St. Lawrence Seaway: Potential Opportunities for the Application of Information and Communication Technologies

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16. Abstract

This report is the second in a series of two reports focused on identifying opportunities for application of Intelligent Transportation System (ITS) technology – or equivalent – to address challenges and/or opportunities in the St. Lawrence Seaway. The first paper in this series summarized current condition, challenges faced, and potential opportunities for application of ITS on the St. Lawrence Seaway. The first paper also documented existing applications of technology on the Seaway. This paper serves as a companion and presents applications of ITS – or more broadly, Information and Communications Technology (ICT) – and other novel technologies in maritime transportation operations elsewhere in the world. It also documents some initial parameters of several candidate applications for the St. Lawrence Seaway, which were previewed in the first paper as "Opportunities for Applications of ITS".

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The contents of this paper reflect the research findings and recommendations of the Volpe Center authors, and not necessarily the opinions of the other organizations mentioned above.

Contents

List of Abbreviations

Abbreviation	Term
AIS	Automatic Identification System
ATON	Aid to Navigation
CMTS	Committee on the Marine Transportation System
ConOps	Concept of Operations
DGPS	Differential Global Positioning System
DIS	Draft Information System
DOT	U.S. Department of Transportation
DUKC	Dynamic Underkeel Clearance
eATON	Electronic Aid to Navigation
EC	European Commission
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigation Chart
EU	European Union
GL-SLS	Great Lakes-St. Lawrence Seaway [system or region]
GNSS	Global Navigation Satellite System
ICT	Information and communications technology
IMO	International Maritime Organization
ITS	Intelligent Transportation Systems
LOMA	Lock Operations Management Application
MICE	MonaLisa in Ice
MSAP	Marine Situational Awareness Portal
RIS	River Information Services
SLSDC	Saint Lawrence Seaway Development Corporation (U.S.)
SLSMC	St. Lawrence Seaway Management Corporation (Canada)
STCC	Ship Traffic Coordination Center
STM	Sea Traffic Management
UKC	Under keel clearance
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Volpe	John A. Volpe National Transportation Systems Center (an entity of U.S. DOT)

1. Introduction

Maritime transport is a critical component of the worldwide economy, enabling cost- and fuel-efficient movement of goods around the world. In light of the logistics challenges, adverse operating conditions, valuable payloads, and other factors, maritime shipping has served as a vital, though perhaps overlooked, source of innovation in the transportation sector. The St. Lawrence Seaway is no exception, with its pervasive use of automatic identification systems (AIS), recently-deployed use of a draft information system (DIS), and the introduction of several lock technologies to facilitate faster and safer transits. A companion paper documented the Seaway's use of these and other technologies as part of a larger effort to identify opportunities to further apply Intelligent Transportation Systems (ITS) technologies or applications in pursuit of improvements in operations and safety.

1.1. Purpose and Organization

This paper documents applications of ITS – or more broadly, Information and Communications Technology (ICT) – and other novel technologies in maritime transportation operations elsewhere in the world. It will also document some initial parameters of several candidate applications for the St. Lawrence Seaway, which were previewed in the first paper as "Opportunities for Applications of ITS" (see section 6). The paper begins with an overview of maritime technology currently in use, organized by application type. The project team chose to highlight a selection of existing technologies based on their level of maturity combined with their potential relevance to the Seaway. The second half of the paper discusses several candidate applications identified through the Volpe Center's initial research and stakeholder outreach.

In conjunction with the companion paper completed in February 2016, this paper will inform additional stakeholder outreach and coordination to select an ITS application concept for further consideration and document its general parameters and requirements in a concept of operations (ConOps).

1.2. Summary of Seaway Challenges and Opportunities

This project is considering applications of ITS or equivalent technology in the context of the conditions, challenges, and opportunities of the St. Lawrence Seaway. Based on the initial research conducted for this project, it is evident that identifying a particular technology that can benefit the Seaway and its stakeholders will prove to be a challenge. As a binational, seasonal inland waterway with almost all single-chamber locks and a diverse array of operational organizations and stakeholders, the Seaway faces a unique set of challenges and constraints, many of which cannot be met through technology alone. These challenges and opportunities for applications of ITS were detailed in the project's first paper, and are briefly summarized below. Section 3 will further explore some of the potential ITS applications or equivalents for consideration by the Seaway managing organizations and their stakeholders.

1.2.1. Challenges

The project team identified the following challenges facing the St. Lawrence Seaway and its stakeholders through its background research, including discussions with key individuals of the U.S. Saint Lawrence Seaway Development Corporation (SLSDC) and the Canadian St. Lawrence Seaway Management

Corporation (SLSMC) and representatives from their stakeholder groups (e.g., shipping associations, ship owner/operators, and ports).

- *Multiple Jurisdictions* – The St. Lawrence Seaway is not only a binational waterway managed jointly by the U.S. and Canada, but it also spans eight U.S. states and two Canadian provinces. SLSDC and SLSMC representatives interviewed for this project reported excellent working relationships and coordination, but the sheer number of agencies involved in the operation of the Seaway make ongoing coordination a challenge.
- *Lack of Redundancy* – All 15 locks within the Seaway, with the exceptions of the Flight Locks (Locks 4, 5, and 6 in the Welland Canal) are single units. Not only does this arrangement limit transits to a single vessel travelling in a single direction, but it also means that failure of or damage to a single lock can delay traffic throughout the Seaway.
- *Seasonality* – The Seaway closes for approximately 90 days each winter, typically from late December through late March. This closure is necessary due to ice conditions in the canals, rivers and locks, while also allowing maintenance of the locks (particularly the single locks) and other Seaway infrastructure. However brief, this recurring interruption in operations likely deters many shippers from moving their goods via the Seaway, since they cannot afford to halt goods movement for three months each year, or are unwilling to incur the cost of shifting shipping route and/or mode during the winter. This challenge is often cited as one of the key constraints in developing short sea shipping on the Great Lakes-St. Lawrence Seaway (GL-SLS) System.
- *Lock Physical Constraints* – The physical dimensions of the fifteen locks in the Seaway limit the size of ships that can transit between Montréal and Lake Erie to 740 feet in overall length, 78 feet in beam, and approximately 26.5 feet in draft (ships built to this size are known as "Seawaymax").[1] The physical constraints imposed by the lock size limits the extent to which the amount of cargo per ship can be increased in pursuit of more efficient and cost-effective movement of goods on the Seaway.
- *Ship Dynamics within Locks* – SLSDC/SLSMC representatives interviewed for this project pointed to ship dynamics within locks as a potential source of transit time variability and potential damage to locks, lock equipment, and ships. A ship entering a lock chamber too quickly may build a volume of water ahead of its bow, which will exert a rearward force as a ship reaches its desired mooring position; it will then require additional time for the vessel to adjust its position before closing the lock gates. Similarly, a ship attempting to enter a lock at a low speed to mitigate this phenomenon may be less maneuverable, which can also increase lockage time.
- *System Delays* – During certain periods of the year, when ship traffic moving through the Seaway is heavy or when two pilots are required in the absence of floating aids to navigation, ships transiting the Seaway may experience time delays due to a shortage of qualified pilots. Technology alone may not provide a resolution for this challenge, but the project team documented this challenge as something that will need to be considered alongside any potential technology application.

1.2.2. Opportunities for Applications of ITS

The project team identified the following areas of opportunity for the application of ITS and/or ICT:

[1] Each lock has a minimum depth of 30 feet of water over the sills at the lock entrances so a 26 foot 6 inch draft vessel has a minimum of approximately 3 feet 6 inches of clearance between the lock sill and the vessel's hull. Vessels equipped with DIS are allowed to operate at a draft of 26 feet 9 inches, leaving 3 feet 3 inches of clearance between the ship and the sill.

- *Maximizing Use of Available Water Column* – Seawaymax-sized vessels already occupy as much of the available space (fore and aft, and side-to-side) in lock chambers as is safely and operationally feasible. Therefore, allowing ships to safely maximize their use of available depth is one of the few options for enabling vessels to carry additional cargo through Seaway locks. The recently-deployed DIS has already begun to leverage this opportunity, but enhancements or complements to this system may be available to further maximize cargo throughput in light of size constraints imposed by lock chambers.
- *Optimizing Lock Entry Speeds* – As mentioned above, the project team learned from St. Lawrence Seaway Corporations that ships can exhibit dynamic motions when entering lock chambers that can compromise their safety, the structural integrity of the lock infrastructure, as well as the overall timeliness of a lock transit. The Vessel Self-Spotting System installed in certain locks serves as an aid for pilots and masters in maneuvering into locks, but additional technologies may be available to enhance situational awareness as they navigate the tight confines of the locks and approaches.
- *Minimizing Delays Due to Pilotage Shortages* – Navigating the complex channels and tight confines of the St. Lawrence Seaway and its associated rivers, canals and locks requires exceptional skill. Vessels must be under the command of masters who possess, or are assisted by vessel pilots who possess, the necessary credentials issued in accordance with U.S. or Canadian law. During the course of its research, the project team learned that during certain times of the year, the demand for qualified marine pilots can exceed supply, particularly when double pilotage is required. The project team investigated whether there are ICT solutions or navigational technologies available that could be implemented that would assist pilots to improve safety and efficiency during the times of peak pilot demand.
- *Overall System Optimization/Coordination* – The project team's background research suggested that opportunities may exist to enhance the coordination of vessel transits throughout their time in the GL-SLS region: from the time they enter, during their navigation to and from their destination, until the time they depart. The goal is to improve the operational efficiency of the GL-SLS System in terms of cost, resource consumption, environmental impact, and/or time.

1.2.3. Other Considerations

The approaches discussed above represent only the technology-specific opportunities identified through the project team's initial research. In the course of this effort, several broader opportunities for the Seaway arose, which may not be addressed purely through technology applications. Overall, the Seaway's managing agencies and their stakeholders are interested in attracting additional ship and freight traffic through the waterway. Attracting containerized and project cargo represent two such opportunities for new traffic. Technology applications that can improve the speed, efficiency, and/or cost of Seaway transits can help attract new traffic, but may not be sufficient absent changes in other factors (cost, reliability, and speed of alternatives, demand for goods, and awareness of the Seaway as a routing option, among other factors).

2. Technology Scan

2.1. Methodology

The Volpe Center team conducted an extensive review of available research and applications of ITS and ICT in maritime transportation along two parallel paths. The primary research approach entailed a general search for and review of ITS- and ICT-based technologies, applications, and projects under development or in use in the maritime sector. This first approach was quite successful, though somewhat challenging given the apparently disparate nature of the field of maritime ITS/ICT. A wealth of research projects and technology deployment initiatives were uncovered, with the most extensive efforts being undertaken in the European Union. This search and its results are discussed in more detail in Section 2.3.

The Volpe Center's secondary research approach involved identifying waterway systems that face operational challenges very similar to those of the St. Lawrence Seaway (and the broader GL-SLS system), then searching for relevant examples where those waterway operators (and other related agencies) employ ITS/ICT technologies to address those challenges. This approach did not reveal as much information directly relevant to the ITS/ICT focus of this paper; however, it did reveal information that may be helpful for the Seaway in addressing some issues more generally. Findings have been summarized in Section 2.4.

2.2. General Findings

In the process of scanning industry and academic publications, the Volpe team arrived at two general findings:

First, ITS applications in the maritime sector have evolved along a very different developmental pathway than those in the surface transportation sector. As a result, this sector appears more advanced in some ways and less developed in others. For example, AIS technology (as discussed in the first paper) widely used in the maritime sector, and pioneered on the St. Lawrence Seaway, already provides much of the functionality that would be associated with emerging surface applications for vehicle-to-infrastructure (V2I) or vehicle-to-vehicle (V2V) communications.[2] Similar to some V2V applications, AIS already provides all ships in the system with a wide range of real-time data on other vessels (e.g., *static data* such as vessel ID, length and beam, type; *dynamic data* such as position, course, speed, heading, rate-of-turn; and *voyage-related data* such as draft, destination, ETA, hazardous cargo). And, similar to some V2I applications, shore-based transmitters broadcast to all vessels, providing information such as: weather and waterway conditions, lock-order turns, and other alerts and advisories.

On the other hand, efforts to build upon the basic availability of AIS appear somewhat region-specific and quite varied in focus. Section 2.3 provides a cross-section of initiatives that, in part, build off of AIS availability.

Second, while surface ITS comprises a fairly well-planned and well-integrated suite of technology applications, maritime ITS appears to have evolved in a more ad-hoc fashion, and in many areas it lacks a clear and unified vision like the one that has been promoted for surface ITS. One outcome of this is that gathering information and assessing the state of the art are quite challenging. Moreover, the characteristics of maritime operations (multinational and involving numerous public and private sector entities) combined with the fundamental nature

[2] In short, V2V and V2I would enable motor vehicles to automatically exchange basic safety information and other data between each other and with infrastructure components like traffic signals. These communications capabilities would enable the use of applications to improve safety, mobility, and environmental impacts.

of maritime equipment and infrastructure (capital intensive, much longer lifespans, etc.) mean that adoption of new technologies can be slow and deployment of many systems appears to span at least a decade or more. This means that coordinated developmental timelines may be difficult to construct or follow, and documentation for relevant example technologies may be sporadic and dated. In recent years, however, major efforts within the European Union have been exploring applications of maritime ITS in a more systematic, integrated way, through such initiatives as the “Motorways of the Sea” and “River Information Systems”, which span a range of projects.

2.3. Relevant Maritime ITS/ICT Examples

The first paper for this project presented several definitions of ITS technology. In general, the four definitions provided (sourced from the government ITS offices and professional societies of both the U.S. and Canada) focus on the integration of advanced communications technologies, advanced information processing, and sensor and control integration and management. More broadly, the definitions refer to the application of these technologies to the integration of vehicles into a larger transportation system, which includes other vehicles and supporting infrastructure (traditionally in surface transportation, but the concepts can apply to other modes). Since ITS applications have traditionally and most commonly been applied to surface transportation, this paper also considers the broader yet related field of *information and communications technologies*, or ICT. Generally, the research team considered applications that incorporated data collection, information and data sharing, and analytics and decision support systems.

The following sections summarize examples of ITS- or ICT-based systems or applications that have been, or are being, deployed on other waterways. Examples are grouped based on the types of systems presented.

2.3.1. Overall System Optimization — Integrated/Coordinated Vessel Movements, Data Exchange, and Intermodal Coordination

This category represents a broad range of projects aimed at strategic improvements in the operation of maritime systems. Because these are high-level initiatives aimed at overall system improvement, they tend to involve efforts to optimize across many functions at once. Therefore, a fairly diverse array of work is covered in this section, and some of the issues that these projects engage with may fall outside of the Seaway’s scope. Projects in this area often focus on one or more of the following issues:

- *Improving route planning and coordination among vessels.* These efforts aim to achieve safer and more efficient maritime operations through information sharing and coordination among vessel operators, landside facilities, infrastructure elements such as locks and bridges, and traffic control centers. They often involve adapting concepts from air traffic management. These applications address several of the challenges and areas of opportunity identified for the Seaway, including improving the efficiency and safety of vessel movements, optimizing lock transits, and minimizing delays.
- *Improving efficiency of data exchange.* The research team identified a number or projects aimed at advancing systems that are paperless, standardized, and involve single points of data entry in order to improve the efficiency of data exchange.
- *Improving Intermodal Coordination.* Coordination across modes is commonly seen as a key impediment to increasing the amount of freight carried by water, so a number of system-optimization projects include elements aimed at improving communication and expanding coordination among ports, maritime operators, and surface transportation systems. The ultimate goal is often to achieve a level of integration where the freight system is as close to “seamless” as possible. Section 2.3.3

presents several examples of projects in this area, which focus on general improvements to maritime operations, including many focused on short-sea shipping, and which are likely to fall outside of the Seaway's scope.

2.3.1.1. MonaLisa 2.0 (efficient voyage planning and traffic management, through distributed, collaborative decision-support systems)

MonaLisa 2.0 is a comprehensive effort underway in the European Union (EU) to modernize and improve the safety and efficiency of maritime operations by taking advantage of emerging ICT as well as concepts already in use in other transportation modes. MonaLisa 2.0 encompasses four areas: the first two are focused on developing tools to support a comprehensive Sea Traffic Management (STM) system; the remaining two are focused on improving the management of search and rescue operations, and securing the operational safety chain in ports and coastal waters.

For the purposes of this project, STM appears to be the most promising and relevant component of MonaLisa 2.0. STM is an approach to managing the complex environment of maritime transportation that leverages the experience and practices from air traffic management. STM builds upon the availability of data generated through AIS transceivers, now required by the International Maritime Organization (IMO) on ships of 300 gross tons and upwards engaged on international voyages, cargo ships of 500 gross tons and upwards not engaged on international voyages, and all passenger ships irrespective of size.

In its basic form, AIS provides position, speed, and course information to nearby ships and coastal authorities, but these data primarily provide only an instantaneous snapshot of a ship's current status. While origins and destinations may be shared, the route plan or changing intentions are not. Other systems onboard, like electronic charts, may contain all the necessary data about the ship's intentions. The concept of STM seeks to combine these data, along with other sources relating to a ship's voyage, and integrate them into a distributed and collaborative decision-support system.

Though STM builds upon the experience of air traffic management, research supporting the MonaLisa 2.0 project recognizes many distinct differences between maritime and air transport in terms of operational, industry and economic, and institutional characteristics and constraints. Instead of the centralized management and decision-making that characterizes air traffic control, STM is envisioned as a decentralized system, in which each ship contributes and receives information that enables improved situational awareness. Each crew then uses this additional information to make decisions that support system-wide goals, including reduced environmental impact, more cost-efficient operations, and better safety performance.

As part of developing and demonstrating the STM concept, the MonaLisa effort has validated several subcomponents, any of which may hold interest and relevance to the St. Lawrence Seaway and its stakeholders. The first MonaLisa project experimented with dynamic and proactive route planning. A ship entering waters covered by the project could send its voyage plan to a shore-based Ship Traffic Coordination Center (STCC). The STCC would validate the voyage plan for under keel clearance (UKC), areas to avoid, and separation from other ships. As a ship proceeds along its agreed-upon route, the STCC could issue route advice to the vessel master based on route planning information provided by other ships as well as other factors, including weather, ice, and traffic restrictions.

In addition to advising masters on their optimal route in light of prevailing traffic and weather conditions, the MonaLisa 2.0 project has considered the application of dynamic route-planning to merge data on scheduled berth departure times with projected arrival times, thereby avoiding situations in which a ship follows an optimal route, only to find its intended berth still occupied by another vessel. Instead, MonaLisa 2.0 has proposed using dynamic route-planning information to advise a ship's master when it may be appropriate to reduce speed in order to arrive in port when a berth is available (instead of using extra fuel to arrive at port sooner, only to be forced to wait at anchor or at a lay-berth for another ship to depart). Due to U.S. domestic law and the international legal concept of the "freedom of the seas," it may be difficult or impossible to implement vessel management systems that actively direct ship movements. However, the kind of "tactical route exchange" and related advising efforts proposed by the MonaLisa 2.0 project seem to avoid conflicting with these principles.

The MonaLisa 2.0 effort also included a research project aimed at applying STM to improve situational awareness in Arctic maritime operations. The MonaLisa in Ice (or MICE) project developed and applied a version of STM to improve coordination of icebreaking operations. Under the proposed system, an icebreaker can send information about newly cleared routes directly to a ship's navigational system. MICE also enables icebreakers to monitor surrounding ships in areas that are beyond the reach of AIS or radio communications. The MonaLisa project demonstrated this system in 2013 and 2014 during summer expeditions of the icebreaker *Oden*. The EU has plans to extend the concepts demonstrated in this project (particularly the capability to exchange recommended ice route information) to tests in the Baltic Sea as part of the EU's "STM Validation project" [1].

The MonaLisa 2.0 STM development effort is currently transitioning between the concept-definition and concept-validation phases. Development and deployment of the STM system is anticipated to occur through 2030. Comprehensive information about MonaLisa 2.0 and STM is available at www.monalisaproject.eu.

2.3.1.2. Maritime Single Windows (standardizing and streamlining reporting processes)

Inefficient and often redundant reporting requirements have been widely observed to impact businesses involved in international trade. In recent years, additional security-related requirements have complicated matters further. A number of projects in the EU have addressed (or are currently addressing) these challenges as they relate to the maritime sector, especially those involving transits through multiple jurisdictions. Most of these efforts fall under the "Maritime Single Window" concept, which is based on the original "Single Window" concept developed by the United Nations to facilitate international trade. The concept is centered on standardizing reporting formats and documents and providing single entry points to comply with all import, export, and transit-related regulatory requirements.

An EU project that analyzed the effectiveness of Single Window initiatives found that over 30 countries have established single window facilities, with a number of confirmed benefits, including: reduction of time and resources required by businesses in preparing, presenting and processing reporting requirements (and an associated decrease in trade transaction costs); improved trader compliance through more complete, accurate and timely data submission (and an associated increase in government revenues); and more efficient and effective border management and control [2]. While the Seaway involves only two nations, these efforts may be highly relevant, given the patchwork of environmental and other regulatory authorities that exist at the state level throughout the GL-SLS system. The following are examples of EU projects involving maritime single windows:

- *E-MAR* was a research project funded by the European Commission (EC), completed in 2015. It developed components of an "information management infrastructure" for acquiring, handling, and sharing data. Among the tools developed were "single window building blocks" to enable individual jurisdictions to implement their own single window programs. Support for member states was also provided, along with resources to guide the implementation process, including a Single Window Development Guide. More information is available at www.emarproject.eu.
- *ANNA* (or "Advanced National Networks for Administrations") was an EC "Motorways of the Sea" project completed in 2015. It supported integration of national Maritime Single Window development to improve communication between the national systems, and involved 14 nations

across the continent. More information is available at www.annamsw.eu. A similar project, *BASIS* (or "Master Plan Studies for Development of the Baltic Sea Information Motorways"), was completed earlier, in 2008, and its aim was to establish a "one-stop-administrative shop/single window" for nations in the Baltic Sea region.

- *Miele Middleware* was an EC "Motorways of the Sea" project that developed "middleware" to allow exchange of data/interoperability among different systems in multiple ports across five nations. Completed in 2013, the project involved facilitating data exchange across maritime single windows systems and port systems. More information is available at http://www.onthemosway.eu/miele-2/.

2.3.1.3. EfficienSea2 (data exchange and route optimization through the "maritime cloud")

In May 2015, the EU initiated the EfficienSea2 project focused on developing a coherent set of applications designed to facilitate safer and more efficient maritime operations. The project is centered on the development of a secure, standardized communications framework – the "Maritime Cloud" – that will enable streamlined information sharing among stakeholders. The Maritime Cloud will host end user services and applications, including automated reporting to reduce administrative burdens as well as route exchange, route optimization, and no-go area services (similar to DIS and Dynamic Under-Keel Clearance, discussed later) to enhance safety and operational efficiency [3]. More information is available at http://efficiensea2.org.

2.3.1.4. EU River Information Services (enhanced management and integration of inland waterway transport)

European trade relies on an extensive system of rivers and inland waterways covering 40,000 km, half of which are navigable by vessels of up to 1,000 metric tons [4]. Though inland waterways carry just 6.9 percent of the total ton-km of inland freight in the entire EU, some individual countries in the EU rely far more heavily on this extensive system, in some cases over 47 percent [5]. In an effort to facilitate the optimization of vessel traffic through Europe's inland waterways and more thoroughly integrate the maritime mode into the intermodal logistics chain, an EU-funded initiative began in 1999 to develop and implement a Europe-wide River Information Services application, or RIS. The RIS includes numerous components and applications, all with the goal of facilitating safer and more efficient vessel operations and better integration with the other components of Europe's multi-modal freight transportation system. The ultimate implementation of the RIS will offer the following services:

- *Fairway Information Services (FIS)* – Information provided to vessel operators and fleet managers on geographical, hydrological, and administrative data to support decision-making; FIS data covers waterway infrastructure only and does not include information on other vessels.
- *Traffic Information Service* – RIS facilitates traffic information services in two forms, tactical and strategic. The Tactical Traffic Image application supports immediate navigation decisions by captains and relies upon vessel position, speed, and heading data shared via Automatic Identification System (AIS). The Tactical Traffic Image appears similar to the Seaway's current use of AIS. The Strategic Traffic Image adds to AIS-generated data information about nearby vessels' intended voyage, dangerous cargo, and requested times of arrival at locks and port terminals. This latter application reflects a potentially valuable opportunity for the Seaway to expand its use of AIS to facilitate better coordination and optimization of vessel traffic.
- *Traffic Management* – Just as in the St. Lawrence Seaway, local authorities are responsible for managing utilization of inland waterways through the following services:

- Local traffic management – Vessel traffic service centers monitor traffic in their jurisdiction and coordinate safe movement of vessels in congested waterways. Similar to Seaway traffic management centers, the Vessel Traffic Service centers within the EU's RIS operate based on information provided via shore-based radar stations, AIS, and vessel-supplied voyage reporting systems.
- Lock and bridge management – The Strategic Traffic Image supports optimal planning of smooth lock operations. Lock planning based on the RIS can allow lock operators to inform captains of their estimated time of arrival (compared to their requested time of arrival) and allow them to optimize speed and fuel consumption in response.

RIS has been demonstrated in numerous locations and is in the process of full implementation. Moreover, the RISING project is currently exploring how to further develop RIS applications to improve the efficiency of inland waterway transport [6].

2.3.1.5. U.S. River Information Services

Much of the development of the RIS concept has taken place in Europe, where certain countries rely heavily on inland waterway transport. In the U.S., development of a comparable system has been far less evolved and extensive than efforts in Europe. The U.S. Army Corps of Engineers (USACE) has been coordinating the development of a U.S. RIS since 2009 within a general strategic framework for e-Navigation established by the U.S. Committee on the Marine Transportation System (CMTS). The CMTS's strategic action plan generally envisions a national RIS Center, which would serve as a central point of aggregation and dissemination of real time information about lock conditions, hydrodynamic and meteorological conditions, ice and debris, notice to mariners, waterway security, and chart updates [7]. One of the more significant developments within USACE's RIS efforts has been the development of the Lock Operations Management Application, or LOMA, discussed later in this section.

2.3.1.6. Wireless Waterways (wireless communications network for data exchange, transparency, and application development)

The Port of Pittsburgh Commission has taken a new approach to using ICT to enhance the safety, efficiency, and integration of inland waterway operations. In 2013, the Commission launched its Wireless Waterways project, an effort to deploy a neutral, wireless broadband network to serve as a platform for supporting a "system of systems" (see https://www.wirelesswaterways.com/). The resulting network deployed through this project provides a means of exchanging a wide array of data provided by infrastructure operators, vessels, and independent services. As part of this effort, the Commission also developed the Maritime Situational Awareness Portal (MSAP) as a web interface for displaying and interacting with data shared via the wireless network. Finally, the Wireless Waterways project provides a public-private test bed venue for independent developers to test new applications alongside waterway users. These applications generally rely on the communications link established by the wireless broadband network and could ultimately feed additional data into the MSAP.

As of 2014, the Commission had installed wireless base stations covering 120 miles of Pittsburgh's "3 Rivers" area, which includes 14 locks, the Allegheny and Monongahela Rivers, and the portion of the Ohio River that runs through Pennsylvania. The base stations consist of (1) a 4.9GHz multipoint radio array, (2) long range Wi-Fi radios, and (3) a backbone radio link. In June 2014, the Commission invited technology developers to participate in interoperability test bed exercises using the broadband network. Applications tested as part of this exercise included (but were not limited to): a system for crowd-sourcing bathymetry data (see http://ushydro.thsoa.org/hy13/pdf/0326A_02_05.pdf for additional information); USACE's Lock Operations

Management Application (covered in additional detail in a later section); an AIS-based analytics platform to enhance lock transit efficiency; and several applications to enhance situational awareness.

2.3.2. Improving Fundamentals of Navigation and Communication

Where section 2.3.1 presented numerous examples of ITS- and ICT-based systems and projects intended to enhance the efficiency and integration of marine transportation, ITS/ICT has also seen use in more narrowly focused applications. The examples presented in this section aim to improve fundamental components of the navigation and communications process, without fundamentally altering them.

2.3.2.1. eATONs (electronic aids to navigation)

Electronic aids to navigation, or eATONs, are meant to augment the functionality of traditional fixed aids to navigation (ATONs) by electronically marking hazardous navigation features. eATONs appear on a vessel's electronic chart display and information system (ECDIS) but the source of the underlying position data varies across three general categories of eATONs:

- *Virtual ATON*s – ATON symbols that appear on a ship's ECDIS in a location where no physical ATON exists, generated by a message broadcast from another location.
- *Synthetic ATONs* – ATON symbols that appear on a ship's ECDIS in a location where an actual ATON exists, generated by a message broadcast from another location.
- *Real AIS ATONs* – ATON symbols that appear on a ship's ECDIS, whose signal is broadcast from equipment installed on a physical ATON.

Key benefits of eATONs, particularly of the virtual and synthetic variety, include: 1) they can be deployed where water depths are too great for physical buoys; 2) they are never off station (e.g., they cannot be hit by ships or displaced by ice); and 3) they can be deployed on a temporary basis to call attention to temporary conditions (e.g., wrecks or regattas), or even to temporarily replace a physical buoy destroyed by a storm [8].

2.3.2.2. ARIADNA (Maritime Assisted Volumetric Navigation System)

The EU-funded ARIADNA project is focused on optimizing the use of maritime and inland waterway infrastructure and improving the safety and efficiency of inland navigation through the application of ICT navigation aids. The ARIADNA project has proposed a new concept for navigation situational awareness that associates the geographic position of a vessel with a three-dimensional volume rather than a single point. The resulting volumetric navigation system takes into account a vessel's hull shape, size, displacement, speed, drift, course, wind effects, hydrodynamic effects, and maneuvering capabilities (given the preceding variables) to calculate a safety "volume" surrounding the ship. This volume represents the area that the vessel could occupy within a given time window given prevailing conditions and its operational characteristics.

In broad terms, the proposed safety envelope calculation that is central to the ARIADNA project begins with a ship's position generated from Global Navigation Satellite System (GNSS) combined with its length, beam, and draft. The system then overlays a time dimension, which calculates the potential position of the ship given its speed, displacement, maneuvering characteristics, squat effect, and environmental risk factors (e.g., visibility, wind, and current) [9].

The ARIADNA project team envisions that this predictive positioning information could be shared via AIS between ships and between vessels and a shore-based Local Control System. Navigators could use it as a decision support system for navigating in congested waterways while shore-based traffic management centers could conceivably use aggregated volumetric navigation data to more safely and efficiently issue advisories and recommendations to ships within their purview.

To date, components of the ARIADNA system have been field tested in the Danube River and in the Strait of Gibraltar. The former trial focused on the system's collision avoidance functionality while the latter focused on providing navigation support to ships in their approach, entrance, and navigation within a congested port environment [10].

2.3.2.3. Dynamic Under-Keel Clearance - Improving Capacity in Light of Vessel Size Limitations

The first paper completed for this project highlighted the recent deployment of the DIS on the St. Lawrence Seaway. Systems relying on similar concepts have been in use in major ports around the world since the early 1990s in the form of Dynamic Under-Keel Clearance (DUKC) systems. Like the DIS, DUKC systems allow vessels to safely navigate with deeper drafts than would otherwise be allowed by fixed UKC rules, which typically account for a wide range of sea conditions and conservative estimates of a vessel's deepest possible draft while in motion. DUKC systems produce near real-time UKC predictions based on numerous environmental- and vessel-based factors, allowing vessels to maximize their loading under a given set of conditions and also allowing ports to make maximum use of their tidal window in scheduling vessel arrivals and departures [11].

2.3.2.4. USACE Lock Operations Management Application

In 2011, USACE released version 1.0 of its Lock Operations Management Application (LOMA), an application that integrates AIS-generated data with Electronic Navigation Charts (ENC), weather, and lock status information into a web-based interface that provides improved situational awareness to lock operators. Operators can receive automatic alerts when ships enter particular navigation zones and can, in turn, automatically send alerts or messages to those vessels. LOMA also has data archiving functionality, which can facilitate investigations of incidents as well as track lock and overall waterway performance metrics [12]. More recently, the U.S. Coast Guard (USCG) has been testing new capabilities for LOMA to directly transmit weather, water level, and lock operational information to vessels. These messages would be displayed on vessel navigation systems, as well as made available via web services to facilitate voyage and operational planning [13].

2.3.2.5. Smart Lock

In 2003, a group from Carnegie Mellon University completed a study for the Port of Pittsburgh Commission focused on applying e-commerce technology to reducing shipping bottlenecks and improving predictability of transits through the 20 locks between Pittsburgh and St. Louis. The result of their study was a prototype SmartLock system, designed as a navigation aid to provide pilots with accurate real-time information to support safe and efficient lock transits in all weather conditions. The SmartLock system displays to pilots, as an overlay on their ENC, precise positioning of the bow and stern relative to guide walls and bullnoses. The application also overlays condition information related to dam openings, currents, and wind. The SmartLock application does not appear to be in use at the current time, but the Port of Pittsburgh Commission holds patent rights to the technology. More information is available at: http://www.port.pittsburgh.pa.us/index.aspx?page=12.

2.3.3. Additional Relevant ITS/ICT Projects and Technologies

The sections above summarize a selection of ITS/ICT-based systems under development or in use. The Volpe Center team chose to summarize this subset based on their level of maturity as well as their relevance to the St. Lawrence Seaway and the challenges and/or opportunities documented in the first white paper for this project and summarized at the beginning of this paper.

Most notably, a wide range of research, demonstration, and deployment projects have focused on applications of ITS/ICT to improve the overall efficiency and economics of short-sea shipping, particularly in the EU. While many of these projects may be beyond the scope of the SLSDC and SLSMC's authority, they are included here to provide a sense of the range of work being done to advance short sea shipping. They also bear some relevance, given that the SLSDC and SLSMC would have at least some role to play or interest in the outcomes of such undertakings, and may be interested in promoting such initiatives among their stakeholders.

Many of these projects fall under the umbrella of a major initiative, Motorways of the Sea, which began in 2001 with the primary goal of increasing the amount of freight carried by ship within Europe (for more information, see https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/cef-transport-motorways-sea). Numerous projects were completed under this umbrella program and many included a mix of market incentives as well as technology solutions (see the following for project examples that include the latter: Baltic Sea Hub and Spokes: http://balticseahubspokes.eu/; Efficiensea: http://www.efficiensea.org/; Business to Motorways of the Sea: http://www.b2mos.eu/; and Monitoring and Operations Services for Motorways of the Sea: http://www.mos4mos.eu/).

2.4. Research into Analogous Waterway Systems

In its secondary research approach, the Volpe team initially looked for inland waterways with the following characteristics: 1) significant commercial traffic; 2) a system of locks; 3) connection to or among larger inland lakes or seas; and 4) substantial ice coverage in the winter season, comparable to that of the GL-SLS System. The fourth criteria proved to be the main limiting factor, as there appear to be only a few areas in the world where major shipping routes have evolved on inland (or even coastal) waterways that experience major icing problems in the winter.

The most directly comparable waterways to the St. Lawrence Seaway appear to exist in the Baltic Sea region. Within the Baltic Sea Region, a two key examples stood out, the Trollhätte Canal in Sweden and the Saimaa Canal in Finland. Both are inland waterways in ice-prone climates that carry significant freight volumes and incorporate lock systems. Appendix A contains additional information about both waterways.

Overall, the systems investigated did not appear to have implemented – or plan to implement – any ITS- or ICT-based applications to address the operating conditions, challenges, and limitations shared with the St. Lawrence Seaway. Furthermore, while this search uncovered some encouraging findings about the potential for year-round operations – the Trollhätte Canal operates year-round and the Finnish Transport Agency has plans under consideration that would extend the Saimaa Canal's operating season – these generally did not involve ITS/ICT interventions. Nonetheless, the SLSDC, SLSMC, and their stakeholders may wish to monitor developments on these analogous waterways for noteworthy practices, particularly in pursuit of extending the navigation season.

3. Summary of Candidate ITS Application Concepts

3.1. Enhanced Traffic Management

Section 2.3 documented several efforts underway designed to fully leverage the comprehensive availability of AIS in pursuit of more dynamic and coordinated vessel traffic management. In many cases, these efforts intend to integrate data transmitted via AIS (position, speed, heading, vessel characteristics) with voyage planning information. The Seaway Corporations may wish to consider implementing an enhanced traffic management environment that not only allows vessel operators and traffic control personnel to view AIS-generated data, but also enables sharing of information about the intended paths of ships operating on the Seaway. This enhanced awareness could enable several potential benefits.

First, increased situational awareness of the planned routes of nearby vessels will foster higher levels of safety. Perhaps more significantly, given the Seaway's robust safety record, is the potential to improve overall system performance by improving the efficiency of its individual components through coordinated movements of vessels, locks and bridges. This optimization would be accomplished through improved information exchange between ships and shoreside infrastructure regarding position, speed, and intended route of all vessels in a given traffic control area. Such information could enable transiting vessels to adjust their speed to maximize the number of passing entries into locks (i.e., an upbound ship immediately followed by a downbound ship, or vice versa, which minimizes instances of filling or draining an empty lock to accommodate passage of two or more ships traveling sequentially in the same upbound or downbound direction) or potentially to "stack" vessels traveling under lift bridges, thereby minimizing the frequency with which bridges need to be lifted for passing vessels.

The concept could be further expanded to integrate status information from destination ports or terminals, similar to the approach being pursued through Europe's MonaLisa 2.0 project. Data from ports or private terminals on the berth availability and other port conditions could allow captains to optimize their arrival times and save fuel if, for instance, they will otherwise arrive at their destination before space becomes available. Lind et al. (2014) envision the concept of STM allowing maritime to be fully integrated into multimodal freight transportation planning [14]. They also provide an accounting of the data types and sources and actors underlying STM. Though the same concept applied to the Seaway might entail fewer actors and/or data needs, the extensive documentation of the MonaLisa 2.0 STM deployment in Europe provides an excellent foundation as well as data validating the concept's efficacy.

Enhanced vessel traffic management would be far from a simple application to pursue and its benefits would need to be validated in the specific context of Seaway operations. Its development and implementation would involve extensive coordination with numerous stakeholders. This process has spanned decades in the case of the MonaLisa 2.0 project in Europe. Moreover, the benefits would need to be validated as significant enough to justify the investment of resources. Traffic management relying mainly on current ship positions and known destination ports may be sufficient given the Seaway's current levels of vessel traffic. Situations in which vessels are required to tie up at lock entrances, or wait in open water, due to vessels transiting locks ahead may be rare and those situations that due occur may be manageable with current traffic management and navigation aids. However, to the extent that these situations occur with some frequency, applying the concepts being developed through STM and RIS, discussed earlier, could enhance efficiency, safety, and the economic competitiveness of the Seaway, and integrate it more thoroughly into the GL-SLS regional multimodal freight transportation system.

3.2. Enhanced Lock Operations

Navigation through the Seaway's locks entails maneuvering of large vessels in very tight confines, particularly in the case of vessels built to Seawaymax dimensions. Earlier sections of this paper presented several applications that have been developed to enable greater situational awareness of pilots and/or lock operators to facilitate safer, more efficient lock transits. The prototype SmartLock application, developed through the Port of Pittsburgh Commission, allows for precise ship positioning data to support ship maneuvering in locks and lock approaches.

Documentation for the SmartLock suggests two architectural approaches, one vessel-based and one shore-based. In either case, the application displays precise vessel position information over an electronic navigation chart, including distance measurements between vessel boundaries and fixed objects like lock walls and bullnoses. In the vessel-based architecture, the Commission proposes that the ship's boundaries could be located using high-precision differential global positioning system (DGPS) receivers and wireless transponders mounted at the ship's "corners." Alternatively, a shore-based architecture could place sensing equipment at critical points on land and communicate distance information to a ship's bridge wirelessly or via large, shore-based displays. The latter architecture represents a potential enhancement of the Vessel Self Spotting technology currently in use in several Seaway locks.

The project team investigated the issue of ship behavior in locks, which had been identified as an operational concern in the report's first paper. Conceptually, a lock chamber could be fitted with sensors that provided real-time water level data at various locations in the lock chamber (e.g., entry-point, mid-point, far end). These water level readings could provide the vessel master and pilot with detailed information on the build-up of water forward of the ship, which would indicate the potential for the vessel to surge aft as it approaches its final position in the lock chamber. Alternatively, an optimal lock entry speed profile could be developed in advance through modeling and simulation for specific vessel types and loading.

While some research has been done in this area, the Volpe team could find no instances of technology systems under development or in deployment that address this particular concern.

3.3. Enhanced DIS/Dynamic Under-Keel Clearance

The Seaway has already made significant progress in maximizing use of the existing water column through the deployment of DIS, which allows certain classes of ships fitted with DIS equipment to operate with a deeper draft. It was suggested in the course of the Volpe Center's background research that the concept of DIS could be extended to accommodate the squat profiles and hydrodynamic characteristics of individual ships. For example, ships that exhibit less pronounced squat could conceivably carry additional cargo without compromising safety, but may currently be limited by conservative assumptions about their operational characteristics. Or, ships that develop pronounced squat at higher speeds could be loaded deeper and allowed to travel at high speeds in deeper water, but be required to traverse shallow areas at lower speeds to maintain safe UKC at all times.

While such a process would require a highly transparent and impartial process for certifying the conformance of individual ships to particular squat profiles, the potential for ships to carry additional cargo could enhance the operational efficiency and attractiveness of the Seaway as a competitive freight transportation solution.

This concept appears to exist already in the form of DUKC systems discussed earlier.

3.4. Analysis of Market Potential and Associated Environmental, Economic, and Mobility benefits

In the course of its research and discussions with stakeholders, the Volpe Center team has encountered significant interest in attracting additional vessel traffic and cargo to the Seaway. The SLSDC and SLSMC and their stakeholders tout the environmental and economic advantages of marine freight movement (compared to other modes, on a per ton-mile basis) and the location and routing of the Seaway presents potential to alleviate surface mode congestion (rail and road) in a busy freight corridor. However, the magnitude of potential modal shift seems somewhat unclear. Moreover, though many of the technology examples presented earlier in this paper could provide benefits to the Seaway now, their full benefits may not be realized with traffic at current levels.

Therefore, one potential effort to pursue – though not strictly a technology development exercise – would be to structure an evaluation of the potential freight that *could* be redirected through the St. Lawrence Seaway. Such an effort could take the form of an evaluation, or the development of a tool to visualize current freight traffic, identify excess capacity, and evaluate the impacts of various freight modes for a given route. Ultimately, such an effort could provide justification for further enhancements to the St. Lawrence Seaway, including several of the concepts discussed in this paper.

4. Summary and Next Steps

This paper summarized ITS- and ICT-based applications in use or in development in maritime transportation operations that might be relevant to challenges and opportunities facing the St. Lawrence Seaway Corporations and their stakeholders. In selecting applications to profile in Section 2 of this paper, the project team considered both pertinence to the Seaway and perceived level of maturity.

This paper concluded with a discussion of several application concepts that, based on the project team's research about both the St. Lawrence Seaway and the state of ITS and ICT in maritime transportation, might be of interest for further development to the Seaway Corporations and their stakeholders. As a next step, the project team intends to engage with these groups to discuss the merits of the proposed applications and ultimately select a single application to investigate in detail as part of the development of a ConOps document for the selected concept.

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Appendix A: Overview of Comparable Waterways

Trollhätte Canal (Sweden)

The Trollhätte Canal connects Sweden's west coast (near Göteborg) with Lake Vänern, via 82 km of natural and manmade waterways, through six locks with an elevation gain of 44 meters. It is significantly smaller than the St. Lawrence Seaway—ships are limited to a length of 89 meters, a breadth of 13.4 meters, and draft of 5.4 meters—yet it remains a major route for commercial traffic, with an average of five merchant ships passing through daily[3] carrying roughly 3.5 million tons of cargo annually (which has been observed to be roughly equivalent to 350 trucks making the same journey every day of the year).[4]

Trollhätte Canal appears to entail the largest lock system in the world that remains operational through severe icing conditions, as it has maintained constant year-round operations since a major upgrade in 1974. A 1995 U.S. Army Corps of Engineers (USACE) survey of ice control techniques observed that this is accomplished through a program of structural controls (ice booms, rock filled cribs and dolphins) combined with other measures (ice breaking and flushing, bubblers, and lock wall heaters). "Ice-escape tunnels" are also employed in some locks—these allow ice to be flushed out of a lock after it is pushed in by an entering vessel.[5] The use of airborne surveillance is also mentioned.[6]

Saimaa Canal (Finland)

The Saimaa Canal connects the Baltic Sea (via the Gulf of Finland) to an extensive system of inland lakes. Like the Seaway, the Saimaa Canal flows through two countries (in this case Russia and Finland). It is 43 kilometers long, with eight locks that span a total elevation gain of 76 meters, and which are operated remotely by two control centers.[7] The canal is operated by the Finnish Transport Agency, and nearly half of its length runs through land leased from Russia. Ships are limited to a length of 82.5 meters, a breadth of 12.6 meters, and depth of 4.35 meters. It is considered to be the most important inland waterway in Finland, providing maritime access to a region described as a "lakeland archipelago" covering more than 6,500 square kilometers. Roughly 2 million tons of cargo and 40,000 passengers pass through the canal each year.[8]

Similar to the St. Lawrence Seaway, the canal also closes for a portion of the year due to icing, with the average open season lasting 211 days. While the Volpe team did not uncover any new technologies or innovations in use to lengthen the season, plans have been developed (and remain under consideration) to

[3] http://www.sjofartsverket.se/sv/Batliv/Trollhatte-kanal11/Eng_Tys-versioner/trollhatte_eng/

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invest in upgrades to the canal that would enable year-round operation.[9] Studies have supported the technical viability of achieving this through systems using heat for ice-control, but they have also observed that the economic value of such an investment is very sensitive to changes in transportation costs, and also entails much uncertainty around the volume of latent demand that may be realized by providing year-round access.[10] According to the *Maritime Transport Strategy for Finland 2014-2022*[11] the costs of required upgrades and maintenance "cannot be regarded as feasible in view of the current or projected traffic volumes." However, this position is open to ongoing re-evaluation, and the goal remains to "ensure that the navigability season is as long as possible." Generally, it appears that, as in the GL-SLS system, commercial shipping in Finland's inland lakes could benefit greatly from year-round navigation, and the Saimaa Canal may provide a good example for the SLSDC and SLSMC to monitor in the future.

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