6: New PLC and Relay Cabinet

Drive cabinets are also designed with redundancy in mind. Most operating systems are designed with two primary drives that either work together during operation or, when only one is necessary at a given time, automatically alternate to ensure functionality of both is monitored. Even when both drives are used simultaneously during standard operation, systems generally allow for continued bridge operation at reduced speed if one drive were to malfunction. In addition to the primary drives, many bridges also have a separate auxiliary drive system for additional redundancy. It is important to remember that long periods

Figure 7: New Drive Cabinet

of inactivity can result in shorter lifespans in drives, so control systems and/or preventative maintenance programs should account for periodic exercising. This note is also relevant to the consideration of spares. If quick accessibility to spare drives is necessary, plan to ensure they will function when needed and do not expire on a shelf. Finally, keep in mind that each drive is unique to the system voltage and motor size it is used to operate.

HMI Screens

As indicated by the name, the Human Machine Interface (HMI) is where the typical end users interface with the bridge's control system. Clearly, this device is one of, if not, the most important areas of focus for design standardization and uniformity. Detailed graphic requirements should be developed and refined during the design phase to direct potentially multiple different system integrators to the same end result user interface. It is especially critical to emphasize to all stakeholders involved in this process that consistency across the program is a primary goal.

Since remote operators will likely have additional responsibilities and be coordinating multiple operations at the same time, having a standardized user interface and displays allows the remote operator to develop familiarity and be able to seamlessly manage operations at different bridges. HMI screens are most useful when they are highly informative while the design remains clear, organized, and intuitive. Animations used for bridge moving parts proved to be effective in providing the operator with quick feedback on the stage of bridge operation. Strategic use of colors is also important to facilitate operator processing and attract attention when needed. Consideration must also be given to balance quantity of information fit into one screen with legibility of text size, use of abbreviations, etc.

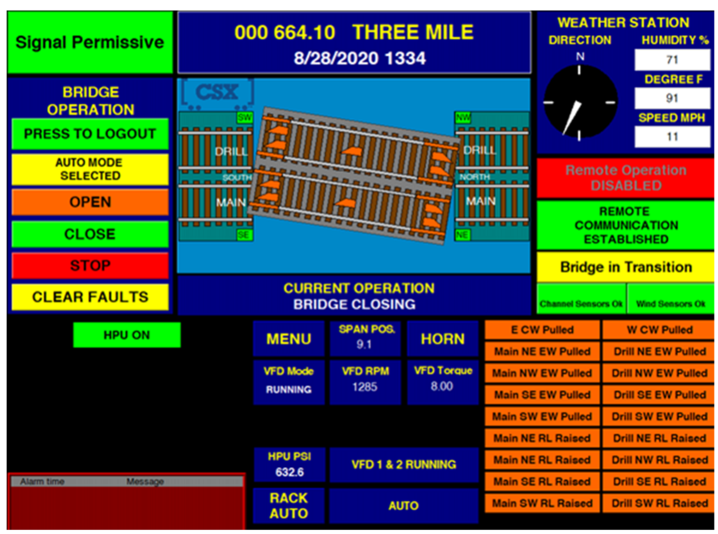

Figure 8: Swing Bridge Main Screen

All useful information will not fit on the main HMI screen so additional screens and a means of intuitively navigating between them must be created. Below is a list of some key HMI screens:

- Main Screen: Displays the bridge name, control commands, and general overview of the bridge status.
- Request for Bridge Open/Close Screen: Allows the operator to log the reason for operation.
- Menu Screen: Used to select the various other monitoring screens
- Alarm History Screen: Displays recent history of triggered messages, alarms, and faults with timestamp. Identifies alarms or faults currently active.
- Input/Output Screen: Displays the real-time status of PLC inputs and outputs. Used for more in-depth system monitoring, issue diagnosis, and troubleshooting.

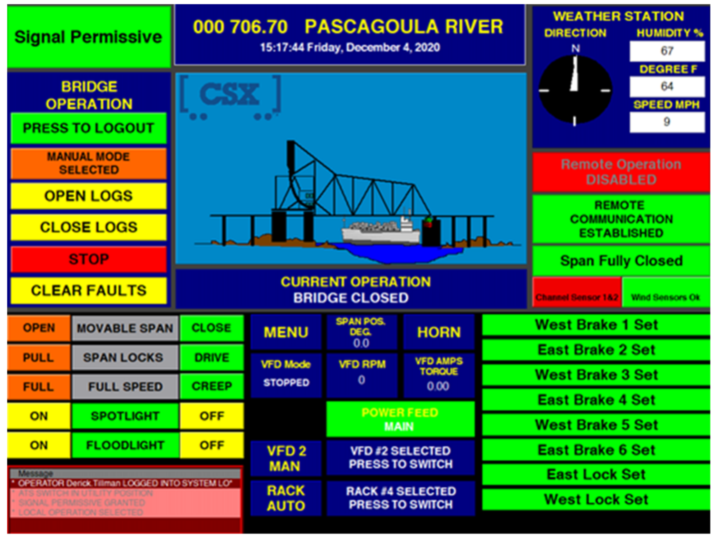

Figure 9: Bascule Bridge Main Screen

Figure 10: Input/Output Screen

- Communications Screen: Provides diagnostic information on the communications between PLC's, I/O racks, HMI, drives, and other devices connected via ethernet.

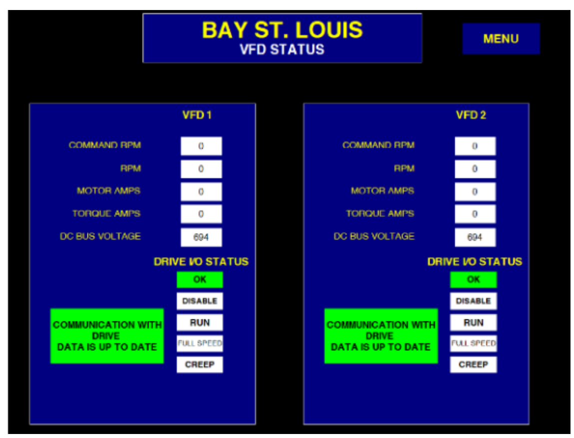

Figure 11: VFD Status Screen

- Drive Status Screen: Provides diagnostic information on the drives.
- Drive Trend Screen: Plots trending information of operating characteristics such as amps, torque, and RPMs against bridge position

Messages, Alarms, and Faults

One of the HMI screen's most useful functions for initial diagnosis and troubleshooting is the display of meaningful messages, alarms, and faults (MAF's) when certain conditions are triggered. These messages should be simple and concise enough for a bridge operator or initial response mechanic or electrician to comprehend while also being descriptive enough to direct response efforts to the correct area. Clear messaging of triggered conditions or events combined with an understanding of the control system's response and available operator actions can greatly reduce time and money spent diagnosing and troubleshooting operation issues. This benefit is compounded when a bridge is operated remotely since response times for onsite diagnosis are likely longer and technical support from controls specialists is likely outsourced.

Another key topic to consider regarding the design of the control system messaging system is the process of development. In the early stages of our automation program, the specifications required the controls integrator to create the MAF list and submit for approval. This may seem like a reasonable and typical assignment that undoubtedly saves time and cost during the design phase of a project, but our team came to realize that this task had too great an influence in the long-term success of implementing a remote, or even local, automation program to not thoroughly discuss and review during the preconstruction phase and clearly define in the contract documents. Again, this importance is magnified when multiple bridges will be involved in a network, and consistency and standardization is needed across an entire remote operation program. In this scenario, it's best if the messaging from one bridge to the next is as interchangeable as possible to improve the efficiency of operators and initial response mechanics or electricians assigned to multiple bridges. Also, the cost of implementing changes to the bridge messaging system only becomes greater as the quantity of bridges completed to date increases.

Remote Control Center

The HMI located at a remote control station should display the same information and screens as the HMI located at the bridge, with the only exception being the login screens. Assuming the remote control center will be used to operate more than one bridge, the home screen will typically be a bridge selection screen containing pushbuttons displaying the names of the remotely connect bridges. This bridge selection screen was implemented as part of our system to allow for each operator station to have the capability of operating any of the bridges designated for operation from that control center, giving the system redundancy in the event one station malfunctions as well as giving the operator flexibility to organize their stations as they wish.

Figure 12: Remote Control Center Desk

CSX's major remote centers have been designed for each operator desk to have five stations, with each station capable of monitoring and/or operating a separate bridge. Note that the number of bridges a single operator can be responsible for is a subject that will likely need to be coordinated with the USCG during the remote authorization process.

On the bridge selection screen, each bridge has two separate buttons, one that displays "CONTROL" under the bridge name and will direct the user to log in for remote operation, and one that displays "VIEW ONLY" under the bridge name and will navigate the user to be able to view all the screens shown on local HMI except that the operational buttons are removed. When one of the "CONTROL" pushbuttons is pressed, a login screen appears. This screen requires a test be performed with the "EMERGENCY STOP" button located on a panel box directly below the remote HMI to confirm the operator and the control system agree on which bridge is to be controlled by the selected HMI and "EMERGENCY STOP" button. Once the login information is confirmed, the operator is directed to the main bridge screen with the operational buttons displayed. The "VIEW ONLY" buttons are intended to allow the remote operator or another user that has less authority or is located offsite from the control center to monitor the status of the bridge without the ability to control.

Lightning and Surge Protection

Large, elevated metal structures in the middle of the water are naturally susceptible to lightning strikes. A lightning protection system generally consists of two major components:

- Passive Protection: Achieved by connecting lightning rods on top of the structure to grounding rods embedded in the earth to create a continuous path to ground.
- Active Protection: Achieved by implementing multi-level surge protection devices (SPDs) that are rated to properly absorb the energy and act as sacrificial components.

One of the challenges with a lightning protection system is that it is commonly installed during initial bridge construction or several years in the past and then taken for granted as always intact and functioning. These systems should regularly be inspected because loss of functionality or failures with these systems are likely over long periods of time. This is especially true with regards to susceptibility of the "passive protection to deterioration and corrosion caused by constant exposure to the elements. Seeing some components of a lightning protection system does not always mean that the bridge is properly protected. In fact, a partially intact system could do more harm than good.

To protect the added investment and increased amount of electrical devices resulting from bridge automation and remote operation, existing lightning protection systems should be reevaluated and reinspected. Overlooking or underestimating the value of this critical protective system may result in extremely costly repair work and loss of service.

Limit Switches

Limit switches are critical to the control system as they provide feedback on bridge conditions to allow the system to make the proper operational decisions. Because limit switches are so prevalent and important to remote operation and automation work, standardization efforts of both the products and the mounting details used can be additionally beneficial and should be prioritized. Some key types of limit switches include, but are not limited to:

- Lever Type Limit Switch: An electromechanical device that consists of an actuator mechanically linked to a set of electrical contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. Used to inform the control system where a bridge component is or isn't located at a given time. Commonly used on machine-and-motor brake arms to identify set and released positions.

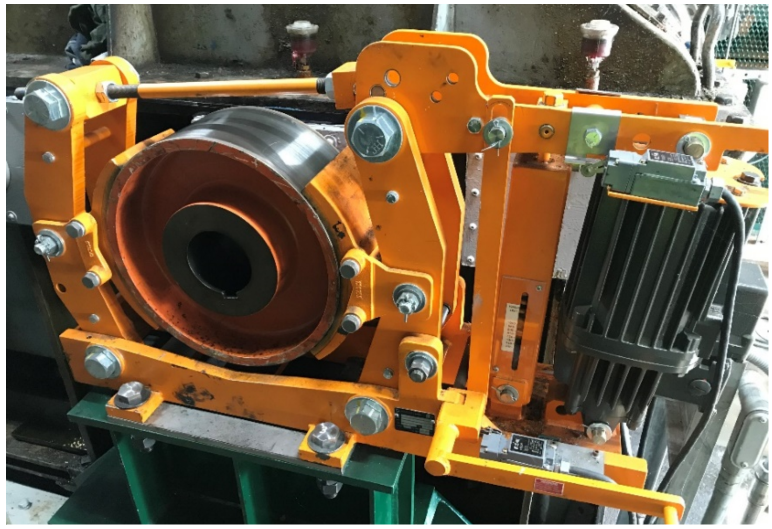

Figure 13: Lever Type Limit Switch on Machinery Brake

- Proximity Type Limit Switch: Performs the same function as lever type limit switches, but without the need for physical contact. This attribute makes this type of switch valuable due to the reduction in external moving parts and the potential for binding, accidental damage, or deterioration caused by exposure to the elements. Commonly actuated by a magnetic field produced by its target object. Sensing distances can range from ¼" to over 3" depending on the strength of the target's magnetic field. Target magnets are not absolutely required but can improve the reliability of the indication to offset the variability inherent in large movable structures without negative impacts as long as designed and implemented correctly. Used extensively throughout the program. Common applications include lift rail raised and lowered positions, wedge driven and pulled positions, lock driven and pulled positions, span fully closed and overtravel positions. These switches can be susceptible to issues and failures from accumulation of metal shavings as well as excessive vibration, especially when installed immediately adjacent to harsh locations such as the rail. Proper mounting and regular inspection and maintenance are important for optimal long-term performance.

Figure 14: Proximity Type Limit Switch on Swing Bridge Lift Rail Hydraulics

Figure 15: Proximity Type Limit Switch on Rolling Bascule Bridge Main Pinion

- Rotary Cam Limit Switch: An electromechanical device used to monitor the location of a target having a repetitive cycle of operation where motion is correlated to shaft rotation. As the shaft rotates, cams actuate contacts at various customizable positions. Used extensively throughout the program to monitor intermediate span positions.

Figure 16: Rotary Cam Limit Switch on Rolling Bascule Primary Shaft

Off-Delay Timers

This learned best practice is likely more relevant to the upgrade from manual operation system to automated control system than specifically for remote operation, but since some projects may make both upgrades concurrently, it's a subject worth discussing. The bridge control system, whether PLC or relay, relies on limit switch feedback to determine when an operation is successfully completed and should be ceased. This generally applies to all movements but take for example the pulling of wedges on a swing bridge or the locks on a bascule or vertical lift bridge. Once the wedges or locks are pulled to the point where the limit switch is triggered, a signal is sent to the control system notifying it of that condition. Assume that the control system is programmed to immediately stop the wedge or lock pulling movement once it receives that indication from the limit switch and then proceeds to the next step in the opening procedure. Depending on the speed of the mechanical operation in comparison to the control system response, the limit switch indication may be just barely within its triggered range. Due to variability in the magnetic field (when using proximity limit switches) or potentially due to minor unintended movement of the wedge or lock during subsequent operations, the "pulled" limit switch indication may be lost while the bridge is in a position where the control system requires that indication for operation.

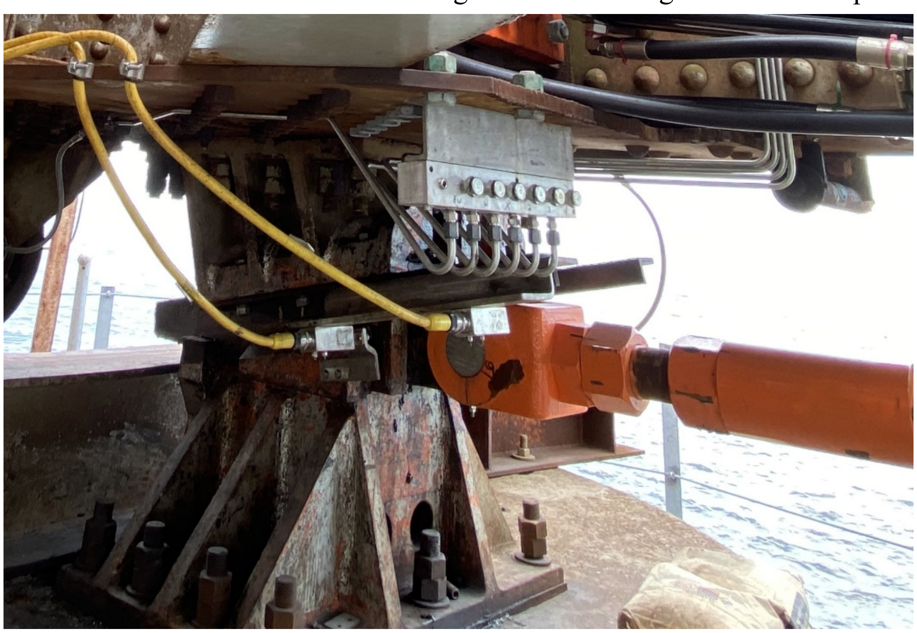

Figure 17: Swing Bridge End Wedge with Proximity Type Limit Switches

Depending on the control system's programmed interlocks and available bypasses, this situation could result in a prevention of remote operation until the wedge or lock "pulled" indication can be restored or the condition confirmed, and interlock bypassed. To avoid this situation, off-delay timers can be implemented into both PLC and relay systems to allow the control system to wait a determined amount of time after receiving limit switch indication before stopping movement so that there is a reasonable buffer within the limit switch's triggered range.

Channel Sensors

Given remote operators' reduced ability to monitor local conditions, the control system's ability to assist with surveillance and detection of hazards is extremely valuable. Railroad owners have the benefit of being able to control traffic over the bridge, therefore being able to better manage the risk of inadvertently operating the bridge with traffic on the movable span. However, they cannot control traffic under the bridge. In order to manage the risk of inadvertently operating the bridge while a marine vessel is within the range of motion, channel or boat detection sensors are strategically installed on the bridge's fenders, dolphins, or piers. In simplified terms, these sensors transmit and monitor an infrared beam or laser to determine if an object passes through a certain area, and then send a signal to the control system if triggered. Channel sensor quantity and location must take into consideration several factors such as:

- Characteristics of the navigational channel or channels
- Type of movable bridge
- Characteristics of fender, dolphin, or pier
- Characteristics of marine traffic
- Type of sensors

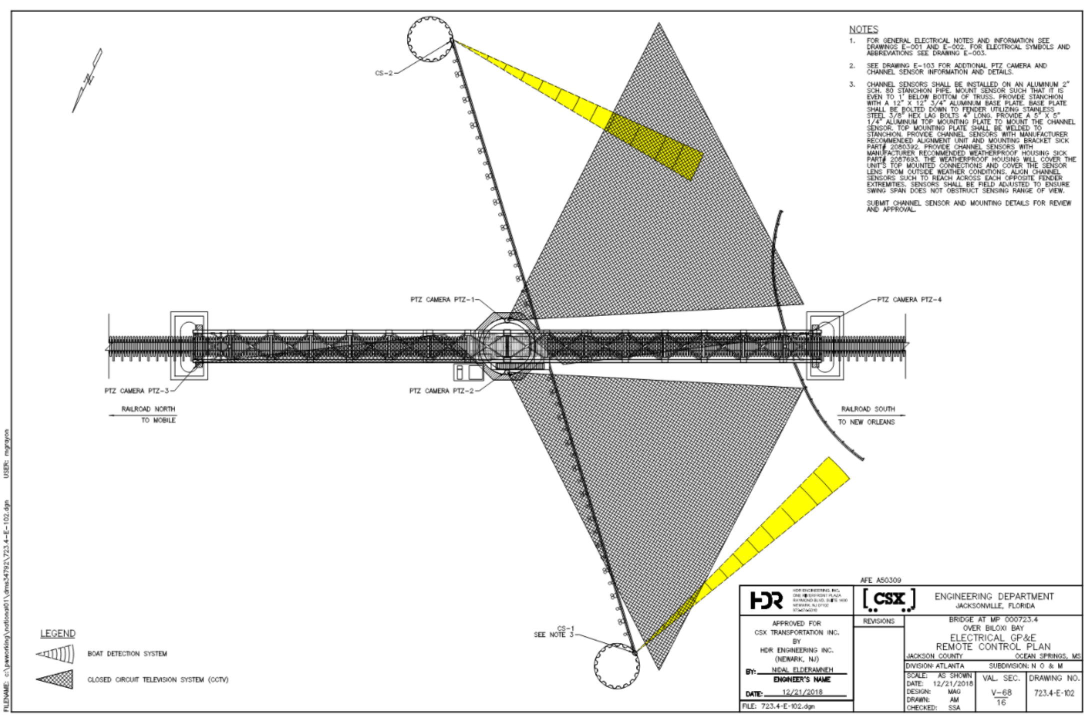

Figure 18: Sample Channel Sensor Layout for Swing Bridge

The ideal location for a boat detection beam or laser is far enough away from the bridge structure so that an approaching boat is identified in time to allow the control system to stop a potentially dangerous bridge movement while also being close enough to the bridge structure to avoid false alarms. The ideal height of the sensing beam or laser should also be considered so that only boats of specific size trigger the system.

Some early projects implemented a two-part channel sensor system where a transmitter installed on one side of the navigational channel sent a beam across the channel to a receiver mounted on the other side. This system had limited success due to a few different issues.

- Challenges with maintaining proper transmitter/receiver alignment due to:
  - Wide channels requiring long sensing distances
  - Regular fender sway
  - Harsh environment and inclement weather
- Non-existing, limited, or unique configurations of fenders, dolphins, or piers on some bridges
- Durability in harsh environment

Another system implemented on some early projects avoided many of the challenges of the two-part system by functioning without the need for a separate receiver on the opposite side of the channel. This system also seemed to hold up well in harsh environments. The one issue we had with this system when considering making it the program standard was that the manufacturer had exclusive agreements with some select specialty controls contractors and was unable or unwilling to work directly with the program's primary team or other specialty controls contractors working on other bridges throughout CSX's network.

The channel sensor system eventually selected as the program standard has now been implemented at more than ten locations with great success. The main challenge still faced with channel sensors, especially on bridge locations susceptible to tropical storms and hurricanes, is improving the survival rate of the system or at a minimum reducing the repair/replacement costs following severe weather. To accomplish this, mount locations, mount designs, wiring products, wiring installations, and storm preparation procedures have all been modified over the years.

Figure 19: Current Channel Sensor Standard Installation

Surveillance Cameras

Cameras are essential to remote operation as they provide the remote operator with a clear view of the bridge and its surroundings to ensure safe operation. Pan, tilt, and zoom (PTZ) allow for a broader field of view and ability to pinpoint and verify physical conditions. Within our program, each bridge is typically designed to be equipped with four cameras, two on the movable span looking at the tracks opposite directions, and two cameras on the fixed span or fender looking at the navigational channel in the upstream and downstream directions. Camera displays should be organized in a clear and uniform way for easy viewing by the operator or other end user. Assigning preset views for easy navigation and control can help in accomplishing this goal. Default views can be set such that when the operator pans, tilts, or zooms for a specific short-term need, the default setting will be recovered after certain time to maintain standardization and uniformity. These cameras not only serve to improve safety but may also be beneficial for documenting marine allisions or other physical damage done by trespassers.

Specific mount locations require thorough consideration of multiple variables, including but not limited to:

- Optimized field of view
- Impact of bridge and traffic lighting on nighttime views
- Ability to maintain visibility during inclement weather
- Ability to withstand heavy vibrations caused by traffic and operation
- Obstruction of camera on traffic across or below bridge
- Accessibility for maintenance and troubleshooting
- Wired or wireless connection to communication panel

Figure 20: Sample Surveillance Camera Installation

Marine Signs

Along with the removal of an onsite bridge operator and potential changes to the request for opening procedures comes the need to communicate those changes to nearby marine vessels. Signs identifying the means of communicating with the remote operator must be mounted in clear view from the navigational channel.

Lighting

Adequate bridge lighting is made even more essential to safe access during regular maintenance and occasional troubleshooting of bridge equipment when remote operation removes the onsite bridge tender, likely reducing the familiarity with the bridge of the responding personnel. The use of photosensors and/or motion sensors should be considered to reduce unnecessary energy consumption.

Another type of lighting that must be considered during remote operation preparation is marine navigation lighting since the USCG will likely evaluate its status during the approval process.

Maintenance and navigation lighting have the potential of being overlooked during the design process since they may seem less critical to bridge operation and because most scoping visits are not performed during nighttime hours.

Auxiliary Operation Options

In addition to the control system redundancies discussed in earlier sections, there are a few other means to incorporate additional redundancies. Obviously, issues with the bridge's primary electrical feed can be overcome with a backup generator that is sized sufficiently to operate all necessary equipment. If designed properly, the system should be able to continue remote operation under backup generator power without issue. To increase the reliability of the backup system, generators are best located on the movable span where practical, thereby eliminating some points of possible failure such as a submarine or droop cable.

Figure 21: Hand-Tool Motor Crank on Electromechanical Wedge Operating System

Some other available redundancies may not allow for continued remote operation but may provide emergency options for local responding personnel. One of these options available for a hydraulic operating system is to incorporate an independent backup gasoline or diesel motor into the HPU and design a means of simple manual solenoid activation such as hardwired key switches or pushbuttons. For electro-mechanical operating systems, another emergency option is the implementation of manual or hand-tool powered cranks on the backside of motors. It is worth mentioning that hand crank capable equipment should incorporate a safety limit switch that is electrically interlocked with the motor starter to prevent unintentional powered operation when personnel could be exposed to the dangerously spinning equipment.

Remote Communications

The communication path between the remote and local PLC's, and the speed and reliability of it, is obviously one of the most critical components of successful remote operation. The local and remote bridge PLC must maintain constant communication to ensure bridge operation is always under the monitor and control of the remote operator. Both PLC's exchange a "heartbeat" or "ping" and monitor to confirm their outgoing ping is received by the other PLC, altered, and then returned within a set allowable time. If this allowable heartbeat return time is not met, both PLC's fault and the local PLC activates an emergency stop if bridge operation is underway.

When available, hardline connections such as fiberoptic, ethernet, or a combination of the two have been utilized throughout our program as the primary communication path and have worked as needed to maintain required heartbeat exchange times. Occasionally, short wireless point to multipoint broadband connections have been required to communicate across the gap between movable and fixed structures when submarine or droop cable use was not available or feasible. In our experience, the use of these connections has not been found to substantially impair otherwise hardline connections.

In certain isolated bridge locations, a hardline connection may not be available. Such was the case with two bridges located out in the middle of the South Alabama bayous. On these two bridges, a satellite connection was selected as the primary communication path. After connection was made and testing began, it became apparent that the allowable heartbeat return time initially set based on hardline connections needed to be relaxed a bit for satellite connections to maintain reliable operation. This decision must be discussed in great depth considering the potential impacts to bridge safety. Relaxing the requirement too much may reduce the remote operator's ability to monitor and control conditions on the bridge, but frequent emergency stops triggered by unmet heartbeat return times may put excessive stress on the bridge machinery and structure. Another item to consider when communicating via a satellite connection is the potential impacts caused by heavy cloud cover or inclement weather.

Most, if not all, bridges have a cellular connection implemented as the backup that is configured to automatically take over if the primary connection is lost. This functionality is especially important when the primary connection may be unreliable to avoid excessive service calls to the communications department. Additional consideration may be needed to ensure that unacceptable latency is recognized the same as complete connection loss by the automatic switching program. Note that cellular connections, especially in isolated locations, may also have challenges meeting the required heartbeat return times.

As technology continuously improves, the challenges of wireless connections will likely eventually be eliminated, but until that can be confirmed, heavy emphasis should be placed on the value of reliable communication provided by hardline connections.

Data Logging

A major aid when diagnosing, troubleshooting, or investigating issues is having a stored and recoverable record of conditions and events. It's likely that all bridge owners considering remote operation will want some form of data logging. However, the specifics of what information will be logged and how that information will be transmitted, stored, and viewed is a much more complicated subject.

A successful data logging system can enhance troubleshooting, aid in incident management, and may even be able to assist with monitoring of system health, early detection of deficiencies, and processes improvement.

Some topics to consider when developing a data logging system include, but are not limited to:

- How much information is needed or wanted?
    - This question relates to the overall functionality of the data logging system. Data logging can be used for analytics, troubleshooting, events logging, or just operation logging.
    - Alarms and messages could occupy a large amount of the PLC's memory. An effective way to reduce the amount of data stored is by developing a system of nomenclature to shorten the messages while still maintaining comprehension and uniformity. This could be done by assigning equipment, conditions, or events a short name or acronym that is readily understandable or easily translatable by the operator yet occupies less memory space.
- How much information should be stored and where?
    - The team must consider whether the data will be fully stored locally, temporarily stored locally then transmitted to a centralized location, or immediately transmitted to a centralized location. PLC memory is very limited and can get expensive. Also, the available bandwidth of the communication path(s) for data transmission must be considered. These decisions may impact the question of what and how much information is able to be collected
- How long can the information be stored?

    - The team must consider the capacity of the final storage location.
- How will the information be organized, viewed, and/or monitored?
    - The team must consider if the owner already has a system that may be used to increase usability, reduce training time, and potentially save software or hardware costs. If not, there are countless options for answering this question.

Cyber Security

As stated in HDR's 2020 report titled *AASHTO Guidelines for the Operation of Movable Bridges from Remote Locations*, "Of particular concern is the cyber-security risk associated with remote operating systems and considerations for reducing that risk. Cyber-attacks on these systems have the potential of causing major loss of life and severely damaging the nation's critical infrastructure, equaling, or exceeding the effects of conventional attacks." This topic is much too intricate to fully address within this paper, but all owners considering the implementation of remote bridge operation must thoroughly assess the vulnerabilities of and consequences to their system from potential cyberattacks. A detailed memorandum of the research conducted by HDR on this topic can be found in the above-referenced report. The key take-away from the report is to design the movable bridge control system such that internal network security is maintained and utilized in accordance with the National Institute of Standards and Technology (NIST), and "remote access" as defined by the NIST is avoided.