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Remote Bridge and Lock Operation

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1.0 Introduction

The technologies needed to safely remotely operate structures and process has been available for 30+ years. The advances in computing power, communication networks, remote sensing devices, camera technology, etc. has greatly enhanced both our ability to operate remote structures in real time and reduce the overall cost of ownership. Paramount to any remote operation project is the safety of the public, our employees and our assets. Adherence to the latest safety regulations must always be given top priority. The adoption of the latest mechanical and electrical standards also aids in improving reliability and reducing costs.

There are many similarities between lock and bridge remote operation, this paper will focus on remote bridge operation. Most of the design considerations discussed can equally be applied to lock remote operation.

2.0 Background

The St. Lawrence Seaway (the "Seaway") is a 3,700 km binational inland waterway stretching from Montreal to Lake Erie and comprising of 15 United States and Canadian locks and a series of canals connecting the world to the heartland of North America. The St. Lawrence Seaway is managed jointly by the Canadian St. Lawrence Seaway Management Corporation (SLSMC), and the Great Lakes St. Lawrence Seaway Development Corporation (GLS), part of the U.S. Department of Transportation (DOT).

Figure 1- Geographical Area Associated with the St Lawrence Seaway System

Vessels are lifted a total of 168 meters (551 feet) as they transit the Seaway system. There are 13 Canadian locks, 2 U.S. locks and 19 movable bridges. There are 41 ports associated with the Seaway system. If all of the United States and Canadian Provinces that border the Seaway system were a single country it would represent one of the top 5 largest world economies[1].

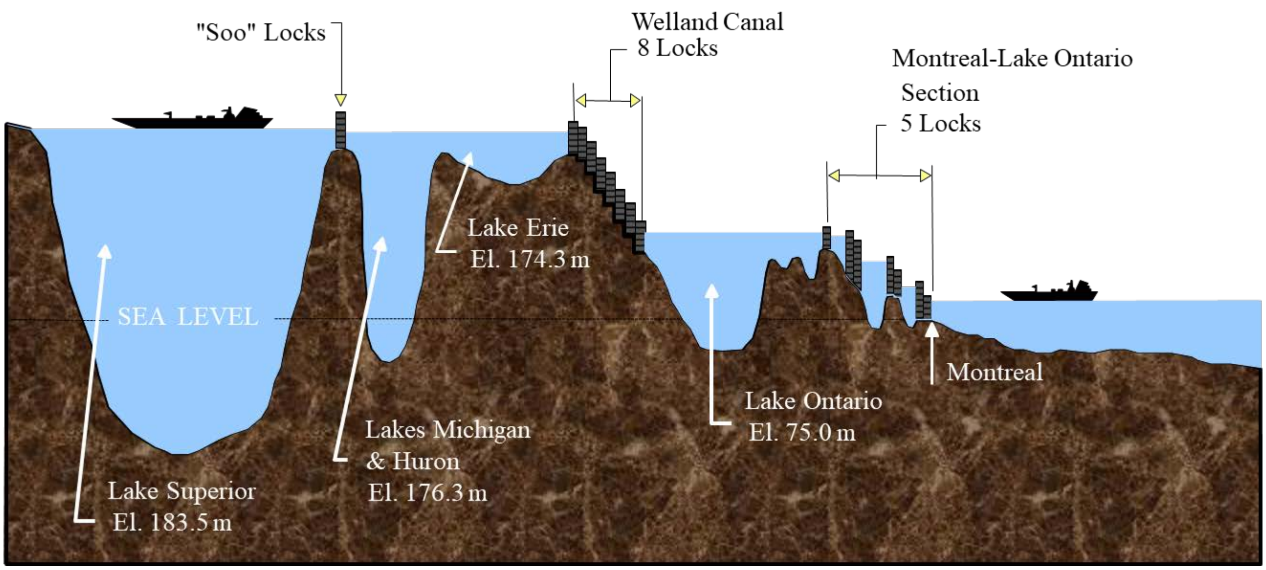

Figure 2 - The St Lawrence Seaway Profile

3.0 History

In the early 2000s, research began to determine the feasibility of remotely operating 8 of the largest movable bridges of the St Lawrence Seaway. Economic challenges at that time necessitated the reduction of operating costs and remote operation was seen as an opportunity to optimize staffing levels.

Shortly prior to the start of this research recent infrastructure projects had installed state-of-the-art control equipment and advanced communication networks at each of the local structures including the 8 bridges being considered. A local control room was created at each structure. All of the equipment for each structure was operated from these control rooms. With the Operations staff still stationed at each structure very few cameras were required.

The existing Traffic Control Centers already monitored and managed maritime traffic remotely. The adoption of the Automatic Identification System[2] (AIS) into the Seaway system in the late 1990s allowed vessel positions and speeds to be tracked by computer and plotted on monitors. The old Traffic Control Centers have become our new Operation Control Centers.

Studies were also conducted to determine the optimum number of cameras and their placement to provide the required views of the remote bridges. Care was taken to provide camera views that allowed the

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[1] Economic Impacts of Maritime Shipping in the Great Lakes-St. Lawrence Region [United States Department of Transportation, 2018; Economic Impact Study | Great Lakes St. Lawrence Seaway Development Corporation (dot.gov)]

[2] Automatic Identification System (AIS); The automatic identification system (AIS) is an automatic tracking system that uses transceivers on ships and is used by vessel traffic services (VTS). [Wikipedia, 21 July 2022; Automatic identification system - Wikipedia]

operator to watch for pedestrians and vehicles crossing the bridge. Additional cameras were used to monitor the vessel as it approached and passed under the bridge.

Ten (10) years later the St Lawrence Seaway embarked on a project to expand remote operation of the remaining movable bridges and locks.

The St Lawrence Seaway now has twenty years (20) of remote structure operation experience, the resulting Operations Control Centers (one in the Niagara Region and one in the Maisonneuve Region) are state-of-the-art facilities where all vessel movements and structure operations are executed.

Figure 3 - Operations Control Center

4.0 Remote Operation Design Considerations

When planning the remote operation of any structure, there are a number of important considerations that must be considered. The establishment of a sound infrastructure provides a foundation on which remote operation will be most likely to succeed.

Understanding and complying with local safety standards and industrial design codes is important to ensure safe and reliable operation. In some jurisdictions devices must meet strict safety design standards because of human presence on or near the structure while it is being operated.

5.0 SCADA Systems

The design and installation of a strong SCADA system is an important first step. Whether the structure already has a control system or one is being considered, there have been many advances in computing speed and functionality which support remote operation.

The design of the control system should consider redundancy if high availability is required. Typically, bridge operations are relatively slow compared to other industrial processes and redundancy is not required.

Sensor and actuator selection should be considered to meet overall system performance and resiliency objectives. Critical sensors should have a back-up so that the failure of a single sensor does not cause unsafe conditions. For example, bridge position encoders may be employed to determine when the bridge is at the fully raised position. In most cases a second "over travel" sensor should be employed to protect the structure from mechanical damage.

6.0 Communication Systems

Fast and reliable communication is essential to allow a remote operator to be aware of what is happening at the bridge and so that control commands are delivered reliably.

Most modern communication systems are based on Ethernet technology. This provides for readily available components and industrial level devices are common. Care must be taken when designing a communication network to consider:

1. ***Security;*** as most remote operation applications are some distance from the control center, where the operator is located, it is common to use third party networks. Cyber security becomes a key factor for protecting against intrusions.
2. ***Resiliency;*** as large distances are typically involved a redundant communication path (or "ring" topology[3]) should be considered. The failure of a single device should not compromise the communication system.
3. ***Bandwidth;*** when designing the communication system care must be taken to ensure sufficient bandwidth to reliably support SCADA system communications, camera streams, audio communication (public), radio (vessels), etc.
4. ***Segmentation;*** most modern network equipment allows for the segmentation of communication traffic. Different traffic types should be separated and a "Quality of Service" configuration established to ensure that critical data is delivered without interruption from data of lesser importance. For example, high priority should be given to SCADA and camera data. Audio and radio data can be given less priority because the data rates tend to be slower and small interruptions (static) are less noticeable.

[3] Ring network; A ring network is a network topology in which each node connects to exactly two other nodes, forming a single continuous pathway for signals through each node – a ring. Data travels from node to node, with each node along the way handling every packet. [Wikipedia, 14 July 2022; Ring network - Wikipedia]

7.0 Camera Systems

Safe operation depends on the operator being situational aware during all phase of the bridge movement. Camera systems do not provide the visual perspective of the human eye[4]. The design and placement of cameras are important so that the operator has unimpeded views to the critical areas around and on the bridge. Environmental (light levels, fog, heavy rain, snow, sun position, etc.) conditions effect the operator's ability to see clearly. Obstructions caused by the bridge superstructure must also be considered when selecting optimum camera locations.

Camera Installations

Cameras should be mounted to provide an unobstructed view of the bridge approaches (pedestrian, vehicle and vessel). Consideration should be given to mounting the cameras on poles or towers sufficiently strong to withstand strong winds in order to provide stable images at all times. Many new cameras consume less communication system bandwidth when the field of view is not changing. Camera movement tends to require higher bandwidth.

Cameras should be of sufficient number and be installed to provide adequate views of road gates, safety barriers, roadway, sidewalk, vessel channel and bridge span on both sides of the bridge.
Camera configuration (colour vs. black and white, frames per second refresh rate, etc.) must be considered in the bandwidth calculations.

The decision to use fixed or moveable (PTZ[5]) cameras should consider reliability and cost. Using moveable cameras allows for overlapping coverage. If a camera fails another camera can be used to compensate.

The type of camera selected should consider local environmental conditions. For example, dome cameras provide mechanical protection for drive components but often do not come equipped with wipers to clear rain or snow from the lenses.

Camera Locations

Cameras should be mounted to provide an unobstructed view of the bridge approaches (pedestrian, vehicle and vessel).

Infrared Cameras

Consideration shall be given to use infrared camera[6] in sufficient number to detect humans and animals in a dark environment. However, care should be taken to consider other environmental conditions when deciding to use infrared cameras. For example, infrared cameras are sensitive to fog. Fog attenuates the heat of the object being viewed and infrared cameras are usually not precise for small objects.

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[4] The Camera Versus the Human Eye. [Petapixel, 17 November 2012; The Camera Versus the Human Eye | PetaPixel]
[5] Pan–tilt–zoom camera; A pan–tilt–zoom camera (PTZ camera) is a camera that is capable of remote directional and zoom control. [Wikipedia, 13 March 2022; Pan–tilt–zoom camera - Wikipedia]
[6] Thermographic camera; A thermographic camera (also called an infrared camera or thermal imaging camera, thermal camera or thermal imager) is a device that creates an image using infrared (IR) radiation, similar to a normal camera that forms an image using visible light. [Wikipedia, 5 August 2022; Thermographic camera - Wikipedia]

8.0 Detection Systems

Ancillary detection systems are often employed to enhance the operator awareness of conditions at the bridge.

Radar

Consideration should be given to the use of radar to detect and measure the position of vessels approaching the bridge. Most large commercial vessels are equipped with an Automatic Identification System (AIS) which provides vessel position and speed. However, smaller vessels (pleasure craft, service vessels, etc.) may not be equipped with an AIS system. Integrating the radar and/or AIS into the control system must be considered in the design.

Care should be taken as radar can create interference with motor drive systems. One option is to turn the radar off during bridge movements.

Fog Detectors

Fog detectors should be considered to improve operator visibility.

Wind Measurement

Anemometers should be considered to allow the operator to make decisions regarding the safe operation of the bridge. Often this wind information (speed and direction) is passed to the vessel to aid their approach.

9.0 Other Systems

Other systems can be considered depending on local conditions and the overall objectives of the project.

VHF Radio

VHF radio is used to communicate with the navigators and maintenance crews. The communication network should be designed to carry voice communication from the remote operations center to a transmitter installed locally at the bridge. Radio traffic on the communication network should be encrypted.

Buzzers and Sirens

All equipment that is automatically or remotely operated should include an audible warning buzzer or siren to warn the public of pending movement.

Microphones

Microphones (pubic address) can be considered to allow the operator to communicate with the public regarding bridge and traffic barrier operation.

Speakers

Speaker (pubic address) systems should be considered to allow the operator to communicate with the public when giving instructions related to safety and security.

Variable Message Signs

Consideration can be given to the use of variable message signs as an alternate way to communicate with the public. For example, the variable message sign could be configured to indicate the remaining time before the road is open again after the bridge operation is complete and other information related to traffic and bridge conditions.

Navigation Lights

Navigation lights should be used to indicate the bridge availability and position to approaching vessels.

10.0 Operator Interface

Consideration for the Human Machine Interface (HMI) should be given to meet the following requirements:

1. A local HMI shall be available on the bridge or in a local control room with an unimpeded view of the bridge. The HMI should be positioned to allow the local operator an unobstructed view of the bridge deck, pedestrian walkways, roadway and vessel approach. Local camera monitors can be considered to enhance operator awareness.
2. The remote HMI should have the same appearance and functionalities as the local HMI.
3. Only one HMI can have control of the bridge at a time. Each HMI shall have an indicator showing which operator station has control of the bridge. In addition, the HMI having control shall have the possibility of releasing control of the bridge in order to allow another operator to take control of the bridge with another HMI.
4. The position of the bridge in the HMI should respect the operator point of view for local and remote HMI.
5. Consideration shall be given to use the following standards in designing of the operator interface:
    - IEC18.2 Alarm management[7]
    - ISA 101 High performance HMI[8]

[7] ISA-18.2, Management of Alarm Systems for the Process Industries [International Society of Automation; ISA-18.2, Management of Alarm Systems for the Process Industries]

[8] ISA101, Human-Machine Interfaces [International Society of Automation; ISA101, Human-Machine Interfaces-ISA]

11.0 Remote Operation Control Center

General

When designing the Remote Operation Control Center (OCC) considerations should be given to meet the following requirements:

1. Sound absorption elements to reduce noise reverberation.
2. An ergonomic study should be performed to ensure that all screens and control consoles in the operator's environment are well positioned to optimize operational efficiency as well as minimize fatigue and errors.
3. Communication monitoring should be established between the structure and the OCC, between the PLC[9] and all the Operator Interface Stations. Alarms should be generated when communication failure occurs.
4. An operation contingency plan should be established for loss of communication (controls, cameras, etc.) or a major failure between the bridge and the OCC.
5. A risk analysis should be carried out to validate whether all control equipment, personnel, control desks, and the various contingency plans put in place for remote control are viable and safe for the public, operators, customers and maintenance teams.

Single Bridge Control Station

A single bridge control station should meet the following requirements:

1. Have a dedicated operator interface for the bridge control.
2. Have a dedicated remote emergency stop for the controlled bridge using safety control devices and a safety network communication link with action to be taken on loss of communication.
3. Have a camera management system with enough display screens to select any camera on any display screen.
4. Have a radio and telephone communication system allowing communication with vessel and the various maintenance services.
5. Consideration should be given to the use radar and/or an Automatic Identification System (AIS) interface for vessel localisation and identification.
6. Have an identification sign clearly showing the bridge being controlled. The size of the identification panel and its letters should be large enough to be readable from a distance of at least 3 meters.

[9] Programmable logic controller; A programmable logic controller (PLC) or programmable controller is an industrial computer that has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, machines, robotic devices, or any activity that requires high reliability, ease of programming, and process fault diagnosis. [Wikipedia, 8 August 2022; Programmable logic controller - Wikipedia]

Multi-structure Control Station

A multi-structure control station should meet the same requirement of the Single bridge control station and the following requirements:

1. Have a way of selecting the structure to be controlled.
    a. The cameras, the emergency stop button, the operator interface and the identification screen should be adjusted automatically with the selected structure.
    b. The structure selection should be allowed only when the structure is not in movement.
2. Have a separate identification screen showing the structure under control. The size of the identification screen and its letters shall be large enough to be readable from a distance of at least 3 meters.
3. The number of display screens shall be sufficient in number for all the structures to be controlled.
4. Multi-structure control stations allow a single operator to control many structures with the same control station allowing cost and space reduction. However, consideration can also be given of using multi-structure as a backup control station when another control station has failed.

12.0 Remote Control Advantages and Disadvantages

Advantages

1. Improved operator effectiveness with the reduction inactivity and distraction.
2. Improved operator interaction with their peers for problem solving and collaboration.
3. Improved ease of doing training.
4. Reduction of personnel since one operator can operate many structures.
5. Elimination of solitary work and risk of errors.
6. Improved operator environment and comfort.
7. Better point of view since more camera are installed.

Disadvantage

1. Less interaction with bridge operation and bridge users.

13.0 Implementation

When planning remoting projects that will involve multiple bridges/structures it is recommended that initial work be planned for a single bridge/structure. This allows the project team to work out the best solutions to many of the issues discussed above. Care should be taken to always consider the desired outcome for all of the structures when making these initial decisions so that the solutions applied can be scaled to accommodate the entire project scope. Lessons learned from these initial efforts will then be easily translated to the balance of the project.

The overall project schedule will be determined by the ultimate scope and number of bridges/structures being considered. The project schedule should allow time to properly investigate and design critical systems. Also, time should be allowed to accommodate the proper testing of the first or prototype system if multiple bridges/structures will be considered. The gathering of operator feedback regarding the operation of the bridge/structure should be considered before moving forward. In the current environment of supply chain limitations, care should be taken to consider possible delivery delays for key components.

14.0 Conclusions

Starting with the foundation of a strong communication network any bridge/structure can be safely and effectively remotely operated. With the advent of smarter more powerful automation systems and advances in sensor technology the stage has been set to facilitate the move to remote operation. Technologies used for remote operation of bridges are common to the automation industry and a wide variety of consultants are available to assist with the design and/or implementation of these projects. The ongoing improvements in smart sensor technology also facilitate the design and implementation of a safe and reliant system.